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Fishery in Open Waters

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1

INTRODUCTION

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INTRODUCTION

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The majority of people in an inland country regard freshwater fishery as fish breeding in ponds or alternatively on fish farms (directly managed waters). Nevertheless, fishery also includes so-called open waters within which all types of the original aquatic environment, such as lakes, brooks, rivers and their tributaries as well as pools isolated from the main stream can be classified. Fish, however, managed to occupy without difficulties not only the artificial environment of dam reservoirs, navigation and irrigation channels, but also water formations that originated due to the extraction of minerals and construction materials, such as flooded quarries, stone pits, gravel pits, sand pits and loam pits. In contrast to ponds, in most cases this is an environment that fish cannot be harvested from, at least, not by common fishing methods. Targeted fishery management of open waters only started to develop relatively recently. Pisciculture in ponds, so-called fish breeding, experienced its biggest expansion in the 15th – 16th century, although the first reference to more intense fishery management of open waters dates back to as late as the 19th century. At that time, fish farms were established that first concentrated on fry production intended for stocking open waters with fish. In the 20th century, fishery was gaining more and more importance in the same way as civilization's pressure on natural resources and the environment was growing stronger. The existence of several species of fish in many European rivers had to be saved by means of their artificial reproduction and stocking. There are millions of Czech Crowns being invested each year in the import of juvenile eels, attempts to rescue salmon have been registered for more than 150 years and at present rescue programmes even, for example, for sturgeons are emerging. The driving force of the current open water management system is recreational fishing. Nowadays, recreational fishing is ranked among the most popular and mass leisure time activities of Czech Republic residents. There are approximately three hundred thousand people who engage in recreational fishing, which represents 3% of all inhabitants of the Czech Republic. Fishing expresses, above all, many people's desire to spend some time in the nature and to understand it. Fishing has become a phenomenon of relaxation, adventure and a mood enhancer rather than a subject of food provision, as it used to be in the past. Since there is a relatively small amount of open waters in the Czech territory, the pressure of recreational fishing on the wild fish population is rather high in many locations. Wild fish are at the same time increasingly negatively influenced by a number of other factors, such as modifications and constructions that are being built on streams which is related to the existence of a large number of migration barriers, frequent incorrect fishery management, disobedience of recreational fishing rules, changes of flow-rates in streams, growing pressure of piscivorous predators, water pollution caused by anthropogenic activity, etc. As long as some fish species are to remain part of recreational fishing or just to stay present in the extremely loaded European waters, it is necessary to pay attention to the support of their population.

This book is intended for experts as well as non-professional people interested in inland fishery, particularly for fish farmers, anglers associations as well as private fishing grounds managers, for students of fishery and water management branches, state administration employees, water management experts as well as environmentalist. Its aim is not only to describe the current state of the management of open water fishery, but also to look into the future and to propose possible measures and procedures that would lead to the improvement of the fish population and biodiversity conditions in general, and at the same time that would improve the quality of leisure activities of those residents who engage in recreational fishing.

2

THE IMPORTANCE AND HISTORY OF FISHERY IN OPEN WATERS

J. Vostradovský

THE IMPORTANCE AND HISTORY OF FISHERY IN OPEN WATERS

J. Vostradovský

The aquatic environment and fish were attracting human attention already in the previous millenniums. Findings of scientists who studied archaeology and sociological human needs since prehistoric times have proved so in different places in the Czech Republic as well as in the world. Water and fish together always influenced the temporary or even permanent presence of prehistoric people along rivers and lake sides. The freshwater environment always represented a natural need of "*Homo sapiens*". Fish living in this environment enabled people to survive if no other food was available. It was already prehistoric man who soon discovered that even the deepest inland contained aquatic animals that represented suitable and easily accessible food. In addition, it was not only fish but also other organisms (e.g., bigger crustaceans) that were accessible throughout the whole year and these animals did not represent any threat during the catch. Fishing usually took place in the shallow aquatic environment and the most common methods were hand fishing or fishing by means of leisters, spears and arrows. Later, they started to use strings with hooklets and other suitable fishing gear. Fish hunters soon discovered that fish were easier to catch during certain seasons and at certain places. Fishing could also be practised by children, women or whole families, which was truly beneficial for all hunters (Fig. 2.1.). Fishermen's settlements were therefore more often established in places where rivers burst their banks widely into the countryside during spring seasons and when water returned back into the river bed, the fish that did not manage to return together with the drop in water level became an easy catch in areas where the water was drying up. In the Czech territory, these

Fig. 2.1. ***Netting and catching of crabs by hands from under the stones. Period wood engraving that originated at the end of the 16th century (Jost Amman 1591).*** *(The museum library at the Ohrada castle situated close to Hluboká nad Vltavou – Historical publication called "Od vody až po lov ryb" (From water as far as fishing).*

places were situated in the south Moravia since there were numerous side river tributaries of the middle and lower reaches of the Morava River or in the Elbe Valley. Other places in Europe included, for example, the Odra, the Danube, the Rhine Rivers and other rivers as well as their many tributaries. The same situation occurred also on bigger rivers elsewhere in the world. Netting on the Nile River was depicted in the picture at Mashaba (Tomba) at Aktihetep. It originated in 2500 BC (Maar et al., 1966).

2.1. Archival documents and fishery exhibits that are to be found in museums in the Czech Republic as well as in neighbouring countries

Flint microliths were often found in sand and gravel that had sedimented in locations where rivers used to burst their banks. They served as primitive knives or they were fixed in spears with back spikes (middle Stone Age) and were used for fishing and fish processing in the Elbe Valley, in the Ohře River Valley, on the Wisla River, on the lower reaches of the Rhine River as well as in many other locations. Often it was connected to places where large migratory fish species moved from seas to freshwaters (salmon, beluga, sturgeon) or where other common riverine fish gathered during the spawning season, or alternatively to places where fish hibernated (especially the cyprinid species). In the Czech territory, it was Andreska (1972, 1987, and 1997) who described in total the discoveries that originated in that period and afterwards. His extensive documentary pictorial photographic supplement included in the Agriculture museum publication documenting the oldest as well as newer museum collections (Andreska, 1972) and reminding of the professional fishing on the Czech and Moravian rivers should be especially appreciated. The most extensive collections of fishing gear are concentrated in the Czech museum collections that are to be found at Ohrada castle close to Hluboká nad Vltavou, in Litoměřice, Uherské Hradiště as well as in Třeboň, Písek and České Budějovice (more to be found in the fish breeding relationship). Individual museum fishery collections are very rare in neighbouring countries. In Slovakia, one can find historical facts about the local fishery development in the Svatý Anton Museum, a vast collection of historical equipment of Polish fishermen may be encountered in the Ethnographic Museum in Torun and in the Wisla Museum in Tczew. In Germany, the Dresden Museum (Museums für Tierkunde) exhibits the original gear that was used for fishing on the Elbe River – Atlantic salmon (*Salmo salar*) in particular.Stuffed female sturgeon (*Acipenser sturio*) measuring 2.6 m which was caught in 1880 in the Elbe River near Dresden (even 3000 pieces were still caught in Magdebourg in 1834) is also exhibited here. The Museum of hunting (Deutsches Jagdmuseum) situated in Munich reminds us of fishing in the Danube River, the local Austrian ethnographical museums in Orth an der Donau and in Wels possess similar collections of river fishing. Extensive original historical fishing gear that belonged to fishing on the Danube and Tisa Rivers as well as on the Balaton lake, that documented the past fishing methods and the local fishermen's way of life, can be seen in the Hungarian Horgászcentrum Aranyponty fishery museum. One of the last beluga (*Huso huso*) that was caught in the Hungarian part of the Danube River is also exhibited there. Similar historical exhibits are scattered around Europe and other places, most frequently in museums focusing on ethnographical collections. It results from other discoveries that by the end of the first millennium and in the early second millennium A.D. boats were already used for fishing. At that time, boats were either fired or carved always in one tree trunk, which was often from an oak-tree (these boats can be seen in some collections of the above mentioned museums).

2.2. The beginning of domestication of wild fish

Common carp (*Cyprinus carpio*) is still a commonly kept fish not only in European ponds. This fish that has its origin in wild river carp (sazans) has also its own extensive fish breeding history. Gaius Plinius (who lived between 23–79 A.D.) wrote about artificial ponds (*piscinae*) where also carp was introduced later on. During the Roman military expansion river carp was harvested from rivers (e.g., the Danube River and its tributaries) and introduced into "ponds" close to military camps and settlements to serve as a "reserve" since here they were available any time (not only in Slovakia, Hungary, but also in Italy). Theodor The Great ordered in the 6th century the transportation of sazans from the Danube River into Ravenna in Italy. Cloisters that acquired their own land, forests and waters embraced the opportunity as well. Domestication of sazans – carp in the Czech ponds took place probably no later than five centuries later. According to Andreska (1975) it was only much later that the introduction and domestication of some other species that had their origins in open waters, e.g., pikeperch, took place. The process in the Czech ponds dates back to as far as the second half of the 18th century. When professional fishermen were fishing in the rivers, they were usually obliged to hand over part of their catch e.g., to cloisters or owners of manors. They also had their share in transfers of riverine fish into "reserve" ponds that served for the fasting seasons. The outflow of fish from artificial reservoirs contributed to the permanent spreading of different fish species into river basins where the relevant species had not occurred before. The same thing was probably happening in different places not only in the Czech territory, but elsewhere in Europe too. In colder seasons live fish could have been transported to new military stations. Findings of carp bones located in the former military camps (for example Roman legions) testify to that fact. The 19th and the 20th century were marked by the intentional introduction of numerous species of fish, particularly into lakes and for fish breeding in ponds (e.g., rainbow trout, whitefish and herbivorous fish).

2.3. Fish depicted in symbols and legends

The extraordinary importance of open water fish in human nourishment left an indelible mark in the folklore, legends, fasting seasons as well as in heraldry. Fish scales represented wealth, fish eggs fertility. The mysterious life of fish under the water was for centuries full of mysteries and assumptions, it attracted the attention not only of professionals, but of the whole public as well. Most of the mysteries and legends always related to sea animals. Let us, however, stay in inland fresh waters, because there are many curiosities and legends that were told throughout the past centuries too (Norman a Greenwood, 1963).

Sometimes these led to false conceptions, for example, concerning fish reproduction (an example can be Aristotle's description of the mysterious life of eel who supposed wrongly that eel were born from decaying mud and worms). Fish were also recognized as a remedy for internal as well as external application. Oil of some fish was used as laxative (Castor-oil-Fish) or for treatment of eye diseases. "Oil" bearing the name "*Liquor hepaticus Mustelae fluviatilis*" that was extracted from burbot's liver and used for a treatment of ocular trachoma could have been bought in pharmacies as late as at the beginning of the 20th century. At some places crushed fish otoliths were used as a prevention of colic or it was held as an amulet protecting against being bewitched. The powder of dried fish was used for a long time to cure headaches, toothache or to reduce fever. In the oldest publications we can read about healing powers of the tench slime which was allegedly the reason why pike did not eat tench because it used the slime to treat its wounds (today's fishery science and practice have disproved it – pike regularly eat tench). Fish might have become fasting food already back then when starving people at the Tiberian (Galilee) lake were fed with fish thanks to a miracle. This "miracle" may be explained by annual mass spawning since at that time large schools of mango tilapias (*Sarotherodon galilaeus*) were swimming close to the water level and local people have called these fish "St. Peter's fish" up to the present time. It is said that young fish in the lake had a dark stain on their dorsal fins ever since – which is considered as St. Peter's mark. There are also other "holy" fish. For example, catfish belonging to the Ariidae family which can be found in the mouths of some rivers that empty into the Central and South American seas are called "Crucifix fish" since they have bones in their head skeletons arranged in such a way that if one uses ones imagination a bit it looks like an image of crucified Christ. This fish was sold as a fetish protecting against danger and diseases. The phenomena of fish falling from the sky (or more likely from the clouds) in Scandinavia was not explained for a very long time (which was documented in the oil painting Historia de Gentibus Septentrionalibus by Oleus Magnus in 1555). In 1806 frozen crucian carp with a length of 40 mm were falling down during a heavy storm in Essen. Even bigger and heavier fish (up to 2.5 kg) were raining down from the sky in Jelalpur (India). Fish were also raining down for two days in north Australia close to the Lajaman settlement and these fish came from a fish farm that was hundreds of kilometres distant from that place. Raining of fish caused by a tornado suction effect was recorded in Europe and the fish falling from the sky were not only herring, trout, smelt, pike and perch but also other freshwater and sea fish species (Norman and Greenwood, 1963). This section dealing with verified pieces of information as well as legends comprised also of news concerning the abnormal size of fish (length and weight). There are so many pieces of information that they could be published in an individual book. Unverified and therefore untrustworthy pieces of information that originated in the remote world reached Europe gradually as well and there was news about a fish called "Pirarucu", which was the Brazilian arapaima the great (*Arapaima gigas*), that allegedly measured 5 m and weighed over 200 kg. Similarly, the strictly protected sinarapan fish (*Mistichthys luzonensis*) that lived in the Luzon lakes in Philippines (in Camarines Sur province) attracted attention due to its size since this fish grew to the size of only 1 cm. Female adult cyprinid fish *Paedocypris progenetica* located in Sumatra measured 7.9 mm. A giant marked pike that was introduced in 1230 and caught in Württenburg in 1497 (i.e., after 267 years) measured 5.5 m and weighed 249 kg. This fish was brought to European fishermen and historical publications' notice by Gessner in 1588. The fish was pictured in a painting at the Lautern castle in Swabia (its copy is in the Natural History Museum at South Kensington), the skeleton can be found in the Manheim Cathedral. However, when its vertebrae were counted it was proved that it was a fake comprising skeletons of more pikes. Giant fish in the lower Morava River could have been the large belugas that migrated in the past through the Danube and its tributaries. These fish might have also reached the Czech territory through the Morava River which can be inferred from the fact that the King Matyáš I Korvín kept usually up to 60 giant belugas in a pond situated under the Totis castle near Komárno and he used the fish to amaze his guests with in the second half of the 15th century. Belugas were swimming around the mouth of the Morava River as far up as Austria and probably even Germany. Carp were often described as a fish with a long lifespan that might have lived up to 150 years (sclerites on fish scale were considered as their age by mistake). Carp's age limit was afterwards decreased to 38 years and carp in today's fish farms live to the age of approximately 15 years. Contrariwise, there are fish that live only for several months. In Africa, *Nothobranchius* is a representative of the genus that can live even in puddles of tree cavities (Rass, 1971). While the parents die fish eggs survive periodical drying of the environment. The genus *Cynolebias* from South America have several small representatives (up to 4 cm), some of which are kept by aquarists. The species *Aphia minuta* (goby from the Black Sea) hardly reaches the size of 5 cm and lives to the age of one year. More species of small-sized gobies were confirmed to live an extremely short time.

2.4. Historical importance of fish

The cult of fish was pursued in many religions. Buddhists considered fish as one of the nine symbols of success. The symbol of fish (Ichtys in Greek, Ichtus = fish) accompanied according to the Gospel the life of Jesus Christ and for persecuted Christians it represented a secret sign. The drawing of fish dating back to the beginning of the 3rd century was revealed even on a tombstone that was kept in the National Museum in Rome. A simple contour of a fish body has meant for Christians a personal expression and allegiance to their faith until now (current stickers with the fish contour can be seen on cars). Christians have retained the legend that related to miraculous feeding of many people with fish (see the previous mention of mouth-breeders in the Tiberian Lake). Fridays represented for Christians a fast day and the only meaty food they could eat was fish. Fish could have also influenced migration of peoples when, for example, the Norwegians started to settle in Iceland, the promised land with fish, in the 10th century. Fish even caused war which was aimed at taking advantage and control over fishing grounds around Newfoundland (France fighting with England in 1623–1713). In the Far East, Russia wrangled with Japan over the best fishing grounds of salmons, tunas and other fish as well as aquatic organisms not only at sea but also in brackish or fresh waters. Some people valued fish so much that they started to protect them as soon as indications of their decline appeared. According to Balon (1966) it was the Chinese from the Ming Dynasty (14th – 17th century) who started to protect fish first. Fish with mature fish eggs were proclaimed inviolable (their fishing would have been punished by divine retribution) and the first ban on fishing in spawning grounds has been introduced already during the Ching Dynasty (17th – 18th century). The word "fish" in the Chinese language always meant abundance and plenitude and when fish was given as a present, it meant the best wishes for its recipient (Berka, 2008). The Czech best known fish, which is indisputably carp, has a much longer history in China than in Europe. Carp has even become a symbol of courage. Carp represented the expression of "swimming against the current, against anger, laziness, rage as well as indifference". Balon (1974) elaborated on ideas of carp domestication during the thousand-year-old history of China before the beginning of our era. He mentioned that carp spread as far as central Europe through the mediation of Roman legions as well. The pieces of information concerning the history of fish life have always been accompanied by legends relating to fishing and fishermen's lives since the Middle Ages. These pieces of information testify to the great importance of fish throughout thousands of years of human history. Therefore some settlements and towns have included fish in their coat of arms. The coat of arms of the Litovel town situated in Moravia depicts carp and pike in a vertical position with the fish heads oriented down, the Aš town has chosen three graylings. If a fish appears in heraldry, there are usually two colours – a silvery colour for fish and blue for water (Markus and Pilnáček, 1933). Despite the fact that the biggest volume of fish catches was from sea-waters, freshwater fish have always had a great importance in the nutrition of people living deep inland. Many areas around the world would have become depopulated without their presence. This threat still applies to the deep inland situated close to the African large rivers and natural lakes (the Malawi, Tanganyika and Victoria Lakes) and the situation is similar elsewhere in the world too. Fish found their way from here even further into the interior (in most cases fish were dried or salted, later they were preserved otherwise). Furthermore, the 20th century contributed to the construction of dams built on large rivers that created new large water areas. The main reasons for their construction were to gain electric power, navigability and accumulation of fresh water, dams, however, brought new possibilities of fishing as well. Not only Europe, the whole of Russia with the large dam reservoirs situated on the Rivers Volga, Donand other great rivers, but also water structures on other continents can represent examples of the 20th century. The Kanji Reservoir in Nigeria, the Mantasoa Reservoir in Madagascar, the Nubia Reservoir in Sudan, the Volta Reservoir in Ghana, the Naser Reservoir in Egypt, the Cariba Reservoir in Zimbabwe or Cahora Bassa Reservoir in Mozambique have become famous in Africa. New fishing grounds exceeding many hundreds of thousands of hectares have been established due to large reservoirs' construction. Their banks have been settled on by fishermen and new fishing villages as well as local manufacturing industries have been established.

2.5. Development of fishing on Czech rivers

Professional river fishing has had its thousand-years-old tradition even in the territory of today's Czech Republic. Historians claim that part of the Slavs came to the Czech territory from the direction of the Black Sea coastline and therefore it cannot be excluded that they could have brought their experience of fishing in open waters with them. The Czech technical literature frequently connected fishing with many large species of fish that reached the Czech territory by upstream migration. In the Elbe River it was particularly Atlantic salmon (*Salmo salar*) and sturgeon (*Acipenser sturio*) that migrated from the North Sea, sea trout (*Salmo trutta trutta*) that migrated from the Baltic Sea through the Odra River, several species of the Black Sea sturgeons migrating from the Danube to the Morava River. At the same time domestic species of fish non-migrating long distances and occurring permanently in large numbers were also harvested in the Czech rivers. Andreska (1997) elaborates on the topic concerning earlier fishing on the Czech and Moravian rivers and he reminds us that it was already in Kosmas' chronicle at the beginning of the 12th century that clear waters and quality fish of the Czech countries were mentioned in writing. More information related to river fishermen's lives were preserved from places where they concentrated in larger numbers, such as in Prague, where 46 river fishermen lived in the second half of the 14th to the beginning of the 15th century. As late as at the end of the 14th century and in the following centuries only a few of them were acknowledged as burghers which indicates the lower position of fishermen within the citizen's hierarchy. Fishermen always belonged, due to their profession, to people for whom fish represented a relatively poor subsistence. They definitely could not have got rich by performing this profession. When there were not enough fish, fishermen lived a miserable existence and they were forced to earn some extra money in another way. They tried to sell their best catches. If they caught too many fish it was difficult to sell them at a good price. The fishermen's lives remained permanently on the same level; more often the level was rather low. River fishing was therefore maintained close to towns which assured better demand for fish. When the Czech oldest valley dam Jordán in Tábor was built on the Tismenický Brook in 1492, netting as well as angling were rented on the dam (Šedivý, 1956). The first emptying and fishing out of the dam took place in 1830.

It was not until 1848 when servitude was abolished that some fishermen became sole traders, although high-quality fish, especially anadromous species migrating into the Czech territory occurred less and less. It is stated that up to 80 families made their living by fishing on the Morava River, a similar situation most probably also occurred on the Czech Elbe River and professional fishermen were fishing in smaller numbers in other rivers too (e.g., on the Ohře River, etc.). Andreska (1997) described what the Czech fishing trade looked like and how it differed from a common farmstead – "a fisherman's house was situated closest to the river. It was possible to recognize a fish shop from afar since nets, fish baskets and fish traps were drying everywhere in the area, boats were fastened to the shore and live-boxes were floating on the water level." Fishermen themselves made almost everything they needed for fishing. Fish traps and other simple net and wicker traps were made of natural products that decomposed easily, which is why not many of these tools have been preserved up to the present. Various metal spikes that were used by poachers for fishing of large fish were preserved the longest. Seine nets and other kinds of nets started to be weaved from hemp fibre and it was mostly women who made the nets mainly during the off-season. Original fishing boats were carved in one trunk of a soft wood tree, e.g., a poplar tree, but there were also more durable oak boats that had the inside space for a fisherman and his catch carved in, in what is known as the fire technique.Production methods of these first fishing boats were identical on other continents as well. Similar fishing boats have been preserved in some countries up to the present. In South America more durable fishing boats were made of mahogany, the boats with a shorter lifespan were made of soft wood similar to poplar wood. In Peru, fishing boats of a similar shape were even made of sugar cane stems. In Africa and elsewhere, we can still see the "monoxyles" (which is a name for boats that are carved and fired in one tree trunk) that are called "banana-boats" and these boats still serve very well to individual native fishermen who fish predominantly for themselves and their families. In Africa, individual fishermen use these boats for fishing with mainly modern surface and bottom gill nets that are machine-made of synthetic fibres (these are made predominantly in Japan and China). Fishermen gain these for harvested and sold fish. Majský (2011) wrote about monoxyles that were found in the Czech Republic in Bzenec in 1922, in Veselí nad Moravou in 1928, in Spytihněv in 1929 and in other places as well. The more recent discovery of a monoxyle found in 1999 and deposited

Fig. 2.2. ***An fisherman fishing from a boat – monoxyle (a boat made out of one tree trunk) into a hand lift net and fish basket in the 15th – 16th century*** *(museum library at the Ohrada castle close to Hluboká nad Vltavou "O vodě až po lov ryb" (From water as far as fishing).*

in the Olomouc Museum comes from a gravel pit in Mohelnice. The similar "dlubanki" (can be seen in the Kartuzy Museum in Poland) that were still used on some lakes in Poland as late as at the beginning of the past century, were made of pine and oak wood and sometimes even of poplar or ash wood, Fig. 2.2. (Litwin, 1991). Brandt (1964) described what these boats looked like and how the professional gear for fishing in open waters have developed throughout the time, while Andreska (1972) concentrated on the situation in the Czech countries. Nonetheless, it can be stated that passive fishing gear with respect to their shape and practical application have not basically changed throughout the past centuries, perhaps only the scope of their usage has undergone a slight change. Naturally, the materials of fishing equipment have changed. The hemp plant that was used for net weaving was replaced with synthetic materials in the 20th century, wood that was used for production of floats (sometimes they were decorated) was replaced with plastic. Later, especially in the second half of the 20th century, machine production of fishnets made of synthetic fibres expanded. Shapes of passive fishing gear, e.g., fish traps, fish baskets, hooped nets, fyke nets, gill nets, etc. have been used in fishing of different open water fish species for centuries (mainly in lakes, but also in river tributaries as well as shallower places). This fishing equipment has proved effective for thousands of years. Fishermen had to learn how to work with wood and twigs they used for production of traps, live boxes and vessels. They found these habits of many years and the mastered craft of production of fishing equipment useful even later when the quantity of river fish decreased and when the interest in using the equipment in proliferating fish breeding increased (in the 13th century and later). Fish scales were used for production of decorative objects, eel and burbot skin served for strengthening of joints of wooden tools, such as flails, whip-stitching of saddles, sewing of coats, etc. (Hanzák et al., 1969). The decrease of some of the more valuable fish species attracted the attention of professionals and it was already in the 19th century when artificial stripping of fish (brown trout, rainbow trout and salmon) started to be enforced. Remy and Gehin became famous in France (1840), Jacobi in Germany (half of the 18th century), dry method of fertilization was introduced by Vrasskij in Rusia (1856) and by Green in America (1864). Rummerkirchen started to practice stripping in Horažďovice (CZ) as early as in 1823, professor A. Frič engaged very progressively in salmon stripping between 1853–1869. Podubský and Štědronský (1967) wrote about the history of artificial reproduction of salmonids in more detail. Artificial stripping spread out gradually throughout the 20th century to other species of riverine fish not only in the Czech territory, but also in the world.

As we shall learn subsequently, angling organizations started in Bohemia relatively late (by the end of the 19th century). The situation was similar in other European countries too (Vasiliu et al., 1987). Fishery (or more precisely fishing) in open waters on rivers was carried out until then mainly on the basis of the size of a stream and the quantity of fish present in a stream, how well the fish sold, the level of interest in the fishing ground (the number of settled professional fishermen dependent on this fact) and naturally who owned the river lands. Not until much later were provincial laws emerging that considered not only property relations, observance of boundaries related to fishing rights, conditions of lease or sale but also who the more rare species of fish that were caught (or their share) had to be offered or surrendered to. There was an old-established tradition originating in this period that not only estate owners, mayors but also other significant representatives of local authorities were granted large salmon or catfish (or other large fish). The Mayor of Prague was annually granted large salmon, later on it was catfish, which was gradually recorded in fishery magazines. The first magazine was Zemský rybářský věstník (The Provincial journal of fisheries) which represents the outset of today's magazine called Rybářství (Fishery) which was established in 1897.

2.6. Atlantic salmon in Bohemia

When dealing with the history of fish and fishery in the Czech open waters, we cannot refrain from mentioning Atlantic salmon – *Salmo salar* (previously known also as the Elbe salmon). This fish has become the

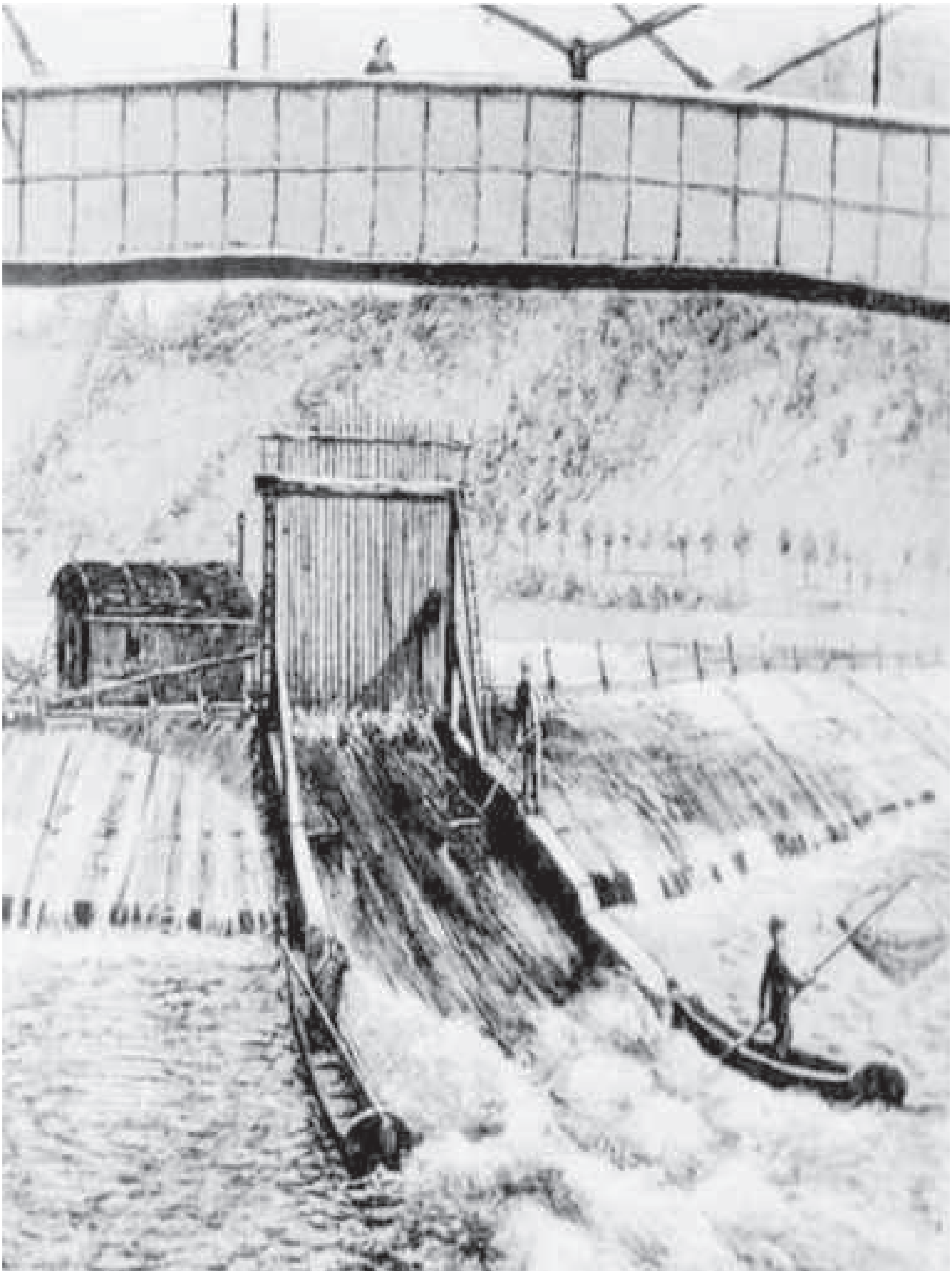

Fig. 2.3. ***Salmon fishing in the Prague salmon catching area in the second half of the 19th century*** *(drawing taken from the study by Frič, 1893 – Salmon of the Elbe, Biological and anatomical study).*

best known fish migrating from sea to inland waters even amongst the European historians who engaged in natural history. We can find many facts concerning salmon in a book written by Dyk (1946) who also quoted domestic authors who engaged in studying salmon and other riverine fish throughout the Czech history since the 11^{th} century (Balbín, Frič, Kafka and others). The majority of not only Czech but also German authors quoted the exceptional study related to "Salmon of the Elbe" written by Frič (1893) that also contained period pictures depicting fishing of salmon in the Prague salmon catching area (Fig. 2.3.). In Bohemia, salmon is still considered as the most important riverine fish in fishing's history. Salmon started to attract attention again by the end of the 20^{th} century in connection with the reconstruction of migration passability and with improved river cleanliness in the whole Elbe basin. Lelek and Bushe (1992) described the situation related to salmon and its historical development on the Rhine River and its Dutch, German and Swiss basins. Flasar and Flasarová (1974) gathered historical facts about salmon in the Elbe River in northern Bohemia in the 19^{th} century as well as at the beginning of the 20^{th} century. Fülner et al. (2005) concentrated on the situation in Germany in the Saxon part of the Elbe River. Andreska (1997) provided historical details that included individual memories of eyewitnesses of the Czech salmons, methods of their fishing and facts about anglers on the Czech rivers. Baruš and Oliva (1995) summarized findings related to salmons in the Czech territory in a well arranged manner and these authors mentioned a literary source written by Georg Handsch von Limus (1529–1578) as the first record of salmon in Bohemia (undated). Salmon attracted attention in the countries of the northern part of Europe with the streams emptying into the North and Baltic Sea. Most salmons migrated in Europe via the Rhine River (Lelek and Bush 1992). Therefore, it is no wonder that salmons were marked as early as in 1852 and an enormous migration was discovered of a salmon of Scottish origin since it covered a distance of 552 km in only four days. The catches of salmons in the Czech territory were considerably unstable in consecutive years until the beginning of the 20^{th} century which depended on the hydrological situation, intensity of fishing in the German part of the Elbe River and other factors too. Andreska (2010) summarized older as well as new facts and reflections on the future of salmon in Bohemia.

2.7. Historical methods of fishing in open waters

Apart from the application of personal physical abilities and various traditional and sometimes even primitive tools, fish hunters have always tried, from time immemorial, to use natural resources. As Perevoznikov and Burmakin (1979) stated, 233 kinds of plants were used for fishing throughout the world in medieval times and as late as by the end of the 19^{th} century. Leaves and bark of the *Piscida erythrina* tree were used for this purpose in Jamaica, the fruit of liana *Entada scadens* was used in Indochina, leaves, bark and root extraction of the *Gilia macombii* plant were used in Mexico until a few years ago, the plant called *Verbascum songaricum* was used for fishing in rivers and brooks in Tajikistan and many other plants or their parts were used for the same purpose. Plants were dipped in the aquatic environment where their substances (e.g., saponin) leached and the dazed fish swam to the water level afterwards where they were collected by fish hunters. Their consumption, however, required removal of the fish guts in due time. Natural ichtyocide rotenone (which was originally isolated from the Lonchocarpus nicou plant in French Guyana) was used by American Indians in South America until recently. Later on (20^{th} century), it was produced synthetically in large quantities and it was used as a very effective ichtyocide for elimination of undesirable and overabundant species of fish in closed waters (lakes). Most frequently it was applied in the United States (in 1953 it was still permitted in 49 states). The substance was later used for the same purpose in Europe as well as elsewhere in the world. In the Czech territory poachers used the seeds of fish berries (*Anamirta cocculus)* that originated in India and that contained poisonous picrotoxin alkaloids. Crushed seeds combined with other alluring baits caused that stupefied and poisoned fish emerged on the water level. Dyk et al. (1956)

described similar domestic plant resources that were used mainly by poachers in the Czech territory in the past. For example, cyclamen rootstock (*Cyclamen europium*), the Paris herb (*Paris quadrifolia*), euphorbia (*Euphorbium*), mullein (*Verbascum*), henbane (*Hyoscyamus*) created milder effects. It was already Bedřich II (in 1212) who first attempted to ban fishing with these resources.

Another method of fishing was by way of using certain animals. The first reports documenting human employment of animals came from the days of Marco Polo who witnessed the first fishing with otters during his travels in the second half of the 13th century. According to other historical sources, this method of fishing was practiced in other places as well, for example, in Indochina and Malaysia. In India people fished with trained otters on the Indus and Ganga Rivers. Isaak Walton wrote in 1653 that it was necessary to train otters for fishing as early as possible, preferably when they were three to four months old. Nowadays, fishing with cormorants (*Phalacrocorax capillatus* and *P. sinensis*) practiced in China is considered rather exotic. A ring was attached to the cormorants' neck; therefore they could not eat their catch. In Japan cormorants were transported in special cages even to more remote fishing grounds on the Nagare River in the Gifu prefecture. Professional fishing applying this method (although on a smaller scale) continued still in some Asian countries in the first half of the 20th century, while today it remains only a tourist attraction.

Only small changes in fishing methods and their survival throughout hundreds of years led to the fact that it was as late as 1920 when a Japanese scientist declared with certain pride at the Honolulu fishermen's congress: "Our fishermen work proudly with the same fishing gear as our old predecessors did". Since that time it held no longer true. Many things have changed since the second half of the 20th century and not only in Japan. Technology, the scope as well as gear of fishing have considerably improved especially in saline waters. It is less the case inland, especially in areas where fishing is done on a smaller scale until today and where some traditional fishing methods have remained in existence.

2.8. Expansion of artificial reproduction, stocking and introduction of fish

If we view the species composition of fish populations in open waters from a historical angle, we will find that it was as late as the 19th and 20th centuries when significant changes occurred. By the end of the 19th century and especially in the 20th century, owing to the development of transport technology and methods of artificial fish reproduction, introduction attempts spread substantially even to those places where it was previously impossible due to the limited availability of suitable places and excessive time limits necessary for transportation of live fish. Many species of fish that inhabited exclusively concrete inland waters, rivers and lakes until then were transferred from one river or basin into another river, lake, basin or even a continent. In some places they became gradually extinct but in other places they became naturalized in new conditions. In those days it was, for example, brown trout (*Salmo trutta*) that was introduced into Africa, Australia or South America and rainbow trout (*Oncorhynchus mykiss*) was introduced from the United States into Europe (mostly in the second half of the 19th century). Some transfers had a long history and attempts at their naturalization in the new environment were at times successful or failed. The whole spectrum of fish species adapted to their new living conditions insomuch that they became naturalized in the new environment and they were also used permanently for stocking into open waters for centuries. An assessment of the introduction of fish and crustaceans in the world was summarized by Welcomme (1988) who stated that 1354 introductions of 237 fish species took place in 140 countries and on different continents. Hanel et al. (2011) described findings concerning the introduction of exotic fish species into European waters. They listed 109 introduced species with at least 39 becoming locally naturalized. Some of these were realized intentionally with a certain aim but at the same time they contained risks, e.g., bringing in new diseases, environmental degradation as well as negative socioeconomic influences. An example of a negative introduction can be the stocking of Nile perch (*Lates niloticus*) into the African Lake Victoria which eliminated 300 native species of cichlids. Even though it was easier to catch and its meat quality was initially of benefit to anglers, the negative impact of this introduction influenced other elements of the lake ecosystem as well (Goldschmidt et al., 1993). The introduction and subsequent naturalization of freshwater "sardine" – lake Tanganyika sardine *(Limnothrissa miodon)* from the African Lake Tanganyika to the Kariba Reservoir situated on the Zambezi River had an opposite positive effect. From here it migrated to the Cahora Bassa Reservoir by downstream migration. In both reservoirs extremely large populations grew up which were harvested in many thousands of tonnes during the night by the fish being lured into nets by means of artificial light (Vostradovský, 1984, 1986). Lake Tanganyika sardines have provided fishermen and local residents with attainable and necessary protein resources since they permanently suffered from their lack. At present, the introduction of new species of fish is subject to professional reviews carried out by introduction committees in many member countries of the European Union and the suitability of new fish species should be thoroughly examined by technical institutes before its introduction. That should be the same in the Czech Republic.

2.9. The end of capture fisheries in the Czech territory

Many species of fish migrating upstream (anadromously) were endangered due to continuing construction of weirs, pollution and channelizing water streams together with technical modifications of river beds and shorelines. In the Czech territory, the situation related to the Elbe, Odra and Morava Rivers with their tributaries where anadromous migration of several species of fish nearly stopped in the first half of the 20th century. At that time professional river fishing gradually stopped too (apart from small exceptions in the frontier part of the Morava River). Rychecký (1966) wrote that it was Mr. Horák (the similarity with fish farmers bearing the name Horák in the Třeboň area is a mere coincidence) who was fishing on the Elbe River in Roudnice for the longest period of time and who paid 50% of the fish he caught above the weir and 30% of the fish he caught under the weir to the angling union and who caught annually 1.11 tonnes of fish at most. Jaroslav Hulík (1898–1983) was fishing the longest in the Elbe River in Kolín, with more information to be found in Andreska (1977). Hulík was repeatedly visited by researchers working in the Research institute of fish culture and hydrobiology in the 1950s and the author of this chapter was told (by Volf in person, 1960) that Hulík was catching eels of an extraordinary size and weight exceeding 5 kg as late as the forties to fifties of the 20th century. Fishing on the Elbe River between Ústí nad Labem and Děčín was carried out on a limited scale by angler organizations for half of the 20th century with the aim of gaining fry for other closed waters, for example, for a mine depression. It was expected that the Elbe fish would lose its disagreeable taste due to the then river pollution.

Some farmers from local anglers organizations were on an irregular basis attempting to harvest eels (*Anguilla anguilla*) in the Elbe River close to Liběchov in the 1950s (Fig. 2.4. depicts an angler catching "white fish" with a drop net and eels with classical wicker fish traps in the Elbe River in the 1956). Since there were much more brown bullheads (*Ameiurus nebulosus*) rather than eels caught in the fish traps, the fishing was ended. We cannot omit professional fishing that was carried out by the former State fishery companies by classical methods (seine nets, fish baskets, gill nets) predominantly in the Slapy, Lipno, Jesenice and Orlík Valley Reservoirs that lasted almost twenty years (since the 1960s–1980s). For example, in 1964 they netted 162279 kg (in comparison to 122974 kg of fish that were angled) mostly of cyprinid fish (Hanzák at el., 1969). Krupauer and Vostradovský (1966) stated that 35.9 kg of fish were caught in the Lipno reservoir 4 800 ha (netting and angling in total), 29.9 kg were harvested in the Orlík Reservoir (2700 ha) and 72.4 kg were harvested in the Jesenice Reservoir (750 ha) within one hectare of water surface in the same year. In those days the forgotten experience of netting was drawn even abroad (mainly in Poland). With the development of recreational fishing in the valley reservoirs and due to political and economic changes, the netting in valley reservoirs in the Czech Republic was ended as well at the turn of the 1980s and 1990s.

Fig. 2.4. ***One of the last fishing attempts with wicker fish traps and drop nets on the Elbe River close to Liběchov in 1956*** *(photo: J. Vostradovský).*

2.10. Angling (sport, recreational fishing)

Even though angling in inland open waters was initially aimed at direct fish consumption, this kind of fishing has gradually grown into a favourite pastime. Some historical drawings and first written texts that originated in the 15^{th} and 16^{th} century indicated that higher social classes engaged in angling for fun. Czech Květy magazine, issued in 1868, described an Egyptian relief in mausoleum with the words "standing on the boats, they are angling." Archaeologists found bone, iron and bronze fish hooks attached to hemp fibres, horsehair etc. that originated even earlier (Andreska, 1997). The application of ethics and cultivated approaches to angling have been apparent from the end of the 16^{th} and throughout the 17^{th} century when several specialized publications appeared that elaborated on this topic. The English fisherman Issak Walton and his work called "The Compleat Angler", issued in 1653, is usually mentioned in this context. There is an obvious positive relationship with the nature, morale and treatment of caught fish to be noticed in his book. More publications, some of which were even specialising in particular fishing methods (especially with respect to trout and salmons) were available in England in the 17^{th} century. Progressive fishing equipment and grouping of anglers into clubs in England (The Angler's Guide, London 1815) gradually hit Europe too. One of the larger publications issued in the Czech territory was called "Fishing sport" with the subtitle "Angling and instruction to catching and hypnotization of crayfish", was written by the local Czech author (Bucek, 1879). The author stated that the publication was intended for "those who desire to engage in fishing and who are interested in the mysterious aquatic world". Bubeníček's book with the title "About fish and fishing" which includes an interesting supplement concerning extermination of harmful otters and kingfishers is worth mentioning as well (Bubeníček, 1898).

2.11. Organization and angling associations, the beginning of legislation

It is evident that by the end of the second half of the 19th century, anglers started to form associations. This fact was connected with the appearance of the first offers of miscellaneous fishing gear. These associations rented stretches of rivers only to be able to practice the sport of fishing. The Opava association was established as far back as in 1873 and more and more associations were subsequently established, some of which belonged to agricultural subjects, the army, etc. Different problems and complications emerged especially in such cases in which the associations lay down rather flexible rules, when conflict situations with professional fishing appeared, when the number of members had to be reduced artificially or when licensing authorities had little understanding of the situation. The first anglers' club rules were rather flexible as well. There were plenty of fish in the Morava River and the general public was interested in them. In 1922 there were 42 applicants who wanted to form an association in Litovel with only 33 subsequently becoming members. They were angling with 4 rods and lines and initially they were using drop nets as well (during the initial years most members were traditionally using "drop nets, nets and bladders" until a ban was imposed in 1929). The situation was very similar also in Napajedla. It was only the wealthier people who owned a real fishing rod. The Morava River was already then subdivided into several fishing grounds and a permit allowing fishing within one ground in Litovel cost CZK 6. In 1921 an association comprising 20 members was established in Sedlčany on the Mastník Brook. Fishing was carried out with 3 rods and lines and with only (!) one night line (more lines were used earlier). The magazine "Fishery" brought information about jubilees commemorating 90–100 years of anglers associations mainly after 1990. One of the oldest Czech anglers associations (clubs) is The First Anglers Club in Prague which was established in 1886 by 27 members. In 1986 a publication called "100 years of sport fishing in Prague" containing abundant period illustrations was published and one can read here, among other things, that a permit for fishing on several grounds on different rivers cost in Prague in 1886 CZK 16 and that the club was established by people of higher social classes which probably had at that time a positive effect on the easier acquisition of fishing grounds not only on the Vltava River, but also on other rivers. The number of associations was increasing and as Spurný et al. (2010) stated there were 40 associations to be found in Bohemia after 1918 and in Moravia there were even 56 associations established after 1923. Associations merged into provincial groupings and in Bohemia they were based in České Budějovice, and their Moravian seats were in Velké Meziříčí and in Brno. The first unification and formation of "Unie rybářských spolků a družstev v Československé republice" (Union of anglers associations and cooperatives of the Czechoslovak Republic) took place in Prague in 1923. (The Moravian Provincial Association comprising 56 societies was established in the same year). In 1924 there were already 242 Czech, Moravian and German associations. Sýkorová (2007) and Spurný et al. (2010) expanded on other details and organizational changes within the association activities until the establishment of the Czech and Moravian Anglers Union. These two associations have been ensuring management of most open waters in the Czech Republic to the present day.

The first Fisheries Act came into existence in 1883 (it was registered under the number 22/1883). It was intended for The Lands of the Bohemian Crown (it was not published in the Imperial Code of Law until 1885). This Act ended free fishing in streams and new terms, such as salmonid and non-salmonid waters, private and public waters were introduced. The Act determined the implementation of fishing licenses, the nature of offences, methods of inspection of anglers, legal lengths of fish, etc. This Act was adopted as amended for Bohemia and Moravia even after the establishment of Czechoslovakia in 1918 and it took thirty years until the Act was substantially amended by a Decree issued on 1 May 1938. The subsequent Fisheries Act no. 62/1952 fulfilled already the requirements of the new political administration of the country. Even though the act created much confusion and ambiguity (for example, different groups belonging to the union movement and public enlightenment organizations were also able to take care of fishing grounds and fishery), the activity of anglers associations continued. Conditions of open water management were later adjusted by the Acts no. 102/1963 Coll. and 99/2004 Coll.

This chapter allowed us a quick glance at a small part of the rich history of fishery in open waters and to get acquainted with its importance for human needs. Specific conditions for fish life and fishing developed in the past on every continent and in every region that included a river or a lake. However, they have always had a common denominator. Fish provided people with an important source of nourishment and kept them alive when there was no other food available. We can notice a similar situation in several places in Africa or Asia even today.

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OPEN WATERS AND THEIR CHARACTERISTICS

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3

OPEN WATERS AND THEIR CHARACTERISTICS

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3.1. Basic division of open waters *(J. Kubečka)*

3.1.1. Running waters

Running waters can be defined as waters with a measurable one-way flow occurring in the majority part of their longitudinal profile which is caused by the Earth's gravity (and not by any other factor such as wind). Provided that planktonic organisms are present in running waters, the vast majority of them are being drifted down the stream. Running waters also differ from lentic waters due to the fact that most of their secondary production does not originate in the stream itself but rather a substantial proportion comes from the surrounding terrestrial systems (e.g., insects falling into the water).

If the stream springs at a sufficiently high altitude, a **gradient** of hydrological, physical and environmental conditions is formed along its longitudinal profile. The local communities of organisms correspond to such gradient. The stretches on the longitudinal profile are defined on the basis of the most typical fish species **–** the so-called **fish zones**. The concept of fish zones was designed by a renowned 19th century researcher, Professor Antonín Frič (1888), and gradually the five most typical zones were established (Tab. 3.1.1.). The concept of fish zones should be perceived as an attempt to generalize the regularities that occur in the complex system of the river continuum. There are many cases in which this concept cannot be applied (see chapter 3.2.). Defining the exact boundaries is also problematic. However, most running waters can be classified into individual zones and the zone division also reflects the division into the salmonid and non-salmonid fishing grounds quite well. **The trout and the grayling zones** usually correspond to the salmonid fishing grounds. Non-salmonid fishing grounds on the running waters in the Czech Republic usually include the **barbel and bream** zone. The **ruffe and the plaice zones** are typical for estuaries. Estuaries are very interesting stretches where freshwater fauna meet with various types of brackish waters. Salinity,

Tab. 3.1.1. ***Selected characteristics of the fish zones.***

Fish zone	**trout**	**grayling**	**barbel**	**bream**	**ruffe/plaice**
Stream type	mountain stream/brook	stream	river	river	river up to large stream
Bottom	rocky	rocky, gravelly	rocky, gravelly	gravelly, sandy, muddy	mostly sandy, muddy
Slope (%)	over 0.4	0.1– 2	0.03–0.15	below 0.08	below 0.05
Flow-rate	very fast	fast	fast	very fast	tide-dependent
Maximum temperature (°C)	12–18	18–20	18–22	20–25	22–30
Typical fish and lamprey species	brown trout, rainbow trout , bullhead, char, lamprey	grayling, rifle minnow, common minnow	barbel, nase carp, vimba bream, Danubian salmon	bream, catfish, pikeperch, silver bream, ruffe	bream zone and brackish water species (mullet, plaice, ruffe, goby, stickleback)

water level height and flow-rates are largely influenced by the high and low tide. These are also stretches through which diadromous fish pass during the spawning migration between the sea and freshwaters. Water in these stretches, mainly in large streams, is usually polluted and often very turbid due to tidal phenomena. Estuarine systems do not occur in the territory of the Czech Republic.

The trout zone represents the highest parts from the spring to the first 3–5 confluences with brooks of approximately the same size (the stream order is usually from 1 to 3, may be higher in mountain areas, see chapter 3.2.). These areas often feature the highest river slope, the cleanest water, the greatest oxygenation and the lowest temperature (Fig. 3.1.1.). The character and the extent of a salmonid zone depend on the altitude – most typically it is formed above 500 m from sea level. In lowland areas, the salmonid zone may not be formed even in streams of the first order (in headwaters). Typical salmonid streams in the Czech territory are up to 10 m wide and most of the stream surface is, under normal conditions, shallower than 0.5 m. The character of a stream is sometimes significantly modified along its course by the construction of artificial obstacles, i.e. weirs of various heights. Low steps may diversify the stream and create new habitats for fish, while, with respect to larger weirs, negative influences prevail that may complicate or stop fish

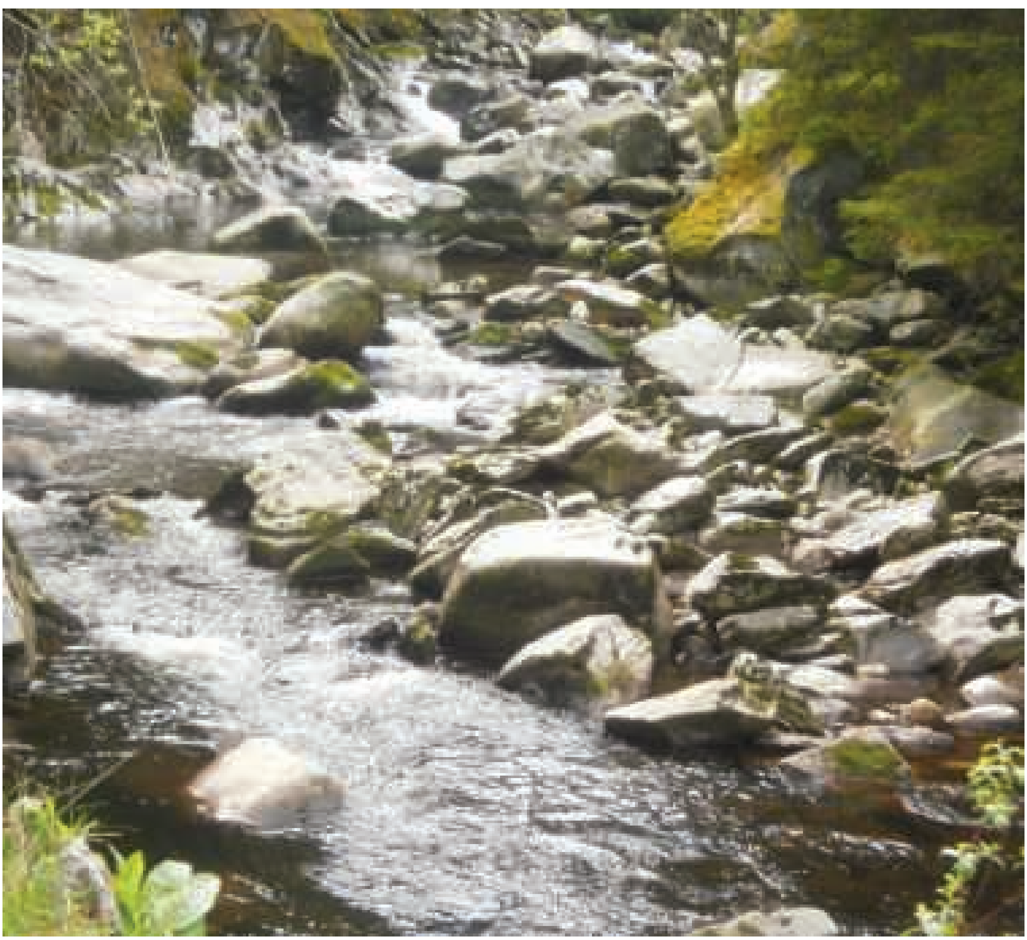

Fig. 3.1.1. *The salmonid zone – The Vydra River near Antýgl* *(photo: J. Kolářová).*

and invertebrate migrations. A major problem of small streams may be flow-rate fluctuations that have unfortunately been increasing recently as a result of climate change. Large flow-rates (floods) are usually tolerated easier by the stream inhabitants than the minimum flow-rates, when the living space diminishes considerably and, mainly in summer, the temperatures are rising. The adverse effect of extreme flow-rates is reinforced especially in regulated and straightened streams.

The main food source for fish is insects and their larvae (mayflies, caddis flies, stone flies, black flies and midge flies) or terrestrial insects' stages. Vegetation found in streams is represented mainly by periphytic algae, or by water moss (*Fontinalis*). The fish species community is usually very poor, the most common species being brown trout and bullhead. The amount of fish can vary. Poor mountain streams tend to have hundreds of fish and dozens of kilograms of fish biomass per hectare at the most, while rich submontane and highland brooks can have thousands of fish and hundreds of kilograms per hectare.

The grayling zone is typical for submontane areas where the river bed slope significantly decreases. The stream tends to be more than 8 m wide and features shallow long flows with a predominance of laminar flow (Fig. 3.1.2.). Flows may alternate with shallow pools that are inhabited by many species and are typical for lower-situated zones. The typical grayling zones occur in the Vltava River around the Volary town, in the rivers under the Beskydy Mountains and in the Bohemian-Moravian Highlands at 400 to 600 m above sea level. Similarly to the barbel zone, a number of grayling zones have fallen victim to weir and dam constructions. The structure of habitats is very varied (flow sections as well as more protected stretches with small particle sedimentation) and is reflected by an increased number of animals and plants. The groups of insects living here are the same as in the salmonid zone. In calmer areas there are tufts of water moss, water-starwort (*Callitriche*) or water crowfoot (*Batrachium*). In addition to the most characteristic fish species mentioned in Tab. 3.1.1., the grayling zone shares a wide range of species with the salmonid and barbel

Fig. 3.1.2. ***The grayling zone on the Malše river*** *(photo: FISHECU).*

zone. Most certainly, however, the species that require running waters prevail here, mainly the so-called true reophiles (reophiles of the type A, see Schiemer and Waidbacher, 1992; the overview of ecological groups is provided in chapter 3.2.). The fish abundance usually reaches thousands of individuals per hectare and the biomass reaches hundreds of kilograms.

The barbel zone was previously abundant in the Czech Republic but most stretches have been lost to weir and dam construction that has led to stream fragmentation (Lusk, 1995). Weirs often complicate the migration passability and they create stretches of several kilometres that correspond to the bream zone. The use of the river slope energy and anti-flood prevention have caused in many streams that individual weir pools with slowed water followed one another. The impoundment of the weir level that is lying lower starts immediately under the weir and stretches with running water have virtually disappeared. Valley reservoirs represent even a greater disaster for barbel streams since they have stopped fish migration in the reservoir profile altogether, and they have often changed tens of kilometres of streams into lentic water. Moreover, they modified the flow or even the temperature conditions in long stretches below the reservoir.

Typical barbel zones were located in lowlands and in geologically old, deep valleys of the majority of larger Czech rivers. Contemporary examples include stretches of the Berounka River located near Pilsen, the Otava River near Písek, the Elbe River near Střekov, the Bečva River close to Valašské Meziříčí, etc. (Fig. 3.1.3.). Typical barbel stretches feature long flows that are more than 1 m deep. In view of the high speed (more than 0.5 $m.s^{-1}$) and the bottom roughness, a large part of the flow is turbulent with frequent reverse flows. The content of nutrients and organic substances is considerably higher than in salmonid grounds mainly due to splashes from the catchment area and waste waters. There is increased vegetation and invertebrate productivity and consequently higher densities and fish biomass that can reach up to thousands of fish and many hundreds of kilograms per hectare.

Vegetation of the barbel stretches usually consists of diatoms, green algae and tufts of higher plants (the most common is *Batrachium* sp.). The benthic population tends to be abundant and it includes mainly caddis flies, midge flies, shellfish and larvae of mayflies. Similar to the grayling zone, the most common fish

Fig. 3.1.3. ***The barbel zone in the Bečva River*** *(photo: FISHECU).*

species in the barbel zone are the true reophiles. The most typical species are mentioned in Tab. 3.1.1. They include barbel, nase carp, vimba bream, and outside the Czech territory, in the Danubian River basin, Danubian salmon (*Hucho*). In addition to these species, reophiles with a large valency and spread which extends to the neighbouring fish zones are also common in the barbel stretches (chub, ide, dace, gudgeons, burbot and asp). Along the shorelines there are also some eurytopic species (roach, European perch and pike).

The bream zone. Before stream regulation in the Czech territory, bream stretches were far less abundant than they are today where they represent the most common type of river zone. As mentioned above, bream stretches have formed even in waters with grayling and barbel features due to the fact that a large number of artificial obstacles have been built. Bream stretches are located either in stretches with a low bottom river slope or in stretches that are impounded by weirs (Fig. 3.1.4.). The flow is slower and soft sediments are often found on the bottom as they are continuously carried by the flow from the higher elevation stream zones. Larger sediment transport occurs only during floods. The slower flow, the greater depth and the smoother bottom with sediments determine a large share of one-way laminar flow. As the stream basin grows, so does the amount of nutrients and in most streams traces of pollution can be observed (high share of organic and often extraneous substances, turbidity, heavy bacterial growth and sub-optimal oxygen saturation). If the lowland stream is not overloaded with waste waters, planktonic and periphytic algae abound in waters as do various aquatic and amphibious plants in shallower stretches. The benthos includes mainly larvae of midge flies, sludge worms, leeches, shellfish and larvae of mayflies and caddis flies. The primary production, the phytoplankton in particular, may cause oversaturation of water with oxygen, especially during sunny days. The water temperature is higher in the bream zone and the flow slows down, therefore, species requiring running waters give way to eurytopic species which represent, due to their flexibility in flow conditions, the transition between the rheophilic to the limnophilic species (the lentic water species, mainly bitterling, crucian carp, tench, rudd, weather fish, and sunbleak, see chapter 3.2.). Typical species include common bream, catfish, pikeperch, silver bream, ruffe, roach, bleak, pike, gibel carp and European perch. In addition to these species, some adaptable reophiles may also occur here (chub,

Fig. 3.1.4. ***The bream zone on the Elbe River, a stretch of the stream close to Lovosice*** *(photo: FISHECU).*

ide, dace, burbot, asp, gudgeons) as well as limnophiles, therefore, the number of species and the species diversity in the bream zone are high. The waters of the bream zone are deep and in the deeper parts it is not possible to wade or perform electrofishing easily. As a result, little reliable information concerning fish numbers and biomass in these waters is available. It is estimated that abundances can amount up to tens of thousands of fish and biomass usually reaches hundreds of kilograms per hectare (Pivnička, 1994).

3.1.2. Lentic waters created by geological river activity (river pools)

Streams with grayling, barbel and bream zones generally run through larger valleys where there is enough space for formation of a valley flood plain. The plain is inundated during flood periods and due to erosion and sedimentation, the river bed continuously changes its course unless it has been restricted by the construction of dams and by other flood control systems. Side channels, islands and "blind" river arms may form along the main channel (**eupotamon**). Blind river arms are channels that are either closed at one end, usually the upper end (**parapotamon**), or both ends (**paleopotamon**) (Fig. 3.1.5.). Paleopotamons – **old or dead river arms and pools** are separated from the river for most of the time and specific fish stock develops here which is usually a combination of limnophylic and eurytopic fauna. At the same time, old river arms tend to contain a significant amount of biological diversity with a large number of other animals and aquatic plants that belong to endangered and rare species. Some local anglers' organizations manage larger pools as specific fishing sub-grounds and with respect to fish management it is correct to apply here not only maximization of catches but also ecological aspects. The main game fish is carp, although tench, pike and perch are considered important as well. Blind river arms may also be the result of human activities. A large number of so-called cut-off lakes were created artificially during the regulatory straightening of streams in the 19^{th} – 20^{th} century. However, if

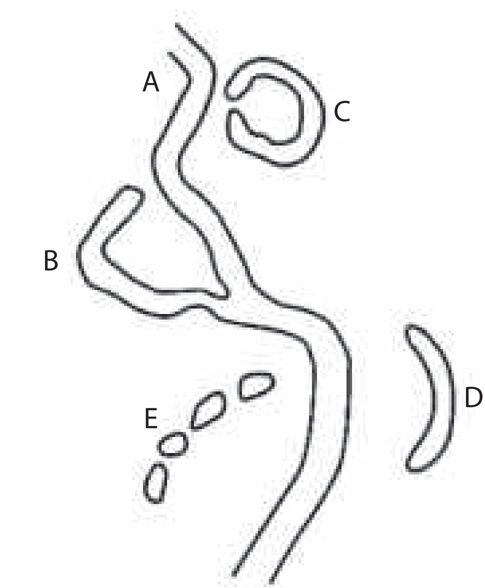

Fig. 3.1.5. ***The scheme of the river arms system.*** *A – the main channel, eupotamon, B – blind arm, parapotamon, C, D, E – dead arms of paleopotamon type (C is in all likelihood a cut-off arm that resulted from an artificial perforation of a river meander, E is a very old arm that split into a system of smaller pools that are threatened by filling with soil) (scheme: J. Kubečka).*

the regulations are carried out insensitively, formation of river arms stops and existing cut-off arms become slowly filled with soil and disappear without any replacement. The area of potentially valuable fishing grounds decreases, in addition, many limnophilous fish species have become endangered.

Old arms and pools are not necessarily always fully isolated from the main stream. If the water level increases, especially during the spring months as well as during floods, they may be flooded with river water. The formation of a typical pool community is subsequently interrupted due to the departure of some of the resident fish and immigration of mainly river fish, of which some may become trapped within an old arm when the water level decreases. In this way the species diversity of the present fish stock is increased. Regularly flooded old arms also represent a significant source of grown up fry for the main river stream. Pools situated at different distances from the main stream are flooded at different frequencies and, therefore, it is possible to find frequently flooded pools with an abundant and a diverse fish community within a well formed river floodplain (large streams with extensive side arms systems are in such cases viewed even as inland deltas) in comparison to arms that are flooded only occasionally. The least frequently flooded arms are at the same time less productive (floods usually bring nutrients) and limnophilous species predominate here. A scourge of non-flow-through old arms in bottomland forests are oxygen deficits, particularly in winter. These are advantageous to limnophilous fish that are less sensitive to low oxygen concentration. The so-called crucian carp's pools represent an extreme case since the oxygen level decreases in winter under the ice to zero and only crucian carp are able to survive these conditions thanks to their anaerobic metabolism.

Blind arms are also characterized by large numbers of vegetation and shelters which are used by phytophilic fish (species that spawn on plants). Pike occupies an exceptional position between these fish since it is usually the main predator and in some pools its predation pressure can determine the situation within the community. The Kurfürst arm of the Morava River situated near Olomouc is a well-described case. It is a parapotamon that functions as a trap for arriving fish due to a large share of pike within the fish community (Hohausová et al., 2000). Pools in well-functioning floodplains often represent good pike fishing grounds. If the catching of piscivorous fish is too profound, the fish stock in such pools tends heavily to overabundance of minor planktonophagous species (roach, sunbleak, bitterling, bream, silver bream and rudd). These species prey on invertebrates, they become stunned and prevent from satisfactory growth of non-piscivorous game fish (pools in the Elbe valley with the biomass exceeding 1000 kg.ha^{-1}; Oliva, 1957).

3.1.3. Draining and irrigation channels

Channels are either wholly artificial streams or modified lowland brooks, usually with a slow flowing. They may be similar to bream zone streams and during dry seasons may resemble lentic waters. They are mainly found in the lowlands and are usually highly productive with a large number of macrophytes which predetermines good conditions for reproduction and survival of fry. The channels are often stocked with grass carp in order to prevent development of macrophytes. The quantity, biomass and species diversity are high and larger channels in particular make for very interesting fishing grounds. More information is provided by Adámek et al. (1995).

3.1.4. Lentic waters

A common feature of lentic waters is the absence of measurable flow in a stream in the majority of the profile and there is usually a developed autochthonous phytoplankton and zooplankton community in open waters as well. Most of the planktonic production is usually created and used in a water body itself and it does not flow away down the river as is the case in running waters. A large amount of waters that are classified as lentic were created by damming the waters that were initially running (valley reservoirs). Similarly to the original stream, valley reservoirs might be of elongated shape (the so-called canyon-shaped reservoirs). From this point of view, it is possible to rather formally distinguish a large weir on a river (running water) from a small valley reservoir (lentic water). The limit that is usually used is the theoretical water residence time that is longer than 3 days when the flow is usually hardly noticeable particularly during summer flow-rates (Hejzlar, 2006). Lentic waters that were formed in streams (reservoirs, ponds) have almost always some type of a dam with gravitational outflow (outlet) and these are usually drainable, at least in theory. There are also lentic waters without a visible outflow and in the Czech territory these are especially mining pits which cannot usually be emptied (they are called lakes). The composition and development of reservoir and lake fish stocks are to be found in the individual chapter 3.5.

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3.2. Fish communities in open waters *(P. Horký)*

3.2.1. Variability of fish communities

Fish communities can be considered to be open systems whose composition can be characterized with a certain level of uncertainty by means of abiotic environmental parameters. The level of uncertainty, as well as the importance of individual factors which influence a community composition, are dependent on the detail related to the spatial level of assessment (Brown and Maurer, 1989). In general, three levels of assessment concerning the composition of communities are recognized: the local level, which assesses variability within a locality, the regional, which compares localities within one region, and geographical, which assesses regions between each other.

The highest level of uncertainty and variability of a community are to be found on the local level (Winemiller, 1996). There are biotic factors, such as competition (Grossman, 1982) or interaction between a predator and its pray (Moyle and Vondracek, 1985), as well as abiotic factors, such as flow-rate (Schlosser, 1985) or habitat heterogeneity (Gorman and Karr, 1978). The level of environmental variability determines whether the local level community compositions are more influenced by abiotic or biotic parameters. Abiotic parameters play a decisive role within an unstable and frequently changing environment (e.g., as a result of repeated flow-rate fluctuation) (Capone and Kushlan, 1991), while a community inhabiting a relatively stable environment is formed rather on the basis of biotic factors, such as competition, etc. (Ross et al., 1985).

From the regional point of view, fish community composition is influenced mainly by abiotic parameters describing longitudinal gradient and the size of the stream, such as stream order, distance from its headwaters or catchment area size (e.g., Kuehne, 1962; Hughes and Omernik, 1983). Qualitative as well as quantitative composition of fish communities changes within the longitudinal gradient. Fish communities in headwaters are thus composed of insectivorous species, whereas omnivorous and piscivorous species predominate in lower stretches of the stream (Oberdorff et al., 1993). Species diversity, which increases in the longitudinal gradient, changes in a similar way (Mastrorillo et al., 1998). The amount of available stream energy and habitat heterogeneity plays a fundamental role in this process (Vannote et al., 1980; Guegan et al., 1998).

From the geographical point of view, the composition of a fish community is influenced mainly by factors such as climate, continent, geographical latitude, speciation and spreading resulting from geographical barriers related to the development of the Earth's surface throughout the Ice Age (Hughes et al., 1987; Oberdorff et al., 1997).

Regional and geographical factors exercise a decisive influence on the composition of fish communities and these factors exceed local factors (Tonn et al., 1990). With respect to typology, which works with a regional and geographical perspective, the influence of local factors can thus be considered constant. Nevertheless, this does not mean that local factors that influence the variability of communities are generally insignificant. Local variability within the monitoring of the population's status is advisable to be decreased, for example, by repeated sampling of the same localities etc.

3.2.2. Hypotheses explaining variability within composition of communities

In order to explain the variability of communities at different levels, relatively large numbers of presuppositions have been expressed which can be summarized into three main hypotheses. The first hypothesis concerns the relationship between species diversity and the area and claims that species diversity increases with the size of an area (Preston, 1962). The second hypothesis, the so-called historical hypothesis, explains the development of species diversity on the basis of re-colonization of ecosystems after the Ice

Age (Whittaker, 1997). The third hypothesis concerns the energy input into a system and states that species diversity increases with the availability of energy (Wright, 1983).

An explanation of species diversity by means of an area can be understood in the aquatic environment from the point of view of the so-called theory of islands. Fish cannot spread across terrestrial obstacles. Rivers and especially individual river basins can be understood in a figurative sense of the word as islands since there is no direct connection between them. From this theoretical point of view, the number of species inhabiting the island is thus considered to be the result of a dynamic balance between immigration and extinction, which is dependent on the isolation and size of the island (MacArtur and Wilson, 1963, 1967). The authors assume that the immigration rate decreases with the distance of individual islands and the probability of species extinction decreases with the size of the island since the occurrence of larger populations is probable on a large island. Species diversity of fish communities was repeatedly proved to be dependent on different parameters which describe the stream size (e.g., size of the catchment area, stream order, etc.; Hugueny, 1989; Oberdorff et al., 1995), and it thus conforms to the basic principle of the theory of islands (MacArtur and Wilson 1963, 1967).

The influence of historical factors on the current composition and diversity of fish communities is minimal in comparison with jointly affecting ecological factors (Oberdorff et al., 1997). Nevertheless, a certain influence of historical factors on species diversity within the geographical scale can be recorded. For example, the influence of the scope of geographical latitude the river runs through is related to seeking shelters during glaciations in the Pleistocene. Fish had a better chance to find a suitable hiding place against the progressing glaciations in rivers running from north to south rather than in rivers running mainly from east to west (Moyle and Herbold, 1987; Matthews and Zimmermann, 1990). The relationship between species diversity and speciation between two continents can be defined in a similar way (Oberdorff et al., 1997).

The influence of energy availability on species diversity was for a long time considered only in the sense that a sufficient amount of energy decreases the extinction probability (Turner, 1992) and no great importance was attached to it (Oberdorff et al., 1997). A change in thinking came with the development of new analytical non-parametric technologies, so-called neural networks. Over 90 percent of variability of fish species diversity was explained on a global scale by means of neural networks, which was just based on energy availability and habitat heterogeneity (Guegan et al. 1998). At present, Wright's original hypothesis (1983), which concerns the influence of energy availability on the composition of communities, can be considered crucial.

3.2.3. Parameters suitable for typology of fish communities in the Czech Republic

As results from the above, it is important to include the variables in the typology which affect the regional and geographical level as well as an explanation of variability of fish communities that is based on all three hypotheses. The reason for taking all three hypotheses into consideration is the fact that even though the third energy hypothesis is considered to be the most accurate the remaining hypotheses which explain the residual variability of communities cannot be neglected.

If we enumerate suitable parameters and proceed from the crudest to the most detailed classification, we can start with geographical parameters. With respect to the size of the Czech Republic it is not meaningful to integrate those factors such as climate, continent or geographical latitude. On the other hand, an appropriate geographical factor can be the sea-drainage area that designates the river basins of the Elbe, Odra and Danube Rivers. The suitability of this parameter consists mainly in the dissimilarity of the Danube River basin, which is considered to be one of the main fish fauna refugia in Europe during glaciations in the Pleistocene, and therefore, it is richer in species than other river basins (e.g., Banarescu, 1989; Tonn, 1990; Wooton, 1991). The sea-drainage area parameter also includes the influence of the so-called historical hypothesis.

The most important regional parameters are those that are basically substitutive for energy availability in the environment. The summary parameter of altitude proves to be suitable as it also includes other parameters which influence the carrying capacity of the environment, such as temperature, vegetation and related primary production in a stream. Longitudinal gradient represents another parameter summarizing stream size in addition to its energy availability (the so-called River Continuum Concept; Vannote et al., 1980), which is expressed by stream order (Horton, 1945; Strahler, 1952). Stream order proves to be a suitable parameter for categorization with respect to its nature; however, there are some limitations (Penczak and Mann, 1990). Its suitability for explaining the changes within communities is, according to the above-quoted authors, dependent on the fact of how well the stream order expresses, in particular, the stream size, gradient and diversity. Incorrect classification can thus be arrived at in extreme cases. In the Czech Republic, this phenomenon can be encountered, for example, in some parts of the Šumava Mountains, where streams of higher orders are formed very quickly due to the large number of streams in the area, but the features of these streams may not correspond to streams of the same order in the rest of the Czech Republic. Despite these imperfections, stream order can be generally assessed as a parameter that is suitable for typology.

Other parameters that are suitable for the typology of fish communities can include river slope, which determines the suitability of the environment for typical fish species summarized into the so-called ecological groups (Schiemer and Waidbacher, 1992) and their mutual relationship. Oxygen and temperature conditions are also important since they determine the physiological boundaries for the occurrence of sensitive species, such as brown trout *Salmo trutta* morpha *fario,* L. (Reichenbach-Klinke, 1976).

3.2.4. Typical fish communities

With respect to local factors and natural variability, it is not possible to define a typical fish community in open waters with absolute certainty. Nonetheless, with respect to the fact that regional and geographical factors have a decisive influence on the composition of fish communities (Tonn et al., 1990), a certain functional framework for estimating the composition of a particular stream community can be defined.

Professor Frič (1872) was one of the first to engage in the typology of fish communities in a longitudinal profile. He defined the main fish zones within the Czech Republic's conditions. The idea of the division of fish communities into so-called zones was later worked out by many authors, e.g., by Huet (1959), who worked on the zonation of Europe, or by Hutchinson (1939, who was concerned with South Asia, etc. Although the majority of running waters can be assigned to particular zones (see chapter 3.1.), it was proved in the course of time that zonation of communities was unsuitable and too simple for the majority of ecosystems. It finds its use, in particular, in those places where sudden changes of conditions occur, for example, due to an abrupt transition from mountain to lowland conditions (Rahel and Hubert, 1991). In other cases it is rather the continuous change in the longitudinal profile based on the above-mentioned River Continuum Concept that is considered (Vannote et al., 1980). Fish communities in running waters should thus correspond, on a worldwide scale, to continuous change of the ecosystem conditions that they inhabit rather than to steep changes within the defined zones (Zalewski and Naiman, 1985).

The findings of Blachuta and Witkovský (1990), who recorded gradual changes within different indicators relating to fish communities in the Kladská Nisa River, which has its source on the borderland between the Czech Republic and Poland, are in accordance with this fact. They proved, *inter alia*, that the majority of the 17 discovered species spread across the whole longitudinal profile and it was only their proportional representation that changed. Similarly, the occurrence of bullhead *Cottus gobio* was proved in the Czech Republic's biggest rivers from the top localities (the Elbe River in Debrné, the Vltava River in Pěkná) up to the lowland streams (the Elbe River in Hřensko, the Vltava River in Zelčín). In all cases these were juvenile individuals that proved reproduction within the conditions of the particular stream (Slavík et al., unpublished data). From the estimation of typical communities' point of view, it is thus suitable to choose primarily the general parameters rather than the species parameters.

It is possible to identify fish species with similar demands on the environment and reproduction conditions within fish communities. Therefore, when classifying fish communities it is suitable to use the classical division into the reproductive (Balon, 1975; Tab. 3.2.1. at the end of the text) and the ecological group (Schiemer and Waidbacher, 1992; Tab. 3.2.2. at the end of the text). Reproductive and ecological groups "correlate biologically" together for the most part. In other words, it is possible to assign species of a particular reproductive group preferring a typical reproductive substrate and reproductive strategy to a particular ecological group preferring a certain type of environment for its life cycle. From this point of view, for simplicity's sake, it is thus possible to combine these groups of fish into three main groups – rheophilic, limnophilic and eurytopic fish species.

A) Rheophilic species (RS)

Rheophilic fish species occur in stream stretches with a higher river slope (rheophilic species A and B, according to Schiemer and Waidbacher, 1992). Rheophilic species spawn on a gravel substrate (lithophilic species) and sandy substrate (psamophilic species) (Balon, 1975). All psamophilic and lithophilic species are thus a subclass of rheophilic species. Rheophilic species represent the majority of natural fish communities in the Czech Republic. They occur throughout the whole longitudinal profile of streams, the only thing that changes is the proportional representation of individual species. Brown trout (Fig. 3.2.1.), minnow, burbot or grayling predominate in lower order streams. Barbel, dace, asp, chub or ide occur in higher order streams.

B) Limnophilic species (LS)

Limnophilic species (Schiemer and Waidbacher, 1992) prefer lentic waters of flood zones and pools (sunbleak, crucian carp, rudd, bitterling, weatherfish and tench – Fig. 3.2.2.). Limnophilic species are at the same time represented by species belonging to the reproductive phytophilic group that reproduce mainly above plants; alternatively they build nests from the rests of plants (ariadnophilic) or harbour in the branchial cavity of bivalves as an intermediate host (ostracophilic) (Balon, 1975). Limnophilic species occur typically mainly in the middle and lower stretches of higher order streams (stream order 7–9 Horton – Strahler).

Fig. 3.2.1. **Brown trout** *(photo: P. Horký).*

Fig. 3.2.2. ***Tench*** *(photo: O. Slavík).*

C) Eurytopic species (ES)

Eurytopic species do not prefer a concrete type of stream for their life cycle. These species are characterized by a large ecological valency and they are thus unspecialized and resistant to environmental changes (eurytopic species, according to Schiemer and Waidbacher, 1992). These species usually also include those species that have no specific demands on a spawning substrate, the so-called phyto-lithophilic species (Balon, 1975). Typical eurytopic representatives are, for example, roach, perch, bleak or common bream (Fig. 3.2.3.). Eurytopic species are usually in the minority within the native communities of higher stretches of streams. Their natural occurrence, however, increases in the higher order streams (stream order 7–9 Horton-Strahler).

Fig. 3.2.3. ***Common bream*** *(photo: P. Horký).*

Rheophilic species dominate naturally within fish communities in the majority of running waters in the Czech Republic. Their occurrence decreases with increasing stream size and they become mixed with limnophilic and eurytopic species. The defined general principles are, however, valid only on the condition that there is no or low disruption caused by anthropogenic influences. If anthropogenic influences increase, such as pollution or fragmentation of stream by artificial obstacles, considerable change in the composition of fish communities occurs (e.g., Peňáz and Šťouracová, 1991; Stanford and Hauer, 1992; Warren et al., 2000). The data related to the longitudinal profile of the Elbe River in the Czech Republic illustrates this fact very well (Slavík et al., 2006). A considerable decrease in biomass and abundance occurs in seventh-order streams, which is represented by the Valy, Lysá and Obříství profiles (Fig. 3.2.4.). A considerable decrease in the abundance of species preferring gravel and sandy spawning substrates (lithophilic, psamophilic species) and higher flow velocities (rheophilic species, Fig. 3.2.5.) has also been recorded. These species were replaced by species with a low ecological value that have no specific demands on a spawning substrate and flow velocity (phyto-lithophilic, eurytopic species). The abundance of species preferring native substrates and higher flow velocities rose again as far as the lower part of the Czech stretch of the Elbe River (the stretch from Ústí nad Labem to Hřensko), which has not been influenced by the construction of weirs until now. It can be supposed that the changes have been caused by the negative influence of anthropogenic factors that have modified the character of the middle stretch of the Elbe River. Canalization and segmentation of the stream multiply here its effect together with the sources of pollution (e.g., Pardubice, Neratovice). It has also resulted in a substantially higher concentration of extraneous substances in fish occurring in this part of the Elbe River (Randák et al., 2004, 2005). In summary, anthropogenic modifications altering the original river slope and the overall stream character occur together with pollution differences within the natural composition of fish communities.

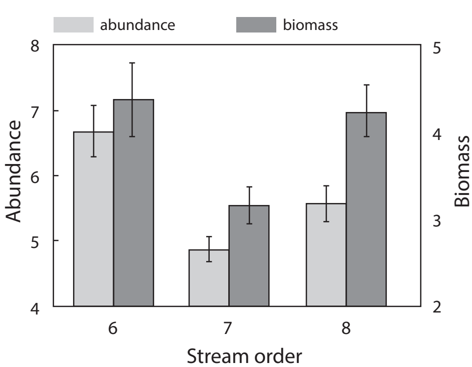

***Fig. 3.2.4.* Abundance and biomass of adult fish communities versus stream order within the anthropogenically modified Elbe River.**

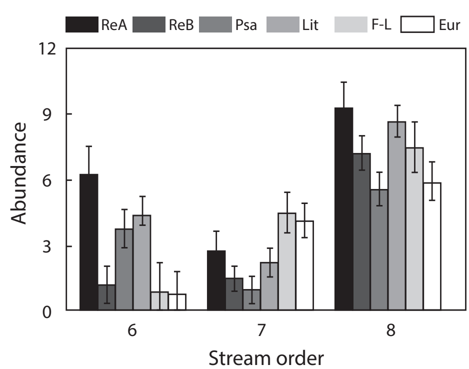

***Fig. 3.2.5.* Abundance of different ecological and reproductive groups versus stream order within the anthropogenically modified Elbe River** *(ReA – rheophilic A; ReB – rheophilic B, Psa – psamophilic; Lit – lithophilic; P-L – phyto-lithophilic; Eur – eurytopic).*

Tab. 3.2.1. ***Classification of fish into reproductive groups*** *(according to Balon, 1975).*

Reproductive group	English name	Scientific name
LITHOPHILIC clean rocky substrate, stones and coarse gravel	asp white eye blue bream little chop chub grayling nase carp rifle minnow barbel vimba bream rainbow trout brown trout common minnow	*Leuciscus aspius* *Abramis sapa* *Ballerus ballerus* *Zingel zingel* *Squalius cephalus* *Thymallus thymallus* *Chondrostoma nasus* *Alburnoides bipunctatus* *Barbus barbus* *Vimba vimba* *Oncorhynchus mykiss* *Salmo trutta* m. *fario* *Phoxinus phoxinus*
PHYTO-LITHOPHILIC no specific demands on spawning substrate	common bream ide dace Balon's ruffe ruffe stripped pope European perch bleak roach topmouth gudgeon	*Abramis brama* *Leuciscus idus* *Leuciscus leuciscus* *Gymnocephalus baloni* *Gymnocephalus cernua* *Gymnocephalus schraetser* *Perca fluviatilis* *Alburnus alburnus* *Rutilus rutilus* *Pseudorasbora parva*
PHYTOPHILIC aquatic or flooded, living or dead vegetation	pikeperch Wolga pikeperch silver bream common carp crucian carp Gibel carp tench rudd weather fish (mudfish) Balkan loach sunbleak European catfish pike	*Sander lucioperca* *Sander volgense* *Blicca bjoerkna* *Cyprinus carpio* *Carassius carassius* *Carassius gibelio* *Tinca tinca* *Scardinius erythrophthalmus* *Misgurnus fosillis* *Cobitis elongatoides* *Leucaspius delineatus* *Silurus glanis* *Esox lucius*
LITHO-PELAGOPHILIC eggs on stones, grubs float down the current	burbot	*Lota lota*
PELAGOPHILIC eggs float down the current	sabrefish	*Pelecus cultratus*
PSAMOPHILIC clean sandy bottom	common gudgeon whitefinned gudgeon Kessler's gudgeon stone loach	*Gobio gobio* *Gobio albipinnatus* *Gobio kessleri* *Barbatula barbatula*
OSTRACOPHILIC branchial cavity of bivalves	bitterling	*Rhodeus sericeus*
ARIADNOPHILIC nests of plants	three-spined stickleback	*Gasterosteus aculeatus*
SPELEOPHILIC eggs in cavities	tubenose goby brown bullhead bullhead Alpine bullhead	*Proterorhinus marmoratus* *Ictalurus nebulosus* *Cottus gobio* *Cottus poecilopus*

Tab. 3.2.2. Classification of fish into ecological groups *(according to Schiemer and Waidbacher, 1992).*

Ecological group	English name	Scientific name
RHEOPHILIC A **all life stages require running waters**	zingel whitefinned gudgeon Kessler's gudgeon dace chub Balon's ruffe stripped pope grayling stone loach nase carp rifle minnow barbel vimba bream rainbow trout brown trout common minnow bullhead Alpine bullhead	*Zingel zingel* *Gobio albipinnatus* *Gobio kessleri* *Leuciscus leuciscus* *Squalius cephalus* *Gymnocephalus baloni* *Gymnocephalus schraetser* *Thymallus thymallus* *Barbatula barbatula* *Chondrostoma nasus* *Alburnoides bipunctatus* *Barbus barbus* *Vimba vimba* *Oncorhynchus mykiss* *Salmo trutta* m. *fario* *Phoxinus phoxinus* *Cottus gobio* *Cottus poecilopus*
RHEOPHILIC B **some life stages require running waters**	asp white eye blue bream common gudgeon ide burbot sabrefish Balkan loach	*Leuciscus aspius* *Abramis sapa* *Ballerus ballerus* *Gobio gobio* *Leuciscus idus* *Lota lota* *Pelecus cultratus* *Cobitis elongatoides*
EURYTHOPIC **live in running as well as lentic waters**	ruffe pikeperch common bream silver bream tuberose goby common carp gibel carp European perch bleak roach topmouth gudgeon European catfish brown bullhead pike	*Gymnocephalus cernua* *Stizostedion lucioperca* *Abramis brama* *Blicca bjoerkna* *Proterorhinus marmoratus* *Cyprinus carpio* *Carassius gibelio* *Perca fluviatilis* *Alburnus alburnus* *Rutilus rutilus* *Pseudorasbora parva* *Silurus glanis* *Ictalurus nebulosus* *Esox lucius*
LIMNOPHILOUS **live mainly in lentic waters**	Wolga pikeperch bitterling crucian carp three-spined stickleback tench rudd weather fish (mudfish) sunbleak	*Stizostedion volgense* *Rhodeus sericeus* *Carassius carassius* *Gasterosteus aculeatus* *Tinca tinca* *Scardinius erythropthalmus* *Misgurnus fosillis* *Leucaspius delineatus*

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3.3. The Water Framework Directive (2000/60/EC) and its impact on fishery management within running surface waters *(P. Horký)*

3.3.1. History and development of the Water Framework Directive

An array of political decisions, as well as EU Member state agreements, which were implemented through the so-called Environmental action programmes during 1973–2000, preceded the formation of the Water Framework Directive. These action programmes focused not only on inspection of hazardous substances and protection of the sea against pollution, but also on international environmental treaties. A large number of directives and decisions that concerned only sub-parts of water management and protection were established. Council Directive 78/659/EEC on the quality of fresh waters needing protection or enhancement in order to support fish life, related specifically to fish.

As the new directions and related documents – more than 80 in total – were being established in response to current needs, the situation began grow unclear. The primary focus on surface waters and omission of groundwaters and coastal waters was heavily criticised. The Water Framework Directive – the Directive 2000/60/EC of the European Parliament and of the Council – was formulated throughout the 1990s on the basis of a large number of scientific and political discussions and entered into force on 22nd December 2000.

3.3.2. Scope of the Water Framework Directive

This directive represents the fundamental as well as the most important legislative instrument in terms of protection and water management of surface waters, brackish waters, coastal waters and groundwaters in the European Union. Implementation of the interim phases is scheduled by 2027. With respect to the large scope of the Water Framework Directive, it is impossible to state all relations and consequences resulting from the directive in this book. The aim is, however, to introduce at least the fundamental principles in the sphere of surface waters with an emphasis on fish communities and related fishery management.

The main purpose of the Water Framework Directive can be found in the definition stated in its introduction: "*Water is not a commercial product like any other but rather a heritage which must be protected, defended and treated as such*." The main objectives of the Water Framework Directive are defined in compliance with this definition as follows, to:

- prevent further deterioration and protect and enhance the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands;
- promote sustainable water use based on the long-term protection of available water resources;
- increase the protection and enhancement of the aquatic environment, *inter alia*, through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of priority hazardous substances;
- ensure the progressive reduction of the pollution of groundwater and to prevent its further pollution;
- contribute to mitigating the effects of floods and droughts.

3.3.3. The fundamental procedures of the Water Framework Directive – running waters

An essential part of the Water Framework Directive's implementation is international co-operation with the aim to prevent incorrect interpretation of the particular measures, to ensure comparability of data and the results of individual member states, etc. For this purpose, the Common Implementation Strategy (CIS) was adopted, which sets out the organizational system supporting international co-operation. Guidance documents (e.g., Guidance no. 7, 2003 on monitoring) are simultaneously issued under the terms of the CIS and define the criteria relating to the implementation of the Water Framework Directive in practice.

The basic administrative unit that the Water Framework Directive works with is the so-called water body, which is defined by means of abiotic typology on the basis of the mutual resemblance of stream stretches. A water body should represent the most homogeneous environment with respect to typology. The general typology of the river network of the Czech Republic includes, for the Water Framework Directive's purposes, four basic variables, i.e., sea-drainage area, altitude, geology and stream order (Langhammer et al., 2009). On the basis of the above-mentioned variables, the river network of the Czech Republic was divided into 23 main types; a more precise classification divides the water bodies further into 47 types and the total number of water bodies is approximately 1000.

In connection with type-specific reference conditions (i.e., the theoretical values of monitored parameters on the condition that there are negligible anthropogenic influences within the particular stream type), the following basic elements of ecological status are monitored and assessed: macrophytes, phytoplankton, phytobenthos, fish, macrozoobenthos and supporting elements of hydromorphology, the basic physico-chemical indicators and specific pollutants. These elements are assessed at intervals during a six-year period which also comprises the so-called action plans that focus on problem identification, corrective measures and at the same time on assessing the status and its development, and submitting a summary report to the EU institutions.

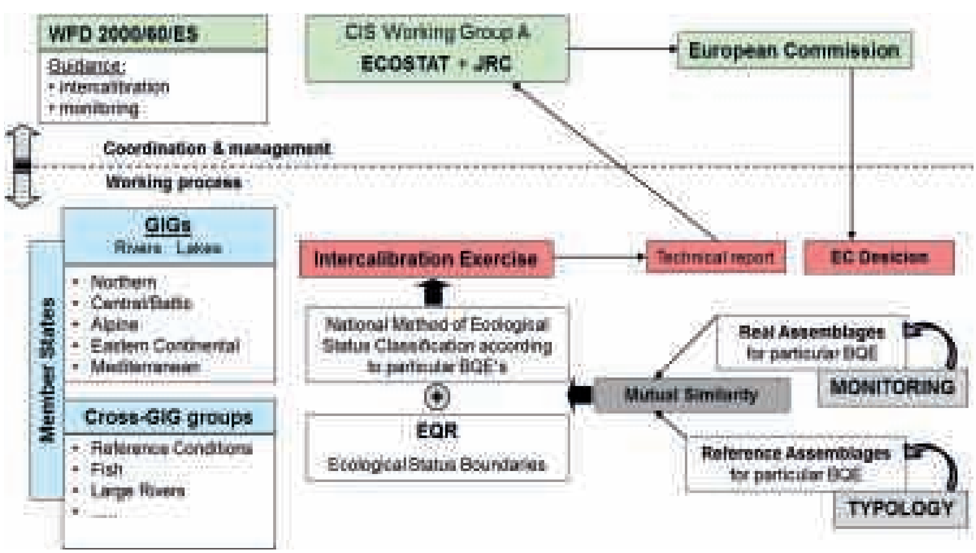

Fig. 3.3.1. ***Diagram of the intercalibration process*** *(edited according to the proposal of A. Slavíková; Guidance – operating guideline document; GIG – geographic intercalibration group; BQE – Biological quality element; EQR – ecological quality ratio).*

Assessment methodology is established at the national level for each element of ecological status (the so-called Biological Quality Element – BQE), which classifies the monitored water body into one of five classes ranging from 'high' to 'destroyed' ecological status. The objective of the Water Framework Directive is to achieve at least the second, which means a 'good' status. In order to be able to compare the assessment results throughout the European Union, the particular national methods undergo so-called intercalibration (Fig. 3.3.1.). On the basis of the intercalibration results, boundaries between the classes of high, good and moderate status have been established within individual national assessment systems. The results of the intercalibration assessment thus directly influence the management of water bodies within the European Union. Intercalibration is carried out on two basic levels. The first level subdivides the member states or their parts into so-called geographic intercalibration groups (GIGs). This classification is defined by the division of the European Union on the basis of abiotic (geographic) parameters. The other classification within the GIG is defined on the basis of particular biological elements. The so-called CROSS GIGs hold a specific position within the intercalibration process. It is typical for these groups that they intercalibrate across the particular geographical groups. An example of the CROSS GIGs which deal with intercalibration of large rivers, or of fish, is the so-called Large Rivers Intercalibration Group or River Fish IC Group. The Joint Research Centre (JRC), which is based in the Italian town Ispra, coordinates intercalibration at the European level. The Czech Republic participates actively in all of the above-mentioned groups and also co-operates on establishing the methodological approach of the whole intercalibration process (Horký et al., 2011).

3.3.4. Impact of the Water Framework Directive on fishery management

As already stated in chapter 3.2., fish communities change predictably as a consequence of the influence of anthropogenic factors. These changes can be classified by means of indices which assess ecological status (more information can be found in chapter 4.1.). Nonetheless, it is not possible to reliably separate the communities by virtue of particular factors. If unsatisfactory ecological status is confirmed in the particular water body all of the pressures influencing the particular biological element are identified and consequently suitable corrective measures leading to their minimization are implemented. The Water Framework Directive thus represents not only an instrument which assesses ecological status, but it also even contains mechanisms leading to its enhancement. With respect to fish, this can be the construction of fishways, sewage treatment plants or an overall revitalization of a stream, etc. Nevertheless, the ecological status of fish communities in the Czech Republic is not only formed by the above-mentioned anthropogenic pressures, but also by fishery management. Therefore, it is evident that unless the ecological status in the particular water body is enhanced after implementation of corrective measures, pressure on the change of fishery management will also be exerted. Fishery management will then be obliged to focus on protection of native populations and their natural reproduction, and the rules related to stocking of fish and fishing itself will be tightened. The particular themes are discussed in the following chapters of this book. With respect to obligations resulting from the Water Framework Directive, considerable pressure will undoubtedly be exerted in the near future within this sphere and it is therefore necessary that angling unions make organizational and conceptual preparations.

The Water Framework Directive determines the so-called heavily modified water bodies that are already modified insomuch that their return to the status of 'good' cannot be expected. It can be assumed that from the fishery management point of view, less strict rules would be required within modified water bodies which would enable more intense fishery use and more liberal management. Other water bodies, on the contrary, require much stricter rules than now. The objective is to increase the efficiency of the protection of ecosystems and subsequent enhancement of their ecological status at the price of reduced fishery use. It might be assumed that the Water Framework Directive will continue in this respect ideologically in the

Council Directive 78/659/EEC concerning the quality of fresh waters needing protection or enhancement in order to support fish life. According to this directive, the protection regime includes even those streams that are currently unsuitable for life of particular fish species due to anthropogenic pressures.

The influence of the Water Framework Directive on fish communities in running waters might be perceived unequivocally as positive. As a consequence of the scope of effect of this directive considerable pressure is exerted on the enhancement of the status of the whole ecosystem which supports the development of natural fish populations at the same time. From fishery management point of view, the data acquired from areal monitoring of the status of populations is certainly valuable. At present, no direct restrictive influence of the Water Framework Directive on the fishery management in open waters has been discovered. In the near future, we may, however, expect noticeable changes within this sphere relating to protection and restoration of native fish communities for the purpose of achieving the ecological status of 'good'.

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3.4. The Water Framework Directive (2000/60/EC) and its impact on fishery management within lentic surface waters *(M. Prchalová, J. Kubečka, J. Peterka, T. Jůza)*

3.4.1. Typology of lentic waters

The Water Framework Directive (Directive, 2001) defines three categories of lentic waters, which differ in the level of (anthropogenic) influence caused by human activity (Fig. 3.4.1.):

i. Natural lentic waters – the original natural character is preserved despite the potential considerable influence caused by human activity in terms of hydrology as well as aquatic ecosystem status and functioning.
ii. Heavily modified lentic waters – valley reservoirs and ponds created by damming natural streams that as a result have lost their original morphology and hydrology.
iii. Artificial lentic waters – water bodies that were created intentionally by human activity (channels) or are the side effects of human activity on the landscape (flooded quarries, sandpits and mining pits).

Fig. 3.4.1. ***Lentic waters in the Czech Republic*** *(from the top): Natural lake – Černé Lake (photo: P. Znachor), heavily modified water bodies – ponds (photo P. Znachor), the Kamýk Valley Reservoir dam on the Vltava River (photo: FISHECU) and an artificial water body – the Medard-Libík mining pit (photo: P. Znachor).*

For an assessment of individual lentic waters it is necessary to develop a system for classification of different water types (typology). The official typology of lentic waters for the purpose of implementing the Water Framework Directive is not currently available in the Czech Republic. Suitable criteria are currently being determined. The following text quotes the study results of Hejzlar et al. (2003) which discusses typology and the reference status of lentic water bodies.

The study defines lentic waters on the basis of the surface area (minimum of 50 ha) and theoretical residence time (three days minimum). Next, lentic waters are not considered to be weir basins on streams and isolated river side channels that connect to a river more often than once every five years even if their theoretical residence time is longer than three days. The overwhelming majority of smaller water surfaces and reservoirs (~ 30000) were eliminated from the list of lentic waters due to the surface area limitation. The study suggested a typology of lentic waters in the Czech Republic that was based on a description of morphological and geographical features that determine composition, as well as the structure of all biological populations inhabiting a particular body. The assessed indicators included geographical location, altitude, surface area, capacity, maximum and average depth, length of the tributary – dam axis, relative width, reservoir inflow and outflow connectivity, average flow-rate, theoretical residence time, water level fluctuation, water temperature and temperature stratification parameters (temperature – density stratification), geology and paedology of a river basin, chemistry (especially trophic level) and physical indicators for inflows and water in a reservoir.

For a better understanding of the measures that are to be implemented within the fulfilment of the Water Framework Directive it is necessary to have a general understanding of the functioning of lentic water ecosystems. A brief summary of the lentic water ecosystem conditions in the Czech Republic follows:

- **Altitude** – ranges from 150 m (Morava River valley close to Břeclav) to 1100 m (Laka and Plešné Lakes in the Šumava Mountains). Altitude considerably influences the type of fish communities in lentic waters. Cyprinid or percid communities predominate usually in reservoirs with a maximum altitude of 600 m, salmonid communities predominate in reservoirs situated above 600 m.
- **Surface area** – for the Water Framework Directive's purposes surface area is defined to be at least 50 ha. The maximum surface area is achieved in the Lipno Reservoir (4870 ha). Surface area plays an important part as the lentic water ecosystem is influenced by the riparian ecosystem (nutrients are absorbed from the shorelines and shading); however, this influence becomes secondary with an increased surface area. With respect to reservoirs above 50 ha, this influence is usually negligible.
- **Maximum depth** – the Dalešice Reservoir is the deepest reservoir in Czech territory (85 m). Depth represents a significant indicator of a littoral or pelagic ecosystem type. One of the principal features of lentic waters is the dynamic nature of relationships within the food chains of two fundamental ecosystem elements – littoral (shoreline zone) and pelagial (open waters). These relationships lead to two alternatives of a stable status – clear water status (littoral ecosystem type) where production of littoral plants (macrophytes) predominate, or turbid water status that is caused by algae (phytoplankton) production in pelagial (pelagic ecosystem type). Macrophytes are advantaged in waters with lower trophic level (oligotrophic to mesotrophic) and with high transparency waters since they use the light on the extensive bottom area and are less dependent on the content of nutrients in the water column than phytoplankton because they can absorb nutrients from the bottom. Fish stocks with a large share of piscivorous species support the dominance of macrophytes since they protect large zooplankton consuming large species of phytoplankton by predation of planktonophagous fish (Fig. 3.4.2.). Phytoplankton, conversely, wins in eutrophic (meso-, eu- and hypertrophic) waters since it creates turbidity and therefore prevents macrophytes from growing due to light limitation (Fig. 3.4.3.).
- **Flow-rate** – is characterized by the residence time that defines how long it takes until the total capacity of the reservoir changes theoretically. The minimum threshold is three days but this can last even up to several years (e.g., the Švihov Reservoir). Flow-rate influences the stratification development of

Fig. 3.4.2. ***Examples of overgrown littoral in the Nýrsko Reservoir on the Úhlava River which is abundant in fry of cyprinid fish*** *(left)* ***and is used by predators*** *(right) (photo: FISHECU).*

Fig. 3.4.3. ***Water with dense cyanobacterial bloom, the Otava tributary of the Orlík Reservoir*** *(photo: FISHECU).*

the water column, whereas stable stratification does not usually develop in waters with the residence time up to 10 days (flow-through reservoirs). Stratification develops together with stratified flowing in semi-flow-through reservoirs with residence time of 10 days up to one year. Inflowing water flows through the reservoir in a stratum corresponding to the water density. The flowing causes considerable spatial differences within the water composition and trophic level, which fish stock reacts strongly to. Reservoirs that are not flow-through and have the residence time longer than one year are characterized by stable stratification and the smallest spatial differences within the water composition.

- **Morphology and surface streams connectivity** – most Czech reservoirs were built by damming a suitable place in a river valley, which causes their canyon-shaped character and relatively long tributary – dam axis (the longest Czech reservoir is Orlík with an axis of 68 km on the Vltava River, 23 km on the Otava River and 7 km on the Lužnice River; Broža et al., 2005). In addition to canyon-shaped reservoirs, there are also basin or pond-shaped reservoirs (the Nové Mlýny and Lipno Reservoirs and ponds), which usually have small maximum depth. Reservoir fish stock is connected to riverine fish communities only at reservoir tributaries since the dam is usually impassable for fish (or more precisely it is passable only in downstream direction when especially young ontogeny stages drift away with the runoff water). The majority of important fish species are able to spawn in the reservoir successfully (bream, perch, roach, pikeperch and catfish). Some species, however, use the tributaries partially as spawning grounds (pike, ruffe, roach, bream and perch). There are also species that are not able to finish their reproduction cycle successfully in the reservoir without spawning migrations into the tributary (asp, bleak and chub). Some species, e.g., chub, use the reservoir as a wintering place (Hladík and Kubečka, 2003).
- **Water level fluctuation** – has an important influence on the development and quality of a littoral community (Fig. 3.4.4.). The natural course of water level fluctuation influences the amount of water in inflows and outflows, whereas the highest amount is reached during spring thawing or heavy rainfall. In summer, on the contrary, the water level usually decreases especially due to water outflow or offtake which exceeds inflow. The scope of daily water level fluctuation is determined by the method of the reservoir use, whereas the highest fluctuation occurs at pumped storage reservoirs that are used intensively for power production (Dlouhé stráně Reservoir up to 22 m per day; Sýkorová et al., 2003, two and 12 m per day at the Dalešice – Mohelno system, respectively; Hrádek, 2003).

Fig. 3.4.4.* Example of a littoral with flooded vegetation** *(left)* **and an exposed littoral after decrease of water level** *(right), the Římov Reservoir on the Malše River** *(photo: FISHECU).*

- **Nutrient concentration** – if natural lentic waters occurred in the Czech Republic they would only reach low to middle trophic level in unmodified river basins (oligo- to mesotrophy). This fact would be caused by the naturally low content of nutrients and other organic substances (Hejzlar et al., 2003). However, unmodified river basins do not occur in the Czech Republic either since nutrients from atmospheric deposition as well as the influence of nutrient retention in a reservoir are added to nutrients from river basins; therefore, the majority of Czech reservoirs belong to the category of eutrophic waters (Duras, 2007). Nutrient concentration gradually stabilizes in the course of the first 10 years of the development of each reservoir, thus also biological elements of lentic waters change dynamically depending on the trophic system status (this development is called succession).
- **Fish community** – fish represent a natural ecosystem element of all lentic waters in the Czech Republic (with the exception of some mountain lakes that do not have an outflow connected to a river system – Plešné and Čertovo Lakes). Despite this fact, there are no native lake species to be found in the Czech Republic, which is related to the absence of naturally occurring lentic waters in the Czech territory. Fish species inhabiting Czech lentic waters are species that originally inhabited rivers and these fish can prosper more or less in lentic water conditions (Fernando and Holčík, 1991). The composition of a fish community depends on altitude and trophic level. Cyprinid fish stocks typically occur in meso to hypertrophic reservoirs (fish biomass one or more hundred $kg.ha^{-1}$), whereas perch stocks occur more often in less eutrophic reservoirs, usually with steep shorelines, without developed littoral and with frequent water level fluctuation (biomass up to 150 $kg.ha^{-1}$). Oligotrophic mountain reservoirs can be inhabited by the salmonid system in combination with bullheads and minnows (biomass up to 50 $kg.ha^{-1}$). When assessing fish stocks it is necessary to take into consideration the general schemes of succession of reservoir and lake communities (chapter 3.5.).

3.4.2. Ecological quality of lentic waters – anthropogenic stressors and quality enhancement

Biological communities are formed dynamically as a result of processes within the whole river basins – river system – reservoir ecosystem and are sensitive also to changes happening outside their own reservoir. An ecological quality assessment therefore includes not only lentic waters but also river basin, its character and larger relations. We should also keep in mind that Czech reservoirs are relatively young (they were usually built during the course of the past 50 years) and their status may have not yet become stable, be it morphology (banks, bottom), chemistry (releasing nutrients from the subsoil) or the development of biological elements. This fact complicates the process of determining ecological quality. Therefore, when assessing quality we must think within a suitable complex framework that can be based on derivation of the features of the ecosystem's biological elements by using a comparison of related reservoirs with similar morphology, trophic status and climatic situation (Hejzlar et al., 2003; Kubečka and Peterka, 2009).

The basic principle of the Water Framework Directive is to determine the current ecological status and its potential enhancement. Since lentic waters in the Czech Republic are heavily modified by human activity, we are not concerned with ecological status, but rather with **ecological potential**. The essence of the assessment is thus to determine the maximum ecological potential and to find the difference between this and the current potential (Fig. 3.4.5.). The maximum ecological potential is in parallel to the reference conditions that are determined for natural water bodies. It represents the maximum qualitative level which might be achieved when all mitigating measures are applied that do not have a significant negative impact on a specific use (specific use is the use whereby these bodies are delimited as heavily modified or artificial). Five levels of ecological potential are distinguished in total. In addition to the **maximum** level, there are **good** and **better**, **moderate**, **damaged** and **destroyed** levels. The objective of the Water Framework Directive is not only to assess the ecological quality of water bodies, but also to improve their quality, which means to reach

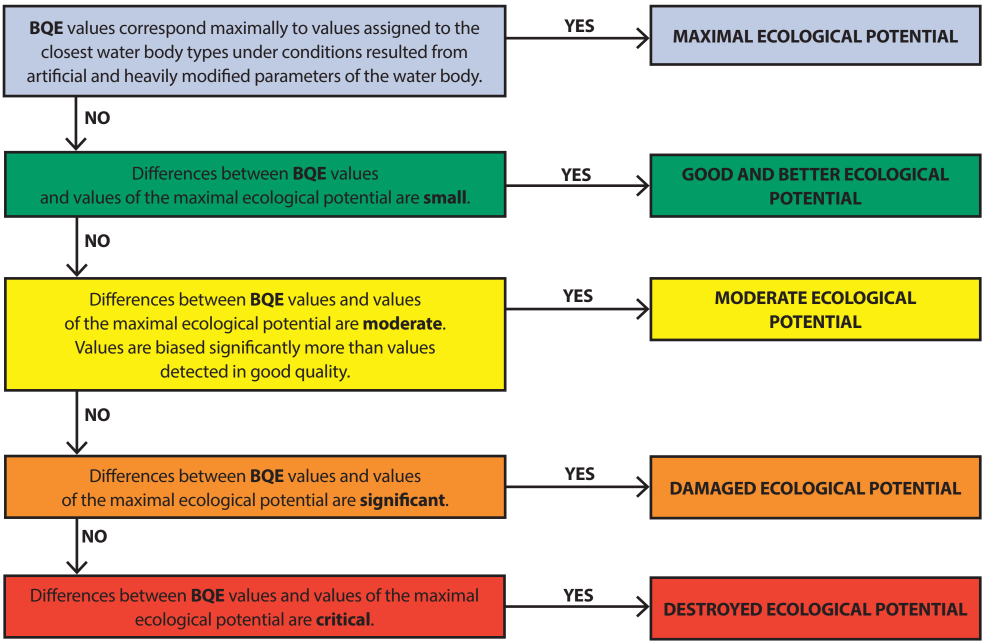

Fig. 3.4.5.* *Diagram of ecological potential assessment according to the biological quality elements (BQE) within the Water Framework Directive *(loosely based on Decree No. 98/2011 Coll. – The decree on the methodology for assessment of surface water bodies states the methodology for assessing the ecological potential of heavily modified and artificial surface water bodies and the requirements of programmes for surface water status identification and assessment, Appendix No. 7).*

the level of 'good' ecological status or potential. Therefore, we must adopt a particularly responsible approach when determining the maximum ecological potential. National methodologies for assessing ecological status/potential are separate for each EU member state's matters, however, these methodologies are subsequently subjected to intercalibration at the EU level in order to compare results. Ecological potential has not been subjected to intercalibration until now, although its potential form is currently being discussed at the EU level.

Human-induced factors that worsen ecological potential are called **anthropogenic stressors** (or also loadings, influences and pressures). Anthropogenic stressors with respect to the lentic waters of the Czech Republic are complex and are related to the almost complete transformation of the natural landscape into a cultural landscape where original ecosystems are situated only very seldom. The biggest and the most common stressor in the Czech Republic is the increase of trophic level (eutrophication). Next, it is acidification caused by mineral acids which results from air pollution (present mainly in mountain areas), increased concentration of toxic substances and hydrologic manipulation (water level fluctuation, disturbance of the natural stratification cycle). Apart from physical and chemical stressors, we can also distinguish biological stressors, which in the Czech Republic include stocking (introducing) non-native or unsuitable fish species that may cause the reduction or even elimination of certain ecosystem elements. Examples can be herbivorous species, such as grass carp, or stocking of carp which increase trophic level by disturbing the sediments, or cyprinid and percid species introduced into salmonid stocks.

It is possible to divide prospective **enhancement of ecological potential** into measures carried out in reservoirs and in river basins (Hejzlar et al., 2003).

Measures practicable within a **reservoir** include:

i. **modifications in the morphology of the bottom and shorelines** – support or suppression of riparian communities and fish habitats;
ii. **hydrological interventions** – inflow and outflow regulation influences nutrient retention, water level fluctuation influences the development of riparian communities;
iii. **sediment manipulation** – sediments represent sources of undesirable enriching of the water column with nutrients; sediments might be extracted and nutrients contained in the sediment might be absorbed with chemicals;
iv. **fish stock manipulation –** can support or slow down the undesirable eutrophication of lentic waters. Reduction of the total fish biomass and predominance of predators or salmonid fish within a fish stock causes a reduction of the system's trophic level (oligotrophication), enhancement of water transparency and supports the development of littoral communities of aquatic macrophytes. High fish biomass with predominance of cyprinid species usually causes water turbidity, eutrophication and a reduction of littoral communities – in such cases we can talk about a shift into a pelagic type ecosystem. Any input of substances for the purpose of increasing fish production (fertilization and feeding) always causes eutrophication of the system. Controlled fish stock manipulations represent demanding measures which do not bring the desired results unless they are applied rigorously.

In addition, these measure are successful only within certain limits of the system's trophic level, otherwise their effects only last a short time. More details on controlled fish stock manipulations can be found in chapter 4.7. Fish stock manipulations also include modifications in fishery management within Angling Union grounds. Nevertheless, the same procedures are to be applied not only in lentic waters but also in running waters (see chapter 3.3.). These procedures comprise, in particular, revisions of stocking plans and fishing rules, protection of native populations and support of their reproduction. These procedures might represent smaller or larger changes in the fishery use of lentic waters. It is advisable to view these changes to represent enrichment of fishing use (enhancement of the fishing experience in an environment with higher ecological quality) rather than its reduction (decrease of fishing intensity).

Measures leading to the enhancement of ecological potential carried out in **river basins** relate especially to the **decrease of pollution** of surface and ground waters (mainly from point resources – communal, industrial and agricultural; diffusion resources – recreational premises, small villages without sewerage systems and waste water treatment; and areal resources – erosion of agricultural lands, extraction of nutrients from soil) and the **increase of the stream's ability to retain nutrients**, the so-called retention ability (revitalisation of minor streams in agricultural areas, restoration and establishment of wetlands).

3.4.3. Assessment of fish communities in lentic waters

Species composition, abundance and the age structure of fish communities and sensitive species are assessed in lentic waters for the purpose of the Water Framework Directive. The assessment requires two basic methodologies – the methodology for sampling and processing fish and the methodology of fish stock assessment.

The methodology for sampling and processing fish in lentic waters (Kubečka and Prchalová, 2006, and its updated version Kubečka et al., 2010) includes a unique combination of three sampling gears. Sophisticated hydroacoustic research is used for estimating abundance and fish biomass and the research is based on an assessment of the reflection of ultrasonic waves from objects having a density different than water. Sonar (echo sounder) devices ensure emission as well as reception of waves. The qualitative composition of fish communities is determined by electrofishing in shoreline areas and by multimesh gillnets in all accessible types of habitats within a particular reservoir. The methodology focuses primarily on sampling the whole age spectrum of fish older than one year (1+ and older); however, fry are also recorded within the catches since this shows reproduction of individual species in a reservoir. Analyses of age composition of populations are carried out on the basis of scale reading, or on the basis of other structures, which is carried out by means of clearly defined annual increases (annuluses). More details on individual sampling devices can be found in chapters 6.1. and 6.2.

The methodology of fish stock assessment for determining the ecological potential of modified and artificial lentic waters of the Czech Republic has not been established until now. In general, to determine the maximum ecological potential it is necessary to choose the closest comparable surface water category, which in the case of lentic waters is the "lake" category. The values of relevant biological elements must correspond to the largest extent to the values assigned to such closest lentic water body type, however, it is necessary to take into consideration the physical conditions that result from heavily modified or artificial features of the assessed water body. Assignment of the closest body type, as well as the definition of reference communities, is rather complicated under the Czech Republic's conditions since there is an absence of natural lakes. Let us at least summarize the philosophical approaches to potential assessment by using accessible international assessment approaches and the expert knowledge of the authors of this chapter. The essential point of assessment methodology establishment, or more precisely a definition of the maximum ecological potential, would be, on the one hand, to determine the balance between lentic water use (for storage, water-supply, energetic, recreational, etc. purposes) and on the other hand, support of the status of the water body community that would be unmodified and close to nature. These efforts often seem to be counter-productive; therefore, finding a feasible compromise represents a great challenge.

The main steps for determining a methodology for assessing the ecological potential of fish stocks inhabiting heavily modified and artificial lentic waters are as follows:

1. defining the reference status and the maximum ecological potential;
2. preparing a list of potential anthropogenic stressors and indicators of the fish community;
3. testing and selecting those stressors and indicators that would occur mutually in statistically significant relationships;
4. determining the value levels of individual indicators on the basis of accessible knowledge in such a way that the levels corresponded to individual levels of ecological potential; and
5. calculating the total **E**cological **Q**uality **R**atio (EQR) and classifying the fish stock into a corresponding level of ecological potential.

There are three possible approaches for determining the **reference status** of fish stocks in lentic waters. The first approach is comparison with a similar system which is not, however, modified by human activity, the second is comparison with similar systems in terms of type that show maximum ecological potential, and the third is usage of historical data (Gassner et al., 2003; Kubečka and Peterka, 2009). It is possible to use neither the first nor usually the third approach with respect to modified and artificial lentic waters since similar unmodified systems as well as historical data concerning fish stocks do not exist. Both these approaches are also difficult to apply to natural lakes since unmodified lakes do not occur in today's cultural landscape either. The most suitable approach thus seems to be the second one, which summarizes similar systems in terms of the type, from which it determines reference states (Garcia et al., 2006). There are, however, some member states with natural lakes that have historical data concerning fish and their management; therefore, these states can apply the third approach as well. Historical data is a product of the time and so they are very often incomplete (the data only relate to commercially important species of fish) and usually consist only of species inventory. If the information that is available is insufficient it is possible to attempt to determine the reference status by expert inference. In Austria, for example, scientists have used historical data from 43 Austrian lowland to alpine lakes, which documented the status from around 1850, which was before the commencement of intense industrialization (Gassner et al., 2005). The list of species inhabiting the lakes at that time can be considered to be very close to the natural status, or precisely, more accurate reference status is no longer possible to determine. Scientists defined four types of lakes on the basis of the fish species that are specific for a particular community – charr, minnow, bleak and pikeperch lakes. When they compared historical fish stocks with the current fish stocks they discovered that 49 % of lakes lost a minimum of one fish species during the course of 150 years. Usually, these were the smaller and sensitive species. On the other hand, the total number of species increased, which was caused by stocking interesting, commercially important or non-native species (Zick et al., 2006).

A large number of indices of fish stocks have been developed in recent decades for different types of water in order to determine ecological quality. The most common and probably even the most effective index is the Index of Biotic/Biological Integrity (IBI), which is always adapted to the local conditions of a concrete application. Biological integrity means an ecosystem's ability to support and maintain a balanced, compact and adaptable community of organisms whose composition, diversity and functional arrangement is comparable to an ecosystem from the same sphere but in a natural unmodified status.

Indicators of fish stock, also called metrics or parameters, which are assessed by the IBI, can be divided into two groups: (1.) species composition and diversity (the total number of species, presence of intolerant species, diversity within an individual fish genus, a share of hybrids and other very tolerant species); and (2.) ecological indicators (fish abundance, share of omnivorous, insectivorous and piscivorous fish, share of deformed individuals). The parameter relating to share of deformed individuals could be interesting for us since it deviates in a way from the list of rather natural features. External deformities of adult fish bodies represent, however, a great indicator of degradation of natural conditions which refers to the long-term exposure of fish to high temperature, mechanical stress or chemical substances (contaminants), which cause lesions, tumours and fin deformities. The term used in scientific literature for this parameter is DELT anomalies (external **D**eformities, **E**rosions, **L**esions and **T**umours). It is mainly the high sensitivity of most fish species, a permanently low share of deformed individuals within reference conditions and a high information value within a wide range of natural conditions as well as stressors that contribute to the usefulness of DELT anomalies that serve as a reliable and exact indicator for the system's ecological quality (Sanders et al., 1998; Benejam et al., 2010).

The index of biological integrity was developed specifically for the riverine environment of all continents (which includes diet and reproduction ecological groups, age structure, growth, reproduction success, etc.), however, modifications of the index to the lake environment lagged behind. A successful attempt to modify IBI that could be applied to European lentic waters was carried out by Austrian scientists on alpine lakes when they were searching for a suitable methodology for assessing ecological status on the basis of the Water Framework Directive (Gassner et al., 2003). The biggest problem was to include the reference status which the original IBI does not consider, and another problem was to find a suitable abundance criterion. On the basis of a study of 67 lowland German lakes, German scientists summarized that to determine the index of ecological integrity via fish stock is, in general, only possible if the analysed lakes are firstly classified into groups based on their depth and at the same time if the main anthropogenic stressor is eutrophication (Garcia et al., 2006). Eutrophication is also the biggest stressor in the Czech Republic (see the previous sub-chapter) and this phenomenon is common across all European lentic waters. This is the reason why fish stocks represent a very good indicator of eutrophication together, for example, with cyanobacteria biomass, cover of aquatic macrophytes and the amount of chlorophyll (Sondergaard et al., 2005; Rask et al., 2010).

Apart from the problems with determining reference states, each assessment of ecological potential must find fish stock indicators that would reflect anthropogenic stressors the best. In this respect fish stocks of French reservoirs have probably been elaborated the best for the time being (Launois et al., 2011). The term **Fish-Based Index (FBI)** is used for modified IBI. The most common species in French reservoirs were common bream, roach, pikeperch and rudd, which corresponds to fish stocks in Czech reservoirs, therefore, the results of the French study are very valuable even for Czech conditions. French scientists gathered information about fish inhabiting 59 reservoirs via a standardized methodology and tested the stressors' influence on 11 groups of fish community indicators. The total number of tested indicators reached more

***Fig. 3.4.6.* Perch egg strand spawned on vegetation, Milada flooded mining pit** *(photo: FISHECU). European perch does not belong to exclusive phytophils; it can spawn on other substrates as well, whereas it prefers dead twigs of flooded terrestrial plants (Čech et al., 2009).*

than 70. However, only eight of the indicators had a statistically significant relationship with the monitored stressors – total biomass, number and biomass of tolerant species, number of omnivorous species, number and share of planktonophagous species, biomass of herbivorous species and share of piscivorous species. Simultaneously, the only stressors that became involved in the relationship with reservoir fish stock were stressors connected with the agricultural use of river basins. Seven out of eight indicators showed a positive relationship with these stressors, i.e., their values increased together with the stressor's intensity. The share of piscivorous species showed, however, an opposing relationship which is confirmed by the general observation of the fact that with an increasing environmental loading the share of predators decreases.

In addition to reservoir fish stocks, the French scientists also analysed, in the same way as in their study, the fish stocks inhabiting 30 natural lakes, which gave a very interesting result – the importance of any reservoir fish stock indicators did not prove true in lake conditions. Only three indicators of lake fish stock had a positive relationship towards stressors, which was a share of biomass of tolerant species towards urban stressors (density of population and roads, share of built-up area), abundance of exclusive phytophils (Fig. 3.4.6.) and share of biomass of planktonophagous fish towards agricultural stressors. The authors suppose that dissimilarity within the reactions of lakes and reservoir fish stocks to anthropogenic loading could cast doubt upon the use of natural lake systems serving as reference conditions for determining the ecological potential of reservoirs.

Efforts to define the ecological potential of heavily modified and artificial waters in the central and the Baltic geographical sphere which the Czech Republic also belongs to are only at their very beginnings. However, considerable progress in the development of methodologies for assessing ecological status for the whole area was made between 2009 and 2012. The best indicators of lake fish stock reacting within the area to anthropogenic loading were: total biomass, share of common bream and roach biomass, share of biomass of species reacting to eutrophication (common bream, silver bream, crucian carp and gibel carp, carp, whitefish) and the presence of littoral species (pike, tench, rudd) reacting to littoral degradation (shoreline modifications, insufficient cover of aquatic macrophytes). Boundary values were determined separately for each of the three morphological types of lakes (mixed, stratified and deep). The basic sampling methodology is standard fishing with gillnets (EN 14 757, 2005; CSN 75 7708, 2005). A tabular sheet was developed for fast and automatic calculation of ecological quality value. Although it must be added that the emphasis was placed mainly on the methodology applicable to the lake environment.

The results of the first year of monitoring fish stocks in the Czech Republic for the purposes of the Water Framework Directive (available at http://www.FISHECU.cz/projects/project-kubecka03/) and the database of the Institute of Hydrobiology, Biology Centre of the Academy of Sciences of the Czech Republic enabled ecological status assessment of 16 Czech reservoirs (the term ecological status, instead of potential, is used intentionally since the methodology has so far been developed for natural lake stocks, see the previous paragraph). The majority of reservoirs received the grade of 'moderate' ecological status (Lučina, Seč, Nové Mlýny II, Orlík, Želivka, Klíčava, Římov, Nové Mlýny III, Žlutice, Žermanice, Nýrsko – the reservoirs are arranged in ascending order according to the increasing EQR value). One reservoir (Vranov) was found to be in a 'damaged status' and four reservoirs achieved a 'good' status (Fláje, Těrlicko, Nové Mlýny I and Lipno). Since each EU member state is obliged to establish the methodology for assessment of ecological quality, the methodology that applies to the whole Czech geographical area and approaches of neighbouring states indicates the potential directions and valuable guidelines for developing of our own Czech methodology.

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3.5. Formation of new aquatic ecosystems – reservoirs, post-mining lakes *(J. Peterka, J. Kubečka)*

3.5.1. Succession – natural development

From a geological development point of view, freshwater lakes and reservoirs represent temporary biotopes which exist until their basins are filled up with sediments (Lellák and Kubíček, 1991). The sediment filling is the basic lake succession and it manifests itself by the decrease in importance of deepwater and open water habitats and by the increase in importance of vegetated shoreline habitats. With respect to deep water bodies of the lower trophic level, the sediment filling may, however, take thousands to millions of years. Therefore, a wide range of fish communities that are developing and persist for long periods may be distinguished and lake succession is mentioned in the strict sense of the word. Changes in the amount of dissolved nutrients and changes in global climatic conditions currently represent the most frequent initiators of lake successions, while both processes are taking effect in synergy and they strengthen each other (Jeppesen et al., 2010).

In the European conditions, Holčík et al. (1989) developed the basic scheme of succession of lake fish and recognized that the focal point of different fish taxons is especially dependent on the increasing trophic level of the environment (Fig. 3.5.1.). Mainly salmonid species (genera *Salvelinus* and *Salmo*) predominate in the poorest oligotrophic systems. In deeper, moderately mesotrophic lakes, whitefish of the genus *Coregonus* are the most characteristic representatives. Perch, with its relatively wide ecological valency from warmer salmonid waters up to eutrophic conditions, and pike play an important role with respect to the further increase in trophic level. Cyprinid species that are mainly accompanied by pikeperch and ruffe from percids predominate in eutrophic or even hypertrophic systems.

Beside the trophic and temperature regime, it is also the depth of a lake that plays an important role in the lake fish stock formation (Szczerbowski, 1985; Mehner et al., 2007), since it changes the proportions of littoral and pelagic components in a community as well as the usability of nutrients. The average qualitative

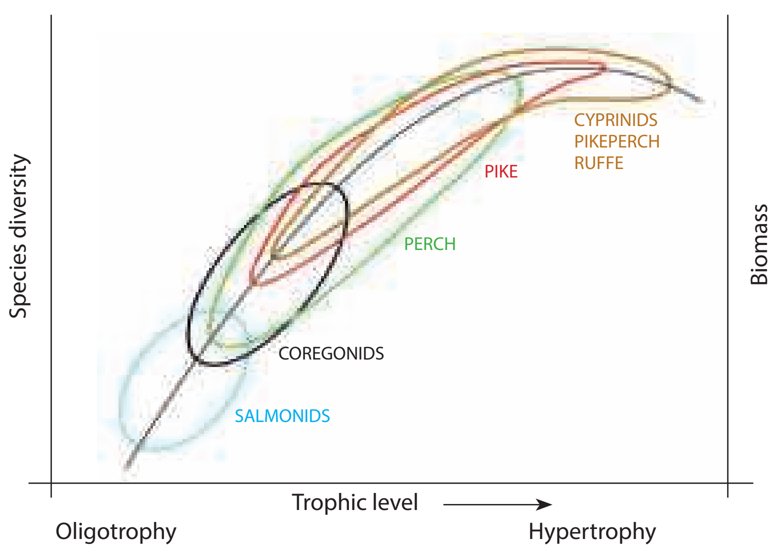

Fig. 3.5.1. ***Succession of fish communities in lakes with a gradual increase in trophic level*** *(according to Holčík et al., 1989, adapted).*

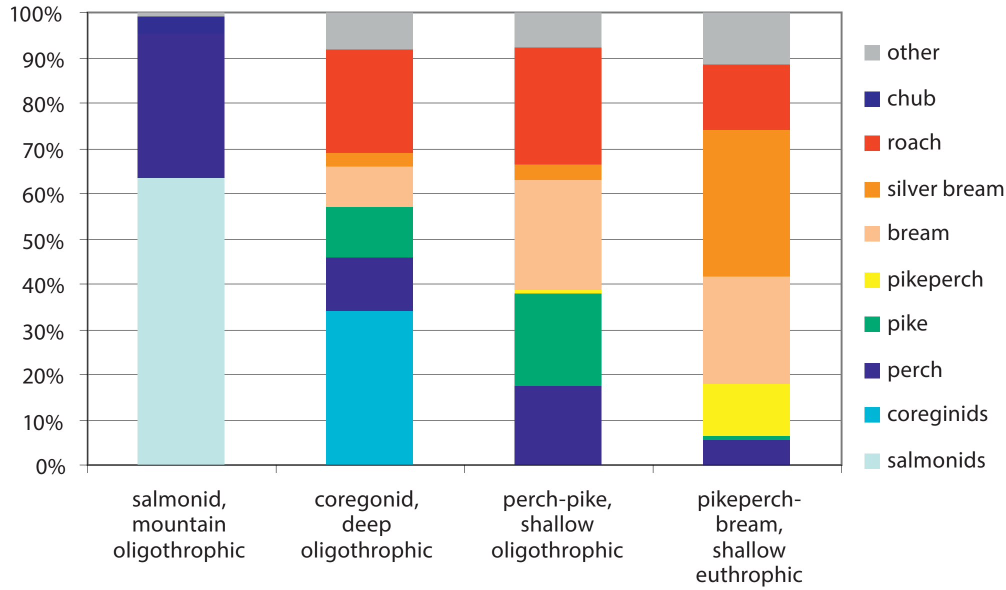

Fig. 3.5.2. ***Average biomass composition of fish stocks in the most characteristic lake types in neighbouring states (Austria, Germany, Poland)*** *(adapted according to Kubečka and Peterka, 2009).*

biomass compositions of fish stocks in the most typical lakes in neighbouring states are shown in Fig. 3.5.2. Salmonid species predominate in the cleanest and coldest lakes, although there is also a high share of perch and chub (or alternatively minnow that tend to be undervalued within the biomass composition together with other small fish due to their small size and sometimes also due to the selectivity of sampling methods). Fish stocks in whitefish lakes can be already relatively varied, they usually represent two-tier systems (Budy et al., 2009) where cyprinid species inhabit warm surface layers and whitefish inhabit the area around the thermocline. That is also the reason why the majority of shallow lakes do not have typical whitefish stocks (Mehner et al., 2007). Shallow lakes are again divided, on the basis of the trophic level and transparency, into relatively clean perch and pike lakes (other significant species are roach, rudd and tench) and eutrophic pikeperch-bream lakes that are also referred to as ruffe lakes (other significant species are silver bream and bleak). In addition to these most basic types, there are deep eutrophic bream lakes that whitefish are not able to inhabit due to oxygen deficits and lack of spawning substrate that is not silted up with sediment (Szczerbowski, 1985) and crucian carp lakes that correspond to small and shallow vegetated waters that are endangered by filling and oxygen deficits (see also Adámek et al., 1995).

As a consequence of human activities, the communities on the left-hand side in the Fig. 3.5.1. and 3.5.2. are more and more rare. The nutrient loading seems to be in general the most noticeable anthropogenic factor that modifies the ecological status of the lakes (Caseé et al., 2012). Fortunately, reverse development, the so-called re-oligotrophication, is also possible which is related to water treatment enhancement (Eckmann et al., 2007), or alternatively, to the decrease in industrial production and pollution (Rešetnikov, 2004). Succession consequently turns to species preferring oligotrophy and the fishing productivity decreases.

3.5.2. Lakes (mostly artificial in the Czech territory)

The succession fish communities in lakes, as natural aquatic ecosystems, was described in detail in the previous chapter. The qualitative classification of the Central European lake types according to fish communities is summarized in the Fig. 3.5.2. However, if we search for some illustrations in the conditions of the Czech Republic, we find that there are practically no examples of natural lakes with evolved fish stock. Glacial lakes in the Šumava Mountains that are the most famous as well as the most significant lakes with respect to the area are not inhabited by any fish and this state will probably continue for a long time even in the future, which is the result of acidification that occurred in the past century (Vrba et al., 2004). The status of other approximately twenty natural lakes, or more precisely, small lakes since their area does not often reach even one hectare, is usually completely unknown. From the point of view of the monitoring of fish populations' development and factors that influence them, far more interesting are artificial lakes, i.e. water bodies with a relatively much extended retention time, that were mostly formed by the filling of post-mining pits – especially sandy gravel pits and stone pits. Recently, **post-mining lakes** that were formed as a consequence of extraction of brown coal have become important as well.

Opencast brown coal mining and the relocation of the vast amounts of rocks related to it had a catastrophic impact on the ecological and aesthetical landscape quality. The hydric alternative of post-mining pits' revitalization is considered to represent promising and natural way of using post-mining pits when the mining is terminated. In coal grounds there are hundreds of mines and mining depressions of various sizes that were filled up with water. Most of them are small (fractions to units of hectares), have existed for decades and their functioning is close to smaller lentic waters. Lakes that have been created by controlled filling of large opencast mines are, however, unique phenomenon. As a result, water bodies with an area of hundreds to more than thousands of hectares, with many tens of meters depth and the total volumes that range from tens to hundreds of millions cubic metres of water have been established. These water bodies are considerably closer to natural lakes rather than to canyon-shaped valley reservoirs that occur in the Czech conditions in relatively great numbers, which shall be discussed in the following chapter. The primary use of newly established lakes should be recreation and support of biodiversity in those areas that have been devastated by mining. A very positive fact is that the development of fish stocks is scientifically monitored in all three currently emerging brown-coal post-mining lakes (Milada, Most and Medard, Fig. 3.5.3.) and fish stocks have been suggested and formed in such a way that they correspond to the reference states of natural lakes in neighbouring countries (Peterka and Kubečka, 2009; Kubečka and Peterka, 2010). In addition to that, measures leading to minimization of nutrient loading are applied and fast oligotrophication of lakes is assumed already during the course of filling or shortly after the filling is terminated. As a result, rare whitefish and perch and pike fish stocks can emerge here (see the Fig. 3.5.2.).

Hydric revitalisations (usually by spontaneous rising of ground waters after mining is terminated) of small and very small residual mining pits have been conducted in the Czech territory so far. Barbora Lake situated close to Teplice is the only bigger residual pit that was hydrically reclaimed by spontaneous filling in the 1970s that is due to its morphometric parameters relatively close to new post-mining pits that are filled in a controlled manner (it is relatively deep, the maximum depth is approximately 60 m, although its area is still rather small, app. 55 ha). Unfortunately, although the development of water quality and lake biota have been monitored since the 1980s, almost nothing has been known about the species composition and quantitative parameters of the basic element of the lake ecosystem – fish stock. From this point of view, the importance of the Milada Lake is fundamental since it is the first mining pit in the Czech Republic that was filled in a controlled manner where the filling procedure as well as the ecosystem development were thoroughly monitored since the very beginning.

The filling of the Milada Lake (residual pit of the opencast mine Chabařovice situated close to Ústí nad Labem) was taking place from 2001 and reached its final area (252 ha) in 2010. Fish stock was realized as

Fig. 3.5.3. ***The post-mining pit lakes Milada*** *(top, 2006),* ***Most*** *(middle, 2006)* ***and Medard*** *(bottom, 2010) (photo: J. Peterka).*

perch-pike type with respect to the typological classification of the lake – oligotrophic, shallow (maximal depth is approximately 25 m, Fig. 3.5.2.) and the stock was formed with the aim to reach a relatively low fish biomass (less than 30 $kg.ha^{-1}$) without a negative influence on the water quality in the lake (Vlasák et al., 2003, 2004, 2005; Kubečka et al., 2006, 2007; Peterka et al., 2008, 2009, 2010). During the course of the ten-year filling of the lake, fish stock dominated by five fish species has been reached – perch, pike, catfish, rudd and roach, completed with other eight fish species and one hybrid. A sharp increase in abundance of undesirable cyprinid species that was reported in 2005 (Fig. 3.5.4.) was stopped due to timely biomanipulative interventions (removing undesirable fish species and stocking of predators) and for almost the whole period of the lake filling the fish community was managed to remain in the so-called perch developmental phase. The current problem of the Milada Lake fish stock is the slowed down recruitment of new strong year classes of perch after its cycling population collapsed (see the chapter 3.5.3.). It was the identified threat of the collapse of the perch population that led during 2005 to 2007 to a decision to considerably reinforce the exclusively piscivorous species populations – pike, catfish and pikeperch, in order to prevent the possible turning of the fish community from perch dominated towards a transitional or even a cyprinid dominated phase. The creation was managed of immediately self-reproducing pike and catfish populations due to stocking of brood fish which reduced the development of undesirable species and categories through their predation pressure. The total abundance and biomass of fish older 0+ was assessed in 2010 to be a very favourable 74 individuals/ha and 8 $kg.ha^{-1}$ (Peterka et al., 2011). From the biomass point of view pike became a predominant species by the relative weighing of individual habitats

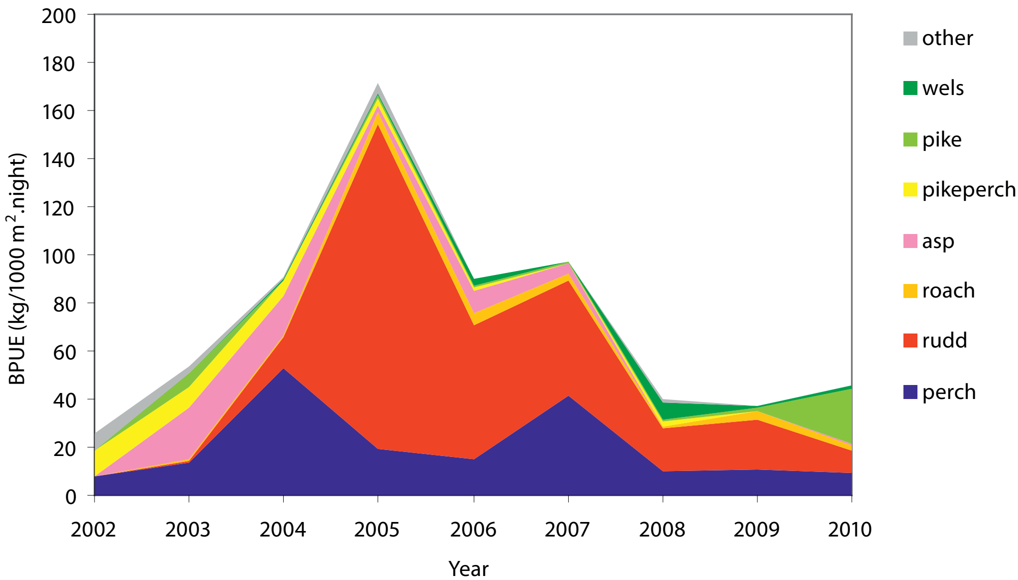

***Fig. 3.5.4.* Biomass development of littoral catches of fish older 0+ per unit of effort with multimesh gillnets in Milada Lake during 2002–2010 period** *(Vlasák et al., 2002, 2003, 2004; Kubečka et al., 2006, 2007; Peterka et al., 2008, 2009a, 2010, 2011), BPUE – biomass per unit of effort.*

(Fig. 3.5.4.) and the Milada Lake kept fully its typological classification – perch and pike lake – in relation to the fish community composition.

The other two mining lakes, where filling is currently taking place, are the Most Lake (near Most) and Medard Lake (near Sokolov, Fig. 3.5.3.). While the Most Lake was in September 2012, after five years of filling, about to reach its final area of 311 ha and only one meter remained to reach the final water level height, the Medard Lake was in the process of being filled three quarters full (the final area will reach approximately 493 ha). In contrast to the Milada Lake, these lakes are considerably deeper with the maximum depth of 70 m (Most) and 50 m (Medard) which corresponds to the typology of whitefish stock type (Fig. 3.5.2.). This fish stock type has also been implemented through stocking of maraena whitefish since 2011. Unfortunately, the short time of maraena whitefish stocking has not enabled more detailed assessment. Both lakes are currently in their initial phase of fish community development and the peak of the sharp increase in fish abundance has not yet been reached (Fig. 3.5.5., see below for details). It is very interesting that the development of the quantitative features of fish stocks in the Most Lake have progressed relatively quickly. The abundance in the lake rose during only two years from 0 to 550 individuals/ha and the biomass reached 60 kg.ha^{-1}, whereas the main source of the increase in population abundance was most likely the enormous reproduction success rate of the fish that came to the lake due to the fact that the satellite small lakes situated around the post-mining pit that was being filled up were flooded and next, it was the high survival rate of fry and their fast growth (Peterka and Kubečka, 2012). Similarly to the Milada Lake, the Most Lake is also going through a typical perch phase and perch will definitely be one of the most significant species in the future. The development of the fish community in the Medard Lake is slower in comparison to the Most Lake, in 2011, the abundance of fish in the lake was assessed to be 60 individuals/ha and the biomass was less than 6 kg.ha^{-1} (Kubečka et al., 2012). The number of known fish species in the lake was, however, almost double (8 vs. 5), which happened as a consequence of the direct filling through a channel from the Ohře River, in contrast to the filling process in the Most Lake which was carried out through a pressure pipeline sucking the water from under the Nechranice Reservoir. Both lakes should differ considerably also in the fish species' composition in the future. While the implementation of the system comprising whitefish-piscivorous species supplemented, apart from maraena whitefish, also with pike and catfish has commenced in the Most Lake, implementation of a whitefish-salmonid system is planned in the Medard Lake. Maraena whitefish will be supplemented in the latter system mainly with lake brown trout (type of species that emerges in lake conditions) that will occupy the role of the dominant predator. In this respect a certain complication is represented by the presence of pike in the Medard Lake that came to the lake probably due to undesirable stocking and it can be expected that it will be the main factor negatively influencing the prosperity of salmonid populations. It should be emphasised that in the future it will be mainly the appropriate fishery management of emerging lakes that will be crucial for sustaining piscivorous and salmonid stocks.

Oligotrophic lakes and their characteristic fish stocks currently belong to one of the most endangered biotopes of the European landscape as a result of eutrophication of surface waters. Oligotrophic lakes with developed fish stocks are currently absent in the Czech Republic conditions. Efforts to sustain salmonid fish stocks exist in several reservoirs in the northern Bohemia and northern Moravia (see below for details), however, sustaining of these fish stocks can not be assured despite the considerable support of populations through stocking, because of hampering caused mainly by the continuous nutrient loading and the reservoir management itself (water level fluctuation preventing formation of a macrophyte community, stocking of undesirable species, etc.). Research carried out during the course of the past twenty years in approximately twenty Czech reservoirs clearly proved that almost all reservoirs reached the status where cyprinid species predominated due to eutrophication and that the initial phases with the perch or even salmonid predominance were rare (Peterka et al., 2009b; Kubečka et al., 2010). In this regard, new lakes that are formed by filling of residual brown coal mining pits represent potential refugia for endangered fish stocks. In addition to that, with respect to their typologically faithful fish stock, they will also serve as model reference localities for comparison and assessment of the ecological potential of artificial water bodies (chapter 3.4.), which has recently become a requirement under the Water Framework Directive of the European Union (Hejzlar, 2006).

3.5.3. Valley reservoirs

Approximately 120 valley reservoirs with a total area of almost 30000 ha have been built in the Czech Republic. The development of fish communities is relatively well known and usually the community develops on the basis of species that are present in a dammed stream and species that are intentionally, or alternatively unintentionally, stocked. Two systems relating to the description of reservoir ichthyofauna development are applied: quantitative and qualitative. **Quantitative systems** try to describe the biomass and productivity development in three stages most frequently (Holčík et al., 1989).

1) The **Initial abundance upsurge** is related to the initial culmination of total production after filling (the so-called trophic upsurge, Straškraba et al., 1993) and it is also related to the fact that a large number of phytophilous and limnophilous species find a surplus of spawning substrate and shelters in the filled up terrestrial vegetation when the water level rises. The increase in abundance of successful species is so fast that during several years their number culminates within levels that usually exceed the long-term environmental capacity (Fig. 3.5.5.). The duration of the initial phase lasts from 2 to 12 years, depending usually on the dynamics and the climatic conditions.

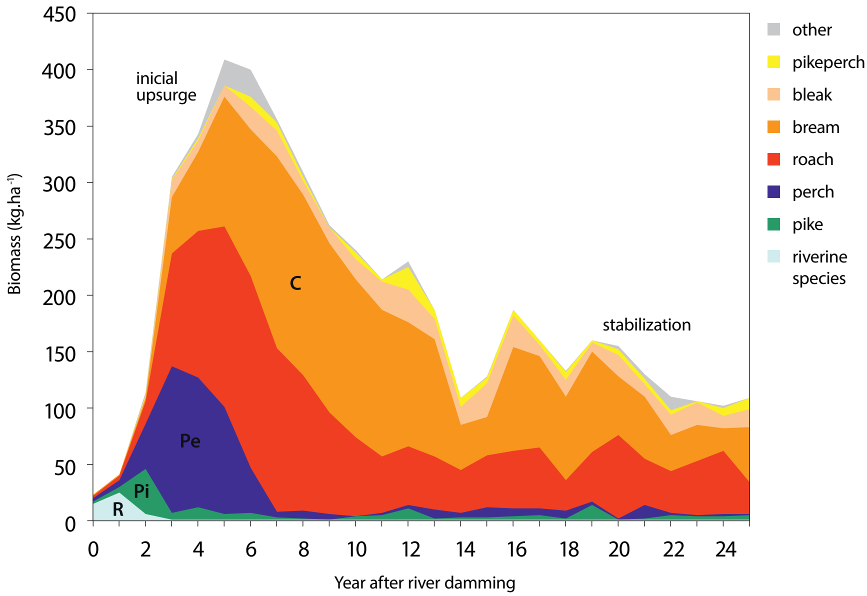

Fig. 3.5.5. **Hypothetical scheme of succession of a fish stock in a newly filled valley reservoir with the main stages being highlighted** *(with the use of studies: Kubečka, 1990, 1993; Seďa and Kubečka, 1997; Pivnička and Švátora, 2001; Říha et al., 2009a of unpublished data). R = riverine species dominance, Pi = pike dominance, Pe = perch dominance, C = cyprinid species dominance.*

2) The **Depression stage** regularly commences when the environmental capacity is exceeded. It is caused by the decrease in food resources after the initial population explosion dies down and also by the considerable decrease or even absence of plant spawning substrate and shelters for young ontogenetic stages. The formation of piscivorous fish populations can also contribute to the decrease. It often results in a multiple decrease of the number of fish in comparison to the initial culmination.

3) The **Stabilization stage** – a balance between reservoir productivity, spawning and habitat conditions is reached by the dampened oscillations (Říha et al., 2009). In general, it is stated that there is a slight increase in the fish production and accessible harvest during the stabilization stage. The main mechanisms responsible for that are cumulative reservoir enrichment with nutrients, sedimentation and population of submerged plants in the shoreline areas and spreading of new fish species that can diversify the use of food resources (Tereščenko et al., 2004). In the Czech conditions an increase in the number of fish does not tend to be observed at this stage and this may be connected to the moderate nutrient decrease that is currently taking place (Hejzlar et al., 2011), and also to the fact that the community formation of aquatic macrophytes in shoreline zones of the Czech canyon-shaped reservoirs is extremely slow (Duncan and Kubečka, 1995). As far as non-native species are concerned, it is applicable for Czech reservoirs that the wholly non-native (within the Czech sea-drainage areas exotic) species are not too successful in reservoirs. The Czech domestic species represent, however, a serious problem if they are unintentionally introduced in mountain and submontane reservoirs where they originally did not occur (e.g. pike, perch, roach, rudd, ruffe in reservoirs with salmonid fish stocks). On the one hand, non-native species increase the biomass, but on the other hand, they considerably damage the original valuable species.

Besides quantitative changes, many reservoirs undergo a succession of qualitatively dissimilar communities. **Qualitative classification**, suggested by Kubečka (1993, Fig. 3.5.5.), is commonly used for the Central European reservoirs:

1) **Community with riverine fish species dominance** is usually characterized by the very beginning of the reservoir's existence when the majority of the community comes from the original riverine species. The species diversity is low if the reservoir is built on small salmonid streams, however, it can be high in larger streams. Non-obligatory reophiles (dace, chub, asp, nase) and psammophiles (gudgeon) can find relatively convenient conditions in reservoirs and they can contribute considerably more to fish stock for many years. The length of the time period for which we can monitor a community dominated by riverine fish species is dependent on the fact as to how quickly the limnophilous and eurytopic species are able to occupy the ecological space of a new lake. In cold and oligotrophic mountain reservoirs, a community with the dominance of riverine fish species may persist for a long time in the form of so-called fish stocks with the dominance of salmonid species. Such development was documented in the Czech territory only in the Morávka Reservoir in the Beskydy Mountains (the most recent data by Piecuch et al., 2007). The temporary salmon phase took place in a large number of other reservoirs that was unfortunately replaced by other communities (Lusk et al., 1983).

2) The **pike developmental phase**, supported by the surplus of vegetation as spawning substrate and habitats for phytophilous pike, always used to be very attractive for recreational anglers and it is surprising how little reliable information on fish communities is in this interesting developmental phase available. The share of pike ranges from 15 to 70% (Kubečka, 1993), the higher numbers are probably overestimated due to the selectivity of fishing methods; therefore, the realistic share of pike in biomass can be between 15 to 20% (Holčík, 1997; Hrbáček, 1981). The pike phase usually terminates very rapidly due to disappearance of

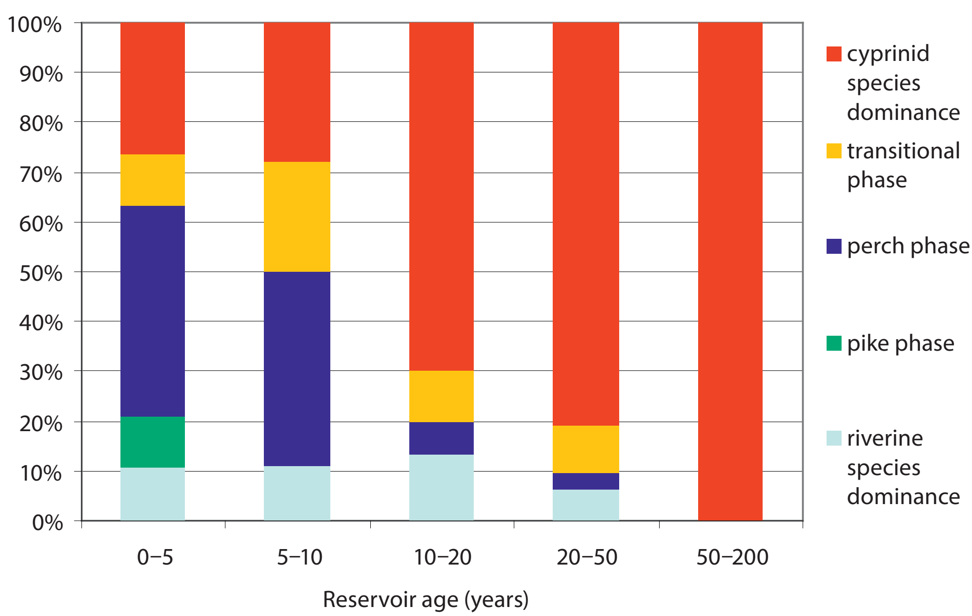

Fig. 3.5.6. ***Occurrence of individual fish stock types in groups of reservoirs classified according to their age.*** *The composition was calculated on the basis of more than 150 published as well as unpublished species compositions in different Czech reservoirs.*

suitable pike habitats (decomposition of terrestrial vegetation) and due to intense fishing, or alternatively, poaching pressure (Kubečka, 1990).

3) The **perch developmental phase** emerges probably due to the fact that perch is present in the majority of dammed streams and is able to reproduce successfully and quickly if there are high food resources within the initial production explosion. Perch fish stock (perch represents more than 50%) may, however, emerge also later, especially if it is introduced in a reservoir unintentionally as late as in the following stage of the reservoir development, and it may be stable (in mesotrophic or acidified conditions, or alternatively, in reservoirs with high water level fluctuation) or temporary (more frequent case, see Fig. 3.5.5. and 3.5.6.). If perch dominate the fish community, the so-called cycling of the year classes' strengths arises, which means that whenever a strong year class occurs, then this year class will not allow several subsequent year classes to have considerable success in a population due to the predation of their own offspring. Only when the strong year class grows rather old, there is a chance for another strong year class to succeed (Kuderskii, 1996).

4) **Transitional community** is distinguished between the developmental phases of perch and cyprinid species' dominance. This type of community where perch abundance or biomass ranges from 20 to 50% is applied either as a temporary stage between perch and cyprinid fish stock, or it may persist for a long time unless the specific conditions enable cyprinid species to suppress the development of perch. An example can be the Slapy Reservoir that would enable from a limnological point of view the development of a community with cyprinid species dominance, but the spawning of cyprinid fish is reduced annually by the diurnal water level fluctuation that is caused by the peaking hydroelectric power station (Draštík et al., 2004). Cyprinid species thus cannot reach the densities which cause the competitive displacement of perch.

5) A **community dominated by cyprinid species** that reaches the highest biomass (even several hundreds of $kg.ha^{-1}$), similarly to lakes, is the most frequent and stable community within the Czech conditions (Fig. 3.5.6.). The massive development of cyprinid species causes a drastic decrease in larger forms of invertebrate food (planktonic as well as benthic) and subsequently an increase in algae density due to trophic cascade. Other fish species (mainly perch) that prefer larger prey are thus considerably disadvantaged not only by the fact that all the prey is consumed but also by the fact that there is reduced transparency and a lower success rate in foraging for prey. Cyprinid species (especially common bream, roach, bleak, or alternatively silver bream in shallow waters) actually strengthen their own effect on the water quality (they support algae development) and at the same time, they reduce the efficiency of piscivorous fish that could limit them (the so-called ichthyoeutrophication). Large fish densities cause their slow individual growth.

The above-mentioned types of fish communities frequently represent the phases of fish stock development after the filling of a reservoir (Fig. 3.5.5.). During the development of a reservoir, all phases can occur or some may be skipped. Reservoirs built on bream zones of rivers represent extreme cases since they rapidly acquire a community dominated by cyprinid species (e.g. the Slapy Reservoir in the 1950s and 1960s and Orlík Reservoir, Draštík et al., 2004). Since the cyprinid fish community is the most stable, the probability of its occurrence increases together with the reservoir age (Fig. 3.5.6.).

Young reservoirs can host any of the above-mentioned communities. In fish stocks that are older than 50 years, it is very rare that other fish stocks than cyprinid persisted (e.g. salmonid fish stocks in acidified reservoirs in the Jizerské hory Mountains, Kubečka et al., 1998; Švátora et al., unpublished data). Similarly to lakes, the reverse development from cyprinid fish stock is possible in theory, however, there are no documented cases (recently, a decrease in roach and rudd and increase in perch have been noticed in relation to a decrease in nutrients in the Nýrsko Reservoir; Kratochvíl et al., 2011).

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3.6. Fish population dynamics *(D. Boukal, J. Kubečka)*

3.6.1. Population dynamics: basic principles and factors affecting population size

Both fisheries managers and anglers visiting a water body over many years will have noticed that the number and total weight of harvested fish do not stay the same but vary in time. This may be caused by variation in fishing pressure: a decrease in interest in a given fishing ground or species leads to lower total catches, while more visits or anglers targeting the species increase its catches. However, changes in the catches very often reflect real **fluctuations of the population** (i.e., the local ensemble of individuals): population dynamics of such species are not **stable**. In the long run, fish numbers in an unstable population may decrease, increase or regularly, irregularly or chaotically fluctuate within a certain range. In the Czech Republic, species whose populations have been steadily decreasing include, e.g., eel, barbel and grayling. On the other hand, invasive species, such as gibel carp and brown bullhead have been increasing. Many other common species, such as many naturally spawning cyprinids (bream, roach, etc.), have quite stable or fluctuating local populations.

Population dynamics are determined by all processes that influence individuals in a given population. Many factors may lead to deviations from the population equilibrium. These mainly include **limited food supply** leading to **intraspecific or interspecific competition** and **fluctuations of the year-class strength** (i.e., the number of fish in the same age category, see below) resulting from interannual changes in reproduction success and survival of the young-of-the-year fish. Populations are also influenced by **abiotic factors** including various catastrophic events (abrupt changes in the water level, water pollution caused by chemical and oil substances, anoxic conditions). Fish populations are also regulated by **predators**, especially by piscivorous fish species, piscivorous birds and mammals and, last but not least, by the top predator – **humans**.

3.6.2. Basic characteristics and processes influencing population size

Population size is characterized by two basic measures: total **abundance** and **total weight (biomass)**. It is better to express both measures in densities to be able to compare different populations. Moreover, both measures can be applied to the whole population or only its part, for example, only to fish older than one year. Population size is influenced by **four main processes** on the individual level: **growth, reproduction, mortality** and **migration** (Fig. 3.6.1.). Migration includes both immigration (influx of individuals) and emigration (outflux of individuals) from a given population. Apart from human interventions (stocking, removal of fish from the spawning stock for artificial reproduction, and catches of recreational anglers), migration plays an important role only in streams and water bodies with considerable inflow and outflow, such as reservoirs on larger rivers. Natural migration can often be neglected in mining lakes and reservoirs built on small brooks.

Long-term population equilibrium requires that the sum of total reproduction and immigration is counterbalanced by total mortality and emigration. If reproduction and immigration exceed mortality and emigration, population will increase; otherwise it will decrease. Individual growth influences population size **indirectly**: all fish must reach a certain body size to be able to reproduce and individual fecundity and mortality strongly depend on body size.

Age and size structure thus provides important information on fish population status. In the Czech Republic, fish spawn seasonally during a relatively short period. The age structure is thus expressed as the number of fish in individual year-classes and includes young-of-the-year fish (abbreviated as 0+), fish born one year ago (1+), fish born two years ago (2+), etc. Older fish that are difficult to age are usually lumped into one category which includes all individuals above a certain age limit (Fig. 3.6.2.). Observed size structure can be more or less continuous due to variable individual growth rates, but is usually divided into pre-defined size categories for practical reasons. The most detailed available division is given by measurement accuracy (usually 1 cm). Age and size categories may overlap due to individual variations in growth (Fig. 3.6.2.).

Separating the age and size structure also has practical repercussions. While population abundance is mostly influenced by the numbers of younger fish, biomass is determined mainly by older fish: the number of fish in individual age categories gradually decreases with age, but their size and thus contribution to the total biomass increases (Fig. 3.6.2.).

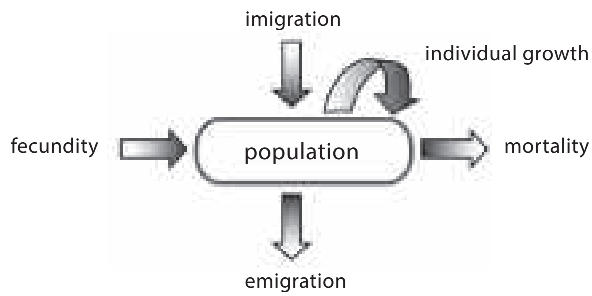

Fig. 3.6.1. ***Main processes influencing population size.***

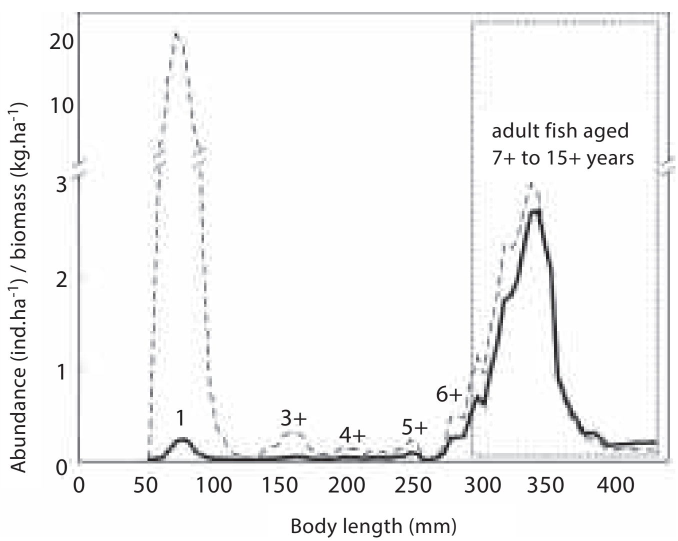

Fig. 3.6.2. ***Example of size and age structure of a fish population: common bream in the Římov Reservoir in 2011*** *(night trawl catches in open water). The Y-axis represents both abundance (ind.ha^{-1}, dashed line) and biomass (kg.ha^{-1}, bold curve). Each data point represents a fish whose length falls within a 5 mm interval with the average value plotted on the X-axis. Abundances of the very strong 1+ year-class born in 2010 are plotted to a different scale indicated by the broken Y-axis. The 2009 year-class (2+) is all but missing; several less significant but discernible age groups (3+ to 6+) are followed by the "old adults" category containing 7–15 year-old fish that cannot be distinguished by size. These large fish provide most of the total population biomass.*

3.6.3. Individual growth

Fish growth is indeterminate. This means that under suitable conditions, including sufficient food resources, fish continue to grow throughout their whole life, even though the growth **gradually slows down** and the length approaches an asymptotic value, which is a characteristic of a given species or population and is referred to as l_∞ or L_∞ (Fig. 3.6.3.). A major reason for decelerating growth in adults is the investment of energy into **reproduction** and hence diminished investment into somatic growth. The decrease in the growth of adult fish may sometimes be noticed in annual size increments (for example, by measuring the annuli on scales or otoliths), which can be used to back calculate the maturation age of the individual (Fig. 3.6.3.). The difference between the amounts of energy an individual is able to gain from food and the total metabolic requirements may also decrease with body size. This applies especially to planktonophagous fish. On the other hand, growth of fish that can switch from planktivory to piscivory, such as perch, usually has two distinct stages: growth first slows down before reaching the minimum size necessary for effective piscivory and then accelerates considerably (Fig. 3.6.3.).

Individual growth is further influenced by the **amount of food** and **indirectly by population density**. Slow growth caused by the lack of resources is characteristic for fish populations in oligotrophic waters and for large populations in water bodies without enough predators including the harvest by commercial or recreational anglers. Fish in such places are thus considerably smaller or even dwarfed. However, even these fish can catch up and reach normal body sizes and weights after a period of increased **compensatory growth** if the trophic conditions improve. **Water temperature** also directly affects growth. Fish, like other ectotherms, derive their body temperature from the environment. Their metabolic rate, including the ability to grow in size, is thus driven by water temperature (Jobling, 2002; Brown et al., 2004). Growth might also be influenced by other abiotic factors such as the amount of dissolved oxygen and water pH.

Many species show **sexual dimorphism** that often involves different body size of males and females caused by divergent evolutionary pressures. While size-dependent fecundity favours larger size in females (see below), both large and small size can be advantageous for reproduction in males (Parker, 1992). Males of the Czech species are usually slightly smaller than females. This is probably caused by lower food intake and, in adults, less efficient conversion of acquired energy into body mass in males (Henderson et al., 2003). Size differences between males and females of the same age may be further accentuated by earlier maturation of males (see below).

Fish growth is most often described by the empirical **von Bertalanffy growth curve** that expresses body length l_t at age t as

$$l_t = l_\infty - (l_\infty - l_0) \exp(-kt) \,. \tag{1}$$

In addition to the asymptotic size l_∞, equation (1) contains parameter l_0 describing the (theoretical) size at birth and the growth rate parameter k. The rate at which the individual reaches sizes close to the maximum l_∞ increases with k (Fig. 3.6.3). Different notations for the von Bertalanffy growth equation are sometimes used, e.g.,

$$l_t = l_\infty \left(1 - \exp\left(-k\,(t - t_0)\right)\right) , \tag{2}$$

where the size at birth l_0 is replaced by the theoretical age t_0 at zero size. Parameter values of equations (1) and (2) for individual species can be found in the literature, including the extensive online FishBase database (Froese and Binohlan, 2000). However, recent studies have called for the replacement of the von Bertalanffy growth curve by other models that reflect the differences in growth of immature and mature fish (Lester et al., 2004, Quince et al., 2008a,b).

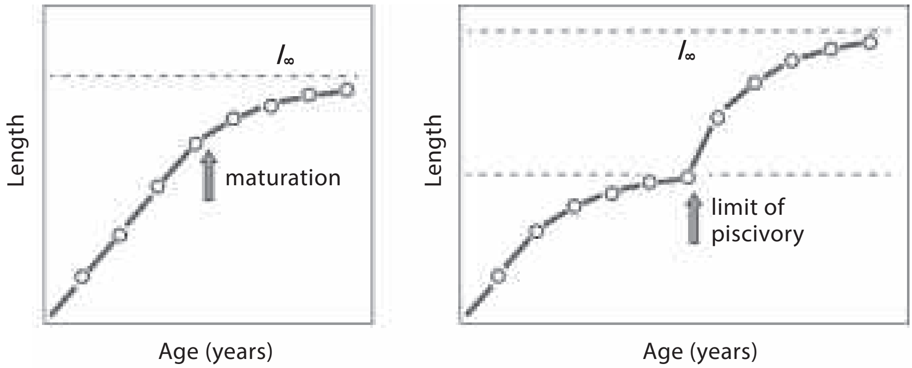

Fig. 3.6.3. ***Fish growth curves.*** *The left panel represents a typical growth curve that agrees well with the von Bertalanffy's equation (1). The right panel represents acceleration of growth after reaching the piscivory limit in perch (simplified from de Roos and Persson, 2001). Empty symbols represent data acquired, e.g., from otoliths or scales. The symbol* l_∞ *represents the maximum body length.*

Weight gains and individual body **condition** are usually monitored in addition to growth in length. Body condition is usually expressed with standardized indices, such as the **Fulton's index** (*K*, see chapter 4.3.). Relatively high values of these indices reflect sufficient amounts of food and good conditions for growth and high fecundity (see the gonadosomatic index below), while low values may indicate starving and overabundant populations.

3.6.4. Fecundity and reproduction

Most Czech fish species reproduce during a relatively short period in spring and summer (Baruš and Oliva, 1995). **Reproductive behaviour** varies among species: some species spawn more or less communally, other species spawn individually or in small groups and often with signs of lekking as several males may compete for females that spawn one after another (Poncin et al., 1996). Species also differ in their choice of **spawning substrate** and **parental care** (see the overview in table 3.2.1.). While most cyprinids abandon their eggs after spawning, other species, such as pikeperch, show at least basic parental care until the eggs hatch. Worth noting is the reproductive strategy of bitterling: females lay eggs into bivalve shells that protect the eggs against predators until hatching. Almost all Czech fish species spawn repeatedly during their life (**iteroparity**); only a few species, such as lamprey and eel, spawn only once (**semelparity**). Interestingly, most semelparous fish species in various parts of the world combine the development in sea and freshwater (diadromy).

Age at maturity differs considerably across species. The differences arise from evolutionary pressures, especially from differences in mortality and the resulting expected lifespan. While short-lived species, such as bitterling and other small cyprinids, mature under favourable conditions already during the first or second year, the majority of medium and long-lived species (e.g., catfish and pikeperch) mature later during their fourth or fifth year of life (Baruš and Oliva, 1995). The highest age at maturation among the Czech species is known in eel with a catadromous life cycle: inland eels take more than 10 years to mature. Not all individuals within a population necessarily mature at the same age. Maturation is strongly influenced by growth since most species mature after reaching some size threshold. The threshold usually lies within a species-specific size interval. Juveniles whose size is close to the lower limit of this size interval have a low probability of maturation in a given year, whereas individuals whose size is at or above the upper limit are certain to mature. The dependence between body size and maturation probability is described by logistic **maturity ogives** (Wang et al., 2009). The underlying mechanisms are probably related to hormonal processes and might be influenced by individual body condition and environmental conditions, such as water temperature.

Female **fecundity** (the total amount or volume of spawned eggs) increases with body size. Data on the fecundity of Czech species can be found in the Czech monograph by Baruš and Oliva (1995), the FishBase database and other publications. Eggs of larger and older females can also be larger and contain larger energy reserves in the yolk, and their fry may consequently have better chances to survive a critical time period after hatching. Many authors thus presuppose that large and old females play an essential role in the reproductive process. Total fecundity of males also increases with body size, but given the copious production of individual sperm and usually high fertilization rates, it is assumed that males do not play an important part in the reproductive potential of a population.

Fecundity usually increases with body size **allometrically**, i.e., proportionally to a power of body length (approximately the third power) and weight. Adults of many species possess a relatively constant ratio between the weight of gonads and the total weight, the so-called **gonadosomatic index** (Fig. 3.6.4.). Its value is species and sex-specific and ranges from negligible values to approximately 30%, depending on individual age and the time of the season. Most species reproduce once a year in temperate and cold climatic zones, but some species (e.g., bream, chub, rudd and bleak) are characterized by repeated batch spawning that may occur between the end of April till the end of July, and rarely even longer: the topmouth gudgeon (*Pseudorasbora parva*) spawns in the Czech Republic from the end of April until September. In some species, especially in marine fish, only individuals in good condition may reproduce in a given year (Rideout a Tomkiewicz, 2011). The individual may thus not spawn every year, but at intervals of two or more years. This phenomenon is known in starlet in the Czech Republic. The proportion of spawning females is probably related to total population density (Pivnička and Švátora, 2001) indicating that a good condition is more difficult to achieve in large populations due to decreased per-capita food resources.

Knowledge of the fecundity of the **spawning stock** (i.e., the fecundity of all females in the population) rarely provides a reliable clue to the **year-class strength** that describes the total amount and biomass of individuals born in a given year and sometimes called a **cohort**. The year-class strength is usually defined for individuals during the first year of life or for individuals that recruit to the fishery (see below). A loose relationship between spawning stock fecundity and year-class strength is caused by the fact that the survival of early fish stages is influenced by various factors that are not fully understood despite extensive research. Moreover, these factors act on very short timescales and, even if known, are virtually impossible to accurately measure and describe. Descriptions of fish population dynamics thus usually rely on an empirical relationship between the spawning stock size and the **recruitment**, the so-called **stock-recruitment relationship**. This relationship determines the number of recruits, i.e., fish that have reached a harvestable size or some other empirically defined category. Two types of this relationship, named after three founders of fisheries science, are usually used (Fig. 3.6.5.). The **Beverton-Holt relationship** between the spawning stock biomass S and the recruits R is defined by the relationship

$$R = R_{max} \frac{S}{S + \tilde{S}}, \tag{3}$$

where R_{max} is the maximum recruitment and $\tilde{S}$ is the size of the spawning stock for which the recruitment reaches half of the maximum value. This dependence describes situations when the recruitment increases with spawning stock biomass. On the other hand, the **Ricker relationship** describes a case when the maximum recruitment occurs for an intermediate size of the spawning stock S_{max}:

$$R = \frac{R_{max} S}{S_{max}} \exp\left(1 - \frac{S}{S_{max}}\right), \tag{4}$$

This dependence accurately describes, for example, a situation when large numbers of fry and juveniles compete for food or when adults from the parental stock cannibalize the offspring. Other available formulas modify either of the two relationships. It is usually difficult to decide which relationship is more suitable for a given population. Survival of fish eggs, larvae and juvenile fish depends on many, more or less random, influences and the resulting empirical stock-recruitment relationship is therefore usually quite stochastic (Fig. 3.6.5.).

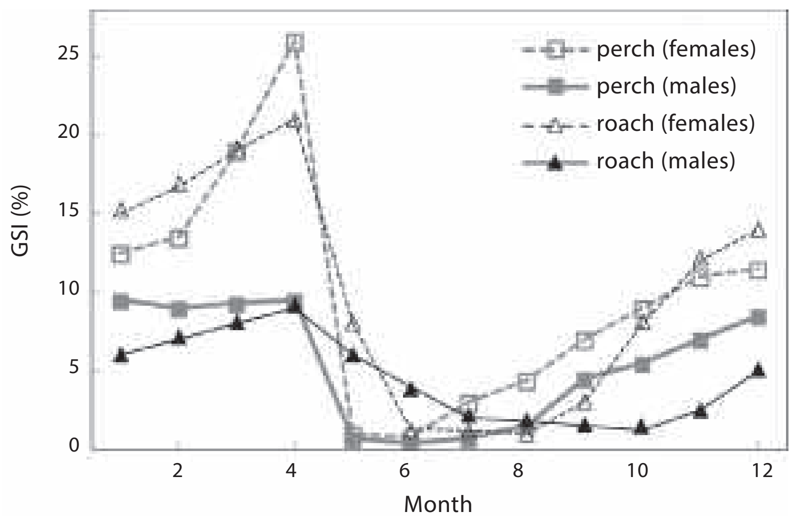

Fig. 3.6.4. ***Seasonal variation of the gonadosomatic index in European perch and roach in southern Russia*** *(modified from Nikolský, 1974).*

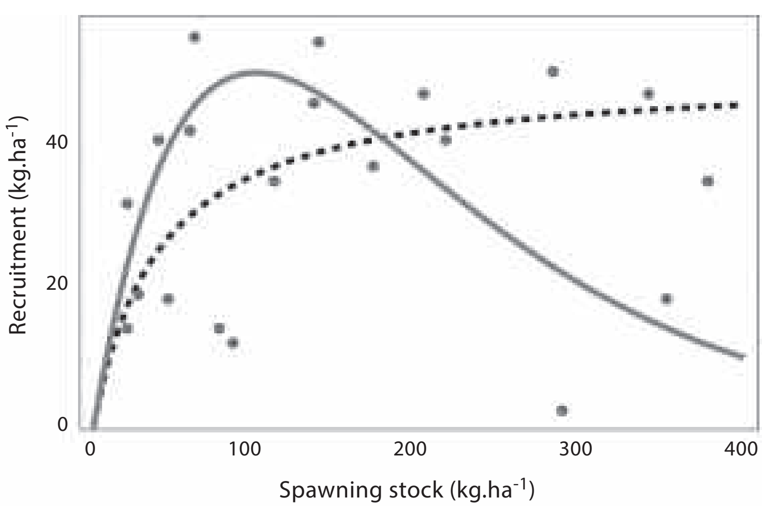

Fig. 3.6.5. ***Examples of stock-recruitment relationships.*** *The dashed line shows the Beverton-Holt relationship (3) and the grey curve shows the Ricker relationship (4) with parameters* R_{max}, $\tilde{S} = 40$ *and* $S_{max} = 100$. *The points illustrate possible variation in data.*

3.6.5. Survival and mortality

Populations in a steady state require that, on average, each female gives rise to only one daughter during her lifetime. High fecundity in fish is therefore offset by the fact that only a fraction of the eggs survive to maturity. Death may be caused by **abiotic factors** (temperature shock, oxygen deficiency, etc.), **diseases,** including parasites, **predators**, long-term lack of food leading to **starvation**, and **senescence**. Mortality in fish typically decreases with age and survival gradually increases since **natural mortality** almost always decreases with body size (Fig. 3.6.6.). Larger fish have fewer natural enemies and may be less prone to starvation during spells of poor conditions due to larger energy reserves.

The most critical period in the life of a fish is the time before and after hatching. Eggs and juveniles are easily affected by abiotic factors, fungal infections and have no defences against predators. After reaching the free-swimming stage and transition to exogenous diet, juveniles might be unable to find enough food. Mortality during the first several days to weeks thus commonly exceeds 90% or even more. Another critical period is overwintering during which many fish do not feed or feed only very little for several months, their metabolism and immunity are lowered and they are more sensitive to stressors. Young-of-the -year fish thus need to acquire sufficient energy reserves during the first season, for which they have to reach a certain minimum size or to gather minimum fat deposits (Huus et al., 2008).

Recreational and commercial fishermen prefer large fish: either because they become trophy fish or because they provide more meat. That is why fishing gear (mesh size, hook size, or type of bait) is adapted to preferentially catch fish above a certain size threshold or within a certain size range, and **human-induced mortality** has an opposite character in comparison to natural mortality (Fig. 3.6.6.). A larger (and older) fish has a higher chance that an angler will catch and keep it. This dependence together with the year-class strength determines the so-called **catch curve** that describes the catch in a given time period by age or size. A typical catch curve first rises as the probability of being caught increases; it subsequently declines after the probability of being caught reaches its maximum and the total amount of fish of a given age (or size) in a population gradually decreases (Fig. 3.6.7.).

During periods with relatively constant mortality rate, mainly after the critical juvenile period, the abundance development N_t of a year-class (or several year-classes with similar mortality rate) at time t can be described by the equation:

$$N_t = N_0 \exp(-Zt), \tag{5}$$

in which the parameter Z represents **instantaneous mortality rate**. This parameter typically consists of the **instantaneous natural mortality rate** M and the **instantaneous fishing mortality rate** F, i.e., $Z = M + F$. The ratio of $S = N_t / N_0$, called **survival probability** (from time 0 to time t), is also useful for monitoring fish abundance. For a defined age group or year-class in a closed population (without immigration and emigration), the sum of survival probability and **mortality probability** $A = (N_0 - N_t) / N_0$ in the same period equals one: $S + A = 1$.

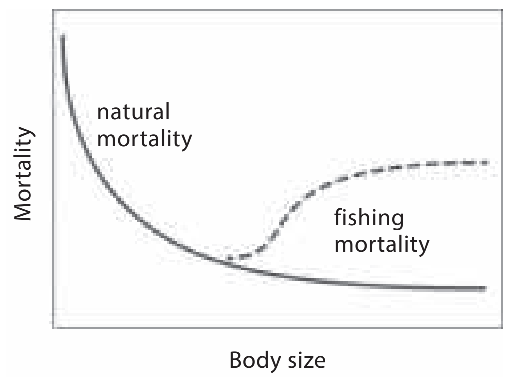

Fig. 3.6.6. ***Size-dependent natural and fishing-induced mortality.*** *The example is typical for species with defined minimum size limits or harvested by gear that does not catch small individuals.*

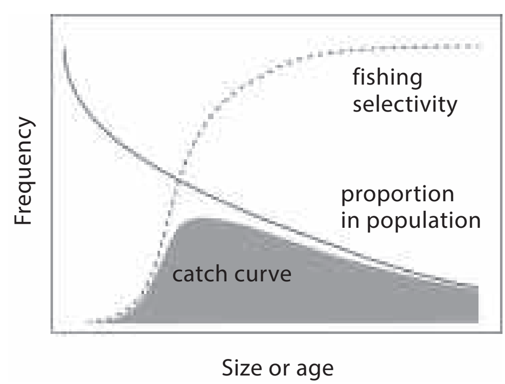

Fig. 3.6.7. ***Typical catch curve and its dependence on the selectivity of anglers and the size or age structure of the population.*** *Frequency on the Y-axis represents the relative proportion of a given size or age class in the population and in the catch and illustrates the probability of catching an individual from that class during a given time period. This example with one peak and declining tail is found in populations with similarly strong year-classes. Catch curves are commonly more fluctuating in freshwater populations with large variability of year-class strengths (see, e.g., Fig. 3.6.2.).*

3.6.6. Population dynamics: models based on total abundance

Interannual changes in population abundance might be illustrated by accounting for all terms that lead to population increase or decrease as shown in Fig. 3.6.1:

$$N_{t+1} - N_t = B(N_t)\ N_t - D\ (N_t)\ N_t + I - E. \tag{6}$$

The symbol N_i denotes population abundance in year i, symbols I and E denote total annual immigration and emigration and the functions $B(N_t)$ and $D(N_t)$ describe per-capita annual reproduction and mortality. Highlighting population size as a variable in the reproduction and mortality terms serves to emphasize that both processes might depend on population size or density. The best known examples of these models are the exponential and logistic growth models (Fig. 3.6.8.; Begon et al., 2006). While the **logistic growth** model can be applied to a wide range of populations that ultimately reach equilibrium, **exponential growth** only accurately describes the initial spread of a population under ideal conditions before density-dependent processes take effect.

Models of population dynamics based on differential equations are also common. They describe an **instantaneous rate of change** of population size *dN/dt* as a function of the instantaneous birth rate *b*, the mortality rate *d* (also called the death rate) and sometimes also the immigration rate *i* and the emigration rate *e*:

$$dN/dt = b\ (N_t)\ N_t - d\ (N_t)\ N_t + i - e. \tag{7}$$

These models can be used to describe changes occurring at both interannual and shorter time scales. Another advantage of these models is the availability of many mathematical approaches that can be used to study the behaviour of these models in detail.

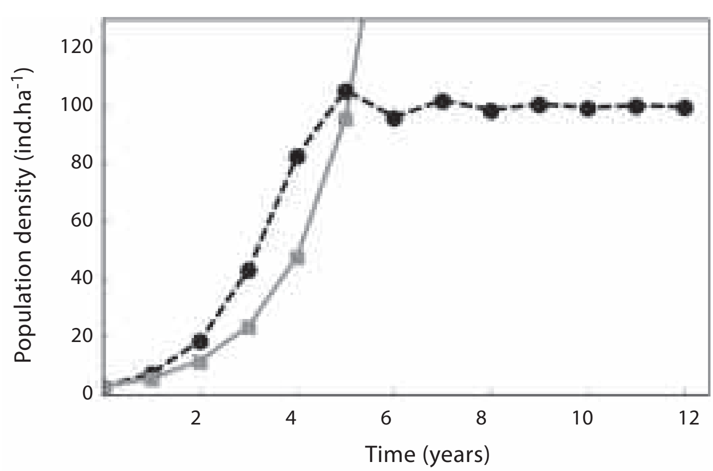

Fig. 3.6.8. ***Logistic and exponential population growth.*** *Example of logistic growth (black dashed line) given by the relationship* $N_{t+1} - N_t = rN_t(1 - N_t/K)$ *with growth rate r = 1.6 and carrying capacity K = 100 ind.ha*$^{-1}$. *Exponential growth (grey continuous line) given by the relationship* $N_{t+1} - N_t = rN_t$ *with growth rate r = 1. Circles and squares illustrate the corresponding annual population density data.*

3.6.7. Population dynamics: age- and size-structured models

A description of population dynamics based on total biomass or number of individuals is reasonable if all individuals have similar fecundity and mortality. This is not true for fish (see above), so these simplified models are used mainly in the absence of more detailed data on population structure. When this data is available, population dynamics are better described by following individual year classes and their strengths.

The Leslie matrix represents an analogy of model (1) for populations with a known age structure or division into some well-defined stages (e.g., age-0 fish, older juveniles, adult fish). The matrix includes changes in all age or stage categories. The Leslie matrix based on age structure has a simple form since it describes the relationship between the number of new offspring N_0 in time t+1 on the spawning stock fecundity and survival of older individuals:

$$\begin{aligned} N_0(t+1) &= f_d N_d(t) + \ldots + f_n N_n(t) \\ N_1(t+1) &= s_0 N_0(t) \\ &\vdots \\ N_n(t+1) &= s_{n-1} N_{n-1}(t). \end{aligned} \tag{8}$$

Fecundity coefficients f_i of adult fish at age i $(d \le i \le n)$ also include, apart from fecundity proper, the survival probability S_i of an individual between age i and $i + 1$; the oldest age category n is supposed to die after reproduction.

Monitoring the dynamics of an age-structured population with a Leslie matrix may demonstrate how a strong year-class that emerges, for example, by exceptionally good egg and fry survival in one year will influence the size and composition of a population in the following years (Fig. 3.6.9.). Such a strong year-class may give rise to another one after maturation. Under certain conditions, this may lead to the phenomenon of cyclic **dominant cohorts:** individuals born in one year predominate in a population and "suppress" one or more subsequent year-classes. This effect is known from the studies of certain planktonophagous fish (whitefish, roach) and might also appear in perch (Kuderskii, 1996; de Roos and Persson, 2001; Pivnička and Švátora, 2001).

Dominant cohorts represent a special case of more or less regularly fluctuating populations. In particular, short-lived and semelparous species (see section 3.6.4.) are prone to fluctuations as the spawning stock is formed by only one or a few age cohorts. Changes in individual year-class strength are thus heavily reflected in the size of the spawning stock. On the other hand, the spawning stock of long-lived and iteroparous (see section 3.6.4.) fish species is usually formed by many year-classes that can buffer against fluctuating environmental conditions and such populations are therefore more stable in the long run.

Mechanisms leading to the emergence of variable year-class strength further include, apart from stochastic factors affecting the survival of early fish stages, intraspecific competition for resources, cannibalism and predation (de Roos and Persson, 2001). All of these mechanisms likely involve size-dependent interactions and their understanding requires application of size-structured models of population dynamics. These models exceed the scope of this introductory treatise. Neither can we explain in detail approaches focusing on **random (stochastic) effects** that might, under certain conditions, even lead to the collapse of an otherwise stable population.

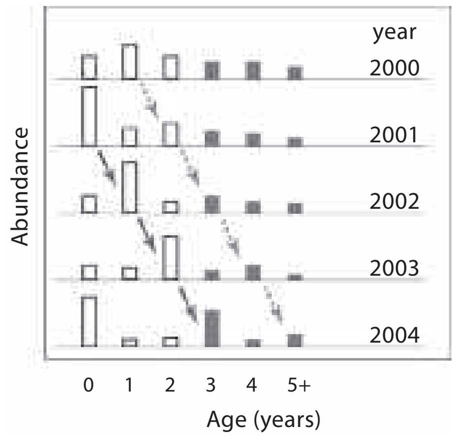

Fig. 3.6.9. Example of the appearance and interannual survival of strong year-class and its influence on population dynamics. *Abundance is plotted diagrammatically and on a logarithmic scale. The arrows represent development of strong year-classes born in 1999 (dashed arrows) and 2001 (continuous arrows). The empty columns represent immature fish and the full columns represent adult fish (assuming three years as the age at first reproduction). Strong year-class emerges randomly (year 2001) or due to a large spawning stock (year 2004).*

3.6.8. Biomass dynamics and production: year-class models

Each year-class begins when the adult fish spawn eggs or release larvae or juveniles. As explained in section 3.6.4., the parental population invests approximately 10% of its total biomass (i.e., the biomass of gametes) into the offspring. This biomass first begins to decline sharply due to the initially high mortality rate and the fact that the offspring must first switch to an exogenous diet. New **biomass production** (i.e., a net increase in biomass) can only be achieved after that switch.

The total biomass of a given fish group (year-class, or the whole population) is defined by the product of its abundance and mean weight. For long-lived fish, it is usually sufficient to determine the biomass once a year. Calculation of the biomass and its production is based on individual growth in length and consequently in weight (see chapter 4.3.). Within the season individual growth first accelerates (after the switch to an exogenous diet and metamorphosis into the juvenile stage) and then decelerates (as temperature drops in autumn), and therefore can be described by a logistic curve (Kubečka, 1994). Interannual length and weight growth of older fish is described in section 3.6.3. Fig. 3.6.10A. shows a typical case when individuals grow for many years; the length-weight allometry underlies the fact that the asymptotic weight w_∞ is reached slightly slower than the asymptotic length l_∞.

Biomass produced by a given year-class can be derived from changes in abundance defined by the **instantaneous mortality rate** *Z* (section 3.6.5.) and changes in individual weight characterized by the **instantaneous growth coefficient** *G*:

$$G = \left(\ln(w_t) - \ln(w_{t'})\right)/(t - t'), \qquad (9)$$

which provides the average growth rate between times *t* a *t'* (usually between two successive seasons). Fig. 3.6.10B. represents typical changes in the biomass of an unexploited and exploited year-class. Production is high at young ages with high growth rates (Fig. 3.6.10C.) that offset even the initially high mortality rate. Biomass gains slowly decline with decelerating individual growth and at a certain age (age of **maximum biomass**), loss of biomass through individual mortality begins to exceed individual gains in biomass and the total biomass gradually declines. The overall shape of the biomass curve depends on the relationship between the growth coefficient *G* and the mortality rate *Z*. Total biomass can peak sharply (especially in species with high mortality rates) or have a flat plateau when individual weight gains compensate for lost individuals for several years (Fig. 3.6.10D.).

Dynamics of a year-class biomass can also be described by the relationship between **total biomass production** *P* (also called gross production since it includes the production of individuals that will have died in the meantime) and **elimination of biomass** *E*. Total production is defined as the rate of change in biomass per time unit, usually per year. Elimination of biomass E_t describes the interannual dynamics of biomass losses of a year-class at age *t* and its production P_t and biomass B_t:

$$E_t = P_t + B_t - B_{t+1} . \qquad (10)$$

Elimination of biomass is slightly delayed with respect to production and usually peaks when production already declines (Fig. 3.6.10C.).

Production can be graphed using the **Allen's curve** which depicts the dependence of a given year-class abundance on individual weight. The space under this curve delimited by the initial and final individual weight defines the production in the given time period (for details see, e.g., Pivnička, 1981). However, this approach is impractical as it requires frequent measurements of the abundance and average individual weight of the year-class. Instead, Ricker's (1975) equation is most often used for calculating production:

$$\mathrm{P} = BG\,(\exp(G - Z) - 1)/(G - Z), \qquad (11)$$

This equation calculates the total production of an initial biomass *B* by using the instantaneous mortality rate *Z* and instantaneous growth coefficient *G*.

Production per unit of biomass is defined by the *P/B* ratio (Fig. 3.6.10C.). It is often considerably higher than 1.0 at young ages and decreases very quickly afterwards as the growth slows down and individuals weigh more; this cannot be offset even by enhanced survival. The *P/B* ratio thus becomes very low in older fish. Since the annual mortality rate is almost always in tens of percents, a large proportion of the production disappears from the population with dead individuals. For example, the total cumulative production of the model year-class in Fig. 3.6.10. (i.e., the sum of annual productions taken from Fig. 3.6.10C.) reaches 1000 kg, but its maximum biomass is less than 450 kg (Fig. 3.6.10B.). The difference is caused by biomass losses.

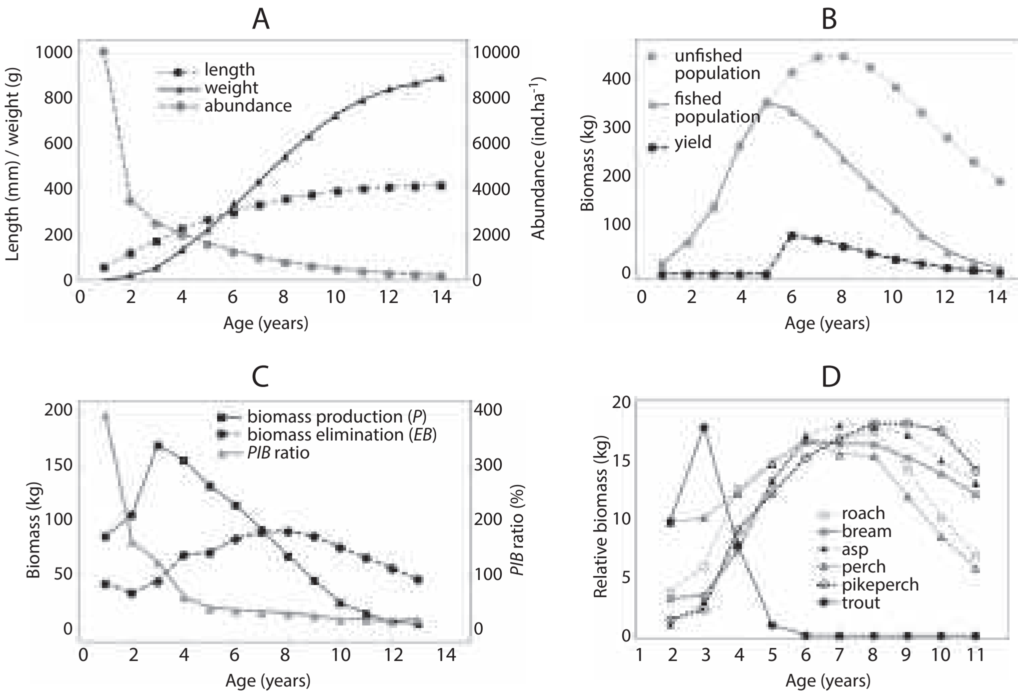

Fig. 3.6.10. ***Dynamics of production and the impact of fishing on a model year-class of common bream*** *(panels A–C)* ***and examples of changes in year-class biomass for selected species in the Czech Republic*** *(panel D). A: growth in length and weight (plotted jointly on the left Y-axis) and changes in abundance (right Y-axis). B: dynamics of year-class biomass in the absence and presence of fishing, given by the annual catch of 15% of all surviving individuals starting at age 6. Compensatory mechanisms, such as faster growth or enhanced survival of individuals in smaller populations, are neglected for clarity. C: changes in production, the P/B ratio and elimination of biomass in the absence of fishing (values for age 14 not calculated). D: changes in relative biomass of different fish species during ontogeny; absolute values given on an arbitrary scale. Average data from several reservoirs were used for bream, perch, asp, roach and pikeperch; data on trout were collected by Libosvárský et al. in the Loučka River (Baruš and Oliva, 1995).*

3.6.9. Population dynamics of harvested populations

Both commercial and conservation interests require knowledge of the limits of sustainable fishing pressure. Commercial fisheries often strive to optimize the pressure close to the regime bringing the **maximum sustainable yield** (i.e., the biomass of fish harvested during a given period), abbreviated as MSY. The underlying principle is simple: very low fishing pressure will keep the population close to the harvesting-free equilibrium, but the yield will be low. On the other hand, the population will be **overexploited** after initially high yields under high fishing pressure, and subsequent yields will become low as well. Fisheries managers thus seek a compromise between both extremes.

The simplest description of a harvested population that can be used to optimize long-term fishing pressure is provided by the **Graham-Schaefer model**. It is based on **latent productivity**, i.e., the rate of biomass increase in the absence of fishing. The model assumes that the latent productivity Q is given by a logistic growth curve and the yield Y is proportional to the effort E and to the population size. The effort can be defined, e.g., by the number of fishing trips or the amount and length of nets. These two relationships can be formalized as:

$$Q = k\left(1 - \frac{B}{B_{\max}}\right)B,$$
$$Y = qEB, \tag{12}$$

with parameter q defining the efficiency of the given effort type. Latent productivity of the population equals zero or becomes negative when its biomass exceeds the value of the carrying capacity $B_{\max}$ and is highest at half of this value $B_{\max}/2$ when it reaches the level of $(kB_{\max})/4$ (Fig. 3.6.11.). MSY is thus gained by sustaining the population at 50 % of its carrying capacity and removing all latent productivity. In model (12), this corresponds to effort $E_{MSY} = k/(2q)$ and mortality caused by this effort equals $F_{MSY} = q\,E_{MSY} = k/2$.

More detailed information on optimal fishing effort including the impact of **minimum size or age limits** of harvested fish is provided by age or size-structured models. When MSY is the target, it is advisable to let the fish grow first and harvest fish of ages or sizes that are close to the maximum biomass production rate. Fish growth in the stagnating or decreasing part of the year-class biomass curve is not advantageous from the MSY perspective. In most species, production is maximized around maturation and the first spawning; even species depending on natural reproduction can be thus harvested after maturation to obtain yields close to MSY. On the other hand, harvesting decreases the biomass of surviving fish and the harvested fish no longer contribute to the production in the subsequent years. The example in Fig. 3.6.10B. shows the effect of harvesting 15% of fish aged six years and older in the population described in Fig. 3.6.10A. The maximum year-class biomass (350 kg, fish aged five years) and total production (865 kg) of the harvested population is lower than the maximum biomass and production in the absence of harvesting. Total yield (sum of annual catches) in this example is about 320 kg.

These idealized examples might suggest that optimal fishing pressure is easy to calculate. However, most populations do not meet the assumptions of simple models. Their productivity may fluctuate randomly and attempts to follow the optimal effort would often lead to overexploitation in such cases. The productivity curve may be asymmetric with the maximum moved to low population densities. Moreover, a one-sided effort focused on maximum biomass production may lead to excessive harvesting of large and old fish from the parental stock and consequently cause deterioration of its genetic quality and threaten population stability (see section 3.6.10.). In these cases, the population may **collapse** if it is unable to sustain the harvesting pressure. One particularly well-known example of commercial stock collapse was Northwest Atlantic cod in Canadian waters in the early 1990s. It is worth mentioning that despite a total fishing moratorium, the stocks in the area have not yet recovered. A plausible explanation of the phenomenon is that cod overexploitation caused an ecological regime shift and the whole ecosystem moved into a new equilibrium. If true, it will not be possible to restore the local cod populations to the previous state.

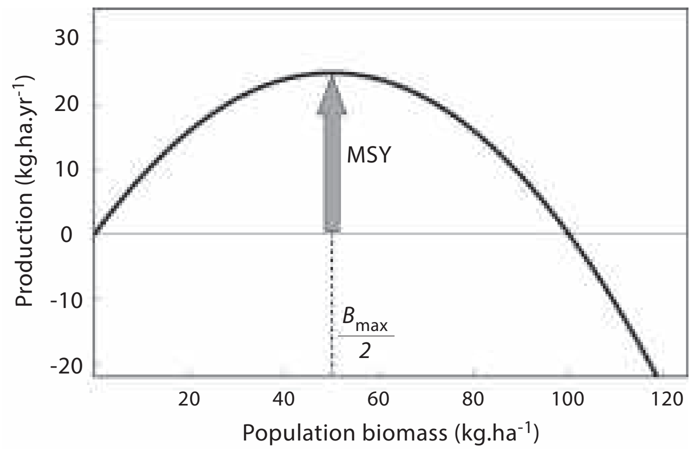

Fig. 3.6.11. Example of the dependence of maximum yield on fishing pressure and population productivity using the Graham-Schaefer model (12). *Maximum sustainable yield 25 kg.ha^{-1} per year is attained by maintaining population density at 50 kg.ha^{-1}. Model parameters: k = 1 and* B_{max} = 100 *kg.ha^{-1}.*

3.6.10. Ecological and evolutionary impacts of fishing

The collapse of the Canadian cod is a warning illustration of the potential negative impacts of excessive fishing. These include, above all, various consequences of stock overexploitation. Gradual decrease of average weight of the catches accompanied with gradual decrease or stagnation of catch per unit of effort are among the first characteristic **signs of overfishing**. They indicate that older fish become more and more depleted and the parental stock consists of younger and younger individuals, unlike the situation in which decreasing average weight of the catches is caused by new strong year-classes from previous years entering the fishery. Along with potential fluctuations and the risk of the collapse of such populations (see section 3.6.7.), individuals that mature early and reproduce at smaller sizes may gain evolutionary advantage. This phenomenon is documented in many marine and freshwater stocks (Jørgensen et al., 2007) and an ongoing debate in the literature is attempting to determine whether and how it might influence long-term yields. For all these reasons, many scientists demand a decrease of fishing pressure well below the theoretical MSY levels and the **protection of old and large fish** (Birkeland and Dayton, 2005; Law, 2007).

In the Czech Republic, overexploitation especially affects piscivorous fish (pikeperch, pike) that are valued for their meat and as trophy fish. For example, a considerable decline of pikeperch in Lipno Reservoir was preceded by gradually decreasing average size of the caught fish. While total reported catches of recreational anglers gradually rose from about 15 tonnes (average of 1991 and 1992 data) to the maximum of 29 tonnes in 2004, the average weight of the caught fish decreased from 2 kg to 1.5 kg. A steep decline followed and annual catches remained under 2 tonnes in 2005–2007. Such overexploited populations require timely action and should be protected by all available means, including the restriction of fishing methods, longer closed seasons or increased legal size limits. Timely and complete **fishing moratoria** can be considered in particularly severe cases. They should be implemented long enough to allow for a recovery of the parental stock structure. This process lasts for one or even more generations depending on the intensity of the previous overfishing and on the details of the stock-recruitment relationship. This means that in the Czech species, the earliest full recovery will occur in three years but the process may last up to 10–20 years.

Given that fish communities at nearly all fishing grounds include multiple fish species, overexploitation of one species might **indirectly influence** the whole community. Depletion of non-piscivorous fish (herbivores and planktonophagous) might disturb the food chain and lead to insufficient food supply for piscivorous fish, which might result in temporary or permanent fluctuations of the community. Overfishing of piscivorous fish might, on the contrary, cause an outbreak of non-piscivorous fish and subsequent depletion of planktonic food supply, potential development of cyanobacteria and possibly also deterioration of fish growth. Therefore, it is desirable to maintain fish communities including the ratio of piscivorous to non-piscivorous fish within certain limits (see chapters 4.3. and 4.4.).

Methods of quantitative description of fish population dynamics and the consequences of harvesting are further explained in detail in the outstanding monographs by Quinn and Deriso (1999), Holborn and Walters (1992) and King (2007). A general introduction to models of population dynamics can be found in various ecology textbooks (e.g. Begon et al., 2006). Methods of the study of age-structured populations can be found in the highly commendable monograph by Caswell (2001). Studies of fish population dynamics based on size-structured models are relatively recent and are mostly contained in scientific articles in foreign journals (e.g., de Roos a Persson, 2001, Andersen a Beyer, 2006).

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web link
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3.7. Spatial distribution of fish in running waters *(O. Slavík)*

The riverine environment is under permanent pressure from civilization factors. Their complex effects on fish populations results in the loss of shelter, food resources and spawning areas. In order to be able to assess this loss and to suggest potential improvement it is necessary to become acquainted with the basic mechanisms that influence selection of preferred areas. The foraging strategy of shoal fish species is based on mutual communication between large numbers of individuals. Shoals of fish, for example, bleak, nase carp or barbel, might be loosely compared to grazing herds of hoofed animals whose position is determined by a sufficient amount of food. If they exhausted all food resources, they move on further downstream. The relationship between a current shoal position and the local environment is thus dependent mainly on food availability. On the other hand, soliter species have a very close relationship with their local environment because knowledge of their surroundings gives them an advantage in foraging for food and in use of shelter. For example, smaller brown trout are able to repel a larger individual when it comes to a fight provided that they can use the advantage of knowing the local environment (Johnsson and Forser, 2001). Non-random placement of individuals in a riverine environment creates an irregular mosaic of spatial structures that are used by fish of a certain size. How is such mosaic created?

3.7.1. Home range, core area and territory

Each fish needs to consume a certain amount of food in order not to starve to death and also to hide in order not to be caught by predators. The size of the area that fish need for fulfilling both these conditions is a resulting compromise of both needs that are often contradictory (Hill and Grossman, 1987). The term that is generally used for the resulting space is the so-called *home range*, which might be defined as an area that an organism requires to fulfil its needs during 24 hours (Mace et al., 1983). For example, with respect to bullhead, it was discovered that their home range is smaller in the day time when they are not active and larger at night time when they forage for food above a specific substrate type (Natsumeda, 1998). The size of a home range corresponds to the energetic requirements of an individual (McNab, 1963), and therefore, it is larger if it is difficult to find food within a range (Schoener, 1968; Slavík et al., 2005; Kulíšková et al., 2009). A home range is often larger if food resources and shelter are distant from each other and vice versa (Chilton and Poarch, 1997; Jakober et al., 2000). As far as the same species and an individual's size are concerned, the size of a home range area is different in lakes (and reservoirs), which are characterized by their low food availability than in rivers that offer a sufficient amount of food. Fish have much larger home ranges in lakes that are poor in food resources than in productive rivers since in lakes they are obliged to forage for food actively, and in addition, food in rivers drifts towards fish (Minns, 1995). The size of a home range changes according to the season. It is the largest when fish species are at their seasonal maximum activity (Slavík et al., 2005; 2007) and it may also be smaller in a degraded environment in comparison to the natural environment that motivates fish to change positions more frequently (Slavík and Bartoš, 2004). The size of a home range relates mainly to an individual's energetic requirements that represent some kind of an account for all needs and behaviour. Generally, the size of a home range increases with an individual's weight (Harestad and Bunnel, 1979). The paradox might be, however, that the size of a home range may be smaller with respect to larger dominant individuals which occupy more advantageous positions in order to gain food (Nakano, 1995). On the other hand, smaller and usually subdominant individuals move at the edges of home ranges of dominant individuals, therefore, their own home ranges are also larger. Subdominant fish thus never represent a stable part of populations (Crisp, 2000). The size of a home range that is measured in nature is always larger than theoretical models derive (Kelt and Van Vuren, 2001). This is due to the fact that food resources are dispersed unevenly and animals are obliged to move towards them (Jetz et al., 2004). Animals also intuitively claim larger areas than they are able to use and in this way they take into consideration the potential influence of competitors (Buskirk, 2004). As a result, it is evident that fish prefer smaller areas even within the home range where they spend longer time periods in comparison with the rest of the used area. These smaller space-time units called activity core areas centres (CA) were initially described in relation to the behaviour of the South American Procyonidae – the ring tailed coati (Kaufman, 1962). Determination of the CA size belongs to the essential features which describe the spatial behaviour of fish. For example, CA localize food resources and reproduction areas, while on the other hand, an absence of CA might indicate even dispersion of food resources, migratory behaviour (if a fish moves only in one direction), etc. The CA size may be derived, for example, from 50% of records, according to which a fish is localized within a home range. The size of a home range might be estimated on the basis of several procedures, e.g., according to Jennrich and Turner's method (1969), or according to the minimum convex polygon (Mohr, 1947). Calculation of the size of a home range by means of these methods (and others – e.g., Kernel's estimation) might be achieved via the Internet, where a large number of free applications are available. It is not the method of the final calculation that is the most important for a precise determination of a home range and the CA, but it is, above all, the quality of the data used for the calculation. Data relating to spatial distribution of monitored fish must be acquired at regular intervals, which should be repeated after one – three hours. The availability of marked individuals in a terrain, as well as the length of their current movements, determines the number of monitored fish during one day. The term *home* that is used in the concept of home range should not automatically evoke the idea that this area is protected against intruders as the "domicile area." An area that is protected in some way is called territory (e.g., Grant, 1997). The territory size as a spatial unit may change dynamically in time and also the specification of *territoriality* as a show of behaviour is not always clear-cut. It is possible to state that shoal fish species are not territorial, while soliter species usually are. A territory is usually constituted by a smaller part of a home range. For example, catfish are aggressive to one another only if they clash with a competitor in a preferred area (Slavík and Horký, 2009). Typical territorial species include, for example, salmonids, whose territory size corresponds to the size of a home range because they defend their food resources (Grant and Kramer, 1990; Keeley and Grant, 1995). However, it is necessary to emphasize that aggressive behaviour, especially direct physical contact leading to an injury, represents rather an extreme manifestation in the riverine environment (Neat et al., 1998; Maan et al., 2001). Fish use a wide range of ritualized manifestations reducing aggression that precede a potential attack, e.g., subdominant trout are darker than a dominant competitor. Besides, territoriality is applied mainly against the same-sized groups that compete with each other for food (Crisp, 2000). Therefore, several size groups of trout occur commonly in pools, but it is more difficult to catch several large individuals of the same size at the same time in one pool.

3.7.2. The abundance of fish in a stream

What should the expected abundance of fish in a stream thus be like? General theoretical models comparing biomass within the interval from a source area to the estuary estimate that most species should occur in the middle part of a river network and a community should reach the maximum biomass here (Vannote et al., 1980). Next, it was discovered that there are more smaller species, insectivores and soliterspecies, to be found in source areas than further downstream (Schlosser, 1982) and that even fish biomass increases in the same direction (see chapter 3.2.). This information has, however, only limited practical use. It may help with assessing damage resulting from pollution incidents if it is possible to prove that the occurrence of species and their abundance is lower in the place of the incident than in the upstream stretch of a river. An individual fish's requirements for space were often considered for estimating optimal abundance of salmonids (e.g., Keeley and Grant, 1995; Steingrisson and Grant, 2011). Several predictive models were designed in the past that estimated, for example, the abundance of salmonids in a stream on the basis of the ratio of body size and to territory size or structure of the environment (Grant and Kramer; 1990). The authors worked on the logical assumption that spatial requirement will increase with increasing fish body size. This should result in a negative relationship between fish size and their number; therefore, there should be only a few large individuals or a lot of small individuals in a stream. Nevertheless, the general validity of this model has never been confirmed. The reasons for this were indicated in the previous chapters – e.g., territoriality applies mainly within the same size groups. In addition, in shallow stretches, the inspection of a territory is easy, because it may take place even during food intake (e.g., when picking up insects from water level). If trout moves up a water level in deep pools it is not possible to inspect the middle and lower parts of the water column. Territorial aggression in pools is thus disadvantageous from the energetic point of view and the amount of individuals is rather determined by the amount of food and shelter. This is also the reason why more trout may occur together in pools while in shallow stretches of streams the spatial distribution of trout corresponds to a mosaic. Other information might be drawn from studies that describe the relationship between abundance and growth rate. Growth rate informs indirectly about productivity, the so-called "trophic level" of a stream. For example, if trout are growing quickly, it may be assumed that they have enough food available and that their abundance will be high. At the same time, the following relationship should be valid – the higher the abundance, the greater the competitive environment – and the growth rate thus decreases. These assumptions are not, however, valid together and for all environments. Trout grow fast in streams with enough food and their abundance is high; nonetheless, it is not possible to find any relationship between abundance and growth rate (Lobon-Cérvia, 2007). On the other hand, it is possible to prove the relationship between abundance and growth rate in streams that are poor in food resources where trout abundance is low as well. If trout abundance decreases, for example, in an oligotrophic mountain brook, the rest will grow faster and vice versa. Moreover, these dependences are valid only for juvenile trout. If trout mature, they invest most energy into reproduction, their growth significantly slows down and this ceases to represent a factor influencing abundance considerably, and vice versa (Jonsson and Jonsson, 1993). However, survival and abundance of juvenile (and subsequently also adult trout) are influenced by conditions that occur during the so-called critical period (Elliot, 1994). At this period, young trout adapt to local food and shelter availability. Abundance of a new generation that is defined by the number and fecundity of reproducing females (Elliot, 1989) goes through the so-called *bottleneck* and the resulting abundance of juveniles (and subsequently adults as well) is determined by the current environmental conditions. In general, it might thus be summarized that estimations of optimal abundance on the basis of predictive models considering body size and subsequent spatial requirements are too imprecise for practical usage. Next, it was proved that trout abundance in streams with low and high productivity cannot be compared. If a stream is of an oligotrophic type, increasing trout abundance decreases the growth rate; whereas there are much more trout in brooks with a high trophic level and their growth is not influenced by their abundance. Therefore, it is evident that optimal targeted abundance of fish in running waters should take into account local conditions and this cannot be derived from theoretical models.

3.7.3. A phenomenon called shelter

Hardly any other parameter of the running water environment has such a comprehensible name and purpose. This concept is usually connected to an aperture between stones, floating vegetation or tree roots under undermined banks. Nevertheless, the term shelter is in fact very wide and difficult to define. A shelter might be any place that helps a fish to avoid any stressor factor. Fish find a certain "sense of security" even in shade that increases their protection against predators (Helfman, 1981). Fish use shelters to hide from predators the most often (Valdimarson and Metcalfe, 1998) and if there is no possibility to hide, they exhaust more energy due to stress, which happens even in case a predator is not present (Fischer, 2000). They also hide from extreme sunshine (Valdimarson et al., 1997), high flow-rates (Valdimarson and Metcalfe, 1998), or if the temperatures

Fig. 3.7.1. ***A sufficient amount of shelter is a prerequisite for a stable population of brown trout*** *(the Malá Vltava River in the Šumava Mountains, photo: O. Slavík).*

are low (Heggenes et al., 1993). Shelters might be occupied by more individuals at the same time (Armstrong and Griffiths, 2001). Nevertheless, fish usually prefer certain exclusiveness because in aquacultures that are characterized by a smaller number of shelters more individuals were found in shelters than in nature (Griffiths and Armstrong, 2002). In general, it can be stated that a shelter decreases cannibalism (Britz and Pienaar, 1992), aggression (Hecht and Appelbaum, 1988) and since it decreases energetic consumption it also accelerates fish growth (Hossain et al., 1998, Benhaïm et al., 2009). The riverine environment that is rich in shelters is complex enough and enables the occurrence of a higher number of fish (Eklöv, 1997). Protection of streams where the stream bed is being shaped by flow effect, spontaneous sedimentation, occurrence of vegetation and dead wood materials is an environment that provides shelters at an optimal level (Fig. 3.7.1.). Conversely, channelized streams with fortified shorelines and straightened stream beds with artificially increased capacity represent an environment that provides fish with shelters only rarely.

3.7.4. Fish movement activity

Fish behaviour can be assessed on many levels (e.g., reproduction, food intake, aggressive defence of territory, co-operation in hunting and stress). With respect to running waters, however, a common observation is the possibility to assess a change of habitat, which is expressed as the distance between two points per unit of time. In other words, fish movement activity is a behavioural parameter that might be observed and assessed relatively easily in rivers. Information concerning fish movement activity is very important for fishery management. The importance of migrations was mentioned in the previous chapters, but the data relating to shorter fish transfers in the currently inhabited environment has a comparable value. Above all, it is necessary to know, for the inspection of quality and fish community abundance purposes, that the occurrence of some fish species is time-limited in a certain environment. For example, some individuals may occur in oxbows and pools only temporarily, e.g., if there are high flow-rates (Harvey and Nakomoto, 1999) and low temperatures (Horký et al., 2008), or only in darkness or, conversely, in the day light (Kubečka and Duncan, 1998; Slavík and Bartoš, 2001). Juvenile fish are present in shallow shorelines in different species composition and abundance at night-time and in the day time (Copp and Jurajda, 1993). It is the changing of light and dark that is the most important factor for the spatial distribution of fish in certain environments.

It is possible to distinguish circadian and diel fish movement activity. Circadian activity is controlled by an endogenous mechanism, and lasts approximately 24 hours, but after removing a fish from a synchronizer (e.g., light) it continues in the same rhythm, even though there is a noticeable deviation (Reebs, 2002; Kronfeld-Schor and Dayan, 2003). Diel activity is dependent directly on the changing of light and dark and may be observed as daylight and nocturnal movement activity. Eel is considered to represent a typically nocturnal species (Tesch, 2003). However, recreational anglers sometimes catch eel even during the day and also in places where there are no typical shelters (shoreline) and where eel must have swam actively to. This unusual activity is explained by the term *dualism*. Many fish species are able to use their environment in the daylight as well as in the dark. It is dependent only on the current environmental conditions that influence the activity. For example, in Nordic countries, fish can be more active in the daytime when the days are getting shorter and vice versa (Løkkeborg a Fernö, 1999). Similarly, burbot *Lota lota* is considered to represent a typically nocturnal species (Carl, 1995; Slavík et al., 2005), but in the north of Europe, they commonly show a diurnal activity (Müller, 1978). During the two-year monitoring in the Berounka River, European catfish (*Silurus glanis*) showed strictly nocturnal activity from September to November, however, from winter to spring, it was active only in the daylight, and in summer it was active both at night and during the day (Slavík et al., 2007). It is probable that many species that were originally considered to be either diurnal or only nocturnal, have in fact dual diurnal activity. Detailed experiments have also showed that dualism is not only connected to some species, but it is also individually dependent (Brännäs and Alänära, 1997; Bolliet et al., 2001; Slavík and Horký, 2012). These authors found that when analysing charr and catfish some individuals within a group always have either nocturnal or diurnal activity. The abilities of dualistic behaviour during the day light and the dark are very often also utilised by brown trout. There is very strong food competition between the same size groups of trout (Elliot, 1994). Dominant salmonid individuals take in food mainly at dusk when there are still a lot of insects flying above the water level and when it is still easy to watch and catch them at this time. On the other hand, subdominant individuals are pushed out into a less convenient time of direct daylight or dark. Food intake is less effective in the dark and, on the contrary, in the day time it is accompanied with higher losses caused by predators (Fraser et al., 1997). It is not a coincidence that a recreational angler catches large trout only at dusk while small trout can be caught almost any time. The above-mentioned examples show that traditional opinions relating to fish use of "light and dark" are too "black and white." Naturally, other factors, such as temperature, influence diel fish activity as well. Trout and salmon shift to nocturnal activity when the water temperature drops below 10 °C because they are not able to escape from predators in cold water in an efficient way (Fraser et al., 1993, 1997; Valdimarsson et al., 1997). At night, they are not only more protected but they are also more successful in the chase for food (e.g., minnow, insect), which protects them against predators by being active in the dark in the same way as the salmonid species themselves.

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3.8. Fish migrations and fishways *(O. Slavík)*

The riverine environment is an open system that is characterized by the longitudinal gradient of slope, flow and temperature, and fish have to adapt their energy regime to this system. A periodic temperature drop is usually accompanied by a decrease in food availability. If the temperatures are low, fish are less able not only to recharge energy resources but also to use them because the performance of their metabolism is also decreasing. When the weather gets colder, summer habitats that are rich in food but energy demanding become disadvantageous. This cycle usually creates the need to change the feeding habitat in order to hide and to save energy – which usually means to migrate. When the weather turns warmer, the whole cycle proceeds in the opposite sequence. Similar spatial distribution changes can be noticed also in connection with reproduction when fish leave winter shelters or summer feeding habitats and search for the species-specific spawning habitat. Such habitat should also provide a certain level of protection against predators and cannibalism and it should minimize the risks for the new generation. Similarly, fish change their environmental requirements on the basis of hydrological conditions (the size of flow-rate and the height of water column), ontogenetic stage (juveniles vs. adults) or just the body size. Fish must have the possibility to migrate in the longitudinal profile of the riverine environment in order to be able to react to all conditions. Migrations are, however, hindered by artificial obstacles that are built as a result of human use of the aquatic environment. In order to reduce this influence, fishways are designed. Fishways are technical structures allowing fish and other aquatic organisms to overcome obstacles during their migration. A brief description of the biological basis of fish migrations and possibilities of migrations to be undertaken also in modified streams is provided in the following chapter.

3.8.1. Definition of migration and its reasons

Migration can be described in the simplest way as a movement of the majority of a population between two or more environments which is undertaken on a regular basis (Northcote, 1984). Diferentiation of migrations with respect to their reasons is currently a generally known assessment that may be found in a wide range of domestic as well as foreign publications (Baruš and Oliva, 1995; Lucas and Baras, 2001). Fish may migrate as a response to basically an infinite combination of environmental factors whose influence increase mutually and vice versa. The current conception of migration behaviour differs from the original definitions that are rather ponderous and mechanistic and that are derived from the general model of reproductive migration. This model supposes uninterrupted movement of individuals between two points that is initiated by exceeding the threshold value of daylight length, light intensity, temperature and flow-rate. With the increase in knowledge, however, migration is understood to be rather a continual, often even inconspicuous process, containing a wide range of conditional connections. Migration can thus be defined also as a strategy of adaptation to current environmental conditions (Lucas and Baras, 2001). Nowadays, it is thus mainly emphasized that the decision where, when or whether to migrate is not specified in advance and it usually depends on an individual, even though there are genetic predispositions to it. Fish migrations in the riverine environment represent a phenomenon that was considered to be well explored already a few decades ago. Eels and salmonid species are probably the best examined fish species and yet, new information concerning their migrations is still being published. In other words, we still do not know enough about migrations. The best known examples (such as migrations of salmons) are not necessarily by far the most complicated. To untangle the mechanism of trout migrations represents a real challenge since there is a part of the trout population that migrates to the sea and the other part that stays permanently in rivers. It is also challenging to describe migrations of Amazonian catfish since their migrations are undertaken in multi-year cycles that are, in addition, irregular. Surprisingly, the Czech information concerning fish migrations in European waters is also very limited. There are only a few known facts relating to a wide range of important riverine species (e.g. chub, dace, ide, asp, etc.). Individual information concerning other species is not available at all (e.g. bleak, tench, rudd, gudgeons, little chops, sabrefish and many others). The trouble is that, nowadays, we can often study only fragments of the original manifestations. It is difficult to imagine that (on the basis of evidence of people who witnessed it) migrations of chubs to the tributaries of the Elbe River (e.g. the Mrlina and Cidlina Rivers) seemed as a never-ending, compact, several meters wide stretch of fish bodies. Today, nobody will probably be surprised at the fact that barbel commonly migrate to locations that are up to several kilometres distant. In recent history, the biomass of barbel in the Czech river network was unimaginably high from today's point of view and the amount of their catches was rather limited by the anglers' physical capacity. Barbels were just everywhere and therefore, no one asked the question of how massive biomass movement must have their seasonal migration represented? Migrations of not only barbel but also nase carp, vimba bream or gudgeon were possible to be compared to continual movements of African and Asian herbivorous hoofed animals. Eye witnesses claimed that it was possible to watch the movement of thousand-headed shoals. Fish burrowing at the bottom even created turbidity in the water or, to the contrary, light contrasting areas where stretching shoals scraped off biological scab. Nevertheless, migrations of these species were not considered to be interesting as much as jumping shows of salmons that were attractive from a culinary point of view.

3.8.2. An example of variability of brown trout migrations

Variability of potential migration behaviour can be demonstrated with the example of brown trout that was, from this point of view, studied really thoroughly. Trout's ability to migrate is genetically encoded (Northcote, 1981, 1992; Johnsson, 1982; Elliot, 1989), however, it depends on the local conditions as to what strategy a population will use. Local conditions are formed by two basic phenotypes – migration and stationary phenotype (Jonsson, 1985; Hindar et al., 1991; Jonsson and Jonsson, 1993; Hendry et al., 2004). It is not important whether the migration phenotype descends to the sea or, for example, migrates to headwaters, the principle is always the same. A migration type is characterized by a larger size and higher ability to overcome river gradient. Nonetheless, there are dissimilarities even within migration phenotype when larger individuals swim for longer distances (Hesthagen, 1988; Young, 1994) and overcome bigger obstacles in a stream (Aass et al., 1989). Migration is influenced by food availability (Wysujack et al., 2009; O'Neal and Stanford, 2011) and, for example, fast growing fish migrate much more often (Jonsson, 1985; Hindar et al., 1991). A relationship between slow growth and higher migration intensity was also proved (Olsson and Greenberg, 2004); in such case, however, it is abundance that plays an important role as well. If trout migrate due to their slow growth, it is expected at the same time that the abundance of the population is high, exceeding the capacity of the environment, and trout thus initiate their migration in response to disadvantageous environmental conditions (Olsson and Greenberg, 2004). Another interesting fact is that migration ability is dependent, to a certain extent, on the individuality of each fish, on its social position. Large or aggressive dominant individuals are less afraid of unknown space and they tend to migrate more in comparison to subdominant, weaker and fearful individuals (Höjesjö et al., 2007). Trout migrations can also relate to seasonal changes of the environment. Summer food resources and the need to find a temporary shelter for the energy-saving regime during winter play a key role (Clapp et al., 1990; Gowan and Fausch, 1996; Carlsson et al., 2004). If only reproductive migrations are assessed that usually represent the longest movement during the year (Young, 1994; Ovidio et al., 1998; Rustadbakken et al., 2004; Zimmer et al., 2010), clarity cannot be expected either. Migrations may be undertaken downstream (Solomon and Templeton, 1976) as well as upstream (Davies and Sloane, 1987), they can be tens of kilometres (Young, 1994) or only several hundreds of meters long (Harcup et al., 1984; Ovidio et al., 1998, Slavík et al., 2012) or they may not be undertaken at all (Jonsson and Sandslund, 1979; Northcote and Hartman, 1988; Northcote, 1992). Migrations may also be influenced by the flow-rate size when an increasing flow-rate serves as a catalytic converter of migrations (Solomon and Templeton, 1976; Davies and Sloane, 1987). Conversely, if the flow-rate is low it may be difficult to overcome obstacles (Jensen and Aass, 1995). On the other hand, some authors (e.g. Jonsson, 1985) describe trout migrations that were undertaken during the low flow-rates. In the Czech conditions, for example, in the basins of the Blanice, Vydra and Vltava Rivers, trout migrate during September and October when the flow-rates are at their minimum (Slavík et al., 2012). Similarly, in the Ohře River, trout preferred migrations during stable and average flow-rates (Slavík and Bartoš, 2004). Trout migrations are shorter in streams with a higher river slope since overcoming the latter exhausts energy resources (Bohlin et al., 2001) and migrations are more intense when there is a new moon rather than full moon because trout hide from predators (Slavík et al., 2012). The influence of the moon phases on behaviour of different fish species is a very common phenomenon (Horký et al., 2006; Takemura et al., 2010) and it is common, above all, for sea coral fish living in a very stable environment. This multifarious (although very brief) overview may be concluded by stating that the nature of trout migrations is determined by local environmental conditions (Jonsson, 1991). There is an important instruction that follows from that for management: published data can be viewed mainly as a source of potential inspiration. However, regional care for populations of salmonids and fish in general must be supported by regional information.

3.8.3. Migrations of other fish species

The Czech Republic is located deep inland in the heart of Europe; therefore, two general migration strategies can be observed with respect to local fish. Strong and persistent migrants specializing in long migrations undertake diadromous migration into the sea environment. Such fish species have always been rare in the Czech fauna. On the other hand, potamodromous species, that are abundant in the Czech Republic, undertake their life cycle either directly in their regular habitats or not too far away from it. The opinion that common riverine fish species did not migrate either at all or only for a short distance predominated for the most part of the past century. This inaccurate opinion was corrected mainly due to the research of the seasonal behaviour of the cyprinid species (barbels, roaches, chubs and daces) that was carried out in Great Britain at the beginning of the 1990s and later also in Germany (see the overview in Lucas and Baras, 2001). Nowadays, the published information concerning migrations of cyprinid and other riverine fish species for distances longer than several tens of kilometres will not surprise anyone. Nonetheless, there were even longer migrations that were described in the Czech territory, more precisely in the Elbe River. While chub and asp migrated for a distance of 20 kilometres in the lower Elbe River located close to Děčín, pikeperch migrations reached almost 60 km (Slavík et al., 2004). With respect to the lower Elbe River, such distance represents migration deep into the German territory. The biggest record holder among the Elbe cyprinid species is indisputably ide that undertook migrations longer than 100 kilometres up to the stream stretch situated between Dresden and Meissen (Kulíšková et al., 2009). Nevertheless, ide migrations of around 200 km were described in Holland (De Leeuw and Winter, 2008). Crucian carp migrations that reached 80 km were recorded in the Elbe River (Slavík and Bartoš, 2004) and in the left-side tributary of the Elbe River, in the Ohře River, there was also an intense migration of burbot (Slavík and Bartoš, 2002). It logically follows that migrations are longer in large streams than in small river basins. For example, migrations of brown trout do not exceed 30 km in small streams (Ovidio et al., 1998; Ovidio and Philippart, 2002; Slavík et al., 2012), while sea trout migrate for hundreds of kilometres in the Rhine River basin. For example, nase carp is also considered to be an active migrant since it responces sensitively to flow-rate and temperature changes (Rakowitz et al., 2008). In small tributaries of the Danube River, nase carp migrate for a distance of 25 km; however, migrations exceeding 100 km were described in the Danube River (Povz, 1988; Ovidio and

Phillipart, 2008). With regard to environmental parameters, it can be stated that fish usually avoid migration in extreme conditions. The majority of fish species occurring in the Czech Republic initiate reproductive migration at the temperature of 10 °C, but species, such as gudgeon or bleak migrate even if the temperature is above 15 °C (Slavík et al., 2004; Horký, 2004, 2011; Prchalová et al., 2011). Brown trout cease their reproductive migrations when the temperature is below 6 °C. It is certain, however, that a large number of fish migrations are not influenced by the temperature. It is suggested, for example, by the fact that for reproductive migrations of cyprinid species it is only the threshold value that is important and when it is overcome, no other relationship is possible to be found. Cyprinid fish usually avoid migrations if there is a high flow-rate in a stream (Lucas and Batley, 1996; Lucas and Baras, 2001; Slavík et al., 2009). Different information can be found even in connection with this case, since, for example, Rakowitz et al. (2008) stated that migrations of nase carp culminate during floods but are undertaken only during the phases when the flow-rate aincreases and falls.

In conclusion, it can be stated that migrations of small species are limited by small energy resources and that is why they are undertaken gradually, more likely as spreading. On the other hand, large species are able to cover several kilometres per day. Fish, however, spread themselves passively within the water flow, which is the so-called drift. The abundance of drift species, mainly larval and juvenile stages, is dependent also on the current hydrological situation, the phase of light, darkness and moon (Reichard et al., 2002a,b). Drift is probably the most frequent movement of aquatic organisms and in tropical large rivers it is an important mechanism influencing the spatial distribution of fish.

Since a certain form of migration can be expected from all fish species it is appropriate to take this fact into consideration with respect to the management of the riverine environment. Restoration of the possibility to undertake migrations should thus become one of the main targets in the longitudinal profile of a stream. In practice, it means not to build new migration barriers and that the existing ones are equipped with fishways. The Czech project relating to river restoration including longitudinal connectivity of the river network is a task that will involve several generations because the rough estimation (there are no exact data) of migration obstacles amounts to more than 6000.

3.8.4. Fishways and their monitoring

Fishways are designed as channels that make it possible to pass artificial obstacles. Their longitudinal gradient is thus lower than the gradient of an artificial obstacle. An obstacle is usually represented by a weir or a dam reservoir, but also a dry river bed where water or a strong source of pollution was drained away from, may hinder fish movement as well. An obstacle may represent a variable notion during the annual hydrological cycle. For example, when the flow-rate decreases, the difference between the lower and upper water level at the obstacle may increase. To the contrary, if the flow-rate increases, flow velocities in some particular stretches of stream may rise to such an extent that fish will not be able to overcome the water velocity. Rough data describing the ability of common fish species to overcome the difference in height may be found in specialized technical documents (DWD-M509; TNV 75 232). In general, it can be stated that for some species, such as bullhead or lamprey, only a 5 cm difference in the height of water levels may be insuperable unless there is a suitable substrate on the bottom that reduces the velocity. The issue of whether a migrating individual can approach an obstacle in a sufficiently high water column and broad area is also important. In other words, in order to overcome obstacles, it is necessary to produce a certain so-called burst velocity (e.g. Wolter and Arlinghaus, 2004). However, the effort to describe precisely the threshold "conditions for overcoming an obstacle" may be rather misleading. There are often disputes over the question of when an obstacle hinders fish migration and when it does not. Such discussions make sense with respect to the restoration of Nordic streams with the occurrence of

1–2 salmonid species. If two species in two size groups migrate through a stream, it is possible to specify the migration conditions very precisely. A fish community in the Czech conditions, however, may comprise tens of species. In order to maintain a community, the possibility of variable spatial distribution and migration as a whole is necessary. If one fish species loses its environment, it is very probable that other losses will follow, for example, due to the disruption of bonds in the food chain. Models ensuring permeability, only with regard to "migration of salmon or cyprinid species" may thus be understood as old-fashioned, or more precisely, non-functional. Therefore, it is appropriate to require that the migration for all potential species as well as sizes and ontogenetic stages is ensured. In this respect, the Canadian legislation made the biggest progress. The so-called *No Net Loss* concept (NNL) has been determined as a general target of corrective measures and this concept indicates that the measures shall ensure original fish production, in other words, the measures shall ensure the full restoration of the ecosystem function (Quigley and Harper, 2006). With respect to fish passing through artificial obstacles, NNL means that the fishway must ensure uninterrupted passage to all life stages of a given species without a consequent impact on their reproduction success. In other words, it requires 100% permeability with a minimum delay under an obstacle or in a particular fishway itself. The so-called principle of *"transparency"* of a fragmented stream for movement of native fish species (Castro-Santos et al., 2009) has also emerged recently and this principle specifies the qualitative indicators of permeability even better. The fishway *transparency* thus means, as a result, that fish should be able to use the channel of the fishway without any delay, energy loss, stress, injury or other negative factors decreasing the individual's body condition. A common feature of the NNL and *transparency* concepts is thus the free passage of all fish through an artificial obstacle with a minimum influence on their fitness, which is the most essential precondition leading to a reduction of the impact of obstacles on fish populations (Slavík and Horký, 2011). The passage of fish through fishway means, in other words, that an individual should be able to migrate through an obstacle without "realizing" that it migrates through a technical construction.

***Fig. 3.8.1.* Example of the bypass channel of the rock-ramp fishway – the complete view** (O*bermaubach, the Rur River, Germany, photo: D. Bůžek).*

Fig. 3.8.2. ***Example of bypass channel of rock-ramp fishway – in detail*** *(Obermaubach, the Rur River, Germany, photo: M. Drahoňovský).*

Fig. 3.8.3. ***Vertical slot fishway*** *(Ladenburg, the Neckar River, Germany, photo: M. Drahoňovský).*

Fig. 3.8.4. **Details of distribution of main streamlines in the chambers of a vertical slot fishway** *(Ladenburg, the Neckar River, Germany, photo: M. Drahoňovský).*

Fig. 3.8.5. **An example of chamber fishway** *(Střekov, the Elbe River, Czech Republic, photo: Z. Vančura).*

***Fig. 3.8.6. Elevator enabling fish migrations over an obstacle**. These species-selective devices ensure migration insufficiently – only at certain intervals (Wyhlen, the Rhine River, Germany, photo: M. Drahoňovský).*

***Fig. 3.8.7.* A special construction for migration of juvenile eels I** *(Geesthacht, the Elbe River, Germany, photo: D. Bůžek).*

***Fig. 3.8.8.* A special construction for migration of juvenile eels II** *(Geesthacht, the Elbe River, Germany, photo: M. Drahoňovský).*

Fig. 3.8.9. ***Brush cover of the fishway bottom (Hassinger, 2002)*** *(the Budín Weir, the Sázava River, Czech Republic, photo: J. Vait).*

Fig. 3.8.10. ***Details of brushes in the fishway in the Sázava River*** *(photo: J. Vait).*

Designs of fishways can be looked up in a wide range of specialized publications (Clay, 1995, Odeh, 1999; Coutant and Whitney, 2000; Larinier et al., 2002, Lauerman, 2010; Horký, 2011; Slavík and Vančura, 2012; DWA-M509 2010; TNV 75 232). Therefore, it is pointless to analyse the issue in detail in this book. In general, it can be stated that fishways are distinguished as technical and bypass channels of a natural type, known as bypasses. Nonetheless, this historically used division is misleading because it forcedly categorizes structures that are to be, in principle, variable and that are to take local conditions into consideration. Basically, all fishways are technical and the difference lies only in the construction element that moderates the flowing water energy. Flowing water energy can be moderated in the fishway channel continually on rough overruns or in chambers separated by walls with orifices. In the first case, fishway channels are roughened by inserted boulders, ribs or vertical slots (Slavík et al., 2012). To make it simple, pool fishways are divided into rock-ramp (Fig. 3.8.1. and 3.8.2.), slot divided (Fig. 3.8.3. and 3.8.4.) and chamber (Fig. 3.8.5.). The overall appearance of a fishway channel eventually carries an architect's implementation vision, however, simple normative hydraulic parameters (gradient, height of water column, flow velocity, moderating of stream energy and width of river bed) are adhered to in the first place. The variable range of implementations of classical conventional fishways is supplemented with, for example, fish chambers and elevators (Fig. 3.8.6.). There are also fishways with special design and substrate, enabling migration of juvenile eels (Fig. 3.8.7. and 3.8.8.). In order to facilitate migration of sea lamprey, glossy metal boards with smooth surface are inserted in fishways – since this facilitates lampreys to use the suckers to attach to firm substrate during rest periods. Brush substrate that was developed for juvenile eels is used for brook lamprey. The so-called brush fishways represent an interesting novelty (Hassinger, 2002) where artificial obstacles and boulders are replaced by plastic bars that are reminiscent of a "brush" (Fig. 3.8.9. and 3.8.10.). This type of fishway is maintenance-demanding because plastic clusters of brushes become clogged with sand and organic material and, what is more, time-worn brushes must be replaced after several years. Nevertheless, these fishways represent a potential alternative with a relatively easy implementation for headwaters, brooks and small streams with salmonid occurrence.

In order to ensure fishways' proper functioning, it is necessary to carry out their monitoring. Testing of functions should be a part of each new fishway implementation. The final inspection of a fishway should be granted only conditionally and the whole implementation should be assessed no sooner than when the functionality test is carried out. Testing of fishway function should regularly last one calendar year, but it is possible to propose special procedures. For example, in streams that are inhabited only by brown trout, it is possible to limit the testing of function only to the period of autumn reproductive migrations. Mainly the spring seasons should be monitored in the middle and lower stretches of streams because it is the time when most of our fish species migrate. Catadromous reproductive migration of eel culminates by the end of summer; however, this migration is usually not noticeable in fishways. On the other hand, anadromous migration of juvenile eels can be expected (especially in the lower stretch of the Elbe River basin) at the turn of June and July and during July when the temperature exceeds 20 °C. Monitoring in the lower stretches of larger and large rivers with the occurrence of ides, daces and asps should be initiated already towards the end of winter when these species start being active in the Czech conditions (Horký et al., 2007, 2008; Kulíšková et al., 2009). Monitoring of salmon and eel migrations represents an independent sphere and these species cannot be recommended for testing of fishway function in the Czech conditions. With the increasing size of a stream, the diversity of the community is rising as well and the reasons for migrations are thus diverse too. Reproductive migrations are in their nature more or less a one-time phenomenon and that is why they are the most easy to prove. Migrations that are undertaken in search of food or shelter may concern the same number of fish, however, these migrations are undertaken in a less synchronised way, or alternatively, their nature is more individual, and they are thus less easily traceable. Finally, with a slight exaggeration, it could be stated that there is always some kind of migration taking place in a river. Although reproductive migrations are the most suitable manifestation of fish behaviour in order to test the fishway function, the all year test will deliver the most objective information.

The methodical approach that is selected for the fishway testing is also important. Basically, there are two methods that can be used for the testing – radio telemetry and bio-scanners. Monitoring by means of catching fish under an obstacle, their tagging and the subsequent research of the success rate above the weir is not very efficient and it stresses fish. A more problematic method is insertion of different types of fish traps and baskets in the fishway. Migrating fish are trapped and restricted in movement here, which is in direct breach of the Act on animal protection against cruelty. Besides, it depends only on the good will of a person performing monitoring whether he/she will inspect the fish traps at least 4–6 times a day and let the trapped fish out. It is usual practice that these devices are inspected inconsistently and fish in traps are being stressed and exhausted. Exhausted fish are pressed and dragged by the water flow against the fish trap walls and the fish are actually being injured which may cause their death. In addition to that, today, it is not possible any more that a fishway is tested without supervision of specialised personnel. The so-called *Design of the experiment* that must be approved by a relevant authority for nature conservation and by an *ethical committee* of the Ministry of the Environment must be elaborated for each test. An authorised person is obliged not only to provide certification permitting execution of the project (a special course in accordance with the Act on animal protection against cruelty) but also the number of animals (fish) used for the test. This obligation excludes use of fish traps because the numbers of fish that are used for the test can be determined only with the use of telemetry. It is not required if bio-scanners are used because fish are neither manipulated nor restricted in their movement.

The use of bio-scanners represents a method where a fish migrating through a fishway passes through a frame in which its body interrupts the infrared light zone. The body contour is "scanned" and the time and direction of migration are recorded. Modern versions of bio-scanners contain also a camera system that is automatically switched on when the scanner unit identifies active movement of fish (it is distinguished from passive movement of, e.g. wood or a plastic bottle). Scanners thus can provide information concerning the species composition of migrating fish. Scanners have one substantial disadvantage – they provide information only about the situation in a fishway, but they do not "indicate" the proportion of a community or a population that occurred, with respect to a community composition, downstream an obstacle. In other words, scanners provide information on the channel permeability but not on the fishway efficiency with regard to a community overcoming an obstacle. Scanners are thus ideal for monitoring of migrants, such as salmon, that migrate irregularly from long distances and whose abundance in a stream cannot be estimated.

Therefore, telemetric methods are the most suitable to test the functioning of fishways. With respect to assessment of fishways' permeability and migration requirements of fish, no other method is considered in the specialized literature (Bunt et al., 2011). There are two approaches – radio telemetry and telemetry of passive integrated transponders (PIT). The principle of both these methods is very simple. Radio telemetry uses transmitting units, i.e. radio transmitters that are attached to a fish body or implanted into a body cavity. The radio transmitter must he lighter that 1.75% of the fish's weight in water and its implantation must be performed by a veterinary surgeon – an expert. The lifespan of the radio transmitter is limited by the weight of its battery. With regard to large (heavy) radio transmitters, the lifespan can be considered to be up to 4 years, but fish must weigh at least 0.6–1 kg. Conversely, radio transmitters that can be implanted, for example, into juvenile trout weighing 15 g can transmit for approximately 3–4 weeks. Radio transmitters are, however, equipped with various mechanisms that enable extension of the monitoring period – they can, for example, transmit only some days in a week, some hours during a day, and the signal of radio transmitters may be produced at longer intervals (2–10 sec). A great advantage of radio telemetry is the possibility to mark a fish before initiation of migrations (for example, in autumn with respect to the spring season) and to monitor its behaviour before it approaches a fishway. Radio transmitters can also be equipped with sensors that monitor temperature, depth (pressure), acceleration of an individual or its energy consumption. Sensors measuring the given energy consumption can also be used in monitoring a fishways' quality. In fact, fish often enter a fishway but then turn around and migrate back. It usually signifies unsuitable migration conditions in a part of the fishway. Such place can be revealed on the basis of too high energy consumption when compared to the norm. Methodical specification is further represented by knowledge of the situation when fish do not approach a fishway at all during the test (and migrate only downstream). If such a case occurs, the fish is eliminated from the total number of tested individuals in advance in order not to decrease the effectiveness of a fishway in comparison to a fish that even though it found the fishway, it did not manage to use and overcome it. The disadvantage of radio telemetry is the higher purchase cost of the receiver (approximately CZK 300000) and radio transmitters (approximately CZK 8–15000 per piece according to the specification). In order for the test to be relevant, it is necessary to use approximately 30 fish. Selection of the species that are to be tested is also important. Although a larger species variety is often available, the most suitable is to use two species as a standard (15 + 15 pieces) with respect to projects that are carried out on small and middle streams up to the size of the Sázava or Berounka River. In order to test large and expensive fishways it is recommended to use up to 4 species with the total number of approximately 60 fish. It is not difficult to select particular species, however, the same species should be used the most frequently. It is due to better possibilities to compare the tests of individual fishways in the same as well as different streams. It is always appropriate to select different morphological types, for example, trout and burbot, grayling and roach or dace, barbel and ide or chub, asp and bream, etc. In order to test large fishways, pikeperch and European catfish can be recommended in a smaller sample as well.

The above mentioned PIT telemetry is perhaps the most accurate method for testing fishways. Tags, passive transponders, do not have their own battery and they work on the principle of an induction coil. Aerial supplies energy for signal transmitting, which a fish that is tagged by the PIT, approaches. Due to the absence of a battery, transponders are very small and light (their dimensions are 12 x 2 mm and weight around 0.09 g) and they can be implanted also in small fish, such as common minnow, gudgeon or bleak. Their unlimited lifespan represents another great advantage because they cannot go flat. In addition to that, they are relatively cheap (approximately CZK 100–200), especially when compared to radio transmitters. Nonetheless, even this method has its limitations, for example, the reading device with aerial cost approximately the same as the radio telemetry receiver. The biggest limitation is, however, that the tagged fish must approach the aerial at least within a distance of 30 cm in order that the individual code of the passive transponder could be read. In order for the tagged fish to be always recorded by the aerial during the migration through a fishway, it is often necessary to insert two aerials next to each other in the channel. Another possibility is to bring fish to the aerial by means of mechanical baffles, such as a perforated submerged wall. The device also requires a source of electrical energy that must be often brought to an obstacle separately. In addition to that, it is necessary to secure its safety against random passers-by. To protect it against theft, it is necessary to lock the control unit in a watertight box, etc. Selection of fish that are to be tagged represents a relatively creative part of the test of fishway function by means of passive transponders. Owing to the low costs per marking of a fish, hundreds of fish can be marked at the same price that equals to purchase of 30 radio transmitters. Therefore, a much wider species and size spectrum of a community can be used. This method also enables the easy tagging of fish several weeks or even months before initiation of fish migrations. At the time of the testing itself, fish will not be stressed and they will be in good physical condition.

3.8.5. Diadromy, potamodromy and the concept of river network restoration in the Czech Republic

Migrations of eel and Atlantic salmon have not been mentioned in the previous text. Migrations of both these species are detailed in a large number of specialised publications (e.g., Baruš and Oliva, 1995; Crisp, 2000; Tesch, 2003). It can only be emphasised that eel is turning into a species with a problematic future

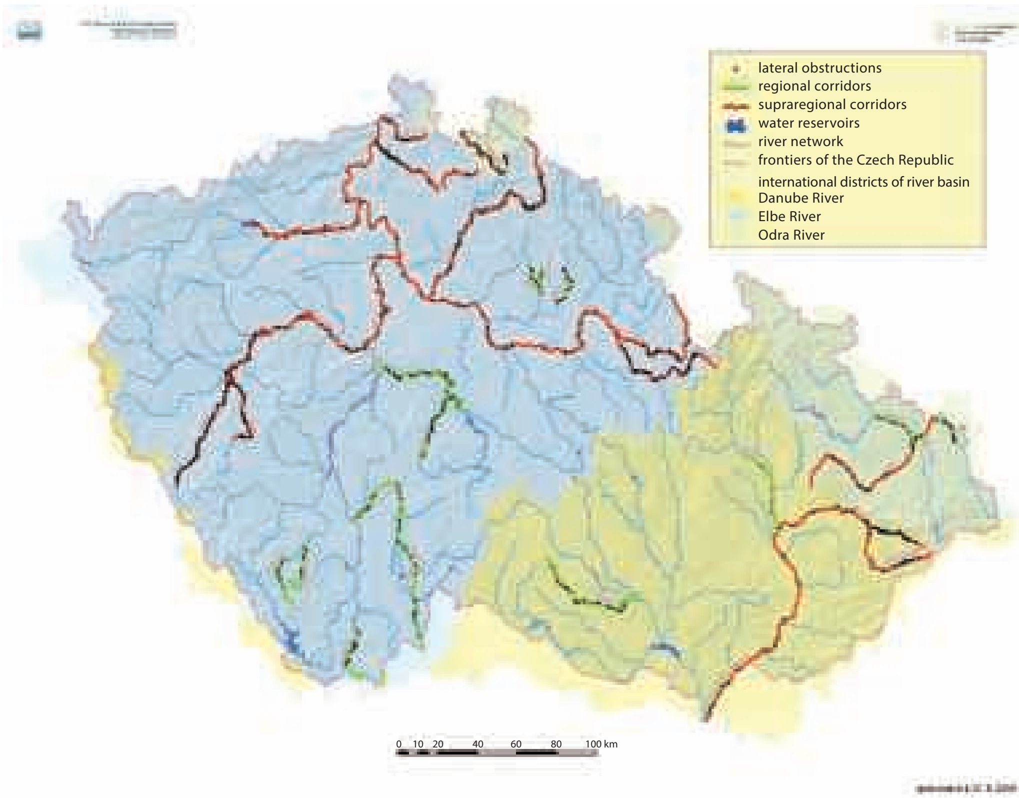

***Fig. 3.8.11.* The concept of the river network restoration in the territory of the Czech Republic.**

all over the world, which is a result of inadequate protection, fast spread of a disease caused by parasitic nematodes and also by hindering of their migration over artificial obstacles in the riverine environment. Although salmon lost its fight with civilization in the Elbe River basin once already, there is an experiment concentrating on restoring salmon's spreading in the territory of the Czech Republic that is currently taking place. The first returns of isolated adult salmons into the Kamenice River provide evidence that the efforts to restore the ecological function of the riverine environment are meaningful. In addition to salmon, some other exterminated species of fish, sturgeons and lampreys can be expected to appear in the future in the Czech territory. Diadromous migrations are represented in the territory of the Czech Republic by catadromous migrations of adult eel towards the sea environment. Conversely, adult salmon undertake anadromous migration. The concept of a river network restoration in the Czech Republic was suggested for diadromous and potamodromous species (that live their whole life cycle in freshwater; Slavíková et al., 2010). This official document of the Ministry of the Environment prepared the strategic framework for removing migration obstacles by means of the construction of new fishways. The concept has two levels – supranational and national priorities. Supranational bio-corridor enables migrations of diadromous species, while the national bio-corridor is focused more regionally on migration of the potamodromous species. However, those streams where migration of potamodromous species will also enable the spread of rare bivalves, mainly pearl mussel and freshwater mussel *Unio crassus,* are preferred. Bivalves' larvae proceed to a parasitic phase after the eggs have hatched. They attach to branchia where they nourish themselves for several months. This host does fish no special harm, sometimes it might temporarily cause unpleasant feelings. In this way, bivalves solved two problems in one evolutionary adaptation – nourishment in the environment that is usually poor in food resources and migration to new habitats. Therefore, if migrations of fish are hindered, the possibilities of bivalves are hindered as well. That is the reason why these streams with the common occurrence of fish and rare bivalves were given priority to restore river continuity. The prioritized streams can be seen in the Fig. 3.8.11. The main supranational migration corridors proceed from the sea up the stream of the Elbe, Odra and Dyje Rivers and they copy the line up to the headwater areas. Rivers with no large dam reservoirs or their cascades were selected for the supranational migration corridors. The reasons are evident – financial resources are limited and the setting of priorities is necessary in general. In addition to that, it is known that the impact of dams on downstream stretches is often devastating. A modified temperature and flow-rate regime change the quality of the environment, the native communities are often replaced by non-native communities, or the native ones do not prosper and they show a low biomass or species diversity (Kubečka and Vostradovský, 1995; Slavík and Bartoš, 1997). Last but not least, it is necessary to mention also the fact that migrants would have no place to migrate to even if they overcame the dams. Riverine fish species, such as barbel, nase carp or salmon would have no chance to survive in the waters of reservoirs, such as Nové Mlýny on the Dyje River or Orlík on the Vltava River. In addition to that, even river stretches upstream dam reservoirs are not usually in such a good ecological condition to enable natural reproduction to rheophilic species. At present, the Elbe migration corridor is thus directed into the Kamenice, Ploučnice, Orlice and Berounka Rivers and into their headwaters and fish inhabiting the Dyje River should first be enabled to migrate to the Morava River, and subsequently to the headwaters of the Bečva River.

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FISHERY MANAGEMENT IN OPEN WATERS

4

P. Horký, J. Kubečka, T. Jůza, M. Prchalová, O. Slavík, M. Hladík, D. Boukal, T. Randák, M. Vašek, Z. Adámek, J. Andreji, P. Dvořák, J. Turek, J. Musil

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4.1. The basic analyses of populations of fish communities in streams *(P. Horký)*

Knowledge of the structure of fish populations in a given area or a fishing ground is crucial for correct decision-making in the sphere of fishery management in open waters. Populations and factors that influence their growth and regulation were the subject of interest of professionals from the turn of the 18th and 19th century (Malthus, 1798). Population processes (birth rate, mortality rate and migration) are influenced by a number of environmental factors and particular features of individuals that have a collective effect on population dynamics (Jarošík, 2005). Knowledge of population dynamics, i.e. changes in population densities in time, is a fundamental prerequisite for the efficient management of commercially used fish populations in open waters. The subject of this chapter is not, and due to the limited space it also cannot be, to document the current state of knowledge of population ecology. The purpose is to introduce basic analyses of the status of fish communities' populations in a given time period, regardless of the dynamic development in time. To obtain deeper knowledge in the field of population ecology, the publications of renowned authors (such as Jarošík, 2005; Berryman and Kindlmann, 2008) are recommended.

4.1.1. Data collection

Before data collection is initiated, it is necessary to consider what information on fish populations is needed to obtain and also what resources (financial, time, etc.) are available for this purpose. Generally, it is true, of course, that the higher quality of information, the more resources are required to obtain the information. A summary of the relative ratio between the obtained information and their value is shown in Table 4.1.1., which is based on the publication of Johnson and Nielsen (1983).

An overview of the main methods used to collect the data concerning fish communities is stated in chapter 4.2. In running waters, a method considered as standard as well as the most commonly used is the method of catching fish by means of a pulsating direct current (Jepsen and Pont, 2007). Output parameters of electrofishing equipment should be adapted to the environmental conditions to ensure optimal performance and to minimize the possibility of fish injury. In this regard, it is the conductivity and the temperature of the aquatic environment in particular that play a significant role. Higher conductivity ensures higher intensity of the electric field and thus sampling efficiency is also higher. The difference between the conductivity of fish tissues and the conductivity of surrounding water increases together with the increasing temperature. Fish are consequently caught easier, however, the risk of their injury or even death increases as well. Electrofishing is standardized in the European Standard (EN 14011; CEN, 2003). The sampling usually progresses upstream. The required equipment and method of sampling vary according to the characteristics of the locality. In wadeable localities, electrofishing is usually performed by means of portable aggregates that ensure the good mobility of a sampler. The sampling in non-wadeable streams is necessary to be performed by means of a boat and so-called deepwater aggregate that provides sufficient power for the sampling of a larger volume of water (Fig. 4.1.1.). With regard to specific requirements for the sampling of juvenile and adult fish communities, those samplings should be performed separately. A detailed procedure of juvenile fish sampling can be found in the methodology of Jurajda et al. (2006). Further information concerning electrofishing can be found in e.g. Snyder (2003) and it is also elaborated on in chapter 6.1.

Tab. 4.1.1. ***The ratio between the relative price and the obtained information concerning a fish community*** *(Johnson a Nielsen, 1983).*

Activity	Obtained information	Relative price	Details
Counting of species	Number of present species	1	Basic planned activity to which relative prices of others relate
Counting of individuals of each species	Relative abundance of present species, ecological or reproductive groups	x 2	Usually, the minimum required level of knowledge
Fish measurement	Length composition of a population, relative strength of individual year classes, relative growth, etc.	x 4	It adds a large amount of useful information at a relatively small unit of effort
Fish weighing	Length and weight relations, condition factor, relative weight, growth, biomass, etc.	x 12	Possible difficulties with accurate weighing of fish in the field conditions
Determination of age	More accurate than use of length frequencies for determination of relative strength of individual year classes, age composition of a population, growth of an individual in each year, etc.	x 120	It requires additional equipment and laboratory analyses with respect to the exact methods necessary to kill an individual (otoliths), for scale analysis there are possible errors dependent on experience of the evaluator, trophic status of the locality, age of an individual, etc.
Marking (conventional marks, telemetry…)	Population size or exact growth of an individual (recapture), movement of individuals, used habitat, in case of telemetry it can be supplemented with used area (home range), energy consumption, etc.	x 1200	Accurate and detailed information with great applicability, high cost of equipment

Fig. 4.1.1. ***Sampling by means of the deepwater electrical aggregate*** *(photo: P. Horký).*

In order to achieve adequate results when electrofishing, it is necessary to meet the basic requirements for the selection of a representative stretch of a stream (Jurajda et al., 2006; Horký et al., 2011). This stretch should conform to the general physical and ecological features of the assessed stream, especially in terms of the type of occurring habitats and effects of various anthropogenic pressures. With regard to the time demands of selecting an appropriate representative section in the field, it is appropriate to perform a preliminary inspection of the situation by means of available satellite maps (e.g. Google Earth). It should not thus occur that for the general assessment of the status of fish communities, the sampling is performed only in the stretch of stream directly below the sewage treatment plant outfall, etc. In the sampling itself, all types of habitats are sampled in the ratio in which they occur in the representative section of a stream. This ensures proportional composition of fish in the sample corresponding to a representative composition of the whole community.

An essential factor influencing the representativeness of the obtained data is also the size of the sampled area/length of the stream. The optimal length of the sampled stream should correspond to its width that is multiplied ten to twenty times, whereas the minimum length should be 100 m (FAME consortium, 2004).

The composition of the obtained sample is also influenced by the season. Sampling in the late summer or early autumn (preferably the period from August to September; FAME consortium, 2004) is considered to be standard. At this time, there is a long lasting minimum occurrence of extreme hydrological phenomena and flow-rates generally remain at low levels, which facilitate sampling. It is also the period when many fish species do not reproduce, the samples of the community are thus not influenced by migrants and at the same time the electrofishing does not influence reproduction as such. At this time, the fish are also in a good physical condition and they can bear the manipulation connected to the sampling itself far better.

4.1.2. Basic analyses

The starting point for further analyses is the recorded basic features of sampled individuals, such as species, length, weight and also other information (gender, external damage, etc.). The obtained data are subsequently subjected to meta-analyses where the species are combined into functional groups and their proportional representation in a community is expressed (see chapter 3.2.). At the same time, the abundance and biomass per unit of the sampled area and other indicators, such as the diversity of a community or its length and frequency composition, are determined (more details to be found in chapter 4.2. or in Southwood and Henderson, 2000). The possibilities are relatively broad and further processing of the obtained data depends on the questions posed.

4.1.3. Ecological status assessment according to the Water Framework Directive

The efforts to monitor the quality of the aquatic environment by means of various biological indices began in the early 20th century (Kolkwith and Marsson, 1908, 1909). Since then, the methods of monitoring have been modified several times until the most common assessment method was defined. Nowadays, it is thus assessed by means of the structure and composition of the communities (an overview can be found in Fausch et al., 1990). This principle was also adopted for fish communities that were initially assessed by means of the index of biotic integrity (IBI, Karr, 1981), the subsequent index EFI (European Fish Index; FAME consortium, 2004), or alternatively, by other derived indices (Jepsen and Pont, 2007). These indices predict, on the basis of abiotic parameters, the composition of the reference community and consequently, they compare it with a real community in a given locality. The ecological status, i.e. ecological quality of a community, increases with mutual similarity of the reference and real community. For a successful assessment of ecological status carried out by this approach, it is therefore important to know the abiotic parameters, since these parameters influence and change considerably the composition of fish communities (see chapter 3.2.). The assessment of fish communities by means of various modifications of the index of biotic integrity represents the basic approach leading to determination of the ecological status of water bodies according to the Water Framework Directive (2000/60/EC).

A methodical approach based on sampling of juvenile fish communities, that has been successfully tested in the Czech territory since the 1990s, has been used in the Czech Republic in order to assess the ecological status according to the Water Framework Directive (Slavík and Jurajda, 2001). Juvenile stages of individual fish species occupy specific habitats that are associated with their ecological requirements (Kryzhanovsky, 1949). Sampling thus brings information about available reproductive habitats in a given locality (Oberdorff and Hughes, 1991; Copp, 1992) as well as ecological functionality and integrity of the entire river system (e.g. Copp, 1989b; 1992; Oberdorff et al., 1993; Schiemer et al., 2003). Juvenile stages of fish are also sampled more easily in large streams than adult fish (Cattanéo, 2005) since they occur in shallow shoreline zones (Schlosser, 1987). The obtained samples of juvenile fish thus better correspond to the real composition of fish communities in the assessed localities (Cattanéo, 2005). The great advantage of sampling of juvenile communities is also the fact that they are minimally influenced by stocking and they correspond thus better to the real ecological status of the assessed locality. The stocking of fish is just resolving the consequences and not the causes of the unsatisfactory status. The causes are based, for example, on the lack of suitable habitats, and they can significantly distort the obtained data. It was also demonstrated on the Great Ouse River in England where the stocking of fish has been proved as an inappropriate solution to the reduction of the impact of anthropogenic modifications of the stream that caused either the complete disappearance (Maintland and Lyle, 1991) or insufficient reproduction of some species (Copp, 1990, 1992; Copp and Mann, 1993). From a practical point of view, sampling of juvenile fish communities is less time-, personnel- and material-demanding than sampling of adult fish. In the case of an experienced person, the determination of juveniles takes almost the same amount of time in laboratory conditions than that of adult fish in the field. The disadvantage of sampling of juvenile communities is the impossibility to determine detailed characteristics, such as length-frequency composition of populations, or their higher susceptibility to be influenced by extreme flow-rates (Schlosser, 1985; Cattanéo et al., 2001; Freeman et al., 2001). These disadvantages, however, are insignificant with respect to common monitoring because sufficient natural reproduction of a given species indicates the vitality and healthy development of the entire population (Houde, 1994) and flow-rates variability explains the composition of samples of juvenile fish from less than 10% (Cattanéo, 2005). An undesirable effect of flow-rates variability on the obtained data can be further decreased in such a way that relative data (% representation of species or groups) will be used for the assessment, which are less susceptible to be influenced by the flow-rates (Cattanéo et al., 2002).

Details about the assessment of the ecological status by means of juvenile fish communities in the Czech Republic in accordance with the requirements of the Water Framework Directive can be found in the methodology written by Horký and Slavík (2011). A detailed description of the development of the modified typology and the subsequent Czech multimetric index of assessment (CZI) is part of this methodology. The composition of expected reference communities was, for assessment development purposes, expressed in values of various metrics. The pre-selection of metrics was implemented on the basis of their ecological relevance and anticipated ability to detect degradation of a community according to the anthropogenic pressures' effects (Noble et al., 2007). In order to identify the differences from the reference status, these metrics were expressed as the so-called Ecological Quality Ratio (EQR), i.e. the ratio between the observed and expected values. The final selection of metrics was implemented on the basis of their ability to distinguish between reference localities and localities that were influenced by anthropogenic pressure. This procedure led to the selection of the following metrics: the occurrence of typical species, the total abundance, relative abundance of rheophilic species that prefer running waters and relative abundance of eurytopic species that are not specialized in a certain stream type and that are resistant to a change of the environment.

The final form of the Czech multimetric index (CZI) that is used for determination of the ecological quality of streams according to fish communities is:

$$CZI = \frac{(T_d + A + R_d) - (E_d)}{4}$$

T_d – EQR of occurrence of typical species
A – EQR of total abundance
R_d – EQR of relative abundance of rheophilic species
E_d – EQR of relative abundance of eurytopic species

With regard to the naturally low abundance of fish at an altitude above 800 m, the A-metrics (EQR of total abundance) was not capable in these conditions to distinguish between reference and non-reference localities. Based on this fact, the CZI for altitudes above 800 m was modified and its subsequent final form does not contain the total abundance.

The CZI for altitudes above 800 m is:

$$CZI = \frac{(T_d + R_d) - (E_d)}{3}$$

The relative abundance of rheophilic fish species is generally considered to be a metric whose value increases with the improving ecological status of streams. However, chub (*Squalius cephalus*), which is also a representative of rheophilic species is more resistant to anthropogenic pressures than the remaining members of this group. With respect to this fact, the community formed by chub may achieve a high proportion in the representation of rheophilic species, which does not necessarily mean good ecological status of a stream. In order to solve this situation, a correction was made in the calculation of the CZI that will automatically reduce the value of rheophilic species if chub is the only rheophilic species that occurs in a given locality.

4.1.4. The applied use of analyses of fish communities

Analyses of fish communities offer many possibilities for practical application. An example can be quantification of the effect of anthropogenic influences by means of indices of biological integrity. With regard to the Czech multimetric index (CZI), sensitivity to artificial obstacles in a stream or chemical pollution was thus proved (Horký and Slavík, 2011). The value of the CZI decreases with the increasing number of obstacles in a stream and with the decreasing distance between these obstacles that is expressed in the relationship to the stream length. In other words, the more obstacles and the shorter distances between them there are in a stream, the more a fish community is deflected from the reference status in a given locality. The reaction of the CZI to chemical pollution is inconclusive if we consider all localities. However, if we consider only those localities with low morphological pressure, the reaction of the CZI to chemical pollution is significant, whereas the CZI reaches higher values in localities with a low chemical pressure (Fig. 4.1.2.). A more complex solution is required for testing of a set of pressures that are acting in a locality altogether. For this purpose, D. Pont and O. Delaigue have developed the so-called "pressure index" within the scope of fish intercalibration that includes the value of 17 individual pressures that are exerted on fish communities. The CZI reacts significantly to this index and its value increases with the decreasing level of acting pressures.

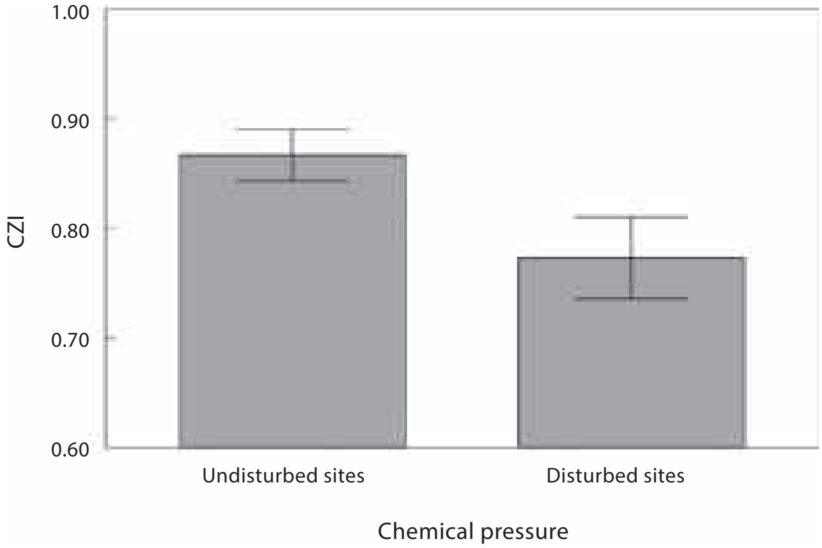

Fig. 4.1.2. ***The CZI vs. chemical pollution*** *(Horký and Slavík, 2011)*.

The management of endangered species of other classes belongs among interesting possibilities on how to use the knowledge about fish communities' status. Freshwater bivalves of the *Unionoidea* superfamily represent a group of endangered species whose life cycle is closely dependent on fish. These bivalves have a short-term developmental stage (the so-called glochidium) that represents a temporary fish parasite (Korschelt, 1912). The ability of glochidia to attach to a host fish is in most cases species-specific (e.g. Barnhart et al., 2008; Strayer, 2008). The full transformation of glochidia into a viable juvenile individual that falls off fish after several weeks is thus possible only with respect to specific host fish species (Dillon, 2000). The poor ecological status of a fish community that is related to lack of suitable host species can thus cause bivalves to disappear in affected localities (Douda et al., 2012). Knowledge about the status of fish communities and their subsequent management are thus crucial for protection of endangered bivalves and these should be included in their rescue programmes as well.

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4.2. The basic analyses of populations and spatial distribution of fish communities in lakes and reservoirs *(J. Kubečka, T. Jůza, M. Prchalová)*

This chapter provides an overview of analyses of fish communities which are necessary for at least a general understanding of the ecological status of fish stock in reservoirs or lakes. The scope of the chapter only covers basic analyses. Depending on the different needs, more advanced analyses, for example, analyses of fecundity, growth, food, health condition, etc., may further follow these basic analyses. The basic knowledge of fish stock includes information about spatial distribution, fish species and age composition. Should this information be available for a longer period of several years, we can think about the factors that cause changes in individual fish populations, the favourable and unfavourable conditions causing emergence and further survival of different species' year-classes which are of different strength. Such continuous monitoring is referred to as **monitoring of fish communities**. In order to monitor the status of fish communities in lentic waters, a methodical guide (Kubečka et al., 2010) that distinguishes between three basic types of monitoring of fish stocks, was published:

1. The basic monitoring of fish communities for the application of the Water Framework Directive. For this purpose, the framework knowledge of abundance, biomass, spatial distribution, species and age composition of fish communities in all major volumes of a reservoir in order to define ecological status or potential of a given water body, should be sufficient.

2. Some of the more derived purposes (e.g., explanation of the dynamics of fish catches, scientific sampling, basic data for decision-making on the management of fish stocks and their commercial value) require more detailed information based on more representative material with mastered error as a consequence of selectivity of fishing gear and spatial heterogeneity of fish occurrence (known probabilities of errors of estimations, confidence intervals, etc.)

3. Monitoring of fry communities represents a completely independent and methodically distinct chapter. In the reservoir and lake environment, the sampling method of fry communities depends considerably on the ontogenetic stage of development of the monitored fish species (Jůza and Kubečka, 2007; Jůza et al., 2010) and the fry habitat. Fry sampling methods are described in chapters 6.1 and 6.2. Night fry trawling and fry seining are usually relatively quantitative methods and provide absolute estimations of fry communities. Point sampling by electroshocking and fry samples from multi-mesh gillnets are, on the contrary, typical examples of semi-quantitative relative values (catch per unit of effort, see below for details).

4.2.1. Methods for determining the amount of fish, estimation of fish stocks

Various procedures for estimating fish stocks, which differ in difficulty and the quality of the information obtained, have been elaborated for different types of waters.

Absolute methods

The results of these methods are the most valuable because they provide, in optimal cases, absolute numbers and biomasses of fish per unit of area or volume, and also usually real species and age composition.

Draining

This is the simplest and a very accurate approach in places where it is feasible (aquaculture fishponds). The main requirement on the quality of the results is, in this case, that none of the monitored fish escape during draining. Ideally, the entire drained volume is filtered through a rack or net systems. In the case of open waters, in practice draining is conducted very rarely, some minor waters can also be pumped out. In any case, draining requires a significant intervention in the ecosystem.

Methods based on the decrease in catch per unit of effort due to repeated samplings

These approaches can usually be used in smaller localities where each sampling run can decrease the abundance of a community in such a way that it has an impact on the catch of the following run. Typically, these approaches are used within electrofishing in wadeable running waters (see chapter 6.1.), but they can also be successfully used in smaller lentic waters.

Mark and recapture methods

The principle of these methods is sampling, marking and releasing a sufficiently high number of individuals that are recognizable by the marking in order that a sufficient number of recaptured fish is achieved in subsequent samplings. The simplest procedure (Petersen's method) assumes the calculation of abundance (N): N = M . C / R, where M represents the number of marked and released fish, C represents the size of the catch in which the ratio of marked to unmarked fish was subsequently examined, and R represents the number of marked and recaptured individuals. The approach is particularly effective in smaller waters, but it has been applied repeatedly in valley reservoirs as well. The marking approaches have been summarized recently in a publication written by Amstrup et al. (2005).

Destructive methods, such as poisoning or use of explosives, are no longer used in the Czech territory for ethical reasons. In exceptional cases, the composition of fish stock can be determined on the basis of fish that have died due to pollution accidents.

Area methods

The principle of these approaches is preferably the quantitative sampling of representative areas if it can be assumed that a similar community is also present in the surrounding non-sampled areas of a reservoir or a lake. In vast and indented waters, it is usually impossible to sample all present habitats by means of one method only. For example, night hauls using seine nets, where highly satisfactory quantitativeness for nets longer than 50 m was produced (Říha et al., 2008 and 2011), are used successfully in reservoir shoreline habitats, such as beaches. The night pelagic trawling also meets the requirements for relatively quantitative estimations of the amount of fish in open water (Rakowitz et al., 2012; Říha et al., 2012). An assured method can be considered to be such method where verification of quantitativeness (efficiency) of sampling (ratio of individuals actually present to individuals estimated in the sample area) was performed. Quantitativeness verification can then provide correction factors that are based on sampling method efficiency. The use of area methods is more difficult in structured habitats (rocky bottoms, stumps, vegetation, etc.), where it is often very difficult to ensure high and defined quantitativeness of sampling. Special cases of area methods are hydroacoustic and optical approaches. Since they are very important for fishery management and they differ essentially from other direct capture techniques (these approaches are described in chapter 6), these methods will be described in detail in a special section.

Hydroacoustic methods are those in which ultrasound devices, such as an echo sounder or sonar, are used for detecting the quantity, spatial occurrence and size composition of fish under water (Simmonds and MacLennan, 1995). Simple echo sounders with LCD displays are used for detecting bottom depth and simple fish presence. Scientific echo sounders that save the data recorded, to be subsequently processed by special software, are used for estimations of the number of fish. The frequency of ultrasound of scientific echo sounders for studying fish usually ranges from 20–500 kHz and devices with a so-called split beam are used most often (Fig. 4.2.1., 4.2.2.). Fig 4.2.3. shows the type of information that is processed by modern scientific echo sounders. The ultrasound transmits in short pulses, one transmission is called the *ping* and it spreads in the shape of a conical beam. After the *ping* is transmitted, the receiver waits for the echoes returning from the aquatic environment, especially from objects that have a density different from water (gas in the air bladder, vegetation, and bottom). The time spent waiting for the echoes is proportional to the distance of the affected objects. Scientific echo sounders measure the distance within an accuracy of 2–3 cm and each registered object is measured several times (upper left part of Fig. 4.2.3.). Individual *pings* are inserted one-by-one into the echogram (right panel of Fig. 4.2.3.), where the X-axis represents time and the Y-axis represents depth (range). The track length of each object depends on the length of stay in the acoustic beam. Records of individual fish usually have around 10 *pings* and a defined thickness. Shoals of more individuals are then shown on the echogram as larger and wider spots. The colours are proportional to the strength of the reflection, which is usually the strongest from the bottom. Multiple echoes are combined with estimations of the quantity of fish by echo-integration of the total reflected energy. An alternative method is echo-counting in which individual fish echoes within a certain distance from the centre of the acoustic beam are analyzed. The quality record is characterized by the fact that for each *ping* it is possible to record the position of a fish in the XY-coordinate system (lower left panel of Fig. 4.2.3.). The distance of each record from the beam axis thus actually determines the examined volume and subsequent records of fish movement through the beam verify their membership to one individual and improve the determination of the acoustic size of an individual (echo strength). This can then be converted to length or weight according to sophisticated relationships and thus complete the calculation of abundance or biomass.

The record in Fig. 4.2.3. and the indicated procedure of the calculation concerns vertical echolocation when fish stock is monitored mostly from the water surface towards the bottom. In eutrophic waters of Central Europe, it is almost always necessary to also use horizontal echolocation together with vertical echolocation, since it is able to cover fish in smaller depths far better. In special cases, it is also possible to perform reverse vertical echolocation when the transmitter is located at the bottom or on a submersible watercraft. The best monitored layers are then the layers just below the water level (Fig. 4.2.4.).

Fig. 4.2.1. ***Transducers in the fore part of the research vessel exploring the reservoir*** *(photo: FISHECU archive).*

Fig. 4.2.2. ***Transducers in the fore part of the research watercraft.*** *A: Elliptical 120 kHz transducer for horizontal "beaming", B: Didson acoustic camera, C: Transducers for vertical surveying: 38, 120 and 400 kHz (photo: FISHECU archive).*

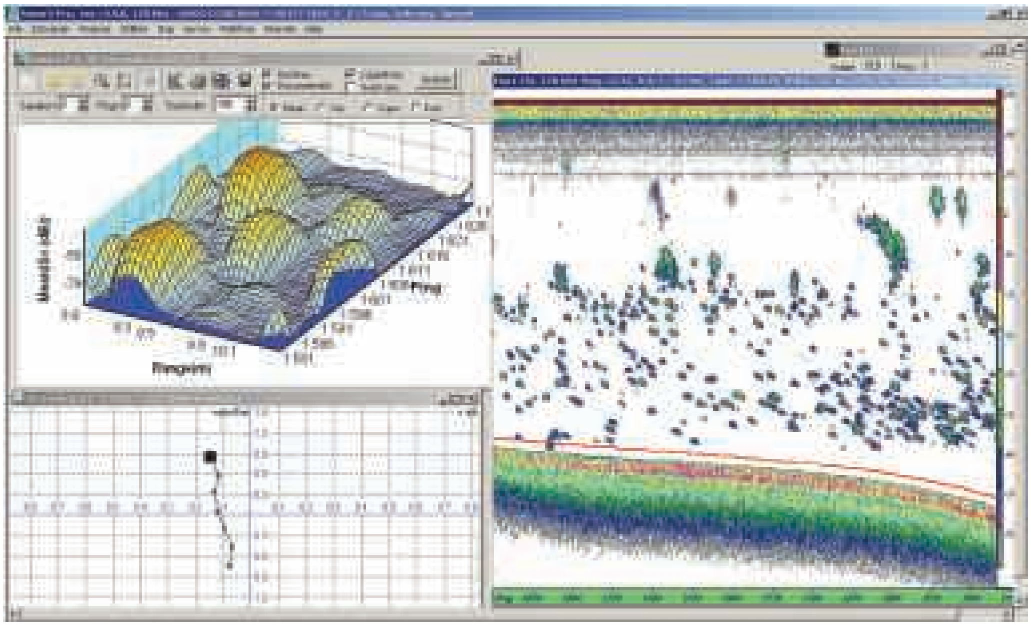

Fig. 4.2.3. ***An example of a vertical echogram during an analysis in the Sonar 5 PRO software.*** *The echogram appears in the right-hand side of the screen. The top left window shows signal intensity with fish echoes of different strengths (hills on the 3D echogram, the height and colour of the hill are determined by acoustic volume backscattering strength Sv). The bottom left panel shows successive records of one fish on a beam cross-section (XY Cartesian coordinate system in metres). The record that is marked with the highlighted square was the last one before the fish left the acoustic beam.*

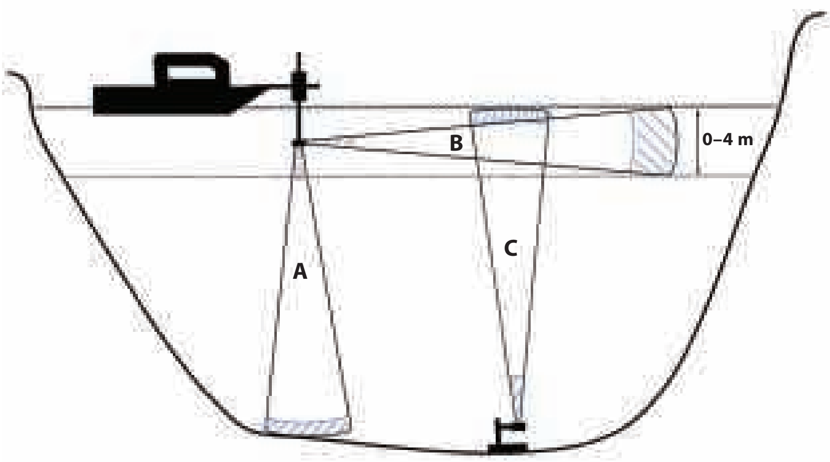

Fig. 4.2.4. ***Diagram of basic echo sounder surveys – vertical (A), horizontal (B) and reverse vertical (so-called up-looking) (C).*** *In each case, ultrasound samples the volume of a conical shape. There is usually a short so-called dead zone in the vicinity of the transducer, the bottom and water level, where the record cannot be used for fish detection (hatched areas in the beams).*

Split-beam type echo sounders provide a three-dimensional image of individual fish occurrence (not fish in shoals) at one instant in relatively narrow conical volume (beam angle less than 15 degrees). Scanning or multi-beam echo sounders, some are also referred to as acoustic cameras, provide a better and larger three-dimensional image. These systems put together information from many *pings* or beams into a compact two to three-dimensional image, in a similar way as an insect eye functions. For example, the DIDSON multi-beam sonar can simultaneously record information from 96 sectional beams with the dimension of 0.3 degrees and thus it covers the angle over 30 degrees (Fig. 4.2.5.). Some multi-beam sonars have high ultrasound frequencies (DIDSON 1100–1800 kHz, ARIS up to 3000 kHz), therefore, it is possible to observe some structures on a fish body (shape of the body, fins) and projections of a body on the background (acoustic shade). All these features help to detect fish species that are indirect and very difficult to recognize with classical echo-sounders. The disadvantage of the high-frequency devices is the short distance of a quality signal (20 m maximum).

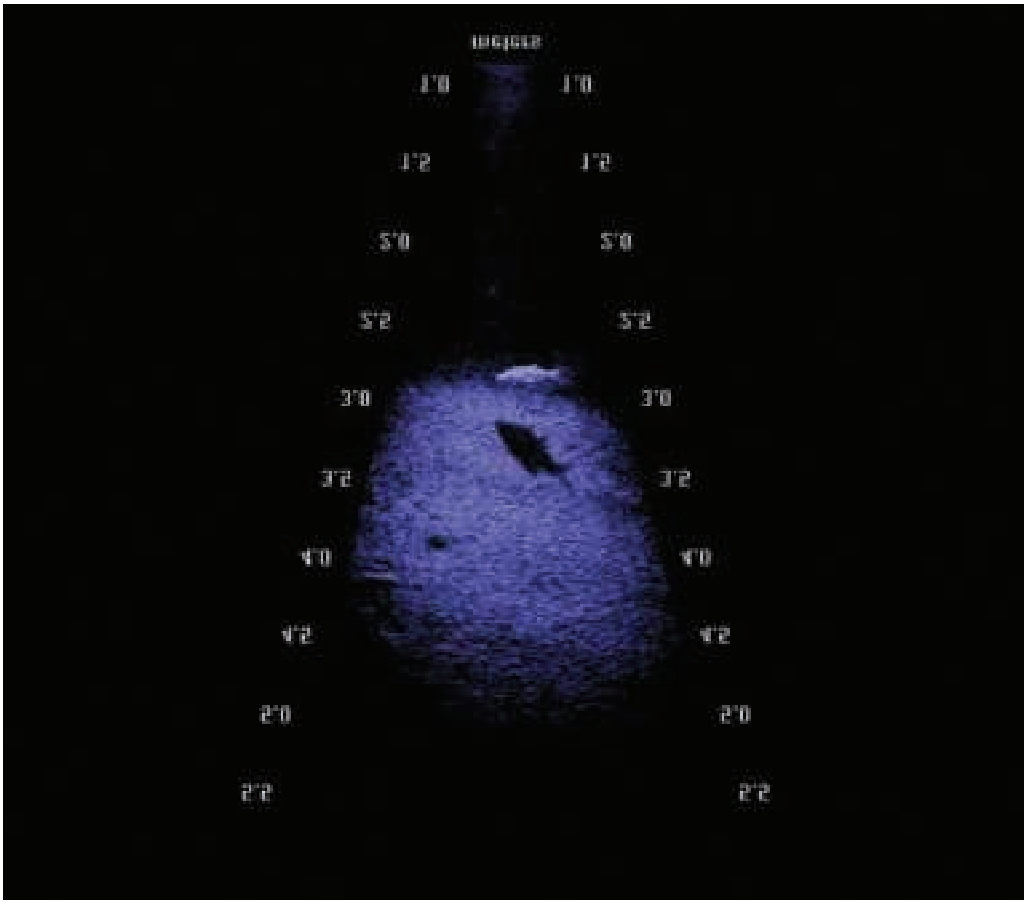

Fig. 4.2.5. **_Bream in the Elbe River on the record of a DIDSON multi-beam acoustic camera._** *The view is inclined from the water surface towards the bottom and it is possible to see the fish and its shadow on the bottom approximately 3 m from the camera (photo: M. Tušer)*

Optical observational methods

Optical observational methods, either direct observation of scuba divers or indirect observation by means of camera systems, are universally considered suitable for determining composition and abundance of fish stocks in their natural environment (Murphy and Willis, 1996). Similarly to acoustic methods, optical observational methods are also used mainly in the sea environment. The use of optical methods in freshwater is mainly limited due to low water transparency, which strongly influences accuracy of the estimation. The visual approach has been successfully used in Czech conditions for counting spawned eggs of European perch (Čech et al., 2011). It is probable that the acoustic and optical approaches will be intensively developed in the near future, since these methods interfere in the life of the examined communities the least.

Relative methods

Relative methods are used if absolute approaches are too time-consuming and expensive. These methods can be used advantageously if some catch effort in a given water body is carried out regardless of research activities (e.g., sport or commercial fishing).

Analyses of fishery statistics

The analysis of statistics relating to fish stocks and catches represents the simplest attempt to determine status. This approach is fundamental for analysis of the development of commercially interesting species and management efficiency. The trends in catches and returns can indicate changes in management conditions or differences among individual fishing grounds. It is always necessary to remember, however, that especially catch statistics are influenced by anglers´ behaviour and by the development of their technical possibilities. Introduction of catch effort monitoring in the form of fishing visits represents a very positive measure. Catch statistics have thus made a move towards recording catches per unit of effort (see below for details). The trouble is, of course, that visits from different anglers can have different validity from the catch point of view; however, the mistakes are partially eliminated by the large number of catch records. It can thus be traced how great the pressure is that fish in different grounds are exposed to and the catch per visit represents the simplest rate of abundance of a given species in a fishing ground. Currently, there are not enough analyses available that would assess the impact of catch effort on the success rate of anglers in Bohemian and Moravian reservoirs. This is caused by, among other things, the fact that the effort has been monitored for a relatively short time period and only in certain fishing grounds. There is no doubt that, in the course of time, information concerning catch effort, in connection with detailed information about catches of individual species, will be used in order to enhance fishery management. The quality of catch statistics can be verified and other specific information can be obtained during direct inspections of sport anglers´ catches directly in the terrain, which is the so-called creel census. In countries with a developed commercial fishing industry (mainly marine countries) catch statistics can be used as rates of abundance and biomass of harvested species.

Estimations of relative abundance or biomass according to catches per unit of effort by means of research devices

There is a whole range of defined sampling methods that produce, if applied correctly, the defined catch per unit of effort (**CPUE**, sometimes also C/f; **BPUE** for biomass). Nowadays, the standardized area catch rate (usually 1000 m^2) of multi-mesh gillnets is by far the most frequent estimation of relative abundance (see chapter 6.2., examples of the use as the BPUE are also stated in Fig. 4.2.12.). In order that the catch per unit of effort reflects the real amount of fish, the catch effort must be standardized in relation to time of catch, season and the possibility of net saturation by a larger amount of fish in a catch (Kubečka et al., 2010; Prchalová et al., 2010 and 2011).

4.2.2. Typology of lentic water habitats

Fish communities do not inhabit reservoirs and lakes equally. For each monitoring of fish stock it is essential to know which habitats the given water body contains. On the basis of the lake model, there are three basic environments in lentic waters that differ in fish stock composition: shoreline shallow habitats – littoral zone, open waters – pelagial zone and deeper bottom habitats – profundal zone (Fig. 4.2.6.). The following passages describe general patterns in fish use of habitats during the high growing season in Czech and surrounding waters. The peak growing season (August to September) represents the season when the reproduction period is over (or has not yet started), fish communities fully use production resources of a reservoir and distribution changes connected to wintering are not yet to occur. This season is the most suitable for determining the fish stock status.

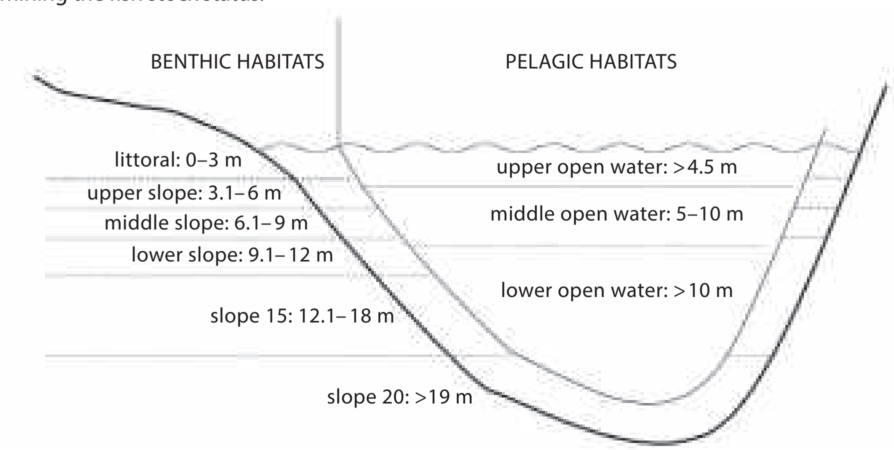

Fig. 4.2.6. ***Diagram of basic habitats on the cross-section profile of a dam reservoir:*** *shallow littoral zone in depths where light is falling, open water and deeper bottom (benthic profundal) habitats. According to the gillnet standard EN 14757 (CSN 757708), shallower benthic habitats are classified after three metres. There are usually not too many fish in large depths and the classification can be less detailed. Five-meter levels were usually used for vertical classification of pelagic habitats, however the development moves towards using the same 3 meters intervals in open water as well.*

Shoreline shallow habitats – littoral zone

Shoreline habitats are always present in comparison to other habitats. These habitats are often overgrown with aquatic vegetation in close-to-nature conditions. The littoral fish community is usually more diverse, especially if aquatic plants are present. In the majority of valley reservoirs, the water level fluctuates a lot, which has fatal consequences for littoral vegetation. Genuine aquatic submerged vegetation is often missing, only if the water level is increased, shoreline wetland vegetation is flooded, which is the most important during the spawning period. A community is usually the most varied even in reservoirs with strongly impoverished littoral (no living plants), since there is a combination of favourable temperature and oxygen conditions with the presence of substrate and shelters. A community is thus formed not only by abundant species that occur elsewhere too (roach, bream, silver bream, bleak, rudd, carp, asp, European perch, pikeperch, ruffe, eel and catfish), species seeking structures and plants (pike, tench and crucian carp), but also by shoreline specialists who use absolute shallow waters as shelters against predators (young dace and gudgeon). Non-specialised abundant fish species (adult bream, roach, pikeperch, carps, European perch, ruffe) often stay during the day further away from the shore and set out to shallow waters towards the night (Říha et al., 2011). Conversely, age-zero fry of many species live by the shores during the day and swim out to open waters at night. This behavioural pattern is, with respect to Czech species, typical mainly for bleak and also partially for roach. Bream and pikeperch fry swim out to open waters at night as well. These two species, however, do not inhabit the shallowest littoral zone during the day but prefer to stay in deeper parts of shoreline zones (bream) or close to the bottom and in deeper open waters (pikeperch). Littoral European perch fry prefer the littoral zone during the day and night and do not usually undertake mass migrations to open waters for the night. Night abundance of European perch in the littoral zone is, in comparison to daily abundance, usually higher.

Presence of ruffe was detected by means of common fry sampling techniques (see chapter 6.2.) not only in the pelagial zone, but also in the littoral zone only during the night hours. During the day, ruffe fry probably inhabit deeper bottom habitats that are not accessible to common techniques of fry sampling. Fry of other less valuable species in dam reservoirs (asp, dace, chub, and gudgeon) prefer the littoral zone during the day and night and migrations to open waters are very rare.

Open water – the pelagial zone

Open water represents often, with regard to larger waters, the biggest volumes present. Open water provides neither any structures nor shelter and therefore, it is less used by most species. This is the reason why zooplankton food resources are often larger in these zones than in shorelines, which is advantageous for those species and year-classes that decide to settle in open waters. If they are endangered by predators, they must rely on their own escape abilities, and at the same time, they must be able to use the plankton that is dispersed in the water as their food supplies. From the small number of European species that have adapted to open waters, it is possible to list whitefish (Coregonus), which represent in Czech conditions practically the only group of adult fish that efficiently use the food resources of deeper parts of large waters. Silver carp and bighead carp show a considerable affinity to the pelagial zone as well. There are several fish species even among non-specialised species that are able to use open waters efficiently. These are, in particular, adults of roach, rudd, bleak, asp and common bream. Cyprinid species have developed an interesting strategy in open waters, the so-called sinusoidal cycling swimming pattern, when fish swim up and down and seek clusters of zooplankton visually by looking against dark depths or bright sky (Čech and Kubečka, 2002). Another interesting fish community in open waters is ichthyoplankton, the age-zero pelagic fry. In addition to the so-called epipelagic fry that live close to water surface and the littoral fry that live in littoral zone, the so-called bathypelagic fry of European perch and pikeperch have been discovered to stay in the deeper layers of 8–12 m during the day and during the evening move up towards the water surface where they gain most of the food (Čech et al., 2005). Fry and one to two-year-old fish of other species (bleak, bream, roach) set out to open waters to forage for food during the night hours as well.

Deeper bottom habitats – the profundal zone

Deeper bottom areas represent a significant habitat for fish, especially with respect to mixed waters where sharp temperature stratification does not occur in the summer. As far as deeper waters are concerned, these habitats are often very cold during the growing season and contain less oxygen, which considerably decreases their importance for fish life. Percid species – ruffe, European perch and pikeperch show preference for deep habitats. Especially with regard to piscivorous species, the largest individuals often occur in deeper bottom habitats of mixed waters. In autumn, when the water mixes up and temperature and oxygen concentration become homogeneous, deeper layers are used by most adult fish for wintering.

Besides the above-mentioned classification of a reservoir on cross-section profile, classification on the **longitudinal profile** is also usually very important. This classification is very important with respect to elongated canyon-shaped water bodies where the tributary sections are distinguished by considerably higher productivity and densities of mainly cyprinid fish which are multiple times larger (Fig. 4.5.7.; Vašek et al., 2004; Prchalová et al., 2008 and 2009a). Differences in the amount and composition of fish in tributary and lake sections predetermine the fact that both habitat types should always be monitored.

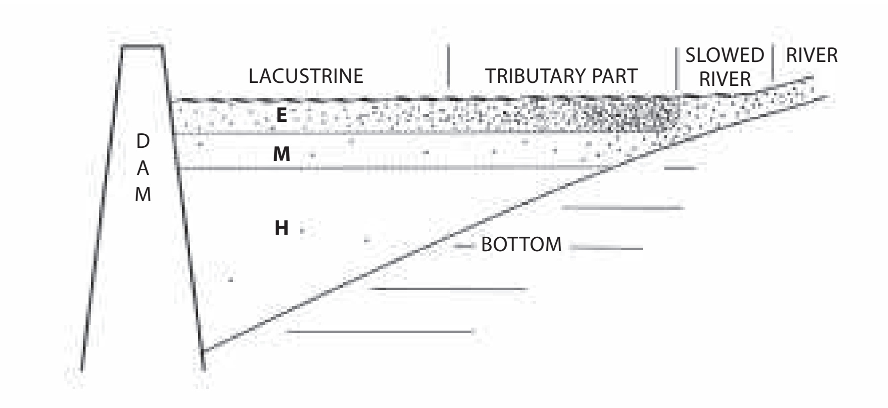

Fig. 4.2.7. ***Illustration of the longitudinal profile of a deep valley reservoir under the usual conditions during summer stratification.*** *The inflowing river (R) is usually colder than the upper layer of the reservoir (epilimnion, E); therefore, it usually plunges, on the basis of its density, into depths that correspond to the thermocline (metalimnion, M). The biggest primary and secondary production, and by far the biggest amount of fish (marked by dotting), are in the inflowing section (tributary part) of the epilimnion lower downstream from the plunging point. Lacustrine sections usually have multiple times less fish. Less fish usually also occur in the reduced zone of a river (slowed river) that is filled up with river water without reservoir plankton. The layer under the metalimnion is called the hypolimnion (H).*

4.2.3. Species diversity and dominance

Information about abundance and fish species composition is the main characteristic of a fish community inhabiting a given reservoir. The most essential information is the **presence/absence** of a given species. If we study the presence/absence of the monitored species in time, we talk about their **constancy**. Better information value is contained in the description of species dominance, or proportions of individual species in total abundance, or alternatively biomass (also called species composition, the proportion of i-th species $P_i = N_i/N$, N_i = abundance of i-th species, N is the total abundance of the pattern, P_i is usually expressed in %). Species composition differs among localities and habitats, therefore, it is the most accurate to perform its weighing on the basis of volumes of individual habitats (Lauridsen et al., 2008). Practically all typologies assessing fish communities in lakes and reservoirs are based on more or less weighted species composition. Primary sources of this composition are usually the CPUE of gillnets. An example of biomass composition of the fish community in the Želivka Reservoir and the weighted average composition of the fish stock as a whole is shown in Fig. 4.2.8.

In order to characterize diversity of a fish community as a whole, the Shannon-Wiener diversity indices are usually used:

$H = -\sum P_i \,.\, \ln P_i$ Note: numeric values differ with respect to the kind of logarithms used

or alternatively, it is possible to use the Simpson diversity indices:

$DIV = 1 - \sum (P_i)^2$

Species diversity consists of two components – species richness and species evenness. The majority of fish populations have a relatively low species evenness since most individuals belong to the small number of so-called eudominant species. The species evenness component can be quantified with the use of the maximum value of the Shannon-Wiener index H_{max} for a given number of species by means of the equitability index:

$EQ = H/ H_{max}$

Besides the simple species composition, metrics that are derived on the basis of relative or absolute occurrence of various **ecological fish guilds** will probably be used increasingly to determine ecological quality or ecological potential (ecological fish guilds are classified according to ecological tolerance – with an emphasis on sensitive, indicative species whose preservation and support should become a priority, methods of reproduction, food behaviour, selectivity towards habitats, etc.) The main ecological guilds are listed at the end of chapter 3.2. The main guilds of ecologically sensitive fish species in reservoirs and lakes are as follows:

species connected to less productive systems (salmonid and whitefish species, burbot and perch) in the sense of lake and reservoir succession described in chapter 3.5;

phytophilous species in valley reservoirs that are limited by spawning substrate, water level fluctuation (the risk of the spawned eggs drying) and shelters (pike, tench, loach species);

valuable piscivorous fish (trout, pike, pikeperch, eel, or alternatively catfish). These species are exposed to excessive harvest not only by anglers, but also poachers. As a result, fish communities are insufficiently balanced and a considerable predominance of non-piscivorous fish can emerge.

Some examples related to information about ecological fish guilds and calculations of biotic integrity are mentioned in chapters 3.3 and 3.4.

In order to characterize the composition of fish stocks, so-called structural indices describing **community equilibrium** are often used. These indices are derived for the most part from classical studies written by Swingley (1950). The so-called F/C coefficient is used the most often and this coefficient considers the weight of present non-piscivorous forage fish (F) and the weight of carnivorous fish in a community (C). There is a close relationship between the F/C coefficient and the proportion of carnivorous fish in a population (top panel, Fig. 4.2.9.). For populations in equilibrium, the F/C coefficient should range from 4 to 6 (15–20% of carnivorous fish biomass; populations have the biggest growth rate and production within this

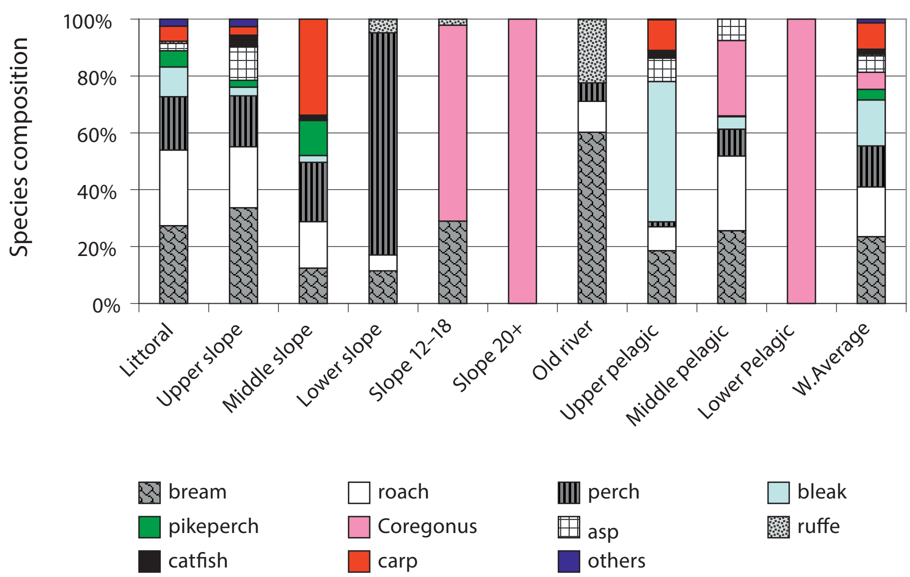

Fig. 4.2.8. ***An example of fish species composition in different habitats of the Želivka Reservoir and the total weighted composition*** *in the reservoir in 2010 (last column).*

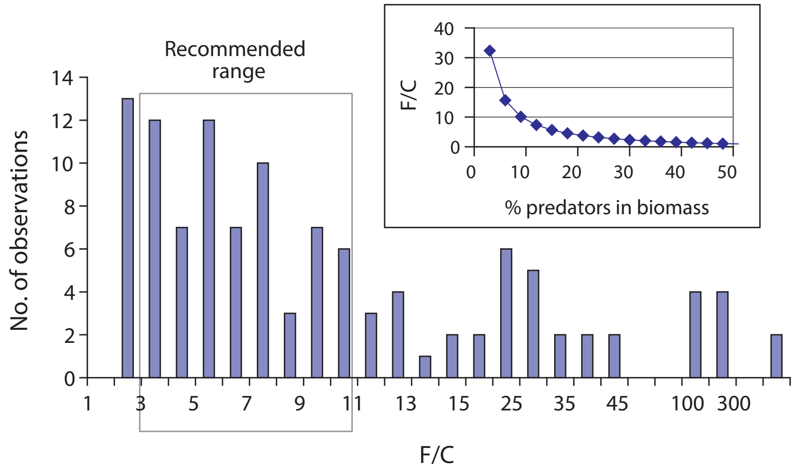

Fig. 4.2.9. ***The values of the F/C coefficient obtained from 116 fish species compositions in open waters of European reservoirs*** *(lower part)* ***and dependence between percentage proportion of carnivorous fish and FC*** *(upper chart).*

range) with a possible fluctuation ranging from 3 to 10. Fig. 4.2.9. shows that in almost half of the cases the discovered F/C values exceeded the value of 10 and that there are too many non-piscivorous foraging fish. This is usually caused by the high harvest of carnivorous fish.

Food provision of carnivorous fish is expressed by the ratio Y/C, where Y indicates the biomass of suitable forage fish in terms of size. Optimal values range from 1 to 3, values below 1 represent an excessive number of carnivorous fish; values above 3 usually represent that a large part of forage fish production is not assessed by predators.

The demographic status of the population can be expressed by the ratio of juvenile to adult fish, or alternatively, by the ratio of age-zero to older fish. Both ratios are dependent on the size selectivity of source data since there is a prerequisite that the size range should be as large as possible (there are not many sampling techniques that cover a community from young up to adult fish).

4.2.4. Sex, size and age composition

Information concerning **sex ratio** is part of the basic information about each fish population. Dissimilar genders can inhabit different habitats, grow to a different size and play different ecological roles. Female composition represents an essential parameter for considering the reproductive potential of a population (chapter 3.6.). Gender is usually easily recognizable in the spawning period with respect to sexually mature individuals. Outside the spawning period, the gender of most species can be distinguished only from the anatomical point of view, and therefore, sex composition has not become a regular part of the basic information about a fish stock. However, determination of sex composition should be carried out especially in such cases where destructive fishing methods (gillnets) are used.

Size composition represents other main information about the population (the lower part of Fig. 4.2.10.). It can be acquired in such a way that we measure a large sub-sample of catch (preferably hundreds of fish) on a measuring board. In order to be able to compare the data, it is necessary to decide whether the lengths would be determined as standard lengths (to the end of scale cover), fork length (to the end of

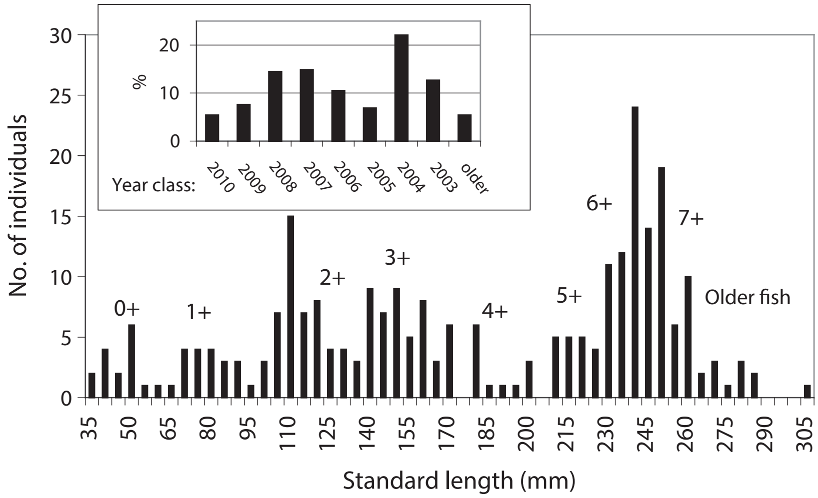

Fig. 4.2.10. ***Example of length** (lower panel) **and age** (upper panel) **composition of roach population in the Lipno Reservoir in 2010.***

the middle caudal fin rays) or total length (includes the entire caudal fin). Size composition provides information concerning proportions between small, forage or alternatively trophy individuals in a population. If interpreted in terms of age composition it also provides very valuable information about population dynamics (see below for details).

Representativeness of size composition is a very serious issue. The need to know reliable ratios of proportions of individual size groups encounters the size selectivity of catches, which is mentioned in chapter 6.3. For example, size composition from multi-mesh gillnets, according to the European Standard EN 14 757, belongs to relatively non-selective one, however, small fish sized up to approximately 10 cm are considerably undervalued due to mechanical reasons (Prchalová et al., 2009b). In such a case, when assessing size composition, we must always keep in mind what groups were under or overvalued. In Fig. 4.2.10., it is evident that the first two year-classes were undervalued and their share in roach population was probably considerably higher than the catch shows.

With respect to the fact that analyses of **age composition** represent a relatively complicated procedure, there has been an effort, in more simple cases, to get round age determination by means of size indices. The most frequently used index is the **proportional stock density index** (**PSD**, Anderson and Neumann, 1996; in the past, practically the same calculation was referred to as the A_t coefficient; Holčík and Hensel, 1972): PSD = the number of fish satisfying catch limits/total number of fish x 100 in the stock (expressed as a percentage). This index can also be applied for species that do not naturally reproduce in a reservoir; therefore, their smallest size is determined by the smallest stocked individuals. As far as fish with natural reproduction and with all size groups are concerned, the problem to determine the number of fish in the stock arises (usually it is necessary to define the minimum size limit for inclusion in the total fish number artificially considering the size selectivity of a sampling method). The usual PSD in American waters ranges from 30 to 60% (Brouder et al., 2009) and in addition to the basic catch rate, PSD for more valuable catches of anglers are determined as well (quality, preferred, memorable or even trophy catches).

In addition to length, **body weight** represents the second main parameter describing size. It is possible to carry out weight calculations that are similar to length calculations; however, a more common procedure is to compare length and weight in order to determine the weight condition. The simplest procedure that

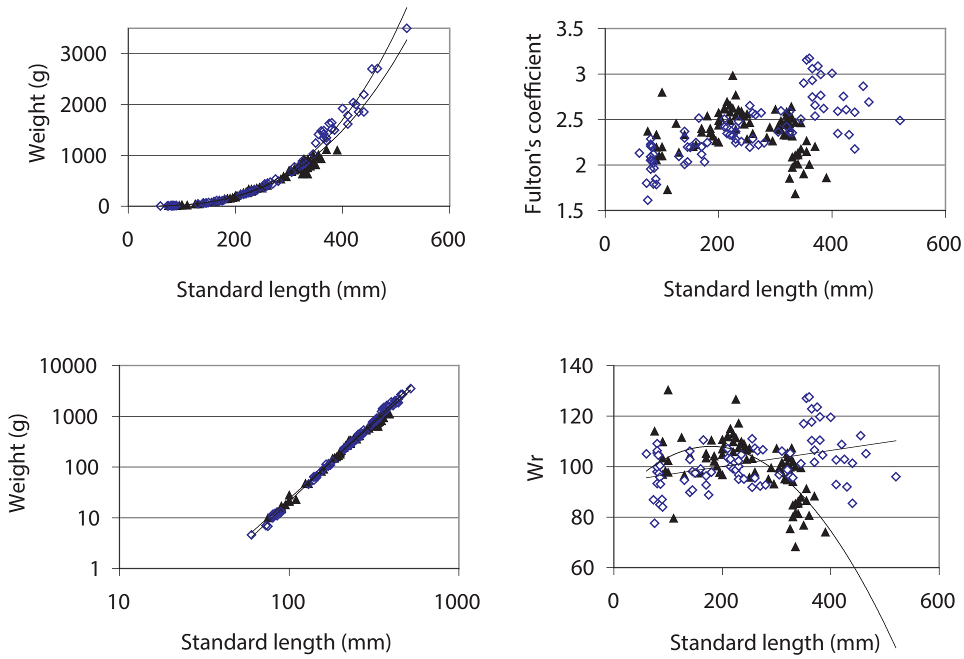

Fig. 4.2.11. ***An example of comparison of weight characteristics of common bream populations in the Římov Reservoir*** *(black triangles and bold lines)* ***and in the Věstonická Reservoir*** *(Nové Mlýny II, empty diamonds and thin lines): Comparison of linear and bilogarithmic expression of the length-weight relationship (left panels), Fulton's coefficient and relative weight W_r. These comparisons show better weight condition of fish from the Věstonická Reservoir with respect to larger fish.*

compares weight with the third power of length (it works on the assumption of three-dimensional weight growth, the most common relationship is **Fulton's coefficient of condition** $K_f = 100000 * W / L^3$ where W represents weight in g and L represents length in mm) is being gradually abandoned because it is not entirely able to reflect changes in allometry of length and weight with respect to fish of different sizes. In order to describe the dependence of weight on length, the so-called length-weight relationship is used: $W = a * L^b$, where a and b are regression coefficients determined by non-linear regression of the relationship between W and L or linear regression of the log-transformed relationship $\log W = a + b * \log L$ (Fig. 4.2.11.). The length-weight relationships enable comparison of the average values of the weight condition with respect to any fish lengths. Nowadays, **relative weights W_r** $= W_i / W_s * 100$, are used for the same purpose for populations as well as for individual fish (compared weight W_i is compared with weight W_s, which is obtained for the same length through calculation of the standard length-weight relationship for a given species). Calculations with lengths and weights that are reached as a standard are elaborated in considerable more detail for North American fish (Brouder et al., 2009).

As discussed in chapter 3.6., **harmonic age composition** represents a common manifestation of an ecologically healthy population as it provides evidence of regular population recruitment. Age composition is usually obtained from size composition by using information concerning age of fish of different sizes. Information about age is obtained by means of special techniques (scalimetric analyses of scales, reading slices of otoliths and branchiostegal rays, Devries and Frie, 1996; Isely and Grabowski, 2007). Fig. 4.2.10.

shows an example of length composition of a population from a valley reservoir and information about fish age (0+ up to 7+) is attached. If length composition is successfully interpreted as age composition, it is possible to determine the proportion of individual year-classes and to get an idea about their strengths (upper part of Fig. 4.2.10.).

4.2.5. Relative abundance and biomass

Considerable progress has been achieved in recent years with respect to monitoring of fish stocks in Czech waters. This area of science and development is still very new since it is necessary that specification of the information obtained is brought to such a state that we can reliably interpret the information obtained and it impacts on fish communities as a whole, as well as on other components of the aquatic ecosystem. The main method that is used throughout Europe is currently the multi-mesh gillnet, which is used by most countries for monitoring for the purposes of the Water Framework Directive. Extensive information databases are thus emerging that have been elaborated in an insufficient and rather qualitative way for the time being (Caussée, 2012). A CPUE and BPUE database is also being developed for Czech reservoirs and lakes. This database should be able to assess how a given community is doing in comparison to other Czech localities. Preliminary comparative analyses have confirmed general influence of trophic conditions on fish (Peterka et al., 2009). Trophic influence is usually demonstrated within one reservoir by the fact that the biomass is several times higher in the tributary section, which is directly enriched with nutrients, than in the lake section (Vašek et al., 2004; Prchalová et al., 2008 and 2009a).

A comparison of different gillnet catches shows that biomass of fish in open waters of reservoirs reacts most sensitively to trophic conditions. Fig. 4.2.12. states the frequency of BPUE occurrence in biomass classes in open waters of reservoirs and lakes. The biggest number of observations is under 50 kg.1000 m^{-2} (the

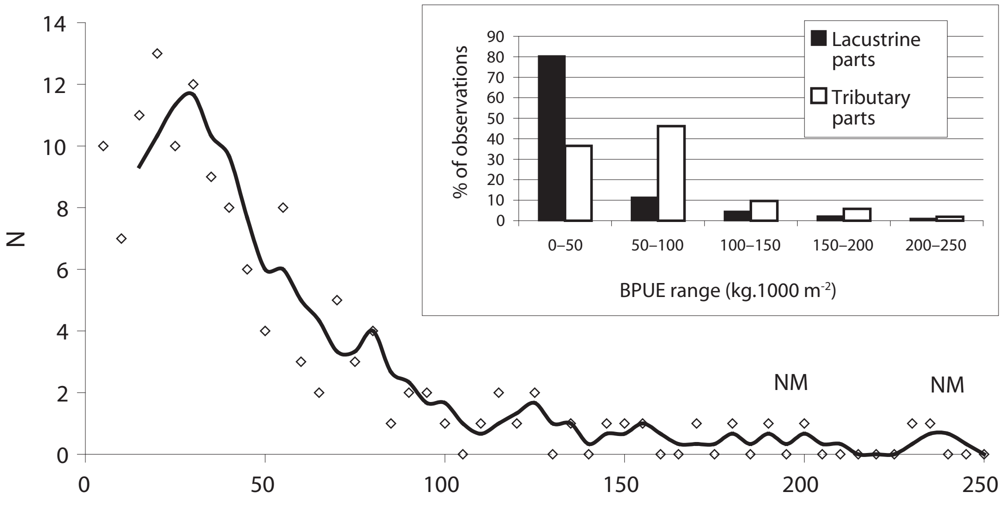

Fig. 4.2.12. *Lower panel:* ***Numbers of samples that fall within individual BPUE classes and the dependence approximated by the curve of moving averages.*** *Upper panel:* ***Frequency of individual BPUE classes in lake and tributary sections of Czech reservoirs.*** *While the most BPUE from lake sections range from 0 to 50 kg.1000 m^{-2}, tributary sections show a peak of BPUE frequency ranging from 50–100 kg.1000 m^{-2}.*

most frequent values range from 20 to 30 kg), however, in isolated instances, the BPUE values can exceed 200 kg.1000 m^{-2}. These exceptionally high values are being reached mainly in three Nové Mlýny Reservoirs situated in southern Moravia, where a large amount of nutrients combine with high temperature and shallow waters. Values from tributary sections of some more eutrophic reservoirs sometimes come close to the BPUE values that are achieved in the Nové Mlýny Reservoirs. The upper panel in Fig. 4.2.12. shows that tributary sections of reservoirs have a BPUE generally higher than lake sections by several tens of kg.1000 m^{-2}.

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4.3. Fish stocking and fishery management *(O. Slavík)*

The aim of many projects related to fishery management and environmental protection is to determine the optimum abundance of fish populations. The key question is: "How many fish should there be in a specific environment and what should their size be?" The answer is very important with respect to rescue and repatriation programmes for endangered species and for compensation for environmental damage. However, the determination of the optimum abundance is also important for the regular management of running waters that are used by anglers. It is relatively simple to designate what the information about fish stock abundance is good for. Nevertheless, it is very difficult to define the above-mentioned so-called optimum abundance or density of a population. Even in a river network that has not been affected by anthropological pressure, habitat diversity, refuge availability and food resources that can be used in the environment, are highly variable in time. The only solution is to study communities for a long period and to calculate the estimated values on the basis of the longest available records. The problem is that the data are not available because the relevant authorities do not carry out such monitoring. The research projects are usually limited only to a few localities and/or river stretches and besides, it is complicated to ensure the monitoring from the financial point of view in a time horizon exceeding the regular granting of resources (5 years). In future, a certain solution is offered by the regular monitoring of the riverine environment for the Water Framework Directive purposes that stipulates a regular 3–6 year interval. This system, however, will be available for use for predictive calculations within the next 20–25 years. For the time being, it may be recommended to estimate optimum abundance on the basis of approximate comparisons of similar streams and indirect indicators (ratio of stocked to harvested fish). Nonetheless, it is important that these estimations are carried out in the first place (which is in contradiction with today's practice) and to proceed on the basis of a single method. In order to facilitate the understanding of the contradiction between stocking and harvesting of fish, several factors that influence the resulting state of populations inhabiting running waters can be stated.

4.3.1. Stocking of hatchery-reared fish

The efficiency and success of stocking of hatchery-reared fish can be relatively high if suitable methodical procedures are followed, however, in general, this method is overrated. The status of fish populations in the Czech river network corresponds to this fact as well – although there are fish worth tens of millions of the Czech Crowns being stocked every year, according to the fishery statistics, catches of a considerable part of attractive species from the fishery point of view (e.g. grayling, brown trout, European perch, etc.) are decreasing each year. In today's technical conditions and methodical experience, it is not difficult to reproduce and rear almost any fish species. After all, nowadays, programmes focused on the rearing of such species as perch or pikeperch in aquacultures have been implemented with promising prospects and even procedures for feeding pike with granular food have been tested! To get healthy fish on the menu is thus easier than before. However, the situation gets more complicated when hatchery-reared fish are stocked in the natural environment. In hatcheries, fish are protected against predators, they are provided with artificial shelter and food. Fish are able to gain information about their environment, to learn and to behave on the basis of their acquired experience. However, hatchery-reared fish are less able to do so, for example, it is more difficult for them to learn to take in different food (Sundström and Johnsson, 2001) and they also take in less food when compared to wild fish (Sanchez et al., 2001). Hatchery-reared fish have a significantly lower ability to avoid predation risk, hence, they show higher mortality rates than wild fish (Alvarez and Nieceza, 2001; Johnsson et al., 2001). Since reared fish are spawned artificially, they do not learn (they are not given a chance) the original models of reproductive behaviour, their manifestations are less noticeable and they are less successful in comparison to wild populations (Fleming et al., 1996). On the contrary, fish reared in aquacultures become highly aggressive because it is the only type of behaviour that is developed when fish are stocked in high densities. The reason is that the fish's fight for food and space several times a day occurs more frequently than in the nature. If they are stocked in open waters, hatchery-reared fish are highly aggressive, if it comes to a fight, they drive wild individuals off, but subsequently, they succumb to their low adaptation abilities. They thus lose the non-aggressive behavioural patterns that are not useful in high densitities of aquaculture (Huntingford, 2004). When compared to wild fish, hatchery-reared fish are more prone to diseases, they have smaller coloration intensity, they have shorther fins and they are fatter (Huntingford, 2004). It is recommended to respect these facts and to try to use technologies that decrease the above-mentioned risks. It is, for example, recommended to stock fish immediately after being hatched, three-month-old juveniles at maximum, even at the cost of a higher mortality rate. Next, it can be recommended to use only parents from the first generation coming from wild predecessors.

4.3.2. "Dear enemy" theory, kinship, and familiarity

During the process of fish stocking it is advisable to consider the fact that fish are not stocked into an empty environment. Occupation of the environment may be partial but it may also be full and it does not always have to correspond to data that are available to the management. During the fish stocking process, wild fish undoubtedly come into contact with new hatchery-reared individuals. The contact of both these groups is thus potentially connected to aggressive behaviour. If the environment is occupied, new individuals may be affected by the so-called "Dear Enemy" effect (Getty, 1987; Frostman and Sherman, 2004). It can be briefly described that the effect consists of higher aggression of local fish towards new individuals than it is applied among local neighbours. In other words, holders of neighbouring territories know each other, they respect spatial delimitation and if they limit their fights they save energy. If an intruder penetrates their area, the aggression is directed jointly against the intruder. If such a case occurs, the stocked individual may end up very far from the intended place of stocking.

Fish recognize each other on the basis of kinship, for example, on the ground of scent or visual features (Brown and Brown, 1993; Brown et al., 1996). This is also important with respect to stocking. Related fish can support each other under certain conditions, but if the living conditions are unfavourable, related individuals are more aggressive towards each other than towards non-related individuals. The reason is the same tactics that is applied within foraging for food or shelter which disqualifies kinship if insufficient resources are available. However, fish distinguish each other not only on the basis of kinship, but also on the basis of the fact of whether they know each other, in other words, on the basis of their previous contact and thus their mutual experience (Brown and Colgan, 1986). This so-called familiarity (e.g. Chivers et al., 1995) can be recognized after repeated contacts during several days (Griffith and Magurran, 1997). If fish meet repeatedly (they thus know each other) they are able to take this fact into consideration by means of enhanced transmission of information and by co-operation. With regard to fish that know each other, mutual aggression decreases (Johnsson and Åkerman, 1998), common protection against predators is enhanced (Griffiths et al., 2004) or food consumption and its foraging is increased (Seppä et al., 2001). As a result of this familiarity, the fish grow faster, they survive more successfully in time (Höjesjö et al., 1998) and they consume less energy than in contact with unknown individuals (Slavík et al., 2011). The familiarity is such a significant factor that it takes effect not only among individuals of the same species, but also among different species. It means that individuals of the same species would give preference to a familiar individual of a different species rather than unfamiliar individual of the same species (Griffiths and Ward, 2006). Mutual interspecific preference between chubs and minnows of the same size was even proved in a scale of the whole of Great Britain. Familiarity is strengthened due to limitations of emigration and immigration possibilities (Griffiths and Magurran, 1997). In other words, it increases in an environment where fish can meet each other (pools, creeks) and it is lower in an environment where fish undertake frequent migrations. Nevertheless, for example, with respect to territorial species, such as salmonids, the familiarity affects functions even in running waters. Stocking of new hatchery-reared fish, no matter how needed from the increase of abundance point of view it may be, interrupts the already established social structure in a population. On the other hand, mutual familiarity strengthens the social environment which is manifested by increased growth rates and health and by a decrease in the mortality rate (Höjesjö et al., 1998; Seppä et al., 2001). On that ground, the target method for sustainable development of fish populations is preferably natural reproduction, rather than fish stocking.

4.3.3. Efficient support of wild fish populations by means of fishery management

It was described in the previous chapters, how difficult it is to define the optimum number of fish in the riverine environment: the variability of population dynamics is high and the nature of populations is influenced by local conditions of the environment as well as by civilization factors. How should we thus find the answer to the question: "What should the target population composition be like and how should this target be achieved?" The solution can be found within two approaches. The first option is to select certain model stream types in each complete river basin where a fish community can be left to their own natural development. Regional "standards" can be derived from determined abundance and biomass values and under these standards management of some species can thus be derived.

The second option, on how to support natural communities, is to enable fish to reproduce naturally. In a viable population there must be a sufficient number of adult individuals who are able to reproduce. Therefore, it is recommended that managers inspect their entrusted streams and determine whether juveniles occurred in populations, as this proves natural reproduction. Next, it is necessary to ensure that not all adult fish of reproductive age and size are harvested. This status should also be determined by means of targeted monitoring. If such attitude is adopted it is not uncommon to find an appropriate balance. We can draw inspiration from the neighbouring Austria and Germany. Both countries are visited by Czech anglers, who are annoyed by the pitiful state of the Czech salmonid grounds, in order to catch large trophy trout and grayling. In these countries, however, the aim is not to kill fish and their uncompromising consumption, but, first of all, the experience of discovering and catching wild animals. Austrian as well as German managers record carefully the population curves and if the fish abundance decreases, they change the management as well as the fishery conditions: fishing techniques, in favour of enhancement of chances of fish, are limited, the rate is increased and contrarily, the number of fish in a catch is decreased, or alternatively, it is forbidden to kill fish. These trends are only vague, partial and insufficient in the Czech Republic conditions. The drastic decrease in the abundance of, for example, brown trout and grayling, that have been occurring each year for the past 20 years, corresponds to that fact. If this trend continues, the collapse of both species populations will take place in several years. Other negative factors that are described in other chapters of this book contribute obviously to this situation as well.

A certain compromise with regard to the above-mentioned situation represents the stocking of the earliest stages of fry (three-month-old fish at a maximum) in open waters under optimum conditions (flow-rate, temperature, food, stream morphology). It concerns especially native rheophilic and salmonid fish species, including grayling. However, this way of management must be based on rearing brood fish and not on the use of wild brood individuals for stock production. The purpose of this method is to complete a fish stock in a stream stretch to the level which would be achieved with respect to the optimum level and success of natural reproduction under conditions in a given stream stretch. In other words, by stocking of fish, an insufficient level of natural reproduction is compensated for (e.g. due to the lack of brood fish, unsuitable conditions for natural fish spawning or successful incubation of fish eggs). In the case of stocking in the early stages, it can be assumed that the potential overstocking of a locality exceeding its food and shelter capacity for a given category will be quickly eliminated by older categories of fish present in a locality. In addition to that, it is possible to assume good adaptability of stocks that results from their short-term stay in the hatchery conditions.

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4.4. Principles of management in fishing grounds *(M. Hladík)*

Management inside fishing grounds represents a relatively wide-ranging set of activities and workings that relate to the care of fish stocks. It includes production and regular stocking of fish, monitoring of fish stocks, protection of spawning grounds, recording and reporting of potential environmental damages, cleaning of banks, and last but not least, recreational fishing. Since the Czech and Moravian Anglers Unions currently represent the dominant entities managing fishing grounds in the Czech Republic, the conditions stipulated within these unions are always specified at the end of each sub-chapter. This chapter focuses mainly on the management of the riverine fisheries.

4.4.1. Legal aspect of management in fishing grounds

All activities connected with management of fishing grounds as well as fish farming in the Czech Republic are embedded in the Act No. 99/2004 Coll. on fishpond farming, execution of the fishing right, fishing warden, protection of marine fisheries resources and amending certain acts (the Act on Fishery, hereinafter referred to as the Act), and in the Decree No. 197/2004 Coll., implementing the Act (hereinafter referred to as the Decree). Of course, there are other provisions of related acts that have an impact on this activity as well. Above all, it is the Act on Water and on amendments to some acts (The Water Act) No. 254/2001 Coll., as amended, and the Act No. 114/1992 Coll., on nature and landscape protection.

Fishing grounds are established mainly in the stretches of streams and reservoirs that are in state ownership, however, stretches of waters that are in private ownership, such as backwaters, sand pits, flooded quarries, raceways, smaller reservoirs and ponds with an area of at least 500 m^2, can also be established

Fig. 4.4.1. Barbel belong to very valuable sport fish species *mainly if caught with fly-fishing equipment. At the same time, barbel represents a very sensitive indicator of the quality of the natural environment, especially of morphology of watercourses (photo: M. Hladík).*

as fishing grounds or their parts. Fishing grounds are declared by a fishery authority that is in most cases represented by the Regional Authority. If the fishing ground is situated in the territory of more regions or in border waters, the fishery authority is represented by the Ministry of Agriculture, if the fishing ground is situated in a national park, it is the Ministry of the Environment, and if it is situated in a military district, it is the Ministry of Defence. Boundaries of fishing grounds are usually chosen in order to be clearly evident in a terrain. Fishing grounds have to be visibly marked at the boundaries and at access roads with tables including the name and number of the fishing ground and the name of the managing entity. The number of the fishing ground is assigned by the Ministry of Agriculture. Fishing grounds with and without suitable conditions for salmonid species are respectively declared as salmonid and non-salmonid grounds. Their management and recreational fishing rules differ.

Fishing grounds are not owned by anyone and fishing rights cannot be rented. The selected user of a fishing ground only receives the right to manage it. This right is provided free of charge but comes with obligations that are prescribed to its user. They include, for example, the requirement to nominate candidates with required qualifications who will become the local fishery manager and his/her deputy (they are consequently appointed by a relevant fishery authority), to nominate candidates with required qualifications for fish wardens, to keep annual stock and catch statistics. In addition to that, the user is obliged to mark the fishing ground as well as protected fish areas correctly in the terrain. The fish stocking plan, i.e. annual stocking of fish in the prescribed species composition, amount and size, is stipulated in the decision on granting fishing rights to a given fishing ground (the so-called decree).

A stretch of a stream or other water body is declared a protected fish area if it is important for fish protection, protection of other aquatic animals, or for fish farming. Protected fish area is declared by a fishery authority (at its own instigation or at the suggestion of a fishery manager or other entities) and the authority also determines the system of management, e.g. stocking plan and limitations or total ban on fishing.

Fig. 4.4.2. ***Protected fish areas should be declared also in dam reservoirs in order to protect fish spawning grounds*** *(the Lipno Valley Reservoir). It is necessary to delimit these grounds also in open waters by buoys (photo: M. Hladík).*

In case a user of a fishing ground does not sufficiently keep any of the prescribed obligations or if he/she violates the rules of fishery management, he/she may be given a fine or his/her fishing right may be revoked. The circumstances and sanctions are also stipulated in the Act and in the Decree. In addition, the Act and the Decree determine also the requirements related to recreational fishing which is discussed in detail in chapter 7.

Within the activity of the Czech Anglers Union (CAU) and the Moravian Anglers Union (MAU), the manager of the majority of fishing grounds is the relevant regional board (thus it is the holder of the decree) and the board also ensures that the functions of the regional manager and his/her deputy (except for the Central Bohemia board of CAU where the decrees are held to a large extent by local organizations) are performed. Individual local organizations are authorized to manage selected fishing grounds where they are responsible for all required activities and they usually also have their own fishery manager. Large valley reservoirs are in most cases managed directly by the regional boards and the individual local organizations situated in the vicinity of the reservoir co-operate with the board.

4.4.2. Organization of management in fishing grounds

Stocking of fish

Fishery authority stipulates in the decision on granting the fishing right to a given fishing ground (the so-called decree) a mandatory stocking plan. The stocking plan is considered to be the minimum required stocking, but if the prescribed limits are vastly exceeded, it is necessary to give reasons in the decision, and it should not have a negative impact on the ecosystem of a fishing ground. Fish species not mentioned in the decree should never be stocked; exceptional cases require prior request for permission from the fishery authority. The amount stocked is usually defined in one size or age category (e.g., advanced fry, one-year-old juvenile, n-year old fish). If fish are stocked in a different category, recalculation of the stocking statistics is required. Obligatory recalculations within individual stock categories are stated in the Decree, Appendix No. 4.

Stocking of fish has three basic targets:

First, it is necessary to support the ecological value of a fishing ground. Stocking supports or substitutes natural reproduction that is limited or made impossible in many waters due to human activities. This can also cover the fact that anglers harvest an important part of the parental stock and fish stocking can substitute its contribution to reproduction.

Second, many fishing grounds are under predation pressure of piscivorous predators that are protected by law (cormorant, otter, etc.); therefore, it is necessary to substitute the fish caught by these predators.

Third, stocking aims to enrich fishing grounds with fish species that are attractive for anglers (carp, piscivorous fish, rainbow trout)

The following documents are usually used to determine fish stocking plans: "Principles for determination of agricultural indicators, especially stocking of fish within assignment of execution of the fishing right" and "The methodology for determination of agricultural indicators of fishing grounds", published by the Ministry of Agriculture in the 1990s, and "Teaching texts for fishery managers" published by the Czech Anglers Union in cooperation with the Ministry of Agriculture in 1996. The book "Fishery in open waters" (Adámek et al., 1995) provides relatively detailed data as well.

The prescribed species' composition and amount of fish are based on long-term experience in the breeding capacity of a fishing ground (area, productivity) and its other characteristics such as expected attendance, type of a fishing ground, level of human-induced influence and, last but not least, financial considerations. Using previous managerial experience and targets in a given fishing ground, it is possible

Fig. 4.4.3. ***Stocking from a raft enables equal fish distribution within the entire fishing ground. A special ring is adjusted in such a way that is does not rub against the bottom in shallow rapid parts*** *(Vltava ground 24, photo: M. Hladík).*

to discuss with the management and to adjust potential fish stocking plans with relevant deputies of the fishery authority. The long-term data concerning stock and catch records can be used for this purpose; however, it is also advisable to use the information from scientific fish monitoring carried out by the public administration.

As mentioned above, fish can be stocked in different developmental stages, from yolk-sac fry, advanced fry, one-year-old fish to fish in catch and trophy length. Each species' ideal stocking size or stage depends on their adaptability to a given fishing ground and on issues of economic return. Each fishing ground has a different ideal composition and age structure of stocked fish and it is necessary to frequently test new methods in order to achieve an optimal result.

If we endeavour to support natural fish populations, it is often advisable to stock fish in early developmental stages because they probably have the best chance to adapt to local conditions or, alternatively, to stock fish of varying sizes. Stocking young fish is also cheaper but high mortality rate should be expected. Fish of harvestable size are more expensive, almost never reproduce, sometimes migrate away and can introduce unsuitable genes into the local population. On the other hand, these fish can be easily caught and represent a higher return on investment for both anglers and fishery managers. It is also necessary to monitor the health status of stocked fish. Injured fish usually die and the investment rendered worthless. There is also the risk of bringing in diseases.

A great part of stocked fish is reared at CAU and MAU facilities, be it the breeding facilities belonging to individual regional boards or local organizations, where not only hatcheries but also rearing facilities and production fisheries are operated. However, CAU and MAU have also been co-operating with commercial fish producers for a long time. Part of the local organizations under CAU and MAU concentrate considerably

Fig. 4.4.4. ***Stocking of advanced fry of grayling represents a promising alternative that could ensure good fry adaptation to local conditions*** *(the Malše River, photo: M. Hladík).*

Fig. 4.4.5. ***Nase carp are also stocked in streams in the Elbe River basin where they have replaced the original vimba bream, even though they come from the Danube River basin*** *(Vltava ground 25, photo: M. Hladík).*

on fish production and they represent significant producers not only of carp, but also of other fish species, including salmonids and rheophilic species.

Risks associated with stocking of fish

The effort to optimize the Czech waters' management has led to the introduction of a whole range of non-native fish species into the Czech waters. Introductions were usually justified by the assumption that the existing community was not able to efficiently use the local food resources. Nonetheless, it has been repeatedly proved that this assumption was false and the introduction of non-native species could be considered mainly as commercial intention leading to improvement of recreational fishing conditions. Each intended introduction should thus be carefully considered.

Rainbow trout (*Oncorhynchus mykiss*) that do not reproduce naturally in the Czech conditions have been stocked into many salmonid and non-salmonid fishing grounds. Any negative impact of this introduction has not been discovered yet, because in open systems, such as rivers, it is very difficult to study the impact of competitive relations. Due to the stocking of rainbow trout, the attractiveness of fisheries has been considerably increased for anglers, because this species can be reared into a large weight. Rainbow trout are also sometimes used as a "buffer species" in order to protect native fish species since anglers who want to catch some fish for the table usually prefer rainbow trout to brown trout (*Salmo trutta* m. *fario*) or grayling (*Thymallus thymallus*). Brook trout (*Salvelinus fontinalis*) are stocked together with rainbow trout to a smaller extent and it is very important for enrichment of river basins and reservoirs that were affected by acidification, because brook trout is more resistant than brown trout. These localities are situated mainly in the northern part of the Czech Republic where brook trout have formed naturally reproductive populations (e.g. the Bedřichov Reservoir and its tributaries in the Jizerské hory Mountains) and they have replaced brown trout in the ecosystem. However, they have demonstrably limited the development of native brown trout populations after the water chemistry was repeatedly enhanced.

Fig. 4.4.6. ***Brook trout – beautiful colourful and combative fish is a suitable enrichment for some fishing grounds*** *(Vltava ground 29, photo: M. Hladík).*

The success of stocking of maraena whitefish (*Coregonus maraena*), for example in the Lipno Reservoir, is disputable. It was a mistake to stock the hybrids together with solely planktonophagous peled whitefish (*Coregonus peled*) and they are very difficult for anglers to catch. The result of this stocking was thus ambiguous. Nonetheless, whitefish disappeared from the reservoir spontaneously due to natural processes. It would probably be highly beneficial to stock whitefish in the flooded surface mines situated in northern Bohemia since the littoral in these water bodies is limited and whitefish, as typical fish colonising pelagial of oligotrophic waters, would be able to use their food potential.

Danubian salmon (*Hucho hucho*) was stocked in some rivers (e.g. the Vltava and Otava Rivers) with the aim to enhance the fish stock of salmonid fishing grounds, however, they did not find sufficient food resources in the Czech rivers. A predator of this type and size is not suitable for the Czech waters exposed to intensive angling as well as piscivorous predators' pressure. In addition to that, morphological modifications occurring in Czech river systems limit the Danubian salmon's reproduction.

The stocking of brown bullhead (*Ameiurus nebulosus*) has turned out to be rather unfortunate since they have showed signs of overabundance in some areas, for example, in the Elbe River valley, they have negatively influenced the native fish stock and they do not represent an attractive fish species from the culinary and anglers point of view either. Stocking of herbivorous fish species, such as bighead carp (*Aristhichthys nobilis*) or silver carp (*Hypophthalmichthys molitrix*), has had limited success. They could increase the attractiveness of some fishing grounds as they are seen by anglers as trophy fish. On the other hand, not only silver carp but also bighead carp are caught very rarely by anglers due to their timidity as well as eating habits. In some localities, grass carp is able to damage the littoral vegetation that is very important from the ecological status point of view. These fish species are more useful, to a limited extent, within fishpond management. Stocking of other rather exotic fish species has not been successful and only in exceptional locations have they formed independent reproducing populations (largemouth bass *Micropterus salmoides*, crappie *Lepomis gibbosus*, three-spined stickleback *Gasterosteus aculeatus*).

Some species have accidentally been introduced into Czech waters with other fish species and their impact on native fish stocks has been definitely negative. Typical examples are gibel carp (*Carassius auratus*) and topmouth gudgeon (*Pseudorasobra parva*). Any stocking of fish from different regions or hatcheries can result in damage of the native fish gene pool. The artificial reproduction and stocking are considered to be one of the significant causes that have resulted in the decrease in the natural populations of grayling and brown trout in Czech waters. It is not connected only with stocking of various hybrids that are able to reproduce (e.g. hybrids of brown trout, the so-called "Kolowrat" or "Ital"), but it concerns also non-native selection of genotypes caused by methods of artificial reproduction and consequently, in relocation of fish within individual river basins. To support natural fish populations, it is necessary to pay close attention to the genetic origins of stocked fish, not only salmonids.

Documentation of management in fishing grounds

Documentation of the management in fishing grounds provides not only important feedback but it is also required by the Act. The fishery manager is obliged to document stock and catch statistics and number of attendances in a given fishing ground. For this purpose there are prescribed forms that are enclosed in the implementing decree to the Act on Fishery. The documentation must be provided for inspection continually and must be submitted to the relevant fishery authority annually until the April 30th.

One of the basic obligations of CAU and MAU members is to return the correctly completed fishing permit and the summary of attendances and catches within 15 days of expiration of its validity (for yearly permits by January 15th of the following year). The reason is to enable CAU and MAU to process the statistical data in time. In addition, an information system called "Grayling" is currently being established that also enhances communication between local organizations and regional boards of CAU, especially with respect to documentation of stock statistics.

The aim of the management in fishing grounds within CAU and MAU is not to obtain a profit, but to ensure the best angling conditions at an acceptable price for their members. The costs of the fishing permits depend usually on the real costs that are connected with the functioning of CAU and with the management in a fishing ground. At the same time, this also represents a type of marketing policy, which means the price that anglers are able to accept and the service that can be provided to them for this price. The sale of fishing permits is thus proof of their satisfaction. Catch statistics provide some feedback and these data can be used in order to increase the efficiency of the use of financial resources. The basic information from the fishery management point of view is the statistics of catches and attendances (a summary of all catches and attendances attained in a given fishing ground). It illustrates the development of catches, their decrease or increase in each fishing ground, especially if it is available for more species and longer time periods (Fig. 4.4.7.). CAU summarises annually the total catches and attendances for individual fish species in each fishing ground, the detailed daily statistics are evaluated only in exceptional cases (but for example, in the Vltava 24 fishing ground, it has provided interesting data related to anglers' behaviour).

The stock-return analysis (the return coefficient, proportion of catches of a given species as % of stocked amount) is more useful than a simple overview of catches. The return-ratio can be expressed in pieces or in weight. If a given species does not reproduce in a fishing ground and if it does not occur in a fishing ground through some unnatural way (escape from another ground or from hatcheries, e.g., during floods), then the return in pieces is always lower than 100% since anglers never catch all stocked individuals and some fish will naturally die (disease, predators, etc.), or alternatively, can escape from a fishing ground. The resulting value of return in weight depends on the ratio of mortality growth. In practice, it thus depends on the productivity of a given ground and the period of time the stocked fish will survive despite the angling or predation pressure. Species that are defined in stocking plans are stocked annually and it is usually difficult in practice to trace the survival of a concrete portion of stocked fish. The simplest method of reaching the average return value is to compare stocks and catches within a period of several years. Such average return is preferably expressed as the moving average calculated for 3–5 years (Fig. 4.4.8.). This gets rid of fluctuations that are caused by different stocking fulfilment and also different angling pressure. The return ratio differs in individual fishing grounds. If there is much angling pressure, there is also a high return ration, for example, return of carp ranges around 100%. The return ratio is always lower in rivers and large water areas than in smaller closed waters with similar angling pressure.

The return ratio as a quality criterion relating to care of a fishing ground recedes into the background in the modern conception of recreational fishing, however, it represents, at a minimum, an auxiliary indicator for managing entity. With respect to a large number of fish species that are subjected to protection measures, for example, grayling and brown trout, the catch statistics cannot be determined and the data concerning a fish stock status can be acquired only on the basis of subjective findings from the angling activity or by means of control catches or monitoring, or alternatively, on the basis of results of angling competitions.

Support of natural reproduction of fish

With regard to support of the natural reproduction of fish in suitable fishing grounds, organizational as well as technical measures are being applied. From the organizational point of view, the natural reproduction can be supported by protection of brood fish by different measures, for example, by imposing a fishing ban before and during the reproduction period, limitation of fishing methods that cause the biggest harm to the target species (see chapter 7) or by high size limits. Another option is to declare the places where fish reproduce or where they gather during migration, e.g. in tributaries, under weirs, etc. as protected fish areas.

Technical measures consist of, for example, construction of fishways on artificial obstacles in streams that enable fish to migrate to suitable spawning grounds. Next, restoration and conservation of natural spawning grounds within the scope of longitudinal stream revitalisation are used. In reservoirs, it is possible to support development of littoral and riparian communities and also to ensure their flooding during

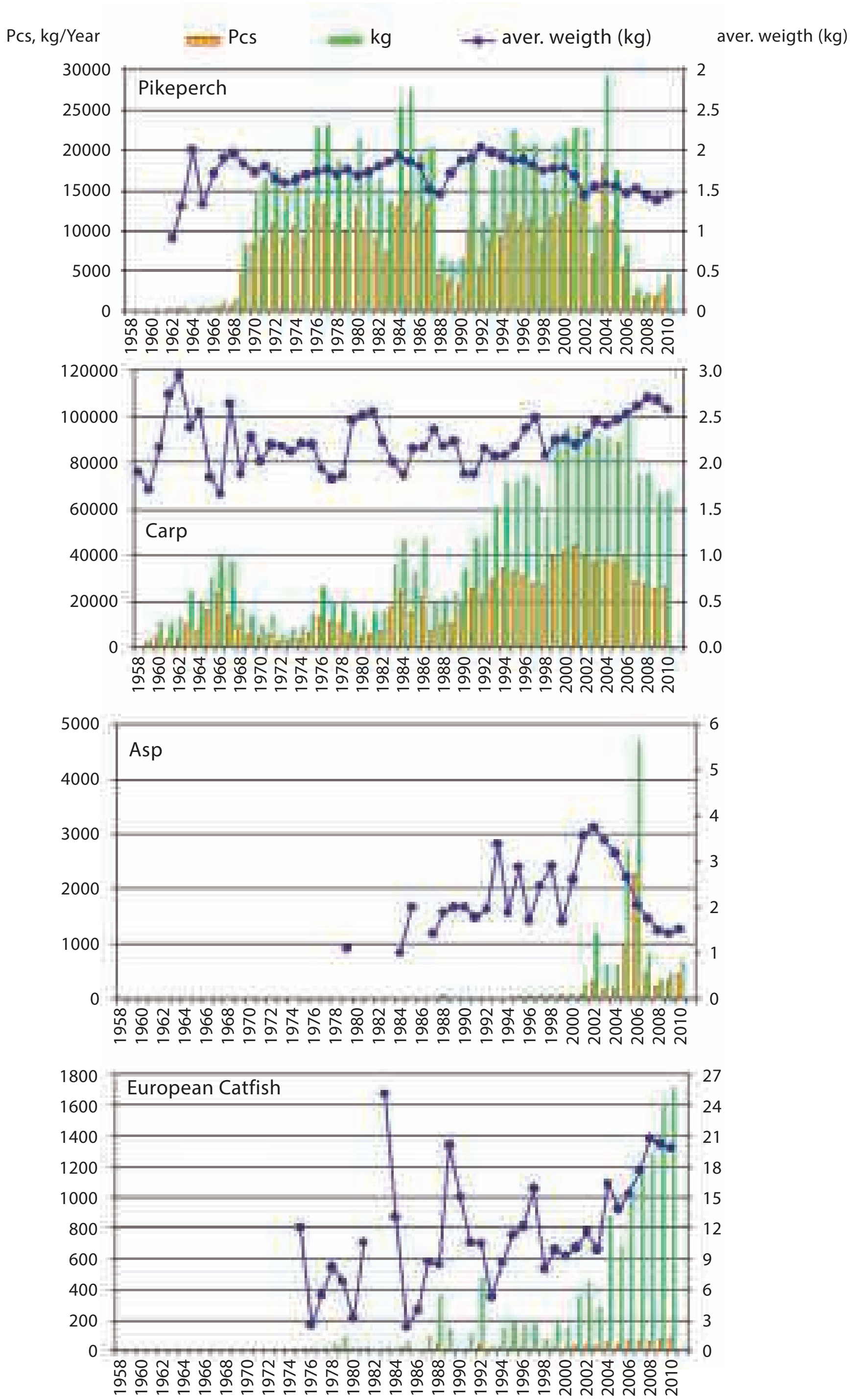

Fig. 4.4.7. ***Total catches*** *(pieces, kg – on the main axis)* ***and average weight of caught fish*** *(kg, minor axis)* ***in the Lipno Valley Reservoir*** *between 1958–2010 (data provided by the South Bohemian Board of CAU).*

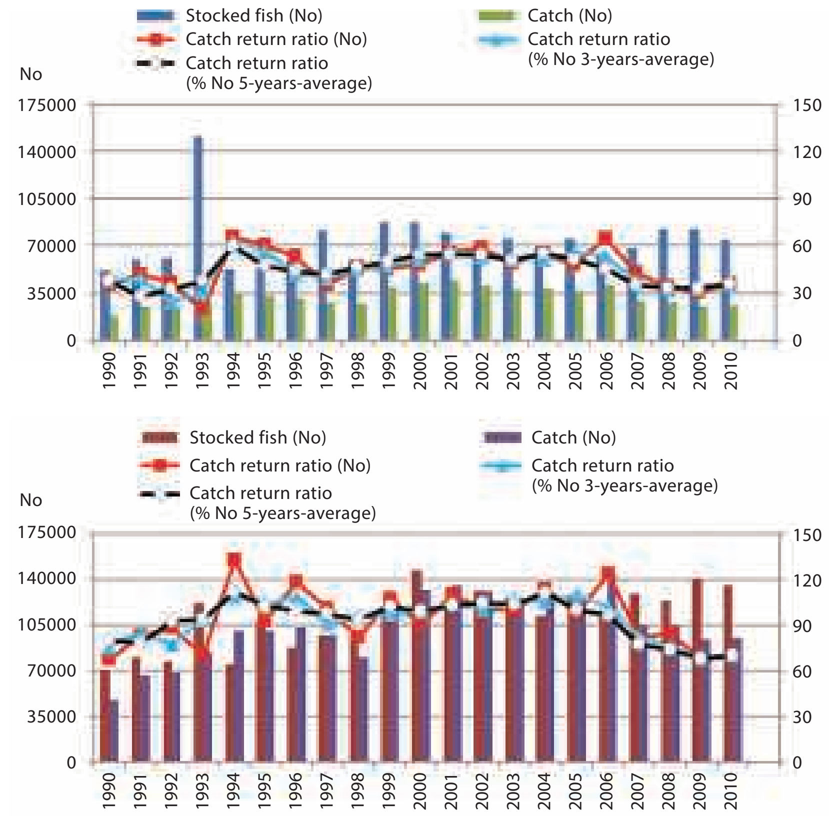

Fig. 4.4.8. ***Total number of stocked fish*** *(pieces and kg on the main axis)* ***and catch return ratio*** *(in % stocks in pieces and kg on the minor axis)* ***with respect to annual number of stocked carp in the Lipno Reservoir*** *between 1990–2010 (data provided by the South Bohemian Board of CAU).*

the reproduction periods by means of suitable management of water level fluctuation. Another option is to install artificial substrates if natural substrate is missing.

Regulatory and control catches

In case of undesirable development of a fish stock, regulatory steps can be taken, especially using different types of nets or electrofishing (see chapter 6). Some reservoirs or ponds may be, in such a case, drained and all fish can be removed. It is necessary to emphasize that all fishing methods except angling are forbidden to be practised in a fishing ground and prior exceptions from the fishery authority must be granted for all catching methods. An exception to practice the forbidden methods, according to § 13 of the Act can be granted only to the user of a fishing ground who may authorize another entity to carry out the catching. The application for an exception must contain the purpose of the intended catch, used methods, dates (these can be specified before the catch) and also the way in which the sampled fish will be treated. We should not forget that fish, as wild living animals, do not belong to anyone under the terms of the Czech law (res nullius), and therefore, they can neither be manipulated nor sampled without the due authorization.

The same conditions must be followed during the control monitoring as well, whether their target is to gain information about the fish stock's status in order to enhance fishery management, monitoring

Fig. 4.4.9. ***Monitoring of fish population status by electrofishing*** *(the Úhlava River, photo: M. Hladík).*

of ecological status according to the Water Framework Directive or monitoring of protected species, the European significant localities of the Natura 2000 system and other scientific purposes. If we follow the provisions of the Act rigorously, this obligation applies to all water organisms without exception according to § 13 of the Act.

Other activities

Some other activities that are connected to management in fishing grounds must be mentioned. Above all, it is the correct marking of fishing grounds that must be placed always at the borders and which should always be placed in access roads as well. The marking of a ground must contain the name and a six-digit number of the fishing ground, information on whether it is a salmonid or non-salmonid ground and name of the user or the basic contact data. Within CAU, fishing grounds are marked by standardized signs that contain the above mentioned data and the CAU logo. Next, it is customary to state also the most important changes that are distinct from generally valid fishery conditions (see below for details). In fishing grounds that are attractive for foreign anglers this information is also stated in English as well as in German. The marking is supplemented in suitable places with information boards that contain a large-format map and multilingual information about the surrounding fishing grounds. These informational boards were installed at Lipno Reservoir with information given also in Russian and Dutch.

The care of fishing grounds involves also other essential activities, for example maintenance of riparian vegetation that is carried out in co-operation with the river authorities, cleaning of banks, mowing of dams in ponds and reservoirs (it is often stipulated in the lease contract) or technical-safety supervision at selected reservoirs.

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4.5. Fishery management in non-salmonid fishing grounds *(J. Kubečka, D. Boukal, M. Hladík)*

The majority of waters where recreational fishing is practised in the Czech Republic (approximately 39 thousand hectares) belong to non-salmonid fishing grounds. These grounds comprise mainly streams with adjacent tributaries, dams and other artificial reservoirs, ponds, flooded pools and pits that originated due to extraction of minerals. Even though there are various types of non-salmonid grounds, single fishing rules apply to these grounds and the main game species are cyprinids (mainly carp) and piscivores (mainly pikeperch and pike).

Fish communities in individual fishing grounds usually include **fish from naturally spawning populations and stocked fish**. In most cases, natural reproduction does not cover anglers' demands with respect to quantity, size structure and species composition and hence more expensive stocking is applied. Stocked fish usually represent most of the catches and stocking thus represent the main expense of fishery management. Stocked fish normally come from production fisheries. In exceptional cases, fish can be transported from other open waters, where they may represent undesirable or overabundant species.

4.5.1. Limnological basis of management in standing waters

Fish communities in standing waters range between two typical states that differ in the **grazing intensity of planktonic communities** (see also chapters 3.4., 4.5. and Fig. 4.5.1.). Most Czech standing waters usually have overabundant non-piscivorous fish (common bream, silver bream, roach, bleak, rudd, gibel carp, stunted European perch, etc.). Water transparency is low and zooplankton is small during the growing period in such waters. This state is typical for a relatively wide range of fish biomass (labelled A in Fig. 4.5.1.). It is probably caused by high fecundity of non-piscivorous species in combination with high fishing pressure on piscivorous fish. Abundant non-piscivorous fish quickly exhaust their food resources, i.e. zooplankton and benthos. Their growth rate declines considerably and condition factor may also decrease.

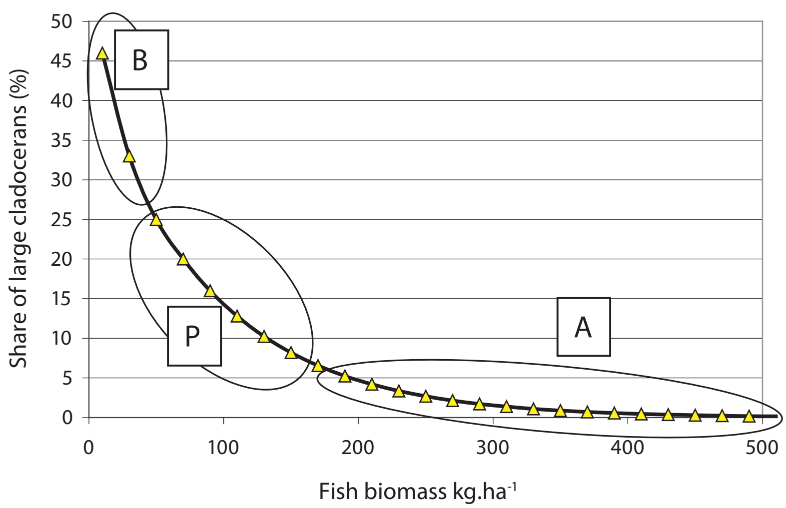

Fig. 4.5.1. ***Relationship between non-piscivorous fish biomass and zooplankton size structure*** *(according to Seda et al., 2000). Typical states labelled as A, B and P (see the main text for explanation).*

This applies to naturally reproducing as well as stocked species, including carp (Pivnička, 1999). The overall biomass of non-piscivorous species is thus large but composed of many small fish that are of minor value to consumers. Production of piscivorous fish also decreases since there are few of them. In reservoirs with an average trophic level, it is thus not important whether 200 or 500 kg of non-piscivorous fish per hectare are present, because their growth is still slow and larger plankton is nearly absent (Fig. 4.5.1.).

State A is characterized by high fish biomass, slow growth and insufficient amount of large zooplankton. State B represents an ideal state of biomanipulative fish stock (waters with desirable low algae production, e.g. drinking water-supply reservoirs) with low fish biomass, fast growing individuals, and abundant large zooplankton. The intermediate state P represents a convenient compromise for most fishing grounds. Zooplankton size structure is expressed as the proportion of large cladocerans that remain on a 0.7 mm mesh sieve in total zooplankton biomass (average from June to October). The relationship applies to drinking water-supply reservoirs and can be shifted to the right under more eutrophic conditions.

Fish communities with smaller non-piscivorous fish biomass (states B and P in Fig. 4.5.1., up to about 100 $kg.ha^{-1}$) allow large cladocerans to increase in abundance and since they usually represent the main food resources in standing waters, fish also grow faster. This biomass range is a convenient target for standing non-salmonid grounds. It can be achieved mainly by means of effective protection of piscivorous fish including good conditions for their reproduction. Abundant piscivores can in turn limit the growth of non-piscivorous fish populations.

It is relatively difficult to determine both fish biomass and the biomass of cladocerans and total zooplankton during the season. Average length of cladoceran shells can in practice serve as a proxy measure. The intermediate state P in Fig. 4.5.1. is characterized by an average length of around 1 mm. Average length smaller than 0.8 mm indicate overabundance of non-piscivorous fish (state A).

In sum, it may be desirable even in receational fishing grounds to decrease the biomass of coarse fish by means of increased protection of piscivorous fish and recommended focus on non-piscivorous fish. The most effective, eco-friendly method is to harvest planktivorous fish, i.e. mainly cyprinids, that are usually overabundant in fishing grounds. Small cyprinids are not too popular to eat in the Czech Republic, but their use should be supported. Last but not least, anglers targeting piscivorous fish should realize that, for each harvested piscivore, they should harvest several times larger biomass of non-piscivorous fish.

4.5.2. Current fishery management in non-salmonid grounds

Most management actions concern "commercially interesting" species (carp, piscivorous fish and so-called herbivorous species). However, these species usually represent minority stocks (see chapters 3.5. and 4.3.) dominated by less valuable coarse species (common bream, silver bream, bleak, roach, European perch, etc.) that reproduce well in Czech standing waters. The main non-piscivorous commercial species (mainly carp, herbivorous fish and recently, for example, sturgeon) require special conditions to reproduce naturally and very rarely become overabundant in fishing grounds. They are usually stocked by local managers or escape from other fishing grounds or hatcheries. Their stocking size usually exceeds the minimum size limit so they can be harvested immediately.

Common carp has provided the largest volume of stocked fish in all but very few non-salmonid fishing grounds for several decades. Carp is by far the most important harvested fish in these grounds. Some 1250000 carp with a total weight of over 3000 tonnes (74% of weight of all catches within Moravian Anglers Union, MAU, 78% of weight of all catches in Czech Anglers Union, CAU) are annually harvested in CAU and MAU fishing grounds. Given the traditional method of rearing in fishponds, carp is most accessible and, at the same time, cheaper to stock in autumn, but spring stocking is practised in many fishing grounds as well. In this way, potential losses in the winter season are reduced, mainly in smaller reservoirs, ponds and rivers.

Conversely, most fish are stocked in the autumn in valley reservoirs since they provide suitable conditions for overwintering. Trophy fish are often stocked in fishing grounds where a maximum size limit, usually 70 cm (so-called K70), has been introduced. Usually 50–100 three-year-old fish per hectare are stocked in rivers. In standing waters, the number of stocked fish is usually higher (see below for details).

Fishery managers occasionally declare a short-term ban on carp fishing immediately after stocking in order to allow them to adapt, although this restriction is usually not necessary. On the other hand, it is true that stocked fish of harvestable size disappear rather fast since they are caught very quickly. The dilemma of prolonged or short residence times of stocked carp in a fishing ground depends on local growth opportunities and mortality risks. If losses due to mortality are higher than production due to growth, it is of no use to protect the stocked fish (e.g. by imposing a higher size limit). The average individual weight of carp catches in the Czech Republic that is over 2 kg represents a good compromise of these processes.

Biomass return statistics represent a good indicator of the ratio of production to losses. In carp, anglers usually catch a similar amount of fish that was stocked (see Boukal et al., 2012). The ratio of stocked to caught fish biomass remain relatively constant over years even if the amount of stocked and caught carp increased considerably in most reservoirs during the last 20 to 40 years, in some places up to 10 times. However, there are also exceptions. For example, conditions for carp are unfavourable in three valley reservoirs on the Vltava river (the Vrané, Kamýk and Štěchovice Reservoirs) located immediately downstream of large reservoirs (Slapy and Orlík). Water in these three reservoirs is rather cold and usually with depleted oxygen because the reservoirs are supplied with cold water from the hypolimnion. Anglers catch only about 50–85% of the total weight of stocked carp at these reservoirs in the long run, and the ratio was only 25–35% in the 1970s and 1980s. On the other hand, some fishing grounds, especially the Nové Mlýny and Mušovská Reservoirs on the Dyje River, offer an ideal environment for carp due to their high trophic level, warm and shallow water, and anglers catch one-and-half to twice the total weight of stocked carp over a long period in these reservoirs. These conditions are rather unique and exceed even carp catches in the Vranovská and Orlík Reservoirs, two reservoirs of the Dyje and Vltava Cascade with the highest trophic level, where the total catch has been about one third higher than the total weight of stocked carp over a long time period.

Large floods have become a significant phenomenon in recent years. They influence not only the riverine environment but also fish stocks. In addition to the impact on natural populations, strong flow can carry away stocked fish from upstream fishing grounds, ponds and hatcheries and leave them lower downstream. The millennial floods in the summer of 2002 influenced the overall results of selected fishing grounds in a substantial way as they brought roughly 30–250 tonnes of carp into each reservoir of the Vltava Cascade between Hněvkovice and Slapy and, in some places, catches during the 2002–2003 period increased up to 10 times (Boukal et al., 2012).

Individual reservoirs also differ in the residence time of the stocked fish. Statistical analyses of long-term data show that in ponds and smaller reservoirs, most carp are caught same or following year after stocking. A significant part of stocked carp probably survives for 2–3 years only in larger reservoirs (e.g., Lipno, Orlík, Slapy and Nové Mlýny). Some stocked fish can of course survive for a longer period, but their numbers are low compared to those that are caught during the first years. The differences in residence time of stocked fish are caused mainly by the reservoir size and amount of stocked fish. Carp are stocked at densities of 100–1000 $kg.ha^{-1}$ per year in small reservoirs below 100 ha in size. Such amount of fish is very attractive for anglers and, moreover, the fish cannot escape the anglers in such relatively small habitats. On the other hand, the stocked amount is only about 5–50 $kg.ha^{-1}$ per year in large reservoirs with an area of several hundred to thousands of hectares.The stocked fish can disperse more easily in a large area and do not represent such an easy catch (Boukal et al., 2012).

Carp as well as other fish species that are not able to reproduce naturally have been naturalized in the Czech waters over a long period, but they are not native and not required in the ecosystem. Their contribution to the ecological quality of a given water body is not significant and they usually cause its deterioration.

Stocking of carp and herbivorous species can, for example, come into conflict with demands on high water quality and presence of aquatic vegetation and may thus negatively impact other aquatic organisms such as amphibians, shellfish, dragonflies and other invertebrates. Other interests (conservation, angling opportunities, biomass production or suppression) thus have priority over the presence of these fish species. A specific situation occurs only in some waters where grass carp is used as a biomeliorative species.

Carp dominate catches in non-salmonid grounds to such an extent that if we want to compare catches of other species, it is useful to remove carp catches first (Fig. 4.5.2.). Among the remaining species, catches of common bream predominate in biomass (almost 25% of weight of remaining catches). **Common bream** represents the majority of present fish biomass in many standing waters and it would be desirable utilize instead use it, at least partially. Fish biomass in many waters, however, is locked in the bodies of large bream since they have low mortality and grow very little. In addition to that, catches of bream have decreased in recent years, which is probably not caused by the decrease in their populations but by the loss of anglers' interest in their meat. Stocking of bream in standing waters should thus be carried out only in well-justified cases if they cannot reproduce or the parental stock is heavily endangered, e.g. in some cascade and energy reservoirs with strong water level fluctuations (Fig. 4.5.3.).

Common bream, roach and other cyprinid species, often generally known as "white fish", and, for example, European perch are stocked in different size categories, often on the basis of the current market offer. Their stocking has become important in many riverine grounds and when the pressure of piscivorous predators, especially cormorants, is growing, it is even necessary. The availability of stocks varies. Usually, these are accessory fish species whose stocking has been rather low in recent years. It also bears the risks of diseases, which means that it is preferable to support natural reproduction of these fish in fishing grounds. Lack of littoral vegetation can be amended by installing artificial spawning grounds for cyprinid species that consists mainly of branches of conifers. Progress in this matter could be very important for fish stocks in some valley reservoirs (e.g. the Lipno Reservoir), where littoral vegetation disappeared due to changes in water level management and the reservoir aging; this has considerably limited the reproduction and growth of fry of all phytophilous fish species.

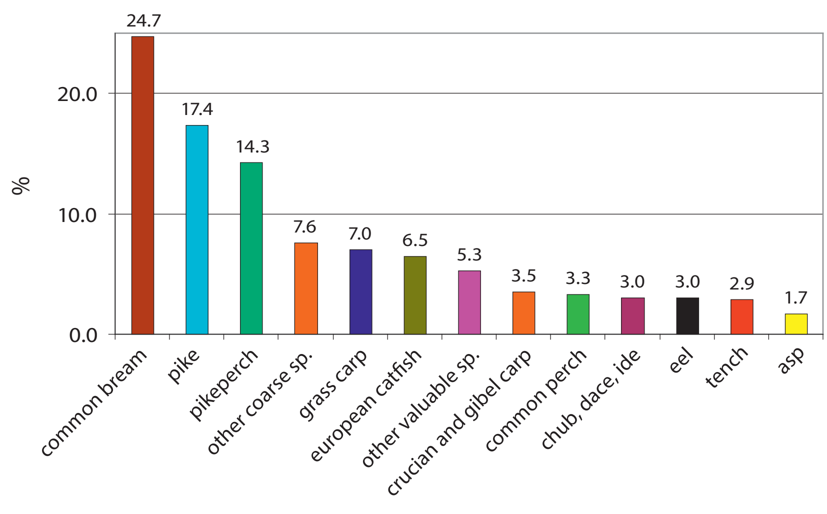

Fig. 4.5.2. ***Average long-time (1990–2010) weight composition of catches in all non-salmonid grounds in CAU and MAU combined after exclusion of carp catches.*** *The percentage of total catches (without carp) is given above each column.*

Fig. 4.5.3. ***Dry fish eggs caused by water level manipulation*** *(photo: FISHECU archive).*

Two popular piscivorous fish – **pike** and **pikeperch** – come next on the list of most caught fish species in non-salmonid grounds. Pike are popular due to their attractiveness, widespread distribution, intense stocking and also because they are easy to catch. Without stocking, this species would disappear from many waters that have a limited amount of submerged vegetation since natural spawning of pike strongly depends on the presence of flooded vegetation. In small vegetated waters, their spawning is usually more than sufficient and stocking is not needed. In larger reservoirs, pike development can be supported by suitable manipulation of the water level, e.g., by targeted flooding of the littoral areas.

Pike are either stocked in a traditional way as advanced young pike, i.e. before they become fully cannibalistic, or as yolk-sac fry. Relatively high losses of the latter stage should be expected. Young pike should be distributed along to littoral areas of the entire fishing ground to prevent losses due to cannibalism (usually one young pike is stocked in suitable shallower parts with shelters within 5–10 m of the shoreline). One- to two-year-old fish at an affordable price have been introduced onto the market in recent years and these fish can be used to support catches in some fishing grounds (Fig. 4.5.4.).

Pikeperch populations have also been supported by stocking in many places. However, unlike pike, this species is able to reproduce naturally even in the relatively hostile conditions of reservoirs and mining lakes. Natural reproduction is supported also by parental care for eggs and the ability to reproduce in deeper waters that are protected against water level fluctuation. Stocking of pikeperch, in contrast to stocking of pike, is often problematic. Pikeperch are very sensitive to manipulation and they show high mortality rates after stocking. They are stocked mainly in the stage of advanced fry (in at lengths of 3–4 cm), or yearling (at lengths of 7–14 cm). The price of the latter stage is excessive and its stocking is therefore rather rare. The approximate annual stocking densities range between 50–100 individual pikeperch yearling (Pp_1).ha^{-1} in standing waters; they are less in suitable bream zone areas of rivers. It is advisable to limit stocking in fishing grounds where sufficient natural reproduction has been proved and it is better to support natural reproduction by means of installing spawning nests. They are made of sedge bults or artificial grass and positioned at depths of 1.5–2 m. It is possible to leave occupied nests in a fishing ground or to transport them into suitable ponds and use them for fry rearing.

Fig. 4.5.4. ***Pike stock in a special boat for transporting live fish*** *(photo: FISHECU archive).*

The following commonly caught group of fish, so-called **other fish,** comprises commercially less valuable species and it was decided long time ago that it is not necessary to keep separate statistics for individual species. This category usually includes **"white fish"**, i.e. smaller cyprinid species, such as roach, rudd and bleak. Their less than 8% share of the total catches without carp is not too significant and has been gradually decreasing in recent years. This decrease, similarly to bream, does not manifest itself as a decrease in fish in fishing grounds, but it is rather because people are getting wealthier and thier interest in small fish has been decreasing since their filleting or other use is more laborious.

Grass carp comes next at 7% of catches. Catches of this species rose in the 1990s and stabilized afterwards. This species is usually stocked as a biomeliorative consumer of soft aquatic vegetation. It can be useful in very shallow ponds and pools that would otherwise disappear due to sedimentation. However, most Czech open waters have too litle aquatic vegetation in the littoral areas and grass carp stocking can be counterproductive. Despite the fact that grass carp are very attractive for anglers due to their combativeness and quality meat, it is always advisable to carefully consider their further stocking.

Catches of **European catfish**, a species with highly mixed reputation, come next after grass carp. Catfish have adapted very well to the conditions in Czech fishing grounds and reproduce successfully in many places. It is also the largest Czech fish that for many anglers represents a supreme trophy fish. For others, on the other hand, they represent a dangerous predator decimating other valuable species and their food. Catfish represent a challenge even for professionals since it is not easy to clarify their role and importance in the ecosystem. In most cases, the rumours concerning catfish predation are exaggerated – this species is strictly territorial and does not reach high population densities. However, truly large catfish can considerably reduce other fish populations, especially those of tench, carp, pike and pikeperch (Vágner, 2010). It is hence forbidden to stock catfish in some fishing grounds. If stocked, catfish are released in several sizes (advanced catfish, yearling, two-year-old stock) in densities ranging between 10–50 catfish yearling (Ca_1).ha^{-1} per year.

A group of other valuable species include mainly riverine species (**barbel, vimba bream, nase carp, burbot and salmonid species**). Their individual proportions represent 1% or less but together they represent over 5% of total weight of catches excluding carp. Nevertheless, catches of these species have been decreasing despite conservation programmes and increased stocking. "Catch and release" strategy that has become increasingly popular in recent years may also be partly responsible because it influences the records (released fish are not entered into the daily recording sheet) and consequently leads to biased information on the status of local fish communities. Rheophilic species, such as barbel, nase carp, vimba bream, asp, chub and minnow are stocked in most cases in the yearling stage and they are reared on combined feed in ground ponds, which means that their adaptability after they are stocked does not cause any troubles. Burbot are probably the only species in the Czech Republic that are stocked mainly in the yolk sac fry stage given their high fecundity. Yolk-sac fry are however characterized by huge losses and stocking of older categories has been applied mor often in recent time.

Recent catches of **Crucian carp** have been represented mainly by the non-native gibel carp, since native Crucian carp have been loosing their habitats and are now classified as endangered. Gibel carp is considered to be a nuisance species in Czech waters and their harvest is recommended. Other species with biomass proportion of around 3% in the total catch excluding carp are **European perch, ide, chub and eel**. Catches of these species have been declining as well. This is especially disturbing in eel that is on a steep decline throughout Europe as a consequence of the construction of migration obstacles, diseases and mortality of migrating adults. Eel are stocked as glass eel that are transported from estuaries of western and northern Europe and have been partly raised on supplementary feeding in recent years, which has probably decreased their subsequent mortality rate. Stocking of eel is subsidized in river basins without any major dam reservoirs since eel represents an endangered species that is protected by European Union. Conversely, stocking of eel in river basins of reservoir cascades has been abandoned due to the fact that migrating adult eel are killed by the turbines of hydroelectric plants.

The remaining species whose weight proportion in catches excluding carp exceed 1% include **tench** with stable catches and a standard stocking programme (usually stocked as two-year-old fish, 50 $ind.ha^{-1}$ in standing waters and 10–20 $ind.ha^{-1}$ in suitable riverine grounds) and **asp** with slightly increasing catches due to the stablisment of successful rearing up to the yearling stage.

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4.6. Fishery management in salmonid fishing grounds *(T. Randák)*

Salmonid fishing grounds are situated in upper streams, in suitable stretches under dam reservoirs and also in some smaller colder reservoirs located at higher altitudes mostly. Fishery authorities designate Salmonid fishing grounds, under current legislation, in those localities where the occurrence of salmonid species and grayling is expected. Fish species inhabiting these grounds require high quality water and a relatively low water temperature. Their reproduction is usually dependent on gravel substrates. Typical representatives are brown trout (*Salmo trutta*) (Fig. 4.6.1.), European grayling (*Thymallus thymallus*) (Fig. 4.6.2.), burbot (*Lota lota*), bullhead (*Cottus gobio*), common minnow (*Phoxinus phoxinus*) and also non-native salmonid species that were introduced in the past and that have been regularly stocked, rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*). The method of fishery management and recreational fishing in salmonid grounds considerably influence the composition of a fish stock.

It is important to note that the upper stretches represent probably the most significant sections of the Czech streams from a biodiversity protection and support point of view. Upper streams are the least influenced by anthropogenic activities and in several cases, these stretches can be characterized by purely natural or close-to-natural conditions (Fig. 4.6.3.). Hence, there are definite preconditions for stable populations of native fish species with a sufficient level of their natural reproduction. Fishery management in these natural localities should primarily support development of populations of native species. All fishery management interventions must be carried out in the most responsible manner and on the basis of proper knowledge of the given issue.

Fishery management in these grounds is currently conducted in compliance with the conditions stipulated in the Decision of the competent fishery authority on declaration of a fishing ground, i.e., the effort to fulfil stocking plans defined in these decisions has been exerted as well. Stocking plans usually emerged on a theoretical level and, in the course of time, were updated on the basis of proposals of fishing grounds' users or directly by the fishery authorities. At present, it is obvious that with respect to support of native fish species – mainly brown trout and grayling – the stocking plans for the major part of salmonid grounds have not been defined in an optimal manner. On the other hand, there are salmonid grounds where fishery management focused on biodiversity support lacks any purpose. The paradox is that this group includes the fishing grounds that have been considered until only recently as the most significant grounds. These grounds are the stretches of streams situated under dam reservoirs and sometimes they are labelled as secondary salmonid grounds. These stretches of streams were characterized by rich fish stocks of salmonid species and grayling unfortunately only until the predation pressure of flocks of great cormorant increased. Nonetheless, it should be noted that large fish stocks of salmonid species in these grounds were reached mainly due to stocking. In these stretches, there is usually only a low level of natural reproduction. Slavík and Bartoš (1997) discovered, for example, that only 1 to 2 species reproduced in the cold water flowing under the Vltava Cascade up to the confluence with the Berounka River. These are thus mainly degraded stretches of streams where fishery management should be aimed at something else rather than biodiversity support. Basically, the same applies to salmonid reservoirs that were created as a result of human activity, or to stretches of streams that were heavily damaged from a morphological point of view.

Fig. 4.6.1. ***Brown trout*** *(photo: T. Randák).*

Fig. 4.6.2. ***European grayling*** *(photo: T. Randák).*

Fig. 4.6.3. ***The upper Vltava River above the Lipno Valley Reservoir belongs to the most ecologically valuable salmonid grounds in the Czech territory*** *(photo: T. Randák).*

4.6.1. Methods of current fishery management in salmonid waters

Fishery management in salmonid waters has been historically connected with production and stocking of fish. **Breeding of brown trout and grayling,** that is based on artificial reproduction and breeding of stocks, has been a tradition in Bohemia as well as in Moravia for more than one hundred years (Pokorný et al., 2003). Professor A. Frič laid the foundations for artificial reproduction of salmonid species in the Czech Republic. Artificial spawning and fish egg incubation were carried out as late as the 1950s. Fry were usually stocked directly in open waters. After 1950, when a united organization of sport fishery was established and the number of people interested in recreational fishing grew considerably, the demands on production of fish stocks increased. A system of "rearing brooks" was established which has been ensuring the majority of production of brown trout stock even today. Progress in breeding of grayling was achieved mainly after 1960 when rearing of yearling in smaller ponds was successful. Since then, grayling have spread practically into all suitable streams in the territory of the Czech Republic due to artificial stocking (Lusk et al., 1987). Concurrently with the spread of grayling, their catches by anglers increased several fold. Fish totalling 5871 with a weight of 2082 kg were caught in Bohemia and Moravia in 1960, the catches reached the level of 89232 fish and 27632 kg in 1982 (Baruš et al, 1995; Pokorný a Kouřil, 1999). As a consequence of the establishment of artificial breeding of grayling and stocking of reared fish, grayling have spread considerably even in Poland (Leszek and Ciesla, 2000) and in Slovakia (Pavlík, 2000).

Current fishery management in salmonid grounds is still substantially based on traditional procedures that originated at the beginning of the second half of the 20th century. The key procedures, with respect to traditional care of salmonid populations, are often based on exploitation of brood fish, usually in absolute numbers for a given locality, their transport frequently beyond the native river basin and intensive stocking of fish. Brood fish for artificial reproduction are usually captured in the periods immediately preceding their spawning. Brood fish are thus often injured and can subsequently die. In addition, natural spawning in their native stream is also eliminated. Harsányi and Aschenbrenner (2002) stated, for example, that with respect to catching brood grayling immediately before spawning, their transport, hormonal induction of ovulation, their own spawning and release back to the stream, the post-spawning mortality of these fish thus reaches up to 100%. The high mortality of brood grayling after artificial spawning was also observed by Randák (2006).

Artificial reproduction of brown trout is usually carried out with the dry method which consists in group stripping of females into a dry bowl and by fertilization of eggs with milt from several males. The stripping technique of grayling is basically similar to stripping of brown trout. Anaesthetic and anti-fungal baths of brood fish are used to a large extent. Since ovulation does not occur relatively frequently in part of the female population due to various influences (water temperature, stress, etc.) and the stripping period is thus very long due to the uneven maturing of females (it takes up to several weeks), hormonal stimulation is sometimes used in order to increase the number of ovulating females (Lusk et al., 1987; Kouřil et al., 1987a,b; Randák, 2002).

The most frequent method of stripping, where sperm of many males are stripped onto large amounts of eggs (from up to dozens of females), so-called polysperm fertilization, has proved to be inadequate with respect to preservation of the genetic variability of offspring. Recent studies have shown that polysperm fertilization causes competition between sperm and most eggs are fertilized by only a small number of males that were originally used for stripping (Kašpar et al., 2008).

Rearing of yearling and two-year-old stock of brown trout is conducted in the Czech environment mainly in **extensive** conditions, i.e., by rearing of stocks in natural streams. Only a small number of fish breeders conduct rearing in controlled conditions. Most frequently fry are stocked in rearing brooks after digesting 2/3 of yolk sac or shortly after the initiation of feeding. Rearing brooks are stocked with fry for a period of 1 or 2 years. A considerable amount of quality brown trout stocks were produced by means of this system in the past (Kavalec, 1989). At present, this system is losing ground. The rearing method of brown trout stocks, where hatchery-reared three-month-old juveniles are stocked, has been implemented in some brooks (Nieslanik, 2005). The author states that, as far as this system is concerned, it is possible to stock approximately only a fifth of the amount of three-month-old juveniles (with a size of 4.5–6 cm) into rearing brooks, in comparison to the amount of stocked fry. The return percentage two-year-old fish ranges around 50%. The sizes of yearling and two-year-old fish, reared under such conditions, are approximately 10–15% larger in comparison with the classic system. It is thus possible that yearling are already stocked in fishing grounds.

Nowadays, technologies of rearing of brown trout stocks in **hatcheries** have been gradually developing. Rearing of brown trout in controlled conditions with the use of complete feeding mixtures is considerably more demanding than rearing of rainbow trout. High quality water and a proper temperature are essential and the water temperature should not exceed 18 °C in the long term even during the hottest months. Trough systems, concrete channels and storage tanks are used most frequently. Ground ponds seem to be unsuitable mainly from a veterinary point of view (Randák, 2006).

Rearing of fry and stocks of grayling is conducted within the Czech conditions in a more intensive manner when compared to rearing of brown trout. Within 3–5 days from hatching, the fry are stocked in rearing reservoirs with a sufficient amount of natural food (plankton), or are fed in troughs. In the past, it was necessary to use zooplankton for feeding during the first rearing stages which was subsequently replaced with feeding mixtures (Carlstein, 1997). At present, mixtures enabling successful rearing of grayling fry even without the use of natural feed can be found on the market. Rearing of grayling fry is conducted by two methods – extensively

Fig. 4.6.4. **Circular reservoirs for rearing of grayling** *(photo: T. Randák).*

in ponds with the use of natural feed, or with extra feeding, and intensively by means of feeding mixtures in the conditions of hatcheries. In this case, trough systems, circular reservoirs (Fig. 4.6.4.), or ground and trench ponds or concrete channels are used (Lusk et al., 1987; Pokorný et al., 2003; Randák, 2006).

The produced stocks, usually one- to two-year old, are stocked in open waters in such amounts, if possible, that correspond to stocking plans. The question is, however, to what extent do these amounts and stocked size categories correspond to the current conditions and needs of localities that are being stocked. Producing stock by means of extensive methods is, however, more and more expensive and it has ceased to be effective even due to the considerable decrease in the rearing capacity of brooks. At the same time, it is still more and more difficult to ensure sufficient numbers of brood fish that are required for stripping by means of their capturing from open waters.

4.6.2. The causes of decrease in brown trout and grayling populations

The gradual degradation of the structure of fish communities has been taking place in the Czech salmonid grounds since approximately the 1990s, which have manifested mainly in a sharp decrease in the native species – brown trout and especially grayling. Simultaneously, the catches of these species have decreased as well (Fig. 4.6.5. and 4.6.6.). Recorded catches of anglers can be considered, to a certain extent, as an indicator of the population status (Lusk et al., 2003).

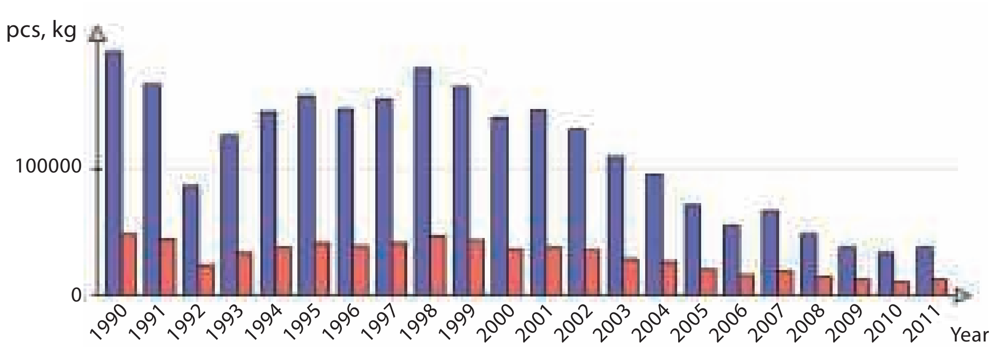

Fig. 4.6.5. ***Catches of brown trout in salmonid grounds in the CAU during 1990–2011.*** *(Source: The Czech Anglers Union – Board; www.rybsvaz.cz).*

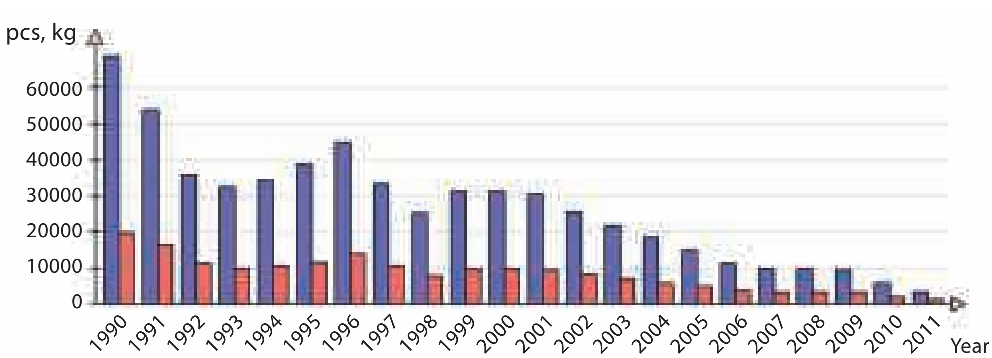

Fig. 4.6.6. ***Catches of grayling in salmonid grounds in the CAU during 1990–2011.*** *(Source: The Czech Anglers Union – Board; www.rybsvaz.cz).*

Such trend has been caused by many reasons. **Successful natural reproduction is crucial for the development of wild populations of salmonid species that ensures the preservation of genetic diversity as well as the stability of these populations**. Successful natural reproduction is dependent on the presence of a sufficient number of brood fish in a given stream. The number of brood fish (and fish in general) in a given locality is affected mainly by a wide range of factors that are often acting in concert. The most important factors are **stream segmentation, hydrological conditions, predation pressure of piscivorous predators, water contamination, recreational fishing and fishery management.**

Stream segmentation

Salmonid species prosper best not only in natural streams that contain a sufficient amount of shelters but also in places suitable for spawning (gravel beds) and subsequently for fry development (shallower zones with a slow flow-rate, backwaters, etc.). A sufficient number of shelters represents, especially for brown trout, a limiting factor, as far as the population size is concerned. The decrease in abundance of native salmonid species can be explained by the construction of artificial obstacles, by limitation of their migration possibilities (Harcup et al., 1984; Ovidio et al., 1998; Slavík et al., 2009) and also by the decrease in suitable habitats in stream beds (Harsányi and Aschenbrenner, 2002). The decrease in habitats is caused by the construction of sewerage systems, shortening of streams, embedding of stream beds and loss of communication with side tributaries, vanishing of shallow riparian zones that are suitable for fry, fortification of banks and excessive off-takes of water for hydroelectrical stations and the water industry (Cowx and Welcome, 1998; Turek et al., 2009). As a result of stream bed modifications, sheltering capacities for fish are thus being reduced, reproduction areas are being devastated and excessive off-takes of water limit even the living space of populations (Fig. 4.6.7.). At the same time, water is getting warmer, which is not favourable to the salmonid species. Harsányi and Aschenbrenner (2002) consider thoughtless modifications of streams, during which side river tributaries that serve as natural refugia for juveniles are removed, to be the most crucial reason for the decrease in the grayling's status in running waters. According to these authors, the presence of these refugia in salmonid streams is essential for the successful evolution of grayling fry, which represents the basis of natural restoration of their populations.

Fig. 4.6.7. ***Common destruction method of a river bed as part of the so-called anti-flood modifications*** *(photo: T. Randák).*

Hydrological conditions

At present, fish populations in streams have also been negatively influenced by the considerable fluctuation of flow-rates throughout the year and frequent long-term occurrence of the minimum flow-rate limits in streams (Slavík et al., 2004; Rogers et al., 2005). This fact relates to extensive land amelioration and to unsuitable farming in headwaters, as a consequence of which the strengthening and washes of arable land have been occurring. Next, it is also connected to the constantly increasing proportions of built-up areas in the landscape. Global climate change should also be taken account of. These factors have caused that the landscape has been losing its ability to retain water. Water drains away quickly which is also supported by the above-mentioned water stream bed modifications. All these factors have resulted in very low flow-rates during the dry parts of the year. Since mainly brown trout are territorial fish that protect their home range, the population size is directly dependent on the number of territories in the stream during the period of the minimum flow-rates. In this respect, it is necessary to mention also the negative impact of small hydroelectrical power stations in salmonid grounds. In the stretches where the flow-rate is considerably decreased due to off-take of water for the use of a power station, the amount of fish considerably decreases. Their migration in the longitudinal profile of a stream is also complicated.

The impact of stream segmentation and flow-rates on populations of brown trout and bullhead was documented in a field study that was conducted by Turek et al. (2009) in a small stream in western Bohemia. Although the flow-rate value Q_{355} is only 0.06 $m^3.s^{-1}$, a small hydroelectrical power station (SHPS) was built on this stream. Inflow to this plant is in the form of a piped channel that draws water from the brook. The users of the SHPS have kept the defined minimum flow-rate in the brook. The total length of the monitored stretch of the stream was 850 m. With respect to this stretch, fish populations were assessed by means of electrofishing in 3 sub-sections (Fig. 4.6.8.) that differed from the morphological (A, B) or flow-rate (B, C) point of view. The A-stretch (Fig. 4.6.8.A.) was paved without any natural shelters available for fish, although this stretch was not influenced by the water off-take for the SHPS. The B-stretch (Fig. 4.6.8.B.) showed natural features, high segmentation and it was not influenced by the water off-take for the SHPS either. Although the C-stretch (Fig. 4.6.8.C.) showed the same morphological features as the B-stretch, it was, however, influenced by the water off-take for the SHPS.

A B C

Fig. 4.6.8. ***The monitored stretches of the small stream*** *– paved bed (A); uninfluenced stretch (B); stretch that was influenced by the water off-take for the SHPS (C) (photo: T. Randák).*

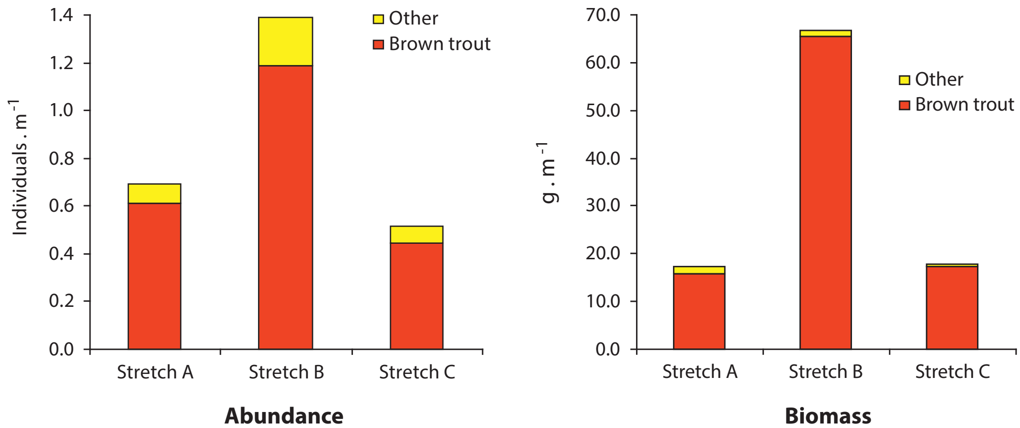

Fig. 4.6.9. Comparison of the abundance and biomass of fish stock in stretches of a small stream that differ from the morphological and flow-rate point of view *(stretch A – paved bed, stretch B – uninfluenced stretch, stretch C – stretch that was influenced by the water off-take for the SHPS).*

As can be seen in the Fig. 4.6.9., the abundance and biomass of fish, which occur in the human-influenced stretches, were several times lower in comparison with the uninfluenced stretch. It demonstrates how important it is for fish populations to preserve natural or close-to-natural conditions of the stream and to preserve natural flow-rates.

Piscivorous predators

The most significant fish predators in the Czech salmonid waters are: great cormorant (*Phalacrocorax carbo*), otter (*Lutra lutra*) and grey heron (*Ardea cinerea*). In connection with the disruption of diversity and environment complexity, the pressure of these predators increases as well, which is mainly evident in streams where improper fishery management is applied. Many authors consider the pressure of piscivorous predators to be a significant factor that causes a decrease in salmonid species in the Czech waters. Spurný (2003) described the strong predation pressure exerted by great cormorant and their impact on fish communities in the Dyje and Bečva Rivers. Mareš and Habán (2003) analysed the impact of the disproportionate occurrence of otter and cormorant on fishery management in fishing grounds of the MAU. Čech and Vejřík (2011) assessed the impact of cormorant on fish populations in the localities of the Vltava River. The biggest losses due to fish predators' pressure occur in salmonid waters during the winter months when rearing ponds freeze over, as these ponds represent the most important feeding base for predators. At present, migrating flocks of cormorant cause serious problems since they are able to virtually fish out the attacked localities within a short time. Predators endanger especially fish inhabiting streams with low sheltering capacity as well as stocked fish that have not yet managed to adapt to new conditions (Čech and Čech, 2000; 2008).

Water contamination

Contamination of water with organic substances, that often resulted in the past in the deaths of fish due to oxygen deficits or ammoniac poisoning, belong no longer to the main reasons of the decrease in salmonid species in the Czech streams. This is caused due to the areal construction of sewage treatment plants. The paradox is that due to the lower supply of organic substances into streams, their trophic status have been decreasing, which can influence fish populations to a considerable extent (Harsányi and Aschenbrenner, 2002). A significant factor that influences fish and other aquatic organisms in some localities is the

Fig. 4.6.10. ***Increased foam formation signalizing the presence of detergent in the water*** *(photo: T. Randák).*

contamination of the water with extraneous substances with a potential impact on exposed organisms that come mainly from municipal waste waters (Fig. 4.6.10.). From this point of view, the problematic stretches of streams are mainly those that are situated under sewage treatment plants (STP) where, in addition to that, the water flowing out from the STP is insufficiently diluted (Li et al., 2011). These streams are often used for the production of brown trout stocks or for catching of brood fish intended for artificial spawning. The reproduction of fish has considerably deteriorated in some localities due to the contamination of the aquatic environment which was also observed during the performance of spawning of brood fish caught in these localities (Kolářová et al., 2005).

Recreational fishing (angling)

Recreational fishing has obviously become one of the key factors that negatively influences the populations of salmonid species inhabiting fishing grounds. A large part of fishing grounds has been influenced by very strong fishing pressure. The techniques and materials that are used in the sphere of recreational fishing are still being improved and made more effective. Unfortunately, by means of these techniques, very large numbers of fish are being caught, including smaller fish. It has been proven that an average fly angler is able to catch up to a high percentage of fish occurring in a given stretch, including yearlings, in a smaller stream during one session. Even if the fishing method of "catch and release" is practised, several percent of the caught fish is usually injured and they consequently die (Rysley and Zydlewski, 2010). It means that with the increasing number of re-capturing of a given fish, its chance to mature and thus to involve itself in the natural reproduction process decreases. The numbers of re-captures are again closely connected to the intensity of fishing pressure. The impact of recreational fishing on fish populations is undoubtedly influenced also by the stipulated fishing rules, i.e., mainly in the closed season, the minimum catch size, limits defining the number of killed fish, methods of fishing, conditions for the maximum careful manipulation of caught fish released back, time-limited wading, etc.). Meka (2004) proved that the rate of fish injury during recreational fishing considerably depends on the type of hook used, the size of the fish and the angler's experience.

Fishery management

The method of fishery management influences to a significant extent the status of fish populations in salmonid grounds. The current situation in this sphere was mentioned above. The **intensive use of wild brood fish for the purpose of artificial reproduction** represents an area of great concern. The crucial issue here is that there are not enough brood fish in a major part of the localities even to ensure a sufficient level of natural reproduction. This applies not only to brown trout but even more so to grayling. Brood fish are usually captured in the pre-spawning period. In order to obtain the required amounts of spawned eggs, electrofishing is still being performed in longer and longer stretches of the rivers including the most significant stretches from a natural reproduction point of view. In some parts of the country, the numbers of fry for stocking are still insufficient; hence stocks are often imported from other regions or even from abroad.

In addition to that, due to the rearing of stocks **in brooks**, the natural development of fish populations in these streams has also been disturbed. This can influence also the quality of populations in streams of a higher order where these brooks empty into.

Non-native fish species, such as rainbow trout and brook trout (Fig. 4.6.11., 4.6.12.) have been stocked into salmonid waters in increasing amounts, since their stocks are more affordable than brown trout and grayling stocks. The impact of such stocking on native populations has been speculated about; nonetheless, the fish that are usually stocked in a catch size and aimed at generating an interest in recreational fishing, are usually caught in a very short period of time and hence no considerable influence on wild populations has been assumed.

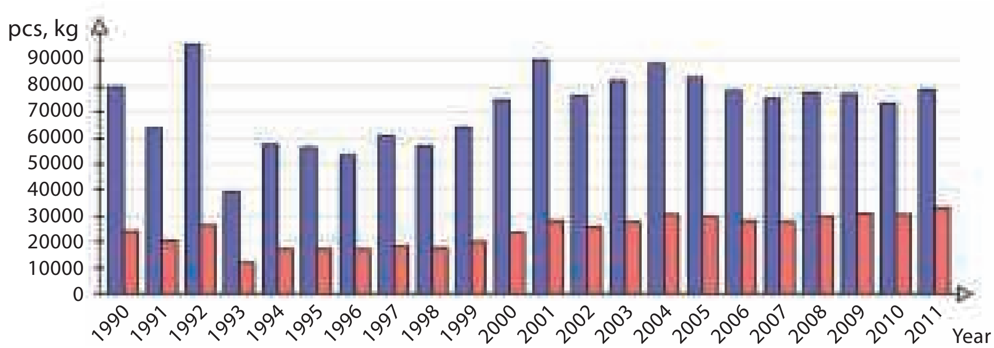

Fig. 4.6.11. Catches of rainbow trout in salmonid grounds in the CAU between 1990–2011. *(Source: The Czech Anglers Union – the Board; www.rybsvaz.cz).*

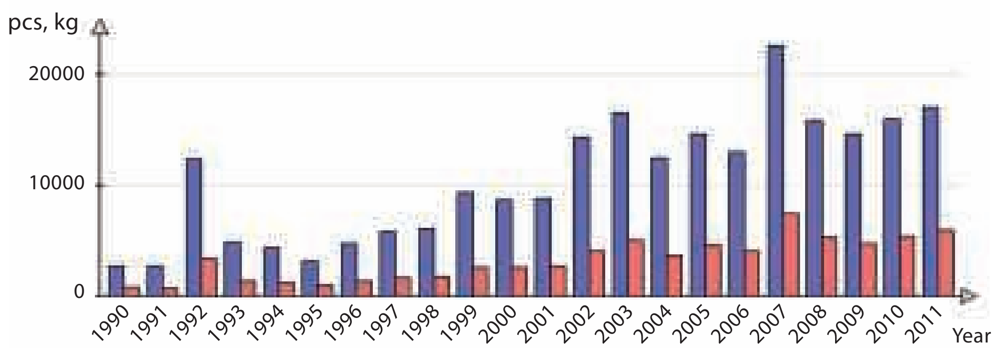

Fig. 4.6.12. Catches of brook trout in salmonid grounds in the CAU between 1990–2011 *(Source: The Czech Anglers Union – the Board; www.rybsvaz.cz).*

On the other hand, **overstocking** with brown trout can also cause serious problems in some localities, which can result in the destruction of the territorial structure of wild individuals, slow growth and loss of the optimal size structure of population. Overstocking is usually carried out in good faith and most often by stocking two-year-old and older stocks into fishing grounds where natural reproduction functions well, and basically where no such stocking is required. Subsequently, negative interactions between individuals and competition for territory or feed occur which weakens native as well as stocked individuals. In the case of the stocking of two-year-old and older stocks, it is virtually impossible to regulate the numbers by means of cannibalism and thus formation of a certain balance corresponding to sheltering and feed capacity of a stream. It thus creates possibilities for fish predators, non-natural fish migrations, or deaths due to exhaustion and deterioration of physical condition of fish.

As a consequence of the insufficient number of brood fish in the Czech streams, the production of stock material of brown trout and grayling does not cover the demands of entities that manage salmonid waters. In order to fulfil stocking plans, it is common to transport or purchase stocks from afar and even abroad. Stocks reared in hatcheries are being used more and more often. It often includes even various hybrids. **Stocking of non-native, mainly hatchery-reared stocks,** represents very serious risks for the stability of native populations. Transport of stocks from afar, stocking of genetically different lines (e.g. Italian, Kolowrat or imports from abroad) have unfortunately become common practice these days. Stocking plans using **intensively reared fish** have been often criticised in the world due to their contradictory results and their purposefulness have been disputed mainly due to the low survival and bad results of stocked fish reproduction (L'Abee-Lund, 1991; Einum and Fleming, 2001). Assessments of the adaptability of hatchery-reared stock in natural conditions and assessments of the impact of these stock on native populations have been elaborated on from the middle of the last century (Fleming and Petersson, 2001; Turek et al., 2010a,b). In the majority of works that have been published until today, authors stated that the survival and growth of hatchery-reared stocked fish is lower in comparison to wild fish (Arias et al., 1995). The low survival of stocked fish is usually connected with the origin of reared fish (Lachance and Magnan, 1990), unsuitable behaviour in foraging for food and low competitiveness (Ersbak and Haase, 1983; Bachman, 1984). Mutual interactions can occur among hatchery-reared stocked fish and wild fish. It can be, for example, competition (McMichael et al., 1997, 1999), predation (Sholes and Hallock, 1979), behavioural anomalies (Sundström et al., 2003) and due to various pathogenic interactions (Coutant, 1998). It has been also argued that introduced genetically non-adaptable material may considerably influence native populations (Saunders, 1991; Waples, 1991).

The past as well as current fishery management in salmonid grounds have been imperfect in many aspects. It has even been often counter-productive from the biodiversity support point of view. The above-mentioned factors do not manifest within populations of salmonid species immediately. Individual impacts can accumulate for several years until they become fully evident. As soon as the population status exceeds a critical limit, it starts to collapse. However, it is very difficult to predict such limit.

4.6.3. Stabilization and support of native salmonid species in salmonid grounds

With respect to support of salmonid populations in salmonid waters, we must endeavour to identify and subsequently **eliminate**, to a maximum extent, **negative factors** which influence concrete fishing grounds. Unfortunately, it is very difficult to influence a considerable part of these factors, with regard to the salmonid grounds' users. Nevertheless, it is necessary to exert the maximum pressure leading to limitation of needless interventions which influence stream segmentation in a negative way, require functioning permeability of artificial barriers, permanently supervise users of hydroelectrical power stations, attempt to change legislation in the sphere of protection of fish predators, localize and eliminate sources of pollution, etc.

Alterations of angling rules

It is possible to consider **alterations of angling rules** that focus on greater protection of size categories of brown trout and grayling as these are key for natural reproduction. **The minimum catch lengths** should exceed 30 cm with respect to both species which would enable fish to engage in natural reproduction several times. Additionally, **stricter limits defining the number of kept pieces** (daily and seasonal) should be established. Fish designated for consumption of anglers should be mainly rainbow trout and brook trout. It must be realised that even if caught fish are handled with the maximum care, the mortality rate of such released fish is several percent. It should be commonplace to use **barbless hooks** which significantly decrease injuries in caught fish when loosening the hook. Greater emphasis should be laid on **careful handling of caught fish**, with those released back into the water in particular. These fish should be released from the hook into the water, in no case should they be scooped up with a landing net. If it is necessary to hold the fish in ones hands, then it is essential to moisten them. These simple acts can considerably decrease fish injury and hence the mortality of caught fish released back in the stream. Another measure is to **protect important spawning grounds** by means of declaring a ban on wading in the period of spawning and egg incubation. **Education** of anglers with a focus not only on interpretation of rules but also on fishing ethics issues is essential as well. As far as **fishing ethics** is concerned, it is necessary to appeal to anglers to focus on catch-size fish and not to catch juveniles only for fun or individuals who are getting ready for spawning.

New approaches within fishery management

Fishery management in salmonid grounds provides significant scope for solving the situation and it should focus not only on the interests of fishery users of salmonid grounds, but also on the **effective support of biodiversity**. The strategy of fishery management must be based, above all, on the nature of a given ground.

Fishing grounds with an occurrence of stable native populations of brown trout and grayling based on their effective natural reproduction cannot be expected for various reasons (e.g., secondary salmonid grounds under dam reservoirs, channelized streams and reservoirs). In such grounds it is **more effective to direct the method of fishery management towards the support of recreational fishing**. These grounds are suitable for increased stocking of rainbow trout and brook trout, or hatchery-reared stocks of brown trout and grayling. Fish should be stocked in catch-sizes several times a year and in amounts that correspond to fishing pressure from an economic point of view. The attractiveness of these grounds can be considerably increased by stocking trophy fish.

In fishing grounds where an occurrence of native fish species populations, including their natural reproduction, is expected but where these grounds have been influenced by anthropogenic activities, fishery management should **support development of native species populations** and at the same time, **sustain also their attractiveness for sport anglers**, by means of limited stocking of rainbow trout and brook trout in catch-sizes. This group comprises the majority of salmonid grounds in the Czech Republic. In these grounds, maximum support is required for the occurrence and natural reproduction of brown trout and grayling, by means of the method of fishery management and establishing of the fishing rules. In case of an insufficient level of natural reproduction of these species, it is suitable to support them by means of stocking quality stock material. **Declaration of protected fish areas** in suitable stretches of these grounds represents also a very efficient measure.

Even in the territory of the Czech Republic there are still localities that can be considered **particularly valuable fishing grounds from the ecological point of view**. These grounds are, in particular, natural upper streams with prospering populations of brown trout and grayling. In most cases, they are the stretches of streams that belong to national parks and protected landscape areas. **No fishery interventions, including e.g., catching of brood fish and stocking of fish, should take place** in these streams and their tributaries. With respect to angling fishing rules, the **ban on keeping native salmonid species** should be valid and **fishing pressure should be limited** by a reduced number of fishing licences issued.

Support of wild populations of brown trout and grayling by stocking of fish

Stocking of fish represents one of the options to support wild populations in an efficient way, in particular, in the localities where natural reproduction does not function in an optimal way. However, the **stocks must be distinguished by high adaptability to conditions of the stocking locality and their genetic qualities must not differ substantially from the genetic qualities of the wild populations where they are to be stocked into**. Quality brood fish bearing the required genetic qualities represent a prerequisite for production of such stocks. At the same time, however, obtaining quality stock should not be based only on the use of wild brood fish for artificial spawning.

A considerable **increase in the number of brood fish** can be achieved by their **rearing in controlled conditions**. Rearing of brood brown trout and grayling is elaborated on in Randák et al. (2009a,b).

When **establishing brood stocks** that are to be reared in hatcheries, it is best to start with native wild populations which occur in a given area. Breeding facilities designed for rearing brown trout and grayling should have a strong all-year round supply of high quality water, the temperature of which should not exceed 18 °C with respect to brown trout and 20 °C with respect to grayling. A natural locality, serving as a source of wild brood fish, should be situated close to such facility. Conditions in this locality should enable effective sampling of these fish (at least in the autumn season). **Protected fish areas** (PFA), where pressure of recreational fishing is eliminated, are suitable localities. When establishing the **PFA**, it is necessary to opt for stretches that correspond to natural streams as much as possible and that are loaded with industrial and municipal waste waters as little as possible. Migration possibilities should be preserved throughout the entire PFA. PFAs should, in this respect, communicate with the adjacent stretches of streams. The size of these areas should enable the occurrence of several hundreds of brood fish at a minimum. No selective measures are recommended to be carried out within the PFA's populations. Brood fish populations in these areas should be completed only by means of **natural reproduction**. In order to ensure efficient natural reproduction, it is necessary to leave part of the brood stock in the PFA (30% minimum) when catching brood fish. It is recommended to release young brood fish in their first spawning season back into the river. Native wild populations of brown trout and grayling inhabiting these localities should serve as parental populations for establishing populations that will be further reared in controlled conditions. Offspring of reared fish should not be stocked in the PFAs and their tributaries.

In order for considerable phenotype and genetic changes, with respect to reared brood fish and consequently their offspring, to not occur as a result of the long-term (several generations) effect of hatchery conditions (Fleming and Einum, 1997; Einum and Fleming, 2001; Verspoor, 1998), it is necessary to rear brood stock from offspring of wild fish that were obtained from the above-mentioned stretches of open waters (e.g., PFA), that have not been influenced by the stocking of reared offspring. If only the first generation of reared fish is used for production of stock material, it can be supposed that the qualities of parental populations will be preserved at a maximum level. In order to preserve native qualities with respect to the offspring to the maximum, it is also advisable to breed only females and to fertilize their eggs with the sperm of wild males (e.g., from PFA).

Culture of brown trout brood fish (Randák et al., 2009a)

Rearing of brood brown trout in controlled conditions should be realised already from the fry phase. Each generation of farmed fish should be reared from the offspring of wild fish. The technology of rearing fry, young breeding fish and brood fish must be adapted to the quality of the water that supplies rearing reservoirs. If reservoirs are supplied from a stream with fish, i.e., there is a real risk of pathogen transmission, it is not recommended to use ground ponds for rearing of brown trout. In such a case, strong flow-through reservoirs with a solid bottom and with the volume of several dozens of m^3 have proven useful.

Rearing of fry and yearling

Once the fry has hatched, the so-called dwell time in rearing follows with the fry lying at the bottom of incubation apparatus and feeding on the nutrients contained in the yolk sac. This period is finished after digestion of approximately 1/2–2/3 of the yolk-sac and the fry starts to swim. The duration of such dwell time usually ranges around 150 to 200 of day degrees (°D) (sum of the day degrees = total of average day-time water temperatures within a defined period). The feeding of fry can be started at the end of this stage (approximately after 3 weeks), directly on the apparatus.

At the beginning of the subsequent "active rearing period", when fry show considerable motional activity and progressive transformation from endogenous to exogenous nutrition, such fry have to be relocated into shallow troughs and then the feeding stage commences. The initial fish stock density in troughs ranges between 30 to 50 pieces.1^{-1}. During the feeding stage and also other rearing stages, only complete feeding mixtures are recommended. The size of granules during the start of feeding should be around 0.5–0.6 mm. The feeding granules should not be floating on the surface, but should be slowly sinking. During the start of feeding, it is optimal to practise hand feeding in smaller rations at high frequency (6–10 times per day) over the entire trough surface. Later, when the fish start feeding readily, it is possible to apply automatic feeding devices (e.g., controlled with a timer), preferably 2 devices per 1 trough. At the beginning, a low water column (approximately 10 cm) is recommended to be preserved within troughs. The use of plankton increases the risk of disease importation in the stock and slows down the custom for feeding on the feed mix. Only in exceptional and short-term cases it is possible to use plankton if problems with feeding mixtures intake occur with fry at the start of feeding. If this occurs, it is advisable to combine the natural feed with the feeding mixture, i.e., combined rations of both. Losses of up to 20% are experienced at the initial stage of rearing.

After 4–6 weeks of the initial rearing, the fry are relocated into larger reservoirs where the rearing process continues up to the yearling stage. Usually, rectangular troughs or circular pools are used. The size of stock depends mainly on the size of the reservoirs and oxygen content in the water. The rate of oxygen content in water at the outlet parts of rearing reservoirs should not drop below 60%. Rearing reservoirs can be fitted with aerating or oxygen supply devices to allow for adequate increase in the stock density. Depending on the growth rate, the fish are divided into several reservoirs in the course of rearing. The course of fry rearing stage should be associated with a preventive inspection of the fry with a focus on parasitic infections and strict attention to the clean environment (i.e., removal of feed leftovers, faeces and deceased fish). The establishment of a habit for consumption of granulated feeding mixtures at the very initial stage of evolution of the fry of grayling provides for further continuation with its rearing in controlled conditions and for obtaining the required brood stock in the final stage. In addition to that, it is not necessary to gain plankton, which is sometimes problematic. The procedure enables regular feed intake in corresponding rations and the risk of parasitic infection transmission is also eliminated to a great extent. The total losses during the rearing of yearling are usually up to 30%.

Rearing of young breeding fish and brood fish

The technology of rearing young breeding fish (1–3 years old) and brood fish has to be adapted to the quality of the water supplying the rearing reservoirs. If the reservoirs are supplied from streams with fish, i.e., there is a potential risk of pathogen transmission, it is not recommended to use ground ponds for rearing brown trout. Flow-through reservoirs with a high flow and a hard bottom (e.g., concrete storage tanks, trench ponds, channels, flumes, etc.) have proved to be suitable in such cases. If there is a source of good quality water with no fish stock available, it is possible to use also ground ponds. It is optimal to keep particular age categories (one to two-year, two to three-year-old, brood fish) in separate reservoirs. Three-year-old fish can already be placed together with brood stock. The oxygen saturation should not fall below 60% in the outlets.

Young breeding fish prosper very well in flow-through reservoirs with a water volume up to 10 m^3. The stocking rate of yearling is about 100–300 $pcs.m^{-3}$. After one year of rearing, it is appropriate to reduce the stocking rate of two-year-old fish to 30–50 $pcs.m^{-3}$. At the same time, the fish should be re-sorted and smaller individuals placed among younger fish categories. In no case is it recommended to carry out any selection, except for removing ill or morphologically deformed individuals. Fish which appear to be "outsiders" in fish farm conditions can bear important genetic characteristic for survival in natural conditions. The losses during the rearing of young breeding fish are usually about 10%.

Fig. 4.6.13. ***Brown trout brood stock reared in controlled conditions within the local organization of the CAU Husinec*** *(photo: T. Randák).*

The brood stock (Fig. 4.6.13.) can be reared in the flow-through reservoirs holding several dozens of cubic metres of water. The stocking rate is about 10 pcs.m^{-3}. The losses during the brood stock rearing are between 10–30% per year, the highest being in the post- spawning period.

If a source of wild males is available (e.g., from PFA) for fertilizing stripped eggs from reared females, it is advisable to remove most of the males before placing young breeding fish with the brood stock. This selection should be done in autumn when the males are easily distinguishable (Tab. 4.6.1.). Only a few (usually 10–20) males are left in each reservoir with the brood stock. The presence of males in the reservoir probably improves the maturing of females. In the spawning period, males tend to fight each other if there are more of them in the reservoir. Injured fish are a source of bacterial and fungal infections which can spread to other fish weakened by the stripping. If there is no source of wild males available, it is necessary to rear them in controlled conditions in sufficient numbers. In this instance, the selection is avoided and males are kept in the reservoirs together with females. The old (large) males can become very aggressive, so they should be removed from the rear. Additionally, it is necessary to monitor carefully the health condition of the fish, especially in the post-spawning period, remove all the individuals with high levels of fungal infection in time and, if required, treat them accordingly in a bath or with antibiotics. It is not recommended to keep males separately from females as they tend to fight more and injuries can cause high and very often total losses of the stock.

It is recommended to use only high quality rainbow trout compound feed during the rearing of young breeding fish and brood stocks. Younger categories are fed with less intensive feed with lower fat content and brood fish with specially designed feed for this category. The daily rations should be at the lower end of the rations recommended for the rainbow trout by the manufacturer of the feed. The size of the granules should be appropriate to the size of fish. The granules should not be floating on the surface, but should be slowly sinking. It is possible to use either hand feeding or automatic feeding devices. Feeding with natural or substitute food (e.g., spleen) throughout the entire course of rearing is not recommended.

Artificial reproduction

Artificial spawning of reared fish is usually carried out in the same periods as the spawning of the parent population of wild fish. Fish populations (wild, reared) must be manipulated separately, in order not to mix them. Sexual dimorphism is clearly apparent in the spawning period (Tab. 4.6.1., Fig. 4.6.14.). It is not required to use hormonal stimulation during the artificial spawning itself. Anaesthetic can be used as a suitable means which eliminates injuries of larger-sized brood fish (Kolářová et al., 2007). It is advisable to bath fish for a short time in a potassium permanganate solution immediately after artificial spawning (Kolářová and Svobodová, 2009) and then to release the fish back into the environment where they were taken from. Eggs of reared females should be fertilized with the sperm of wild males. The quality of genital products of reared brood fish, fertilization, hatching rate and viability of offspring is usually comparable to the parameters that are determined for native wild populations (Randák et al., 2006).

For artificial spawning of brown trout, considering the conditions in the majority of the Czech trout hatcheries, the procedure defined below can be recommended. This procedure enables the preservation of the genetic variability of the gained offspring to the maximum extent.

Egg fertilization should preferably be carried out with the dry method where the eggs are stripped directly into the dry bowl together with ovarian liquid. The eggs can also be stripped to the sieve where the ovarian fluid is left to drip off and the eggs are then carefully moved into a dry plastic container. Each female should be stripped separately, i.e., eggs from each female are stripped into one dry bowl or sieve. The quality of the stripped eggs should be then visually inspected for the presence of blood, clumps of eggs, white eggs or evidently damaged or low quality eggs. If the eggs appear to be of good quality, they are then transferred into a larger container that is intended for gathering eggs from a given stripping. The containers must be covered with a damp cloth and the eggs should never be exposed to sun rays

Tab. 4.6.1. ***Overview of external morphologic characteristics with significant sexual dimorphism, i.e. typical for particular gender of mature fish.***

Sign	Male	Female
enlarged abdomen	indistinctive	distinct
stimulation of abdomen releases	sperm (milt) of white colour	eggs – just before spawning
colour of abdomen	dark	pale
urogenital orifice	slit shaped	oval, swollen
maxilla extends	beyond eye	up to the eye
lower jaw	hooked (older males)	straight
front part of upper jaw (rostrum)	straight (sharp)	rounded
body colour ("wedding dress")	distinct	less distinct

during the entire process (not even during the stripping). The temperature must not differ considerably in comparison to the water temperature where the eggs will be incubated and it is important to prevent the eggs from getting into contact with the water, as the presence of water in the eggs before fertilization significantly decreases their fertilization success rate. When all the females are stripped, the eggs are carefully **mixed** (homogenized) and then they are **divided into smaller bowls**. The number of these bowls is dependent on the number of males who are available for the eggs' fertilization. In order to fertilize eggs in each individual bowl, 2–3 different males are always required. Sperm (milt) is added directly onto the spawned eggs and, similarly to fish eggs, the sperm should be protected from any contact with the water. The genital products are then mixed, and water is added to activate gametes and initiate the process of fertilization. The fish eggs are then carefully mixed again. To prevent excessive dilution of the milt which could result in lower fertility, the water level in the container should not be higher than 1–2 cm above the eggs. After that, the bowls are left to stand for about 3–5 minutes for the process of fertilization to finish. Subsequently, the eggs from individual bowls are poured together again into one bigger bowl, they are carefully rinsed several times in the same water which was used for fertilization and then they are placed into incubation apparatus. The most suitable incubation device is the classic Rückel-Vacek apparatus or trough inserts. The eggs in the apparatus should be placed in one layer only. The capacity of one incubation apparatus is thus around 8–10000 eggs. Incubation eggs are very sensitive to shaking, manipulation and light until they reach the stage of eyed eggs (220–300 °D from fertilization). The water temperature during the incubation should not exceed 10 °C. The length of the incubation period depends on the water temperature, usually between 350–500 °D. For establishing brood stock, approximately 100 fertilized eggs per future brood female are needed. The optimum number of brood stock is at least 100–200 females. Thus for brood stock of 100 females, approximately 10000 fertilized eggs should be available. These eggs should come from as many parents as possible (minimum of 20–30 pairs).

In the course of the first stripping of a given reared fish brood it is advisable to remove the majority of males from the rear. In order to preserve the variability of reared populations, it is not recommended, except for potential elimination of sick fish, to perform any other intentional selections within the reared stocks. In order to estimate the future egg production from reared stock, the following parameters are considered:

Fig. 4.6.14. ***Sexual dimorphism of reared brown trout brood fish of the Šumava Mountains' population*** *(top – male, bottom – female, photo: T. Randák).*

- absolute fertility (number of stripped eggs per female) approximately 1000 eggs
- relative fertility (number of eggs per kg of female weight) 1500–2000 pcs.kg^{-1} of female weight
- 40–60% of females mature in their third year, the rest of the fish mature later. Males usually mature one year earlier than females, therefore, they can be taken out from the rear in their 2nd or 3rd year.

Reared fish usually live longer (about 5–8 years) than fish in the wild nature. Reared fish thus grow bigger and have more eggs than in natural conditions. The weight of females used for artificial spawning is in most cases between 300–1000 g. A fish usually undertakes 3–5 artificial spawnings during its life in the rear. The post-spawning mortality of the reared brood fish (1st and 2nd stripping) is minimal. The fish reared for longer periods can develop morphological (e.g., reduced fins) or behavioural (e.g., loss of shyness, reactions to feeding) changes as an adaptation of the organism to the new environment and impact of unnatural conditions. However, these changes are not likely to be transferred to the offspring since they are not usually genetically fixed. Within a study that compared reproduction indicators, fertilization, the hatching rate and biological quality of eggs between reared and wild brood stocks of a similar origin, no significant differences were discovered within groups of similar-sized individuals (Randák et al., 2006). A very useful tool for fish identification can be tagging, usually by means of chips or coloured tags (e.g., VIE, VIA – see chapter 4.10.).

Rearing of grayling brood fish (Randák et al., 2009b)

If brood grayling are to be caught from open waters, it is better to catch the spawners from streams during the autumn period (e.g., during the catching of brown trout brood fish) and to keep them in suitable reservoirs over the winter period. For the purpose of keeping caught brood fish until spring spawning, it is possible to use, e.g., ground and trench ponds, channels and storage tanks. However, larger flow-through ponds are more suitable (usually up to 1 ha) that are supplied with quality water, a sufficient water column (1–3 m) where fish can find natural feed. In the spring season (usually at the turn of March and April) when fish start to migrate to inlets, the reservoirs are harvested and fish are relocated to smaller manipulation reservoirs that are situated close to the hatchery. If optimum temperature conditions (10–12 °C) are achieved, it is not necessary to use hormonal stimulation. If the temperatures fluctuate considerably, it is advisable to use such stimulation, in order to increase the number of ovulating females and to concentrate the artificial spawning into a shorter time period. The fish are regularly monitored and the matured individuals are stripped. Usually, the majority of fish is stripped during 2 to 3 spawnings, which are usually conducted within 4–7 days. The fish must be handled with the maximum care. Anaesthetic can be used for stripped fish (Kolářová et al., 2007). Its application decreases fish injuries and increases the percentage of successfully stripped females. In order to further decrease the post-spawning mortality, the intramuscular or intraperitoneal application of antibiotics appears to be successful. Spawning should be followed by the application of a short bath in potassium permanganate (Kolářová and Svobodová, 2009). The fish are returned back into the water stream as soon as possible after the artificial spawning. The post-spawning mortality of brood fish, in this case, is comparable to the post-spawning mortality of fish during natural spawning and it enables their re-use during other seasons. The quality of eggs obtained is very good and proven by the high fertilisation rate (usually 70–90%), resulting in the higher effectiveness of the entire breeding process.

A very significant increase in the number of brood fish can be achieved through their rearing. The rearing of brood fish can be conducted in extensive as well as controlled conditions. In order to establish brood stocks that are to be reared in controlled conditions, a similar procedure such as with brown trout is conducted. It is most suitable to base the rearing on native wild fish inhabiting the local area.

Rearing of fry and yearling under controlled conditions

Once the fry has hatched, the so-called dwell time in rearing follows, with the fry lying at the bottom of the incubation apparatus and feeding on the nutrients contained in the yolk sac. This period is completed after digestion of approximately 2/3 of the yolk sac and then the fry starts to swim. The duration of such dwell time usually ranges around 40–60 °D (4–6 days). The feeding of fry can be started at the end of this stage, directly in the apparatus, or the fry can be stocked for the purpose of extensive rearing on its natural feed.

As far as extensive and semi-intensive rearing is concerned, the fry is stocked immediately after its initial swimming even with the remaining part of the yolk sack, or after the initial feeding on troughs, into prepared ponds or reservoirs of a pond type (a natural swimming pool, fire protection reservoirs, etc.) that are abundant with a sufficient amount of natural feed of optimal size (fine plankton). These reservoirs should be filled approximately 10–14 days prior to the stocking. Ideally, they should have a sufficient supply of clear water and a firm bottom free of any thick layer of sediments. It is recommended to apply a reasonable amount of organic fertiliser within (e.g., compost, litter), prior to the filling of the pond which supports development of natural feed for the fish. The water temperature may exceed 20 °C during the first year of rearing. The optimum size of such reservoirs is 0.5–1.5 ha in the case of extensive rearing without any extra feeding, and up to 0.5 ha in the case of semi-intensive rearing with extra feeding of the stock. The size of brood stock is dependent on the size of fish stocked (fry, fattened fry), the quantity of natural feed and the intensity of potential fattening as well as requirements related to the size of fish caught. The initial stock sizes range usually from 1 fish.m^{-2} in purely extensive conditions up to 50 fish.m^{-2} in the semi-intensive culture of three-month-old juveniles. It is necessary to monitor the level of occurrence and size of plankton and if there are any reductions, fattening using complete feeding mixtures must be initiated. The installation of automatic feeding devices at the inlet part of the keeping reservoir is advisable. The rate of losses associated with the above-mentioned methods of keeping usually ranges around 30–70% during the growing season.

As far as the intensive rearing is concerned, the starting stage of the subsequent rearing period, the so-called active rearing period, when the fry shows significant motional activity and change their diet from endogenic to exogenic, the fry must be transferred into shallow troughs and the start of feeding commences. The initial stock ranges usually between 50 to 100 fish.l^{-1}. During the start of feeding and other stages of rearing, it is recommended that complete feeding mixtures are used. The feed for rainbow trout with lower fat content, made by renowned producers, have proved to be suitable. The size of the granules used at the start of feeding should be less than 0.3 mm. Ideally, hand feeding in smaller portions at a high frequency (6–10 times per day) over the whole area of the trough should be practised during the early feeding. Later, when the fish readily take the food, it is possible to use automatic feeders (e.g. operated by a clock), preferably two feeders per trough. The feed rations should be at the lower end of the rations recommended for the rainbow trout by the manufacturers of the compound feeds. The size of the granules should be adequate to the size of the reared fish (according to the manufacturers' catalogues). At the beginning, the water column in the troughs should be kept low (approximately 10 cm). In case the fry struggles to accept the feeding mix, it is necessary to use live or frozen plankton of optimal size. The use of plankton increases the risk of disease importation into the stock and slows down the establishment of the custom of feeding on the feed mix, however, in some cases its use is required in order to prevent the mortality of the fry due to starvation. If plankton is used, it is advisable to combine the natural feed with the feeding mixture, i.e. combined rations of both. The losses are usually less than 20% at the initial stage of rearing.

After 3–4 weeks of initial rearing, the fry (of a usual size of approximately 3 cm) are transported into larger reservoirs (or to ponds or reservoirs of a pond type – see above) where the rearing process generally continues up to the yearling stage. For intensive rearing, troughs or circular pools are used mostly. The size of stocks depends mainly on the size of the reservoirs and the water oxygen content. The rate of oxygen content in the water at the outlet parts of the rearing reservoirs should not drop below 60%. To ensure optimal growth, with regard to the significant temperature tolerance of grayling during their first year of life, such reservoirs should be supplied with water of a higher temperature. During the summer months, the water temperature can reach the level of 25 °C on condition that strict adherence to hygiene requirements and sufficient oxygen content of the water (oxygen content at the outlet exceeding 60%) are observed. It is possible to use aerating or oxygen supply devices, which enable adequate increases in the quantity within the stock. During the rearing stage, the fish are divided into more reservoirs, depending on the growth rate. In the course of fry rearing, it is very important to carry out preventive inspections of the fry with a focus on parasitic infections and strict attention to a clean environment.

Rearing of young breeding fish and brood fish

Rearing of young breeding fish under **extensive** conditions can be conducted using suitable reservoirs of the pond type, channels, etc. The main source of nutrition comes from the natural feed. Rearing of brood fish in such reservoir can be implemented starting with yearlings preferably; however, such environment can be stocked also with two-year-old fish. The brood stocks should be reared under extensive or semi-intensive conditions, i.e., to establish the habit for feeding on their natural feed. The quality of genital products of brood grayling reared under extensive conditions is mostly good. The disadvantage of extensive rearing of brood fish is the low quantity within the stock, i.e., relatively low number of brood fish reared per unit of area of the reservoirs used (usually 100–300 pcs.ha^{-1}), depending on the specific area's productivity. This system allows for rearing of young breeding fish and brood fish together and the purpose of artificial reproduction will be served with selection within the pre-spawning period focused on brood fish with sufficient production of genital products.

Semi-intensive rearing of young breeding and brood fish in ponds is a very effective method. A pond suitable for rearing of brood fish should be sized between 0.5 and 1.5 ha. Its depth should not exceed

1 m over the entire water surface, with one part deeper to allow for successful wintering of reared fish. The necessary prerequisite for this method is the supply of water by means of a sufficient inlet of quality water, ideally from a brook or river. The temperature of the water inside the ponds should not exceed the level of 22 °C during the summer months. Suitable areas include ponds with a sandy or gravely bottom. Muddy ponds are not suitable for grayling farming. These environments can be provided with some water plants as these create suitable conditions for the evolution of maggots of water insects that represent an important part of the natural feed for grayling. The development of natural feed can be further supported with the supply of a sufficient amount of fertiliser into the pond. Ponds located close to urban areas are advantageous since it is possible to partially eliminate the impact of piscivorous predators. Their negative impact can be also reduced by fencing off the pond and stretching wire or meshwork barriers above the water surface. The stock of brood fish should include 300–500 pcs.ha^{-1}. Both genders are reared together. Brood grayling are fed mainly with natural feed, but they may also be provided with extra feeding in the form of complete granulated mixtures. It is advisable to cease the extra feeding in the autumn (in the second half up to the end of October), since excessive fattening of brood fish decreases the quality of genital products. In spring, the fish are provided with extra feeding as late as in the post-spawning period when they are returned back to the pond. The losses that occur mainly in the post-spawning period range between 20 to 40% per year.

Intensive rearing of young breeding and brood fish can be conducted in ground ponds, concrete storage tanks, circular tanks or trench ponds with a water volume of tens to hundreds of m^3. One of the essential prerequisites is a sufficient inlet of quality water, the temperature of which should not exceed the level of 22 °C during the hottest months. Water of a permanently low temperature is not suitable either, since such conditions prevent the fast growth of the fish. Individual age groups (one to two-year-old and two to three-year old brood fish) should be reared in separate reservoirs for optimal results. Three-year-old fish can be included within the brood stock. Yearlings can be stocked in quantities of around 100–300 pcs.m^{-3}, two-year-old fish usually between 30–80 pcs.m^{-3} and brood fish should be stocked in the amount of 5–15 pcs.m^{-3}. Males and females can be reared together. The rate of oxygen saturation at the outlet from the reservoir should not drop below 60% in the long run. Maximum care must be taken when handling the fish. Losses during the rearing of young breeding fish range around 20% per year and these occur throughout the whole year, the rearing of brood fish then suffers a 20–40% mortality rate, especially in the post-spawning period. The post spawn period requires very strict adherence to hygiene principles with timely removal of deceased individuals. Any massive losses should be consulted with a veterinary expert and recommended treatment measures should be applied (baths, antibiotics application, etc.). Feeding of fish during this rearing method must be conducted solely with complete feeding mixtures usually for rainbow trout with the lowest fat content (e.g., 55% proteins, 15% fat). The most convenient practice is to provide feed by means of automatic feeding devices; however, the fish can be fed manually too. It is recommended to stop feeding the brood fish during October, in order to enable absorption of fat stored within the abdominal cavity as a result of feeding with fabricated mixtures that will improve the quality of the fertilising ability of genital products.

Artificial reproduction

In the Czech environment, the reproduction of grayling usually takes place during April to May. The water temperature belongs to the main factors affecting the fish maturing process. The optimum water temperature in this period is approximately 10 °C. Any long-term decrease of a temperature below 6 °C would basically stop the maturing process. Artificial reproduction of fish must be performed in such manner that the maximum potential genetic variability of the offspring gained is ensured. The following method of artificial reproduction of grayling, with respect to conditions within the majority of the Czech grayling hatcheries can be recommended:

Fig. 4.6.15. ***Artificial spawning of grayling female*** *(photo: T. Randák).*

The most convenient method for fertilisation of eggs is the dry process, when the eggs are stripped into a dry bowl together with the ovarian fluid, or a sieve (Fig. 4.6.15.), where the ovarian fluid is left to drip off and the eggs are then carefully moved in a dry plastic container. The process of stripping is similar to the stripping of brown trout. Sexual dimorphism is clearly visible during the spawning period (Tab. 4.6.2.).

The initiation of the fertilisation process can be started using a physiological solution replacing the water (0.9% water solution of sodium chloride), which, in the experience of some fish breeders, increases the percentage of fertilised eggs. The eggs should be mixed using a suitable tool, e.g., clean spatula or scoop (plastic, rubber or wooden); it should not be done by hand. The application of anaesthesia is convenient for fish that are subject to spawning (Kolářová et al., 2007) and after that, a short bath in a potassium permanganate solution is recommended (permanganate) (Kolářová and Svobodová, 2009). The stripped brood fish are returned back into the natural water streams as soon as possible after the disinfectant bath. The establishment of brood stock requires approximately 200 fertilised eggs per future brood female. An optimum brood stock should comprise at least 100–200 females. If we are to establish a brood stock comprising 100 females and 100 males, we will need approximately 20000 fertilised eggs. These eggs should be obtained from the largest variety of parental fish as possible (at least 20–30 couples). With respect to grayling, males are not removed from the farming. The most convenient facilities for the eggs' incubation comprise Kannengieter's vessels. Every such vessel is made of two parts, whereas the volume of the internal part is usually 1 to 1.5 litres. Such vessel can be used for the incubation of approximately 20000 eggs. There are also larger versions of these vessels available, while the incubation capacity increases in proportion with the vessel size. Prior to the development of eye points (usually 80–90 °D), the eggs are relatively sensitive to vibrations; therefore, such vessels must be provided with a minimum flow-through only. The eggs are also sensitive to light. Prior to completion of the incubation process, the eggs are relocated from the incubation vessels in the classic Rückel-Vacek apparatus with openings sized approximately 1 to 1.5 mm or even on trough inserts. The temperature of the water used for the incubation should optimally be 10–12 °C. The duration of the incubation period depends on the water temperature and ranges between 150–200 °D. Preventive baths of eggs can be conducted during the incubation process (Kolářová and Svobodová, 2009). The fertilisation rate of eggs from wild fish ranges around 70–90%. Hatching of fry occurs in the Rückel-Vacek apparatus or trough inserts. This process requires setting the apparatus on the lower flow option and increases the flow-through due to the greater demand for oxygen among the stock and requires the careful removal of the egg casings.

Table 4.6.2. *Overview of external morphological signs with significant sexual dimorphism of grayling, i.e. conditions typical for individual genders during the fish maturity period.*

Sign	Male	Female
enlarged abdominal cavity	dull	significant
abdomen stimulation releases	white sperm "milt"	eggs, prior to the very spawning
urogenital orifice	slit-shaped	oval, swollen
dorsal fin	large flag-shaped, sharp end, colourful	smaller, with rounded end, less coloured
body colour "wedding dress"	contrast to dark purple	less significant

The parameters for estimating future egg production from reared stock are as follows:

- absolute fertility (number of stripped eggs per female) approximately 1500–3000 eggs
- relative fertility (number of eggs per kg of female weight) 8000–15000 pcs.kg^{-1}
- 40–60% of females mature in their third year, the rest of the fish mature later. Males usually mature one year earlier than females

Farmed fish usually live longer (usually 4–7 years), compared to the situation under natural conditions. Due to that fact that they grow into larger sizes they thus produce more eggs than is usual for wild individuals. The weight of females used for artificial spawning ranges mostly between 200–600 g. The number of spawnings completed within the life period of the reared fish generally ranges between 2 to 4. The marking of fish is a very practical instrument for identification purposes. These marks can be applied if the size of the fish complies with requirements related to the specific marking methods, most conveniently during the winter months when the fish are the least sensitive to handling. The spawning period is not suitable for the application of such markings and any such activity would increase the post-spawning mortality to a significant extent. The marking should include the use of anaesthetic.

The introduction of the above-mentioned procedures within the brood fish rearing is a prerequisite for the increase and stabilization of the production of brown trout and grayling fry. Establishment of a regional hatchery system using the local populations will enable the withdrawal

from stocking of non-native populations sourced from other regions or abroad. The breeding of brood fish and adherence to the above-mentioned principles will allow for compliance with the long-term sustainability and stability of the production of quality fry showing characteristics of wild populations to the maximum extent. There will be a simultaneous reduction in mass using of wild brood fish obtained from open waters resulting in support of their essential natural reproduction. The rearing of brown trout and grayling fry and their stocking into open waters is elaborated on in chapter 4.8.1.

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4.7. Food-web manipulation by fish stock management *(M. Vašek, Z. Adámek, J. Kubečka)*

4.7.1. Biomanipulation

The effort to positively influence the ecological processes and water quality in lakes and reservoirs through interventions in a fish community (fish stock) is the subject of food-web manipulation. Fish stock management, whose main objective is to reduce the development of planktonic algae, is called **biomanipulation**. The biomanipulation principle consists in elimination of populations of planktonophagous species (roach, bleak, common bream, silver bream, rudd, common carp, gibel carp), be it by direct removal of these undesirable fish or by their suppression by means of stocking of piscivorous fish. The reduction of the abundance of planktonophagous fish leads to limitation of their predation pressure on zooplankton, subsequently, it allows for development of populations of large species of filtering zooplankton (caldocerans of the *Daphnia* genus) that effectively eliminate small planktonic algae from the water column, which ultimately leads to increased water transparency. Biomanipulation thus represents targeted influencing of lower components of the food chain through fish, as they represent a hierarchically higher link of the food chain (Fig. 4.7.1.).

The fact that fish stocks are able to control the species and size composition of zooplankton and phytoplankton communities as well as their amount, was first discovered by Hrbáček (1962). Subsequently, in the 1970s to 1990s, the manipulation with fish stocks and their impact on the structure and functioning of aquatic ecosystems has become the subject of many scientific studies. The research intensity of this issue has been motivated by a practical desire to reduce the impact of **anthropogenic eutrophication** (undesirable development of planktonic algae and cyanobacteria caused by the surplus of nutrients in the environment due to human activity). At this time, a methodological guide was published called "Managed fish stocks in valley reservoirs" (Lusk et al., 1983), which contains an overview of the importance, creation and use of controlled fish stocks in dam reservoirs. Later, researchers corrected some earlier opinions and, in particular, they defined more accurately the conditions under which biomanipulation is the most effective. Those interested in this issue can find the current synthesis of biomanipulation, for example, in the studies of Hansson et al. (1998) and Mehner et al. (2002, 2004). In the Czech Republic, biomanipulation measures have been implemented, to a varying degree, primarily in water-supply reservoirs that accumulate raw drinking water. Recently, however, interest in using the biomanipulation potential for improving the water quality also in recreational reservoirs and ponds has increased.

4.7.2. Nutrient loading and limits of successful biomanipulation

The key nutrient limiting the development of primary producers (i.e., cyanobacteria, algae and macrophytes), within the conditions of most reservoirs and lakes of the temperate climate zone, is phosphorus. Phosphorus is thus a nutrient that determines the biological production potential of surface waters by means of its availability. Due to excessive input of phosphorus, the trophic state of surface waters sharply increases causing an undesirable development of planktonic algae and cyanobacteria, which finally results in deterioration of the water quality. Depending on the availability of nutrients and the extent of the primary production, water reservoirs are divided into four basic types. **Oligotrophic** reservoirs have the lowest trophic status (< 10 mg of total phosphorus per m^3) possessing a low primary production, high transparency (> 6 m) with relatively low fish biomass (10–30 $kg.ha^{-1}$). These are always deep reservoirs, located mostly in mountainous areas. **Mesotrophic** reservoirs show a medium to large amount of nutrients (10–30 mg of total phosphorus per m^3), lower transparency (6–3 m) and fish biomass generally ranges between 50–100 $kg.ha^{-1}$. **Eutrophic** reservoirs have a large amount of nutrients (35–100 mg of total phosphorus per m^3), low transparency (3–1.5 m) and fish biomass usually exceeds 100 $kg.ha^{-1}$. Reservoirs

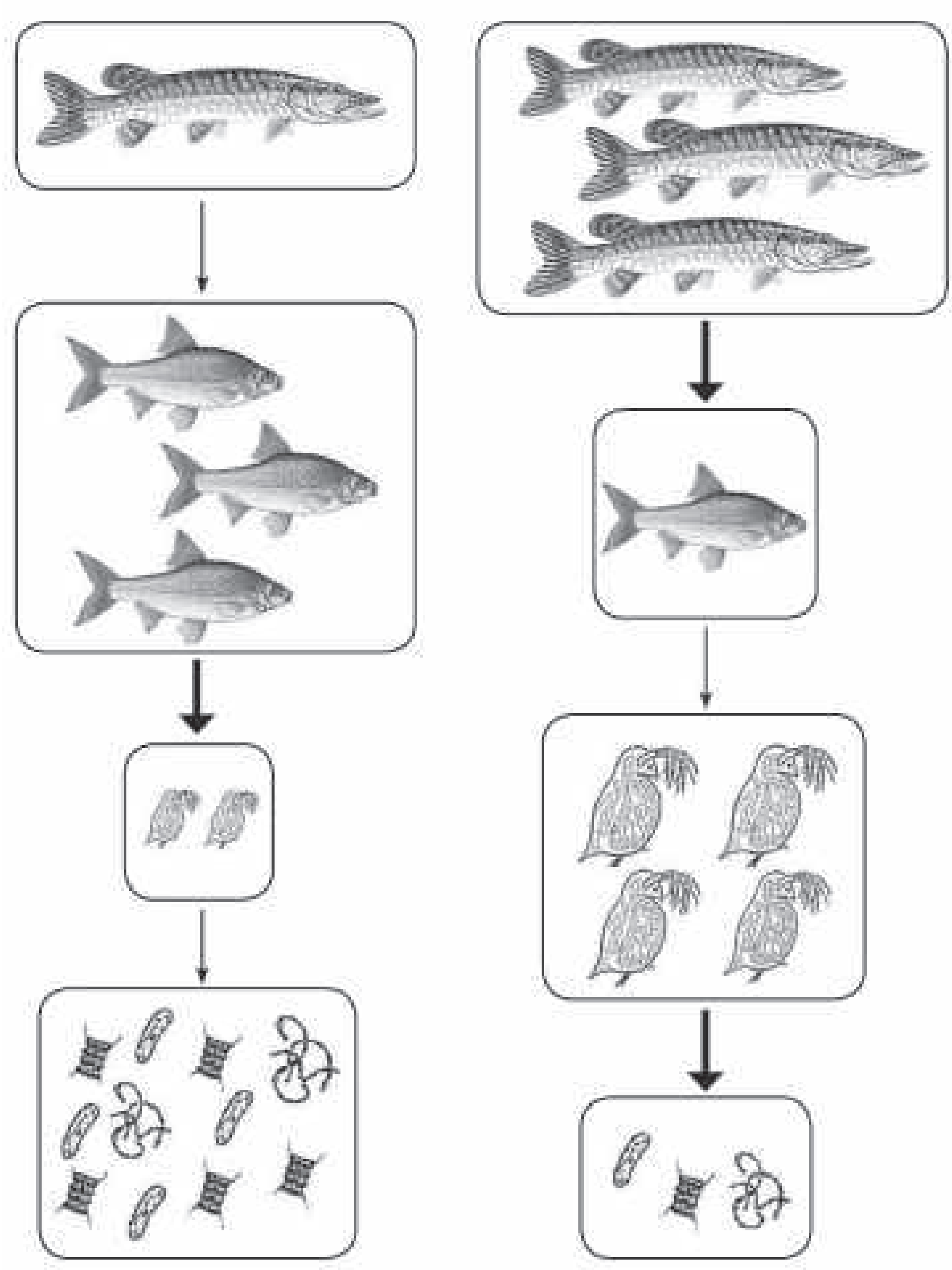

Fig. 4.7.1. ***Simplified diagram of effect of piscivorous and planktonophagous fish on lower links in the food chain (planktonic crustaceans and algae).*** *The intensity of grazing pressure is presented by the thickness of the arrows. Left: an undesirable state with a large amount of planktonophagous fish and strong phytoplankton-caused water turbidity. Right: a desirable state (low amount of planktonophagous fish, well developed large filtering zooplankton and weak phytoplankton-caused water turbidity) which is the goal of biomanipulation interventions (adapted according to Adámek et al., 2010).*

with a very large amount of nutrients (> 100 mg of total phosphorus per m^3) and large production of organic matter are known as **hypertrophic**. These are often shallow reservoirs with quite low transparency (< 1.5 m) fish biomass of which can amount up to several hundreds of kg per hectare of surface or, on the contrary, it can be very low due to fish mortality resulting from extreme fluctuations in the oxygen and free ammonia concentrations and extremely high pH values.

The need to reduce the development of planktonic algae and cyanobacteria arises especially in eutrophic water-supply reservoirs where large biomass of phytoplankton causes significant problems in the treatment of raw water into tap water. One of the possible mechanisms of regulation of phytoplankton biomass is biomanipulation. However, it is necessary to realize that the efficiency of biomanipulation measures has certain boundaries that are defined mainly by the supply of nutrients or nutrient loading and depth of the reservoir. If the **nutrient loading** of the water reservoir exceeds a certain limit, the biomanipulation loses its effectiveness – a significant and long-term reduction of planktonic algae biomass through controlled fish stock is hardly to be expected. Knowledge of the nutrient loading is therefore a necessary prerequisite for deciding on the possibility and suitability of conducting biomanipulation efforts in a particular water reservoir.

The term external nutrient loading means the input of phosphorus from a river basin to a reservoir through the inflow. With respect to deep, thermally stratified reservoirs, this external loading should not exceed the value of 0.6–0.8 g of total phosphorus per m^2 of the reservoir's surface per year (Benndorf et al., 2002) if the biomanipulation measures are supposed to show significant improvements of water quality. With regard to shallow reservoirs and lakes, the maximum annual value of external loading may amount up to 2 g of the total phosphorus per m^2 of the reservoir's surface (Jeppesen et al., 1990). If the external loading of a reservoir exceeds the limit value, firstly, it is necessary to reduce the input of phosphorus into the reservoir through measures in the river basin (improving treatment of municipal waste waters, anti-erosion protection of agricultural land, revitalization of streams in river basins, improving retention efficiency of pre-reservoirs) and only then it is useful to perform biomanipulation. If it is not possible to significantly reduce the excessive nutrient input from a river basin, the quantity of phytoplankton in deep eutrophic reservoirs can be regulated by means of artificial destratification of the water column. The principle of this technology consists in mixing the entire water column when the phytoplankton is being moved into the deep layers, where its growth is effectively hindered by the lack of light – phosphorus ceases to be a limiting source for algae and it is replaced by sunlight.

If the external nutrient loading is lower than the recommended limit value, yet the concentration of total phosphorus in the reservoir water is high, then it is a system with a large internal nutrient loading that is presented by releasing of phosphorus from the accumulated sediment. If the biomanipulation effort itself in shallow lakes (average depth of < 3–5 m) is to lead to a significant improvement in the water quality, the average annual concentration of total phosphorus should not exceed 100–250 $mg.m^{-3}$ (Jeppesen and Sammalkorpi, 2002). The threshold concentration of total phosphorus in relation to the effectiveness of biomanipulation in deep stratified lakes and reservoirs (average depth of > 5–10 m) has not yet been clearly defined by direct scientific studies, and the limit value corresponding to average annual concentration of total phosphorus of 20–50 $mg.m^{-3}$ is assumed (Jeppesen and Sammalkorpi, 2002; Mehner et al., 2004). If the phosphorus limit concentration is exceeded, it is necessary to supplement the biomanipulation with other approaches, e.g., to extract the sediments, apply chemical treatment (in shallow reservoirs) and/or aerate hypolimnion (in deep reservoirs).

4.7.3. Fish stock status

Knowledge of the current state of fish stock in a water reservoir is an important prerequisite for effective planning and implementation of biomanipulation measures. Reliable information on the abundance, biomass and species composition of a fish stock is indispensable. These basic parameters of fish stock are determined by control surveys by means of mass fishing gears. Approaches leading to determination of status and abundance of fish stock are described in chapter 4.2., or they can be found in the guide called "Methods of fish stock monitoring in reservoirs and lakes" (Kubečka et al., 2010).

In terms of water quality, it is desirable that the biomass of non-piscivorous fish (planktonophagous and benthophagous species) in reservoirs and lakes does not exceed the value of 50 $kg.ha^{-1}$ (Seďa et al., 2000; Mehner et al., 2004). The relationship between non-piscivorous fish biomass and the size composition of zooplankton is stated in chapter 4.5. A reduction of non-piscivorous fish biomass to the value of 50 $kg.ha^{-1}$ or lower is a critical requirement for the development of large filtering zooplankton and the resulting improvement of the water quality (reduction of phytoplankton biomass and increase of transparency). A reduction of a non-piscivorous fish stock to a value between 50–100 $kg.ha^{-1}$ may lead to positive changes in the water quality, but these are usually only short-term changes. If the biomass of undesirable fish in a reservoir is not reduced below 100 $kg.ha^{-1}$, an improvement of the water quality cannot be expected.

4.7.4. Methods of fish stock management

Management of a fish stock in order to eliminate biomass of undesirable species is based primarily on reduction fishing of planktonophagous and benthophagous fish and on stocking of piscivorous fish. The intensity and speed of elimination of undesirable fish stocks are key factors that determine the effectiveness of biomanipulation. In order to significantly enhance the water quality, it is necessary to reduce the biomass of undesirable fish below 50 $kg.ha^{-1}$, preferably within one to three years (Mehner et al., 2004). Reduction fishing conducted in the long-term, but with an insufficient intensity, cannot fundamentally reverse the negative conditions in a reservoir ecosystem. In larger reservoirs with undesirable fish stocks significantly exceeding the limit of 50 $kg.ha^{-1}$, it is not feasible to make a rapid reduction of non-piscivorous fish biomass only by means of stocking of piscivorous fish. In such case, firstly, it is necessary to dramatically restrict the biomass of planktonophagous and benthophagous fish by means of various methods of massive fish stock reduction.

It is possible to apply **reduction fishing** by means of seine nets within the reservoir shoreline devoided of obstacles. Beach seining is the most effective during the spawning period (outside the spawning period in large waters especially at night). In the reproduction season, electrofishing of cyprinid fish on spawning grounds is also effective. Mass fishing gears, such as pelagic trawls or purse seines are indispensable for intensive removal of abundant undesirable fish from the pelagial of deep reservoirs (Fig. 4.7.2.). Catches of migratory and spawning fish into traps and fyke nets represent another suitable method of fish removal. The use of traps (Fig. 6.2.10. in chapter 6.2.) is very effective for removal of European perch (Seďa and Kubečka, 1997). A large proportion (up to 20% of the stock) of non-piscivorous fish of many species can be captured by a fyke net system installed across the entire reservoir tributary zone (Fig. 4.7.3. and 4.7.4.). Living fish captured during regulatory fishing (e.g., common bream) can be used for stocking in other water bodies (Fig. 4.7.5.). Dead fresh fish, chilled or frozen, can be offered as food to zoos. If the biomanipulation measures are to be conducted in a reservoir that serves for recreational fishing, it is desirable to allow for all-year-round fishing of non-piscivorous fish (including common carp) without any length and weight limits. Stocking of non-piscivorous fish (including common carp, tench and herbivorous species) into the reservoirs, where the fish stock management aimed at enhancing the water quality is carried out, is undesirable (see chapter 4.7.5.).

The undesirable fish populations can be completely removed only in drainable reservoirs, for example, recreational ponds used by the public as so-called natural bathing waters. This is not usually possible with respect to water-supply dam reservoirs since these reservoirs are rarely drained. It can be performed, for example, only if the dam is to be repaired. It is also possible to remove the entire fish stock by means of specific fish poisons (piscicides). The most known is rotenone (organic substance obtained by extraction from the roots and stems of tropical and subtropical plants of *Lonchocarpus* and *Derris* genera), formerly widely used to control the overabundant pest fish especially in the USA. In the Czech Republic, however, poisoning of fish stocks is not acceptable for legal and ethical reasons, and in case of water-supply reservoirs also for practical feasibility reasons. Another form of regulation of fish stock density is manipulation with water level. Before spawning of cyprinid fish, it is useful to inundate, for a short time period, the shoreline terrestrial vegetation onto which these fish (mainly phytophilous and phytolitophilous species) preferably spawn and subsequently, to reduce the water level so that the spawned eggs remain dry and die, or become food for invertebrates, aquatic birds and mammals living around the reservoir shoreline.

In a reservoir in which the biomass of planktonophagous and benthophagous fish was reduced by means of reduction fishing to the level close to the critical value of 50 $kg.ha^{-1}$, it is important to maintain this favourable status through **stocking and protection of piscivorous fish**. To enable the piscivorous fish to effectively control the production of undesirable species and keep their abundance at a low level, the proportion of piscivorous fish (pike, pikeperch, asp, catfish and large individuals of European perch) in the total biomass of adult fish in a reservoir should range between 25–40% (Mehner et al., 2004). The increase in the proportion of piscivorous fish in a fish community can be achieved by intensive stocking and effective protection. Deep reservoirs and large shallow reservoirs are preferably stocked with pikeperch and asp (Fig. 4.7.6.) which efficiently prey on small planktonophagous fish in the pelagial. An important additional component of stocking represents catfish that are due to their size able to consume also large adults of roach and common bream. Especially in the case of small shallow reservoirs with submerged vegetation, pike is stocked as the main species and the most effective piscivorous fish. Pike are also an important piscivorous fish in the shoreline zone of deep reservoirs and their stocking in this type of water should be supported as well.

Advanced pike fry are stocked in spring, most preferably immediately after the larvae of cyprinid fish have hatched, as these represent suitable food for young pike. The size of stocked pike fry should be as uniform as possible in order to prevent mutual cannibalism. Usual densities of advanced pike stocking are 1 specimen per 5–10 m of a suitable shoreline with appropriate shelters. Pikeperch and asp are stocked most often at the yearling stage. Sometimes, advanced pikeperch fry are stocked as well. However, such fry are very sensitive to transport, handling and potential starvation, therefore, the considerable mortality rate of stock must be taken into account. Advanced pikeperch should be stocked only when they have a sufficient size advantage over their potential prey (ideally, twice the length of the body). In such case, stocking of advanced fry can be the most effective method from an economical point of view; however, the presence of potential predators, mainly perch, must be considered. If an abundant perch population occurs in a reservoir, older fish (two-year and older) should be stocked, since these fish are already characterized by a low natural mortality rate. However, it can be very difficult to obtain the older stock of predators, because the producers may not have sufficient amounts available and also the price of each stock fish is several times higher. The amount of stocked predators in the stage of advanced fry or yearling should annually amount to at least tens, but preferably hundreds to thousands of fish per hectare of the water body surface. Nevertheless, it is necessary to take the reservoir conditions and the fish community characteristics into account. The framework range of stocking densities for the Czech reservoirs have been defined by Lusk and Vostradovský (1978), however, in order to ensure effective biomanipulation impact, it is necessary to stock more than 5 kg of piscivorous fish per hectare and year (Seďa et al., 2000). Transportation of piscivorous fish stock to the destination should be carried out with the required technical equipment (transport boxes provided with aeration). Pikeperch, asp and larger catfish can be stocked together in two or three places in a reservoir. Pike stock and catfish yearlings should be stocked separately or in group of few individuals along the entire reservoir shoreline. Distribution of the stock is conducted by means of a motorboat.

Salmonid fish communities in reservoirs are to be provided with a specific management regime. Salmonid species were present in the early stages of the fish community development of many reservoirs

Fig. 4.7.2. ***Night catch by trawling from the pelagial of the Římov Reservoir. Common bream predominate in the catch*** *(photo: FISHECU).*

Fig. 4.7.3. ***The system of two large fyke nets installed across the inflow zone at the Římov Reservoir. With respect to the dimensions of the chamber and the size of catches, it was necessary to build scaffolding in order to set and manipulate each trap*** *(photo: FISHECU).*

***Fig. 4.7.4.* Harvesting the catch from the trapping chamber of the large fyke net** *(photo: FISHECU).*

***Fig. 4.7.5.* Perforated storage boat represents a useful tool for keeping fish from reduction fishing alive** *(photo: FISHECU).*

***Fig. 4.7.6.* Asp (top) and pikeperch (bottom) are often stocked into drinking water-supply reservoirs to suppress small planktonophagous fish** *(photo: J. Peterka).*

(see chapter 3.5.) and it was attempted to stock many reservoirs with a considerable proportion of salmonid species. The main effective biomanipulation elements are brown trout, rainbow trout and alternatively brook trout. If brown trout of the lake type represent a considerable part of a salmonid population, then such population resembles mountain lakes of salmonid type that are common in neighbouring countries (Kubečka and Peterka, 2009); a large part of the community is potentially represented by piscivorous salmonid fish. At the same time, they serve as a source of high value brood fish (Piecuch et al., 2007). Hrbáček et al. (1986) documented the positive impact of such community on the water quality in the Hubenov drinking water-supply reservoir. The recommended stocking density ranged between 200–500 of one- to two-year-old trout per ha (Lusk and Vostradovský, 1978). In practice, the density is more likely to range around 100 ind.ha^{-1}. Nevertheless, it has been proved that also trout inhabiting dam reservoirs can feed, from an essential part, on the largest individuals of filtering zooplankton, as was the case for example in the Opatovice Reservoir after its filling, where *Daphnia longispina* represented up to 15% of the brown trout diet (Losos, 1976). However, the predation pressure of salmonid populations upon cladocerans is usually incomparable with, for example, feeding pressure of abundant cyprinid populations, and zooplankton in reservoirs with salmonid stocks contain a considerably greater proportion of large individuals of caldocerans (Hrbáček et al., 1986). The majority of fish communities that were formerly salmonid dominated has degraded throughout time to other types, as described in chapter 3.5. It was mainly caused by the introduction of ecologically aggressive fish species (Adámek et al., 1995) that were not native to the reservoir (for example, bait fish of legal or illegal anglers, contamination with undesirable species from ponds and other waters within salmonid reservoir drainage areas, or alternatively, as a result of inappropriate stocking). The primary task of fishery management is to protect salmonid reservoirs. Salmonid reservoirs in the Czech territory are not located at extremely high altitudes (usually 500–750 m a.s.l.) and the species that are common in lower altitudes (perch, ruffe, pike, pikeperch, roach, etc.) can cause considerable damage to the salmonid community or can become serious competitors to salmonid species. Another very important preventive measure is to protect salmonid species from illegal fishing (poaching), or from bird or mammalian predators. To date, there has been only little information concerning the status of salmonid communities in Czech dam reservoirs. They have probably survived in the Morávka Reservoir in the Beskydy Mountains (Piecuch et al., 2007), in acidified reservoirs in the Jizera Mountains (Kubečka et al., 1998) and in the Ore Mountains (Peterka et al., 2009). They deserve the maximum protection and supporting measures since they represent the harmonization of maximum ecological potential with a highly beneficial impact on the water quality.

4.7.5. Supporting biomanipulation measures

Successful biomanipulation in shallow reservoirs is accompanied by the development of submerged macrophytes as a result of increased water transparency. Submerged macrophytes develop also in shoreline zone of deep reservoirs that have low water level fluctuation. Overgrowth of the bottom that was previously blank with submerged plants is considered as a positive result of biomanipulation since the plants significantly contribute to the sustainability and further improvement of water quality, that was previously achieved by reducing the undesirable fish stock (Hansson et al., 1998; Jeppesen and Sammalkorpi, 2002). Submerged plants absorb during the growing season an essential part of phosphorus, which decreases the growth and development of planktonic algae. In addition to that, macrophytes stabilize the sediment surface, thus prevent resuspension of sediment particles which results in an increase of water transparency. With increasing water transparency, macrophytes penetrate to lower depths which further enhance their positive impact on water quality. Furthermore, submerged vegetation is a preferred habitat of piscivorous fish, especially pike and large European perch, and thus creates suitable conditions for their increased abundance and predation pressure on undesirable fish species. As submerged plants represent a stabilization factor of the aquatic ecosystem, it is necessary to protect and support their initial development.

For this reason, it is not desirable to stock grass carp into reservoirs where biomanipulation measures have been applied, as grass carp are efficient consumers of submerged macrophytes. Stocking of benthophagous fish (common carp, tench and common bream) is not desirable either. These species are unsuitable not only because they consume large amounts of zooplankton, apart from benthic fauna, but also because they disturb the sediment during their search for benthic food (the so-called bioturbation) by which they support nutrient release into water (Adámek and Maršálek, 2013). Moreover, they complicate attachment and growth of submerged macrophytes due to their permanent disturbance of the bottom surface. Some authors have recommended using filtering herbivorous species – bighead and silver carp – in order to decrease the amount of phytoplankton in drinking water-supply reservoirs. It must be added that these large cyprinid fish are suitable mainly for regulation of water blooms (colonial algae and cyanobacteria) in hypertrophic reservoirs and lakes, especially in tropical areas, where large species of filtering zooplankton are not naturally present (Xie and Liu, 2001). Bighead and silver carp are not, however, suitable for biomanipulation of reservoirs in the temperate zone (Radke and Kahl, 2002). These species are not only able to effectively consume small phytoplankton but also they feed partially on zooplankton as well. The high stock densities of these fish cause elimination of filtering zooplankton, the result of which may be an increase in biomass of planktonic algae.

Excessive development of submerged vegetation in shallow lakes and reservoirs that are used as natural bathing sites can be considered as undesirable. In that case, the extent of submerged macrophytes can be controlled by means of special harvesting tools and machines. The biomeliorative abilities of grass carp can also be taken into account. However, such option has to be carefully considered. Overabundant grass carp stock is able to eliminate the entire submerged aquatic vegetation, which usually causes the release of nutrients that are bound in plants, and the ecosystem of the reservoir would return back to the initial status characterized by high phytoplankton biomass and low water transparency. To determine the optimum abundance of grass carp stock, that would keep a sufficient amount of submerged macrophytes, have proved to be very difficult in practice. Moreover, overabundant grass carp stock cannot be easily reduced in non-drainable reservoirs.

A sharp increase in the abundance of undesirable species fry can represent a negative secondary phenomenon resulting from biomanipulation interventions, which usually occurs during the first years after the considerable decrease in the amount of planktonophagous and benthophagous fish due to reduction fishing. The cause of this phenomenon is the enhanced growth and survival of the early ontogenetic stages of fish as a consequence of decreased food competition with adult fish. A sufficient amount of predators can prevent the repeated increase in density of undesirable fish populations, therefore, it is advisable to add suitable predators into the biomanipulated systems. The amount of piscivorous fish should be increased, as needed, by their stocking as well as efficient protection. In Czech drinking water-supply reservoirs recreational fishing is forbidden. Nevertheless, these waters attract the attention of poachers mainly due to the easy availability of piscivorous fish. Especially pikeperch and pike are vulnerable to prohibited fishing. It is therefore very important that administrators of drinking water-supply reservoirs, in co-operation with the police, ensure the most rigorous protection of managed fish stocks. In the case of biomanipulated reservoirs that are used for recreational fishing, it is necessary to continuously monitor and flexibly control the fishing for piscivorous fish by suitable means (e.g., increasing the size limits, introducing the "catch and release" regime, restricting the attendance number) in such a way that their excessive exploitation is prevented.

4.7.6. Biomelioration

The most important **biomelioration measure** is the elimination of macrophytes, which means, not only submerged ("soft") but also emerged ("hard") littoral vegetation. In open waters that are not subject to aquaculture fish production, the role of aquatic macrophytes, from the ecosystem functioning point of view, is generally positive, even though assessment of the optimum intensity of overgrowing has differed – the highest fish species diversity was determined in medium overgrown (31–70% of surface), the highest fish density in heavily overgrown (> 70%) and the highest mean individual weight of fish in poorly overgrown (1–30%) reservoirs (Randall et al., 1996). Reservoirs with no macrophytes showed the lowest species diversity as well as fish density; however, the mean individual weight of fish was only slightly smaller than the maximum values found in reservoirs with macrophyte beds, which proves that macrophyte habitats are used mainly by younger fish as their nursery areas.

Submerged aquatic plants also represent important substrate for the development of phytophilous food invertebrates (midge fly, mayfly and dragonfly larvae, aquatic beetles, some caldocerans, etc.) and they enhance the living conditions for ambushing piscivorous fish (pike). The main negative factors of excessive development of submerged macrophytes in open waters are the decrease of light and heat penetration. Overgrowing of littoral with emerged ("hard") flora is considered to be the factor that decreases the production per unit of the reservoir surface, but, at the same time, that increases the biodiversity. The positive feature of adequate overgrowing (up to 1 m in breadth) of shoreline parts with hard vegetation is the protection of banks against erosion caused by waves. The littoral with hard macrophytes is often distinguished by specific fauna and it provides shelters for fish fry and phytophilous species.

The most significant biological method of reducing or eliminating "soft" as well as "hard" aquatic plants is stocking of grass carp. Biomass ranging around 50 $kg.ha^{-1}$ is sufficient to eliminate submerged and floating plants (duckweed) as well as filamentous algae within one growing season. However, it is necessary that grass carp is present in the reservoir from the beginning of the growing season since it is required that they have the possibility to control the development of plant growth already during its initial phase. It cannot be assumed, for example, that grass carp can eliminate duckweed in a reservoir, the water surface of which is already completely covered by this plant. In order to eliminate emerged hard vegetation during one to two seasons, the biomass amounting to 100 $kg.ha^{-1}$ is required, while the long-term control of vegetation development with no total elimination can be conducted by the biomass of up to 50 $kg.ha^{-1}$ of grass carp.

Biomelioration measure can also be conducted through the use of molluscophagous fish that ensure elimination of molluscs, especially snails (*Lymnaea* in particular) which are intermediate hosts of parasitic trematodes or overabundant bivalves – zebra mussel, *Dreissena polymorpha*, whose colonies can plug the inflow and outflow devices. This method, however, is in the research phase so far, as far as the use of typical molluscophagous black carp *Mylopharyngodon piceus* is concerned (Adámek, 1998), however, its stocking as a new non-native species into natural water bodies is in contradiction with current legislation.

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4.8. Breeding of stocks for open waters and their stocking *(J. Andreji, P. Dvořák, T. Randák, J. Turek)*

4.8.1. Brown trout (*Salmo trutta* m. *fario*) and European grayling (*Thymallus thymallus*)

The rearing of brown trout stocks can be conducted by intensive as well as extensive methods, or alternatively, by a combination of both methods (Randák, 2006). If the **extensive** method is applied, fry are stocked into rearing brooks during the period of transformation to exogenous nutrition or after the start of feeding. In practice, a method based on intensive rearing of fry during the first 2–3 months of life and their subsequent stocking into rearing brooks, has also been applied. This method considerably decreases the fry losses during the first months of life. When rearing brooks and reservoirs are stocked, it is necessary to choose the optimum size of stock for a given locality that depends mainly on the trophic status of the environment, stream morphology, hydrological regime (especially flow-rate minimums during the summer period), etc. Rearing brooks are very often relocated, which results in high losses of stocked fish and useless waste of fish for stocking that is often in short supply. If brooks are used for rearing stocks, it is advisable to use only parts of these streams (e.g., lower halves) in order to preserve the genetic variability of native populations. The natural development of local fish populations based on natural reproduction should be taking place in the upper parts.

When rearing capillaries are stocked, it is necessary to stock fry equally along the entire length of the rearing part of the stream. Before the stocking itself, it is very important to pay maximum attention to the acclimatization of the fish to the temperature conditions in the stream. One- to two-year-old stocks are produced in rearing brooks conditions. With respect to extensive rearing of grayling, the fry are stocked into reservoirs of pond types during the period of transformation to exogenous nutrition or after initiation of early feeding. The reservoirs are to contain a sufficient amount of natural feed, or alternatively, it is possible to provide the stock with extra feeding in the form of granular feeding mixtures. One- to two-year-old stocks are produced under these conditions.

With respect to the **intensive** method, the brown trout and grayling fry are fed granular feeding mixtures in high stocking density in special reservoirs. During the first several weeks of rearing, shallow plastic troughs are usually used, later on, trough systems, circular reservoirs or ponds, storage tanks, etc. are used instead. The rearing is usually terminated at the stage of yearling or two-year-old juvenile and fish are stocked into open waters, or alternatively, these reared fish are used for subsequent rearing until the brood fish stage is reached.

The above-mentioned methods of production of the brown trout and grayling fry are disadvantageous for the many reasons already stated in chapter 4.6. It must be noted that the main purpose of the stocking of fish of these species is to **support wild populations**. The above-described methods that have been used until the present, have not often fulfilled the purpose, and in many cases, they have seemed to be utterly counter-productive in this respect. On the basis of the current level of knowledge, it is possible to recommend a method that can potentially and realistically support disrupted wild populations. As far as brown trout are concerned, it can be stocking of **fry,** obtained mainly from spawning of reared brood fish in regional hatcheries, directly into fishing grounds. It is ideal to stock yolk-sac fry or fattened fry (4 to 6 weeks). As far as grayling are concerned, it can be stocking of three-month-old juveniles (approximately of the size of 5 cm) reared most preferably under extensive or semi-intensive methods in pond conditions. The fry should also come mainly from reared brood fish. The use of reared brood fish for artificial spawning considerably reduces the use of wild brood fish for such purposes; therefore, it supports natural spawning. If such a method is applied, it is not necessary to cultivate the brooks, which will create conditions for potential restoration of self-sufficient populations in these small streams that have been traditionally cultivated until now. If brood stocks that originate from local populations are reared, genetic contamination due to fry import from other regions does not occur. The fish that are stocked into fishing grounds are influenced by the conditions of the artificial rearing to a minimum level and they have the potential to adapt easily in natural streams. If a sufficient level of natural reproduction and successful fish eggs incubation do not occur in a stream as a consequence of small number of brood fish or other negative factors, stocking of fry, or three-month-old juveniles, will complete the population of these fish in a given locality. These fish **cannot**, virtually, **overstock the locality**. If the "rearing capacity" of a given fish category in a stream is exceeded as a result of their stocking, it is less difficult for a fish population itself to eliminate the redundant individuals. The same cannot be expected if the locality was overstocked with older fish. If there are enough brood fish in a steam and their **successful natural reproduction is taking place there, then it is pointless to stock fish in support of these populations and it introduces rather negative effects**.

Stocking of brown trout and grayling into salmonid grounds must be conducted in the most reasonable and responsible manner. It is necessary to become acquainted with the local conditions as well as the results of management in a given stream in past seasons. The competent manager should be aware of the facts of what the structure of fish populations in a given fishing ground look like, whether the stocked fish species reproduce naturally, and in addition to that, he/she should be acquainted with the hydrological conditions, stream segmentation, possibilities and status of pollution, the fishing pressure, impact of fish predators, etc. As soon as all the above-mentioned information is known, it can be decided on an efficient method of how to support populations inhabiting a given stream by means of stocking of reared fish. At present, the volumes of fish that are stocked into fishing grounds are based on the so-called stocking plans that have been established by the relevant fishery authorities. The manager of a fishing ground is obliged to stock annually defined numbers of individual fish species. However, the size categories of stocked fish, their origin, method and time of stocking, can be considerably influenced by the fishery manager. As far as the selection of stocks' origin is concerned, fish reared from offspring of local brood fish populations should be chosen. If possible, it is better to use stocks that have been as little influenced by the breeding conditions as possible, so that they can adapt easier to the natural stream conditions. It is recommended to opt for stocking of early fish categories, or older stocks reared by the extensive method.

If fish for stocking are reared by the **extensive method** (rearing brooks and ponds) with a natural diet, they show greater ability, once stocked into fishing grounds, to adapt to new conditions, in comparison with stocks of the same origin reared in hatcheries (Turek et al., 2012). In case of extensively reared stocks, it is recommended to stock older (e.g., two-year-old) fish in order to achieve a higher survival rate. If stocks are reared in **hatcheries**, their adaptation ability to the natural conditions is lower and it decreases with the increasing duration of the stay of the fish under such conditions. In order to provide realistic and efficient support to wild populations, it is advisable, in the case of hatchery-reared fish, to stock as young categories as possible (yearling at maximum). Older categories should be stocked as legally-sized and only with the purpose to be subsequently caught by anglers. The **optimum time** for stocking fish is the spring months (April, May), after the snow-waters have receded and a sufficient amount of natural feed is available. Three-month-old grayling should be stocked in the summer months. Autumn stocking of fish into fishing grounds should be conducted only within two-year cycles of management in some rearing brooks. During the second winter, considerable losses in fish stock occur in such streams. These losses are caused by the relatively large size of the fish, the low flow-rates in the winter months and insufficient number of shelters for the fish which are consequently exposed to fish predators. Some streams can also freeze over. The size of stocks bred in rearing brooks does not change considerably throughout the winter months, i.e., it is possible to stock fish that will be of similar size in autumn as well as in spring of the following year. These fish thus have a better chance in larger streams to survive the winter period than fish kept in cramped conditions in a rearing capillary.

During the stocking of fish into fishing grounds itself, it is necessary to stock trout equally along the entire length of the part of stream, while it is of course advisable to choose natural habitats with sufficient sheltering possibilities. With respect to grayling, groups of fish of several dozens of individuals should be stocked within one place into suitable parts of a stream. Before initiation of stocking, fish must be adapted to the temperature conditions of a given locality.

4.8.2. Rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*)

The volume of rainbow trout (Fig. 4.6.11.) and brook trout (Fig. 4.6.12.) that is stocked into fishing grounds have been constantly increasing. This is due to their high popularity with anglers as well as affordable price. Stocks of both species are produced solely by means of intensive technologies using granular feed (Pokorný et al., 2003). They are stocked into fishing grounds usually as legally-sized in the length exceeding 25 cm and they are designated for fast catching. The demand for trophy fish with the weight of up to several kg has also been rising. For the majority of organizations, the most advantageous solution is to purchase stocks from large producers and to stock them into fishing grounds. Rearing of own stocks is profitable with organizations that have their own hatchery focusing on salmonid species production as well as source of quality water. The water temperature should not exceed 20 °C for a long period of time in the growing season. The technologies that are used for both species are virtually the same.

The fry are obtained by means of artificial spawning of brood fish reared under intensive methods in controlled conditions. Incubation of eggs is conducted in horizontal hatching apparatus (Rückel-Vacek) or in incubation bottles. Incubation periods range between 300–400 °D with respect to both species. Feeding of fry is initiated when the fry has absorbed about 2/3 of yolk sac. The start of feeding of both species is usually conducted in laminated troughs with the use of start-feeding mixtures. The fish density may reach up to 100000 pcs per m^3 at the start of feeding and it is gradually brought down to approximately 20000 pcs per m^3. The initial feeding should be conducted manually in 5–8 day rations *ad libitum*. The granules used should be sinking slowly. As soon as the habit for consumption of granular feed is established, automatic feeding devices can be used. Strict adherence to the hygiene rules is necessary during the rearing process of fry (removal of deceased individuals and feeding leftovers) and the parameters determining the water quality should be monitored. The main important factor is that the content of the dissolved oxygen in the water that should not drop below 6 $mg.l^{-1}$ at the reservoir outlet. As soon as the fry reach a length of approximately 5 cm and a weight of around 2–5 g, they are stocked into larger reservoirs for further rearing. Such rearing is conducted in concrete or plastic reservoirs. Larger fish (of a weight of 10 g and above) can also be reared in earthen ponds. They are fed solely with pellet dry feed made by renowned manufacturers and the size of the granules should correspond to the current age (size) of fish. The feeding rations are recommended by manufacturers

***Fig. 4.8.1.* Rainbow trout is very popular with anglers** *(photo: T. Randák).*

with respect to the conditions. Stocks that are reared in troughs can initially amount to 5000 pcs.m^3, however, they should be proportionately decreased throughout the rearing to reach the final number of approximately 50–100 pcs.m^3 with regard to commercial fish with a weight between 200–350 g. Too low stocking density leads to reduced feed intake due to the wariness of the fish. Again, it is important to adhere to zoo-hygiene requirements, to monitor the content of the oxygen in water and if the content drops below 6 mg.l^{-1} at the reservoir outlet, the feeding rations should be reduced or skipped completely. The same rules apply for rearing in earthen ponds, however, stocks of all age categories should be at a level of 1/3–1/2 of stocks in concrete troughs. Aeration, fencing and roofing of reservoirs are advantageous during both rearing methods.

Stocking of fish into fishing grounds is usually conducted with regard to anglers's requirements and it is usually carried out immediately before the beginning of the fishing season. The **purpose of stocking** is not in this case to **support wild populations**. These fish represent non-native species that were introduced in the past from the North America. Fish are stocked in catch-lengths and there has been an effort for their maximum return in the form of anglers' catches. It is not useful to stock these species in running fishing grounds sooner than one week before the start of fishing. If the increased number of fish stock stayed longer in a fishing ground, it could increase the risk of high losses induced by predators as well as downstream migration. Interactions with native fish stock of a ground represent a very negative phenomenon as well. Usually, spatial and food competition occurs. Such problem is thus minimized if the fishing season is taking place as anglers usually catch the majority of stocked fish very quickly. The selected grounds can be stocked continuously throughout the entire fishing season. Stocking of trophy individuals enhances the attractiveness of a fishing ground even more.

4.8.3. Asp (*Aspius aspius*)

Brood fish are gained most often by being caught from open waters during migration to spawning grounds or directly in spawning grounds. Artificial spawning can be, if necessary, conducted directly in the terrain after the catch, or the brood fish are transported to a hatchery and the stripping is carried out over there. Brood fish can also be reared in pond conditions (Targońska et al., 2008). Artificial spawning is conducted at a water temperature between 11–14 °C (Kujawa et al., 1997). Brood fish are usually not hormonally stimulated; if required, carp pituitary can be used, or it can be combined with choriongonadotropin (HCG) in two doses, or synthetic preparations Ovopel or Ovaprim (Kujawa et al., 1997) in one or two doses. Stripping of males is conducted only after urine has been removed by stimulating the abdomen, and with respect to high dilution of sperm with urine, it is advisable to remove the sperm with a suction unit into an immobilisation solution. In order for the fish manipulation to be carried out easier, it is recommended to conduct the stripping with the use of 2-phenoxyethanol anaesthetics. The relative fertility of females ranges around 27500–108000 pcs.kg^{-1}. The eggs are sticky, of yellowish colour and their size is on average 1.5 mm. Desticking of eggs is conducted by their rinsing several times in water or by classical methods that are used in carp (by milk, clay or talk). Incubation is taking place in Zug jars at a temperature between 14–19 °C (Kujawa et al., 2010). Fry are hatched after 6–8 days, depending on the water temperature, their size reaches on average to 8–9 mm and they absorb the yolk sac for the following 7–10 days. After sac fry start to swim, they are stocked for subsequent rearing.

Rearing of fry is conducted within monoculture in pond or controlled conditions. In the former case, after the sac fry start to swim, they are stocked into small ponds in an amount of 100000 pcs.ha^{-1} As_0. Rearing takes place until the autumn and reared fry As_1 reach a size of 8–12 cm while the losses amount up to 40%. Rearing in controlled conditions within recirculation systems is conducted in rearing reservoirs at a water temperature of 23–25 °C usually for 3 weeks. At the initial stage of rearing, fry are fed by *Artemia* nauplii, later on, artificial feeding is used. The initial stock in these reservoirs is 40–200 pcs.l^{-1} and reared fry usually reach a size of approximately 2–2.5 cm. Losses during the rearing amount up to 35%, depending on the stocking density and feed provided (Turkowski et al., 2008; Kujawa et al., 2010).

Fig. 4.8.2. ***Asp – the only genuine Czech piscivorous cyprinid fish*** *(photo: T. Randák).*

4.8.4. Pikeperch (*Sander lucioperca*)

The reproduction of pikeperch is conducted by natural, semi-artificial or artificial spawning (Steffens et al., 1996). Natural spawning is the least used method of pikeperch reproduction that is realised either in monoculture (similar to the Old Bohemian method with respect to carp) or in polyculture with carp, where 1–5 pairs of brood fish are stocked to C_1 or C_2 per hectare (Fig. 4.8.4.). In such a way, 1000–5000 pcs of Pp_1 with an individual weight of 10–20 g can be obtained until autumn (Čítek et al., 1993; Steffens et al, 1996; Stráňai, 2000).

Semi-artificial spawning is normally conducted in storage tanks or small ponds onto nests (mats) made of roots of sedge, willow or alder tree, or alternatively, also synthetic materials, that are prepared beforehand. Brood fish are stocked into storage tanks at a temperature between 10–14 °C in the ratio of 1♀ : 1♂ per nest, while the area of 5–10 m^2 per pair (Stráňai, 2000) must be taken into account, in some cases it can be even up to 20–30 m^2 (Horváth et al., 2002). The spawning itself occurs within a few days after stocking of the fish with the male consequently protecting the nest with spawned eggs. Brood fish are not usually hormonally stimulated, or the hormonal preparation is given only to females, in order to synchronize the spawning (Horváth et al., 2002; Zakeś et al., 2004). Nests with eggs are carried to a hatchery at the eye points stage, or directly to the locality where rearing of fry will be taking place (Čítek et al., 1993; Stráňai, 2000; Horváth et al., 2002).

Artificial spawning of pikeperch is conducted in a hatchery at a water temperature of 11–16 °C which comes after an anaesthetic of a clove oil solution, 2-phenoxyethanol, MS-222 or Propiscin preparation has been applied (Meddour et al., 2005). Before the artificial spawning itself, brood fish are hormonally stimulated by means of carp pituitary, or alternatively, in combination with choriongonadotropin or synthetic preparations (Ovopel, Ovurelin, Lecirelin), in one or two doses (Horváth et al., 2002; Musil and Kouřil, 2006). The relative fertility of the female reaches 100000–250000 $pcs.kg^{-1}$ and the average size of unswollen eggs is usually between 0.6–1.3 mm. The eggs are greyish-green and sticky. Desticking is conducted by means of suspension of clay, talk, milk, the

Fig. 4.8.3. ***Sexual dimorphism of pikeperch** – female on top, male at the bottom. Males have darkly pigmented abdomen and pectoral, pelvic and anal fins at the spawning period (photo: J. Andreji).*

modified Woynarovich method or by a tannic acid solution only (Steffens et al., 1996; Musil and Kouřil, 2006). The eggs are incubated in Zug jars at a temperature of 12–17 °C and hatching of fry within 3–7 days, depending on the water temperature. Hatched fry are about 4–5 mm large and they absorb the yolk sac for 7–10 days.

Fry are reared in natural or controlled conditions, most often in monoculture up to the size of advanced fry (Pp_a). The eggs at the stage of eye points or yolk sac fry obtained from artificial spawning are stocked for rearing. In the former case, eggs in an amount of 20000–100000 pcs of Pp_e per 100 m^2 are stocked into suitable ponds. After 3–5 weeks of rearing, advanced fry Pp_a reach a size of 1.5–3 cm and the losses during the rearing do not usually exceed 50–60%. In the second case, up to 300 pcs of Pp_0 per meter are stocked into trench ponds. Rearing takes place for 3–4 weeks and the reared fry Pp_a grow up to a size of 2–3 cm. The losses range between 50–70% (Lusk and Krčál, 1988; Čítek et al., 1993; Stráňai, 2000). An alternative to the previous method can be rearing of sac fry of pikeperch in suitable ponds where about 100000 $pcs.ha^{-1}$ of Pp_0 for 4–5 weeks are stocked. Advanced fry grow up to the size of 4–7 cm and the losses amount to 50% (Steffens et al., 1996; Molnár et al., 2004). Rearing of sac fry in controlled conditions is conducted in flow-through reservoirs of different shapes at a water temperature of 18–26 °C for 5 weeks. At this stage of rearing, fry are fed by natural food (*Artemia* nauplii) or commercially produced artificial feeds. The initial stock Pp_0 of 25–100 $pcs.l^{-1}$ reduces down to 6–15 $pcs.l^{-1}$ in the course of rearing (when the total body length achieves approximately 10 mm, i.e. approximately after two weeks). Advanced fry Pp_a reach a size of 4–4.5 cm at the end of rearing and the total losses during the rearing range usually between 55–80%, depending on the feeding technique and type of feed (Ostaszewska et al., 2005; Skudlarek and Zakęś, 2007).

Rearing of older age categories is conducted again either in natural or controlled conditions. Advanced pikeperch are stocked into ponds usually in monoculture in an amount of 5000–30000 $pcs.ha^{-1}$. It is recommended to add brood "prey fish" whose fry serve as pikeperch's food. The losses usually do not exceed 50% until the end of the growing season (Čítek et al., 1993; Stráňai, 2000). Rearing of two- to three-year-old stocks in natural conditions is conducted in stock-ponds or in main ponds solely in polyculture with carp C_1 or C_2. The amount of 50–150 $pcs.ha^{-1}$ of Pp_1, or alternatively, 50–75 $pcs.ha^{-1}$ of Pp_2 are stocked for rearing (Čítek et al., 1993; Stráňai, 2000).

Individual technologies of rearing of older pikeperch stock in controlled conditions, depending on the stocking density, light regime or provided diet, are elaborated on in the study, for example, of Molnár et al. (2004) and Zakeś et al. (2006).

4.8.5. Common bream (*Abramis brama*)

Brood fish are obtained either by being caught from open waters or by rearing in the pond environment. Reproduction of bream is conducted either by semi-artificial or artificial spawning. With respect to semi-artificial spawning, small ponds or storage tanks are stocked with brood fish in an amount of 10 pcs per 100 m^2 in a ratio of 2♀ : 3♂. These reservoirs should be partially grassed over, or more precisely, nests are placed inside in order that brood fish can spawn onto them. Brood fish are not hormonally stimulated during this method. Obtained eggs at the stage of eye points are relocated to the rearing pond or incubation and initial rearing are conducted together with brood fish.

One alternative to such reproduction method is to obtain eggs during the natural spawning of bream from open waters. It consists in installation of spawning nests during this period and afterwards; they are relocated to rearing ponds once the eggs are spawned onto them (Stráňai, 1996, 2010).

The second method of bream reproduction is artificial spawning. Such spawning is conducted in a hatchery at a temperature of around 20 °C. Fish are hormonally stimulated with carp pituitary, or in combination with choriongonadotropin (HCG), or synthetic preparations (Ovopel) in two, or respectively, one dose. Anaesthesia by 2-phenoxyethanol should precede this. The relative fertility of female ranges between 90000–150000 $pcs.kg^{-1}$. The eggs are yellowish, sticky and their average size reaches 1.5–1.8 mm. Desticking is carried out by means of milk or clay suspension. The eggs are incubated in Zug jars at a temperature

Fig. 4.8.4. **Common bream** *(photo: T. Randák).*

of 20–21 °C (Kucharczyk et al., 1999). Hatching begins after 4–5 days, hatched fry is approximately 7 mm large and yolk sac is absorbed within 6–8 days, depending on a water temperature (Ţiliukienë, 2005). Fry that have already started to swim are stocked for subsequent rearing.

Fry can be reared in natural conditions on the basis of natural food, or they can be provided with extra feeding (cereal meal mostly) in fry ponds that are stocked with 50000–100000 pcs.ha^{-1} of Fb_0 for the entire growing season. Losses during rearing reach up to 90% (Stráňai, 1996, 2010). Yolk sac fry can also be reared in cages until the stage of advanced fry over the period of approximately 6 weeks at a water temperature of 17–21 °C and the initial stock of 5000 pcs.m^{-3} Fb_0. Reared fry Fb_a grow up to the size of around 2 cm at the end of rearing (Žiliukienë, 2005). Rearing in controlled conditions is conducted at a water temperature of 25–28 °C over three weeks. Feeding of fry during this rearing method is based on natural food most often (cultivations of Ciliata, *Artemia* nauplii, assorted zooplankton), artificial feeding is provided only to a small extent. Losses during the rearing do not exceed 10% (Kucharczyk et al., 1999).

The most common method for obtaining bream stock is the purchase from pond aquacultures, or it is possible to use fish caught during regulatory catches in reservoirs.

4.8.6. Gudgeon (*Gobio gobio*)

Reproduction of common gudgeon is conducted in Czech conditions mainly by artificial spawning. Such spawning takes place in a hatchery at a water temperature of 16–19 °C. Before the artificial spawning itself, gudgeon female are hormonally stimulated with carp pituitary or synthetic preparations (Ovopel, Kobarelin or Lecirelin) in two, or respectively, one dose (Kouřil et al., 2008). It is usually not necessary to hormonally stimulate males. Milt are obtained in a classical way by stimulating the abdominal part, however, gudgeons should be turned upside down. Released drops of milt are suctioned with a syringe and they are immediately used for fertilization of spawned eggs. The most suitable anaesthetic preparations are clove oil or 2-phenoxyethanol. Relative fertility can be as high as 65000–120000 eggs per kg of a female's weight. The eggs are sticky, greyish and their size is approximately 1.1–1.3 mm. Desticking of eggs is conducted by means of suspension of talk or milk or alcalase enzyme (Palíkova and Krejčí, 2006; Kouřil et al., 2008). The eggs are incubated in small incubation jars with a volume of 0.3–1 litre at a water temperature of 18–24 °C. Hatching begins after 3–4 days, depending on a water temperature (Kouřil et al., 2008). Once the fry have hatched, their sizes range between 3–4 mm and yolk sac is absorbed for approximately 2–3 days. At the beginning of the larval period, fry are stocked for subsequent rearing.

***Fig. 4.8.5.* Gudgeon has recently joined the group of popular fish for stocking into fishing grounds** *(photo: J. Andreji).*

Gudgeon for stocking are obtained most often from natural spawning of brood fish in a pond. For this purpose, smaller ponds with sand or gravel bottoms, or storage tanks with gravel bottoms, are suitable. Hatched fry are reared throughout the entire growing season in ponds together with brood fish (similar to the Old Bohemian breeding method of carp). During rearing, gudgeon fry can be provided with extra cereal meal or sieved granular feed. In autumn, fry with an individual weight between 1–3 g are caught (Kouřil et al., 2008).

Gudgeon fry can also be reared in controlled conditions of hatcheries for about one month. Kestemont and Awaďss (1989) decribe the rearing method in more detail.

4.8.7. Ide (*Leuciscus idus*)

Brood fish can be obtained by being caught from open waters directly in spawning grounds where, if necessary, they are immediately stripped, or it can be conducted after their transportation to a hatchery. Brood ide tolerate manipulation, transport as well as preparation for stripping very well. They mature successfully in flow-through ponds and they can be overwintered with other species of cyprinid fish (Stráňai, 1996). Based on this experience, brood fish reared in pond conditions have been used in the majority of cases (Hamáčková et al., 2008a).

Ide reproduction is secured solely by artificial spawning in a hatchery at a water temperature of 12–15 °C. It is advisable to hormonally stimulate brood fish before the stripping itself. Carp pituitary or synthetic preparations Ovopel or Supergestran can be used for this purpose. Hormonal preparations are applied to females in one or two doses, depending on the preparation used. This issue is elaborated on in the study of Kouřil and Hamáčková (1998). Males are usually not required to be hormonally stimulated. It is recommended to conduct the artificial spawning with anaesthesia to allow for easier manipulation with brood fish and elimination of risks of injury or deformation. Clove oil or 2-phenoxyethanol are the most suitable methods. The relative fertility of females usually equals 130000–150000 pcs.kg^{-1} and an average size of unswollen eggs ranges from 1.9 to 2.3 mm. The eggs are yellowish, slightly transparent and sticky. Desticking of eggs is conducted in milk or talk suspension for 30 minutes. The eggs are incubated in Zug (Weiss) jars at a temperature between 15–18 °C. Hatching occurs after 6–9 days, depending on the water temperature. Hatched fry reach a length of 6.5–7.0 mm and yolk sac is absorbed for approximately 5 days. Once the air bladder has been filled, fry are ready to be stocked into open waters or for subsequent rearing.

Fry are reared mostly in pond conditions. Small and shallow reservoirs and ponds with an area of up to 0.5 ha and a depth of up to 1 m are suitable. If reared in monoculture, an amount of 500000 pcs of Id_0 are stocked per 1 ha, depending on the pond quality. If reared with extra feeding, it is possible to triple the stock. However, it is more suitable to rear ide fry in polyculture with carp, or alternatively, tench. In such case, carp stock C_2 in an amount of up to 500 pcs.ha^{-1} are stocked with ide (Hamáčková et al., 2008a).

Extra feeding can be provided in the form of cereal meal, breadcrumbs from old rolls or granular feeding mixtures (Stráňai, 1996; Hamáčková et al., 2008a). Losses during the rearing until autumn range from 60 to 80%. Rearing of ide sac fry until the stage of advanced fry (Id_a) in trench ponds is also possible. Such rearing is conducted for 2–3 months and the initial stock is about 300–500 pcs of sac fry per 1 m^2. Advanced fry Id_a grow to the size of 30–50 mm and the losses throughout the rearing are 40–60%. Yolk sac ide fry can also be reared in controlled conditions over 3–4 weeks. Small flow-through reservoirs are suitable for rearing into which 50–100 pcs of sac fry per 1 litre are stocked. Fry are fed with natural food (*Artemia* nauplii) or it can also be combined with artificial feeding. If a sufficient amount of quality feed is ensured, it is possible to increase the stock up to 200–300 pcs.l^{-1} Id_0 while the losses during rearing range between 10–20% (Turkowski et al., 2008). Rearing of older age categories is not conducted on purpose, if required, ide can be stocked to carp C_2 as a supplementary fish.

4.8.8. Chub (*Squalius cephalus*)

Brood fish are in most cases obtained from open waters directly in spawning grounds where, if necessary, fish are stripped directly by the water, or after relocation to a hatchery. Brood fish can be also obtained from own rearing in the farm environment (Stráňai, 1996; Kucharczyk et al., 2008). Artificial spawning is conducted in a hatchery at a water temperature of 15–20 °C (Stráňai, 1996). Brood fish are hormonally stimulated beforehand with carp pituitary, choriongonadotropin or synthetic preparations (Ovopel, Ovaprim) in two, or respectively, one dose (Stráňai, 1996; Hliwa et al., 2009). All operations during the artificial spawning are conducted in general anaesthesia with the use of 2-phenoxyethanol preparation. The relative fertility of females ranges between 50000–65000 eggs per kg of weight and the average size of unswollen eggs is about 1.6–2.0 mm. The eggs are sticky and olive-green. Desticking of eggs is conducted by repeated rinsing in water. The eggs are incubated in Zug or Chassé jars at a temperature of 16–19 °C. Hatching of fry begins after 3–5 days, depending on the water temperature. Hatched fry are approximately 6–7 mm large and they absorb the yolk sac for 6–8 days. Once the air bladder has filled, fry are stocked for subsequent rearing or directly into open waters.

Rearing of fry is conducted in natural conditions in trench ponds or smaller reservoirs. Rearing in trench ponds takes 2–3 months, with the initial stock ranging between 300–500 pcs.m^{-2} Ch_0. Reared fry Ch_a grow to the size of 30–50 mm and the losses during the rearing amount to 40–60%. If the rearing is conducted in smaller reservoirs or ponds, an amount of 500000 pcs.ha^{-1} are stocked for the entire growing season, while the losses until autumn reach 60–80% (Stráňai, 1996, 2010). Rearing of fry in controlled conditions is conducted mainly in recirculation systems at a water temperature of 25 °C. The rearing itself lasts for three weeks up to six months, depending on the conditions. Once the chub fry have started to swim, they are stocked in an amount of 50–200 pcs.l^{-1}. At the initial stage of rearing, it is advisable to feed the fry with live food (*Artemia* nauplii), later, it is possible to change over to a dry diet. The losses by the end of rearing reach 5–20%, depending on the diet and stocking density (Kwiatkowski et al., 2008).

Fig. 4.8.6. ***Chub are relatively widespread and abundant fish*** *(photo: T. Randák).*

4.8.9. Common carp (*Cyprinus carpio*)

Carp can be reproduced by means of natural or artificial spawning. The natural methods of reproduction comprise mass spawning (the Old Bohemian method) and group spawning (Dubravian method). The principle of mass spawning of carp consists in natural spawning of a selected group of brood fish (6–12 pcs.ha^{-1}, the gender ratio of 1 : 2 in favour of males) in a suitable spawning pond and the subsequent rearing of brood fish together with the fry over the entire growing season. With respect to the group spawning, natural spawning is conducted as well, however, only of the selected pair (1♀ and 2♂), or alternatively, small group (2♀ and 4♂)) in a small so-called "Dubravian" pond (50–150 m^2). The advantages, or alternatively, disadvantages of both these methods of natural spawning are elaborated on in the study of Krupauer (1964). These methods of carp reproduction belong to the oldest methods of carp reproduction that were used to a large extent as late as in the second half of the 20th century. The establishment of artificial spawning as a new method of carp reproduction in the 1970s caused that these methods have been gradually neglected and nowadays, it is possible to encounter these methods very rarely.

Artificial spawning is currently the newest and, at the same time, the most dominant method of carp reproduction in the Czech territory. The stripping itself is conducted at a water temperature of 21–22 °C. Hormonal stimulation and anaesthesia should precede this. Brood fish are hormonally stimulated with carp pituitary, a preparation on the basis of carp pituitary (Repro-Genol) or synthetic preparations (Ovopel, Dagin). Females are hormonally stimulated in two doses, males only in one (Brzuska, 2006). Clove oil or 2-phenoxyethanol are used for anaesthesia mostly. Relative fertility of carp reaches the value of 100000–200000 pcs.kg^{-1}. The eggs are sticky, yellowish-brown to yellowish-green and their size in an unswollen state reaches 1.0–1.5 mm. Desticking of eggs is carried out by means of diluted whole-fat milk or clay suspension. The eggs are incubated in Zug or Chassé jars at a temperature of 18–22 °C. Hatching begins at this temperature after approximately 3 days. Hatched fry are approximately 5–7 mm large and they absorb yolk sac for another 3–4 days, depending on the water temperature. Hatched fry are stocked into small nursery tanks (also colled "hatching trays") or special incubators until they start swimming. After the swim-up, fry are stocked for other rearing in ponds (Stráňai, 2000; Horváth et al., 2002, Gela et al., 2009).

Sac fry can be reared in natural conditions in fry-ponds or in controlled conditions in a hatchery on troughs. Rearing in fry-pond is the most commonly used method that can be conducted with the re-stocking or without the re-stocking method. The first method with re-stocking consists in rearing of sac fry for the first 4–8 weeks in the fry-pond of the I. order, subsequently, they are caught and re-stocked into the fry-pond of the II. order until the end of the growing season. The initial stock in the fry-pond is 200000–1000000 pcs.ha^{-1} C_0, depending on the scheduled duration of rearing. Advanced reared carp usually grow to the size of 3–5 cm and the losses during the rearing are 55–65% (Pokorný, 1987). Subsequently, the fry-pond of the II. order are stocked with 10000–50000 pcs.ha^{-1} of C_a where they are reared until the end of the growing season. The final product is the C_1 with the average individual weight of 30–50 g, while the losses are not higher than 25%. This method enables the production of fry C_1 with the higher individual weight (Pokorný, 1987; Stráňai, 2000). The second method of rearing in natural conditions is the method without re-stocking where the sac fry are stocked directly into the fry-pond of the II. order over the entire growing season. The initial stock is between 50000–200000 pcs.ha^{-1} of C_0, the final product is C_1 with the average individual weight of 15–35 g and the losses during the rearing amount to 70–95% (Čítek et al., 1993; Stráňai, 2000; Horváth et al., 2002). The rearing of sac fry in controlled conditions is not currently used for rearing yolk sac carp fry. The rearing itself usually takes 3–4 weeks and it is conducted at a temperature of 25–30 °C. Mostly, rearing takes place in troughs where sack fry are stocked after the swim-up, the initial amount is 50000–100000 pcs.m^{-3} of C_0. After a fortnight, the stock is reduced down to 20000–50000 pcs.m^{-3} and after 21 rearing days to 10000–30000 pcs.m^{-3}. The fry reared under such method should be fed natural food (Ciliata, *Artemia* nauplii, assorted zooplankton). The losses during the first two weeks of rearing amount to 20–30%, depending on the type of the feed provided. At the next state, the losses do not exceed 10–20% (Kouřil and Hamáčková, 1982).

Rearing of older age categories is conducted in stock-ponds and main ponds into which the fish are stocked for the entire growing season. In the case of rearing of two-year-old fish, the stock ranges between 1000–5000 pcs.ha^{-1} of C_1, depending on the management intensity. The reared stock C_2 gain the weight of 300–600 g as standard, sometimes it can be even 800 g. The losses during the rearing are usually around 10–30% (Stráňai, 2000). If three-year-old fish are reared, an amount of 300–2000 pcs.ha^{-1} of C_2 are stocked, depending on the management intensity. The reared fish C_3 gain the weight of 1500–2000 g as standard and the losses are only 2–5% (Stráňai, 2000).

4.8.10. Tench (*Tinca tinca*)

Currently, the most common method of tench reproduction is artificial spawning in a hatchery by means of the classical dry method at a water temperature of 21–23 °C, preferably from brood fish of 3–6 years and with an individual female weight of 400–1500 g and male weight of 250–800 g (Pokorný and Kouřil, 1983). Tench females are hormonally stimulated only once with synthetic preparations Kobarelin or Ovopel (Lihart et al., 2000; Flajšhans et al., 2010). It is possible to use carp pituitary in two doses as well (Pokorný and Kouřil, 1983). Males are hormonally stimulated only once with a dose of carp pituitary and they are stripped only after their urine was removed by abdominal massage. With respect to high dilution of tench's sperm with urine, it is advisable to suction the sperm with a suction unit into immobilization solution (Pokorný and Kouřil, 1983; Lihart et al., 2000; Flajšhans et al., 2010). Brood fish should be anaesthetized by a 2-phenoxyethanol solution or clove oil before the stripping itself. The relative fertility of tench ranges between 80000–150000 pcs.kg^{-1}. The eggs are sticky, olive-green and relatively small, on average, they are only 0.4–0.5 mm large. Desticking is conducted by means of alcalase enzyme for 2 minutes, diluted milk, talk suspension or tannic acid solution. The eggs are incubated in Zug jars at a temperature of 20–23 °C. Hatching begins at this temperature approximately after 3 days. Hatched fry is only 3.5–5 mm large and yolk sac is absorbed for 3–5 days, depending on the temperature. Fresh hatched fry are relocated from jars into nursery tanks and after the swim-up, they are stocked into ponds. Apart from artificial spawning, brood fish can also be reproduced by means of natural spawning in monoculture, with subsequent rearing of fry until the end of the growing season (similar to the Old Bohemian method with respect to carp), or natural spawning in polyculture with C_0–C_1 (Pokorný and Kouřil, 1983).

Tench fry are most often reared in natural conditions in smaller ponds in monoculture or polyculture with carp fry, or alternatively, with other fish species. They are reared throughout the entire growing season by way of the with-or-without re-stocking method. If fry are reared in monoculture without re-stocking, they are stocked in an amount of 100000–400000 pcs.ha^{-1} of T_0. Reared fry T_1 reach a weight of 2–3 g and the losses until autumn amount to 70–95%. If fry are reared with restocking, 300000–2000000 pcs.ha^{-1} of T_0 are stocked into the fry-pond of the I. order. After 6–8 weeks, T_a are caught and they are subsequently stocked into a fry-pond of the II. order in an amount of 50000–80000 pcs. ha^{-1} of T_a. In autumn, T_1 at the size of 2–6 cm, or alternatively, 3–10 g are caught, the losses represent around 60–65% (Pokorný and Kouřil, 1983; Stráňai, 2000). Sac fry can be also reared in controlled conditions over a period of up to 11 months (Wolnicky et al., 2006). The rearing itself is conducted in flow-through reservoirs at a temperature of 28 °C. Individual phases of rearing, the initial stock, the size of reared fry and the losses during the rearing are elaborated on, for example, in the study of Wolnicky et al. (2006), Mamcarz et al. (2011).

The production of older stocks is usually conducted in natural conditions either in monoculture or polyculture with carp C_2 or C_3, where tench are stocked in an amount of around 10% of individual carp stock. The losses during the rearing range between 10–30%, depending on the age category of the reared fry (Pokorný and Kouřil, 1983; Stráňai, 2000).

4.8.11. Burbot (*Lota lota*)

Burbot occur predominantly in the streams of a salmonid, grayling and barbel character. Burbot require good quality water and high oxygen content. Burbot belong to psychrophilic species with maximum activity during the winter months. Burbot spawn usually at the turn of December and January. Possibilities relating to burbot's artificial reproduction and rearing of stocks are detailed in the study written by, for example, Pokorný and Adámek (1997) and Pokorný et al. (2003). In practice, there are usually two methods for obtaining brood fish. The first method is based on their obtaining directly from streams by means of electrofishing. Fish are captured mostly in the autumn, together with brood brown trout. Fish selected for artificial reproduction should weigh more than 300 g. They are situated in flow-through storage tanks or ponds with quality water and a sufficient amount of shelters until the spawning period. It is advisable to provide extra feeding in the form of live or dead fish. The second method of obtaining brood fish is rearing them in controlled conditions. Usually, suitable flow-through reservoirs with a sufficient amount of shelters are used. Fish are fed by natural food and if they establish a feeding habit, they can also be fed by feeding mixtures.

In practice, semi-artificial spawning has proved the most effective. If this method is used, brood fish are placed into a flow-through trough at the beginning of the spawning period which is padded with a monofil insert. Fish spawn naturally, usually at night, and they form typical "clumps". Fertilized eggs, that have lost their stickiness due to body movement and flow, accumulate in the lower part of the trough on a monofil mat where they are sucked from in the morning by a hatchery man and subsequently placed into incubation jars.

Sometimes, artificial spawning is conducted as well, which requires individuals with a weight between 250–1000 g. The artificial spawning itself is conducted when the water temperature drops down to 2–3 °C (Pokorný and Adámek, 1997). Females are hormonally stimulated before the stripping itself with a synthetic preparation called Ovopel (Horváth et al., 1997). In some cases, they mature spontaneously without the hormonal stimulation. Males do not need the hormonal stimulation. All previous operations should be conducted under anaesthetic. The relative fertility of burbot reaches the value of 400000–700000 pcs.kg^{-1}. The eggs are distinguished by a big fat blob due to which they can float easily, however, they are not pelagic. Sometimes they are slightly sticky, but when rinsed, the stickiness is easily washed off. Their size varies from 0.8–1.2 mm. Kannengieter or Zug jars are the most suitable devices for incubation (Pokorný and Adámek, 1997; Źarski et al., 2010). Incubation period ranges from 90–190 °D and the hatched fry achieve the size of 3.5–3.8 mm. Fry start to swim after 20–30 °D from hatching and in this period, they are stocked for subsequent rearing.

Burbot are stocked mostly into fishing grounds at the stage of sac fry and it can also be at the stage of a six-month-old juvenile or yearling. These categories are reared usually extensively in suitable ponds with natural feeding. The stock Bu_0 ranges between 30–100 pcs.m^{-2}, depending on the type of pond and time of rearing. They can also be reared in polyculture with carp (C_{1-2}), or with whitefish fry. In this case, the stock of Bu_0 amounts to 5–20 pcs.m^{-2}. The size of plankton during the time of fry stocking should correspond to their need. In the course of the initial rearing, the pond must not be flow-through, because fry tend to escape from a reservoir. They are able to use even the tiniest gaps as they are very small. Fry are usually caught at the beginning of summer at a size around 5–7 cm, or in autumn, and they are stocked into suitable fishing grounds. Rearing of fry in an extensive method in controlled conditions is conducted in troughs or reservoirs for 30–35 days. Artificial rearing of fry is in the initial phases based on cultivation of Ciliata, *Artemia* and subsequently, on dry feed. The initial phase of exogenous nutrition can be particularly difficult due to the extremely small size of fry and obtaining corresponding size of feeding organisms. Subsequently, burbot are able to feed on dry food very quickly. The initial stock Bu_0 ranges between 50–100 pcs.l^{-1} and rearing is conducted at a water temperature of 6–14 °C. Initial feeding of fry usually starts on the second or third day after the swim-up (filling of air bladder). The losses until the end of rearing reach the value of

Fig. 4.8.7. ***Rearing of burbot fry in vertical apparatuses – Lindbergmühle, Germany*** *(photo: T. Randák).*

30–75%, depending on the type of feeding (Shiri Harzevilli et al., 2003). At the end of rearing, burbot fry grow to the size of 13–16 mm. Subsequently, the fry can be used for the subsequent rearing in controlled conditions which is conducted with the use of granular feeding mixtures mostly. This type of rearing has been established relatively well in Germany (Fig. 4.8.7.).

4.8.12. European perch (*Perca fluviatilis*)

Brood fish are obtained either by being caught from open waters or they are reared in conditions of extensive or intensive aquaculture. Perch reproduction itself is conducted by natural spawning, semi-artificial or artificial spawning. The natural spawning takes place mostly in small ponds or storage tanks where spawning substrate, such as dry or fresh branches, are placed, which serve also as a natural shelter. Brood fish are stocked in the period of their natural spawning at a water temperature of 12–15 °C in a ratio of 1♂ : 1♀ (Kucharczyk at al., 1996). As a rule, brood fish are not hormonally stimulated, and if need be, females are stimulated with a one-time dose. If semi-artificial spawning is conducted, that takes place in controlled conditions most frequently, brood fish are placed into suitable reservoirs or cages with the volume of 0.1–1 m^3 in a ratio of 1♂ : 1♀ and an amount of 20–50 $pairs.m^{-3}$. Hormonally stimulated females are stocked, males are not hormonally stimulated (Kouřil et al., 2001; Policar et al., 2009b).

Artificial spawning of perch is conducted in controlled conditions at a water temperature of 12–15 °C, hormonal stimulation and anaesthesia should precede this. Anaesthesia can be conducted with clove oil, 2-phenoxyethanol, MS-222 preparation or Propiscin. Hormonal stimulation is given only to females in the form of intramuscular injection into the dorsal muscles in one, in exceptional cases, in two doses (Kucharczyk et al., 1996). Pituitary, choriongonadotropin (Kucharczyk et al., 1996) or commercially produced synthetic preparations, out of which Supergestran is the most recommended for perch (Kouřil et al., 2001) are applied. Milt is removed by a syringe or stripped directly onto eggs. The higher mortality of brood fish in the post-spawning period, mainly with respect to fish originating from open waters, represents a disadvantage of artificial spawning (Policar et al., 2009b). The relative fertility of perch reaches the value of 100000–135000 $pcs.kg^{-1}$. The eggs are released in the form of egg strands of a creamy to pale yellow colour; they reach a length of up to 1.5 m and the average size of the eggs ranges between 1–2 mm. Incubation of eggs is conducted in flow-through troughs, apparatuses or alternatively, in aquariums at a temperature of 13–18 °C. The incubation period lasts 80–160 °D and hatching begins at these temperatures within 7–14 days (Kouřil et al., 2001). Hatched larvae are carefully removed by suction and they are relocated to the place of the subsequent rearing. Hatched fry is approximately 6 mm large and absorption of the yolk sac lasts for 4–6 days. The particularity is that fry take in feed even before the air bladder is filled (Policar et al., 2009b).

Perch fry can be reared in the natural environment or in controlled conditions. Rearing in the natural environment is conducted in smaller ponds of up to 2.5 ha in monoculture over a period of 1.5–2 months (advanced fry), or until the end of the growing season. When rearing advanced fry, the initial stock is represented by 100000–300000 $pcs.ha^{-1}$ of sac fry. Reared fry grow to the size of 35–50 mm and the losses during the rearing amount to approximately 65–80%. If rearing is conducted by the end of the growing season, an amount of 100000 $pcs.ha^{-1}$ sac fry is stocked. Yearling reach a size of 65–75 mm and the losses are from 80 to 90% (Stejskal et al., 2010).

Rearing in controlled conditions is practised either in concrete reservoirs for a period of about 6 weeks or in plastic or fibreglass reservoirs of different shapes. With respect to the former case, 4000 $pcs.l^{-1}$ of Ep_0 are stocked and the rearing takes place at a temperature of 17 °C. When the rearing is terminated, advanced fry reach a size of about 3 cm, the weight is between 0.2–0.3 g and they are fully adapted to dry feed intake. The losses during the rearing represent 60–70% and the share of cannibals is up to 2% (Policar et al., 2009b). If the second method is selected, the stock ranges from 20–100 $pcs.l^{-1}$ of sac fry. Initial rearing is conducted at lower temperatures (17 °C) than the optimum temperature (23 °C), in order to moderate the development of cannibalism. During the rearing, the temperature is gradually increased up to 22–23 °C. The size of the reared fry as well as the losses during the rearing are comparable with the previous method (Policar et al., 2009b). With respect to rearing of fry, it is also possible to use a combination of rearing in the natural conditions on the basis of natural food until the stage of advanced fry after which rearing in controlled conditions on the basis of pelleted feeding follows (Stejskal et al., 2007; Policar et al., 2009b; Stejskal et al., 2010). Rearing of older fry is conducted either in controlled conditions of recirculation systems in monoculture with the use of artificial feeding at a water temperature of 23 °C where up to 60 $kg.m^{-3}$ are stocked (Mélard et al., 1996). It can also be conducted in pond conditions on the basis of natural food in polyculture with carp mostly (Policar et al., 2009b).

4.8.13. Largemouth black bass (*Micropterus salmoides*)

Reproduction of largemouth black bass can be conducted by several methods. The first method is natural spawning of brood fish in a pond and their subsequent collective rearing with fry (similar to the Old Bohemian method of carp rearing). This method, however, is unreliable and is not highly productive with respect to the small number of reared offspring. Another reproduction method is artificial spawning and subsequent artificial incubation of eggs. Although this method has been worked out relatively well, it has not found wider use within the breeding practice so far (Kouřil and Klimeš, 1999). The most common method in the Czech conditions is the reproduction by semi-artificial stripping in spawning ponds and various modifications of this method. The method of natural spawning in small ponds or storage tanks with sand or gravel-sand bottom is conducted mostly where brood fish are stocked in an amount of approximately 1 pair per 10 m^2. Spawning takes place at a water temperature of 17–23 °C within several days after stocking. After spawning, brood fish are caught at the time when fry start to separate themselves from individual nests into smaller groups – shoals (Dubský, 1982). Another alternative to this method is also natural spawning in a pond, but the spawning is conducted into nests or mats that have been prepared in advance (Kouřil and Berka, 1981; Roncarati et al., 2005).

The fry of largemouth black bass are reared mostly in monoculture directly in ponds or outside reservoirs where the spawning of brood fish and egg incubation have taken place. The initial rearing lasts 3–4 weeks up to the size of approximately 20 mm. Subsequently, the fry are caught in filled pond and are stocked for the subsequent rearing in small shallow ponds. Depending on the rearing intensity and the amount of available food, an amount of 10000–20000, or alternatively, 100000–200000 $pcs.ha^{-1}$ is stocked. The final product is yearling of a size of 7–25 g and a total body length from 80–120 mm. The losses until autumn range between 10–40% (Kouřil and Klimeš, 1999).

Rearing of older categories is not conducted in the Czech conditions on purpose, if required, such rearing can be carried out in pond conditions either in monoculture or in polyculture with carp. In the case of monoculture, it is necessary to stock the pond with a sufficient amount of feeding fish of an adequate size.

4.8.14. Common nase (*Chondrostoma nasus*)

Brood fish are obtained by being caught from open waters in spawning grounds. If required, they are stripped directly in the ground, or are transferred to a hatchery. It is also possible to keep brood fish in flow-through reservoirs, but only for a short time; staying in reservoirs for longer than 2 days would cause deterioration of biological quality of genital products which subsequently lose the fertilization ability, or respectively, deteriorate the embryonic development. Therefore, it is advisable to rear brood fish in suitable ponds or flumes all year long (Hochman and Peňáz, 1989). Artificial spawning is conducted in a hatchery at a water

Fig. 4.8.8. ***Fry and stock of common nase*** *(photo: J. Andreji).*

temperature of 8 to 10 °C. Anaesthesia with 2-phenoxyethanol should precede this. Before the stripping itself, females are hormonally stimulated with carp pituitary or the synthetic preparations Ovopel or Ovaprim, in one to two doses (Hochman and Peňáz, 1989; Targońska et al., 2008; Źarski et al., 2008). Males are not required to be hormonally stimulated (Źarski et al., 2008), however, if need be, carp pituitary in a half dose can be used. In case of an emergency, it is also possible to use male's gonads that have been dissected and pressed through a sieve, in a similar way as pike (Hochman and Peňáz, 1989). The relative fertility of females reaches the value of 30000–40000 pcs.kg^{-1} and the average size of unswollen eggs is about 1.9–2.5 mm. The eggs are of grey yellow to grey green colour and sticky. Desticking is usually conducted by rinsing in water, if the eggs are stickier, it is possible to use talk suspension for about 25 minutes, or other methods that are used for desticking of carp could be applied as well (Hochman and Peňáz, 1989; Halačka and Lusk, 1995). The eggs are incubated in Zug or Kannengieter jars at a water temperature of 8–13 °C that can be increased to 15–16 °C towards the end of incubation which will accelerate and shorten the hatching period. Hatching begins approximately after 2–3 weeks, depending on the water temperature. Hatched fry are photophobic, they reach the size of 8–9 mm and yolk sac is absorbed for about 10–11 days. After the air bladder has filled, the fry start to swim, their photophobia starts disappearing and in this period they can be stocked for the subsequent rearing.

Rearing of sac fry is conducted in natural conditions, in small earthen ponds with a low water column and in trench ponds mostly. If reared in controlled conditions, it is conducted in flow-through reservoirs of a circular or rectangular shape (Hochman and Peňáz, 1989; Fiala et al., 2008). If reared in natural conditions, it is possible to rear the common nase fry until the stage of advanced fry in earthen ponds with a stock of 500000–1000000 pcs.ha^{-1}, or in trench ponds where 400–600 pcs.m^{-2} of sac fry are stocked. The losses after 6–8 weeks are between 40–80% and advanced fry grow to the size of 4–6 cm. Common nase fry can also be reared in earthen ponds over the entire growing season and in such case, 100000–200000 pcs.ha^{-1} of sac fry are stocked. The losses until autumn range from 40–80%. Such fry (Fig. 4.8.7.) grow usually to the size of around 6 cm and to a weight of 1 g (Hochman and Peňáz, 1989). In both cases, the common nase fry are fed small powdery feeding provided on the water surface from the size of 2 cm (flour, cereal meal, sieved granular feeding – coarse meal, etc.) The initial rearing of fry in controlled conditions is conducted in flow-through reservoirs with water column height of 15–25 cm and a water temperature of 25–28 °C. These reservoirs are stocked with 40–100 pcs.l^{-1} of sac fry, depending on the feeding provided, and the rearing takes place for about 3–4 weeks. Fry fed by *Artemia* nauplii, however, commercially produced starter mixtures can be used as well. As soon as the stock reaches the size of 20–25 mm, they are reduced down to one half. After four weeks of rearing, the fry grow to a size of 25–30 mm and the losses do not exceed 10% (Spurný et al., 2007; Fiala et al., 2008, Kujawa et al., 2010). Subsequently, such fry are reared by an intensive method on the basis of artificial feeding for approximately 7–8 weeks to reach a size of 50–55 mm and a weight of around 1 g. The initial stock represents 30 pcs.l^{-1}, and after four weeks of rearing, they are reduced down to one half.

Rearing of older stocks (Fig. 4.8.8.) is conducted in pond conditions only rarely. It is possible to rear Cn_1 in controlled conditions from autumn to spring of the subsequent year at a water temperature of approximately 20–24 °C, complete feeding mixtures are fed mostly. The initial stock of 10 pcs.l^{-1} is stocked in rearing reservoirs that is reduced down to 0.6 pcs.l^{-1} in the course of rearing. During this period, common nase grow to the size of 14–18 cm and the weight of 20–40 g. At the terminal stage of rearing, the water temperature and the feeding rations are being gradually decreased in order to enhance adaptation processes after stocking. During the stocking itself, either of fry or older stock, it is necessary to take into account that common nase are shoal species and that they are able to adapt quickly to new environmental conditions only in a large group. Therefore, it is recommended that they are stocked into one place. Fry are to be stocked in an amount of 500–1000 pcs and at a minimum amount of 100 pcs (Hochman and Peňáz, 1989; Fiala et al., 2008).

4.8.15. Barbel (*Barbus barbus*)

Brood fish are obtained in the Czech territory mainly by means of catching from open waters from May to June in the spawning grounds where these brood fish can be stripped directly or transported to a hatchery (Krupka, 1987). Brood fish can also be reared in flow-through reservoirs in controlled conditions (Philippart et al., 1989). With respect to artificial spawning directly in the spawning grounds, the genital products obtained are transported to a hatchery separately in thermo boxes and eggs are fertilized with sperm in a hatchery, or eggs can also be fertilized directly in the terrain and transported to a hatchery afterwards. If brood fish are transported to a hatchery in order to be artificially stripped, these fish should become acclimatized first of all and then they are hormonally stimulated (Krupka, 1987; Policar et al., 2009a). Artificial spawning is conducted at a water temperature of 16–18 °C. Females are hormonally stimulated solely with synthetic preparations (Supergestran, Ovopel, Dagin), the use of carp pituitary is not recommended with the barbel (Kouřil et al.,

Fig. 4.8.9. ***Fry and stock of barbel*** *(photo: J. Andreji).*

2006). Males are not necessary to be hormonally stimulated. Before the stripping itself, or more precisely, before the hormonal stimulation, it is necessary that the brood fish are anaesthetized in the clove oil solution or 2-phenoxyethanol. Relative fertility of barbel ranges from 36000–85000 eggs. The eggs are usually yellowish with the size of 1.8–2.1 mm and they are slightly sticky. Desticking is not required, it is sufficient to rinse the eggs several times in water (Krupka, 1987; Policar et al., 2009a). The eggs are incubated in Zug jars at a water temperature of 17–18 °C and fry start to hatch after 5–8 days (Krupka, 1987; Policar et al., 2007). The hatched fry measure immediately after hatching approximately 8–9 mm and yolk sac is absorbed for 10–12 days. At this period, fry change over to exogenous nutrition.

Barbel sac fry can be reared in natural conditions in monoculture in trench ponds, where 200 pcs.m^{-2} are stocked, or in small ponds, where the barbel sac fry in an amount of up to 100000 pcs.ha^{-1} are stocked. Reared fry (Fig. 4.8.8) at the end of the growing season reach a size of 5–7 cm and the weight of 1–1.5 g (Stráňai, 2010).

However, fry are reared more often in controlled conditions in troughs or aquariums with the use of live food (*Artemia* nauplii) or feeding mixtures. Rearing in such conditions is conducted at a temperature of 21–25 °C and it lasts from 3 weeks to 3 months, or alternatively, the whole year (Krupka, 1987; Fiala and Spurný, 2001, Policar et al., 2007; Żarski et al., 2011). After three weeks of the initial rearing, sac fry that grow to the size of around 3 cm and the weight of 0.15 g are stocked in an amount of 200 pcs.l^{-1}. The losses during the rearing do not exceed beyond 3% (Źarski et al., 2011). After three months of rearing, an amount of 40–50 pcs.l^{-1} of sac fry is stocked which is gradually reduced down up to 2,5 pcs.$l^{-1.}$ The reared fry is 6–7 cm large and their weight is 2–3 g. The losses during the rearing are not higher than 20–25% (Krupka, 1987; Policar et al., 2007). Rearing of older barbel stock (Fig. 4.8.9.) is carried out mainly in connection with ensuring brood fish for the artificial spawning purposes.

4.8.16. Rudd (*Scardinius erythrophthalmus*)

Brood fish are mainly reared in pond conditions. Artificial spawning is conducted in a hatchery at a water temperature of 16–20 °C. Before the stripping itself, females are hormonally stimulated either with carp pituitary or by the synthetic preparations Ovopel, Kobarelin or Lecirelin, usually in a one-time dose (Horváth et al., 1997; Kouřil et al., 2008). Males are usually not required to be hormonally stimulated. It is advisable to conduct the artificial stripping under anaesthesia, in order to ensure easier manipulation with fish. The most suitable preparations are clove oil or 2-phenoxyethanol. The relative fertility of females ranges to a relatively large extent from 16000–182000 pcs.kg^{-1}. The eggs are yellowish, sticky and their size is around 1 mm. Desticking is conducted by means of talk suspension or milk. The eggs are incubated in Zug jars at a water temperature of 18–24 °C. Hatching begins after 3–4 days, depending on the water temperature, and the hatched fry are approximately 4–5 mm in size. The yolk sac is absorbed for the following 2–3 days. Rudd fry are distinguished by negative phototaxis. At the beginning of the larval period, fry are stocked for the subsequent rearing.

The easiest method of obtaining the fish for stocking is the natural spawning of brood fish in ponds and their subsequent rearing together with fry until the end of the growing season (similar to the Old Bohemian method of carp rearing). Small ponds (up to 0.2 ha) are used where 100–250 pcs of brood fish are stocked per 1 ha, depending on the amount of aquatic vegetation. In such a way, it is possible to obtain up to 500000 pcs of fry of an individual weight of 1–3 g in autumn (Pípalová and Adámek, 2001). Fry can also be reared in controlled conditions in a hatchery in small flow-through reservoirs, where sac fry in the amount of 50 pcs.l^{-1} are stocked after the initial swim-up. Rearing lasts approximately one month at a water temperature of 25 °C. The losses during rearing, if live feed are provided, are about 1–5%, however, if dry supplementary feeding are provided, the losses amount up to 55% (Wolnicky et al., 2009).

4.8.17. Vimba bream (*Vimba vimba*)

Brood fish are obtained mostly by being caught from open waters at the time of migration to spawning grounds, but they can also be reared in a pond environment (Hamáčková et al., 2008b; Łuszczek-Trojnar et al., 2008). Artificial spawning is conducted in a hatchery at a water temperature of 19–20 °C. With respect to the relatively small size of the fish, it is advisable to use anaesthesia in order to secure easier manipulation (clove oil or 2-phenoxyethanol). Before the stripping itself, it is recommended that females are hormonally stimulated with carp pituitary or synthetic preparations (Ovopel, Lecirelin) in one, or alternatively, two doses. Males are not necessary to be hormonally stimulated, however, if they are hormonally stimulated, a larger volume of sperm is obtained.

Milt is stripped directly onto eggs or can be removed by suction and immediately used to fertilize the stripped eggs (Horváth et al., 1997; Hliwa et al., 2003). The relative fertility of females ranges from 100000–200000 pcs.kg^{-1} and the average size of unswollen eggs is from 0.6–2.0 mm. The eggs are of pinkish yellow colour, they have solid elastic peels and are sticky. Desticking is conducted by means of talk suspension for about 1 hour. The eggs are incubated in Zug (Weiss) jars at a temperature of 20–24 °C (Hamáčková et al., 2008b; Łuszczek-Trojnar et al., 2008). The fry hatch after 3–4 days, depending on the water temperature, and the hatched fry are approximately 5.0–6.5 mm large. Resorption of yolk sac lasts up to 14 days, therefore, it is recommended to shorten this period by transferring the fry into water of a higher temperature (around 25 °C) before the air bladder is filled. After the transition of the fry from an embryonic to larval stage, their stocking into open waters can be conducted, or they can be used for subsequent rearing.

Vimba bream sac fry can be reared in pond environment conditions or in controlled conditions. Rearing in controlled conditions is conducted for 20 days mostly (Kujawa et al., 2006; Hamáčková et al., 2008b), however, it is also possible to conduct the rearing throughout the whole year (Hliwa et al., 2003). At the initial stage, the rearing is based on live feed (*Artemia* nauplii), subsequently, on dry feeding mixtures. Rearing is conducted in shallow flow-through reservoirs where the sac fry are stocked in an amount of 40–60 pcs.l^{-1}. The optimum water temperature is 23–25 °C. The losses during the rearing are about 1–10%, depending on the type of feeding. Reared fry reach a size of 1–2 cm after 20 days. After approximately 10 months, Vb_1 reach a size of 8 cm (Hliwa et al., 2003; Hamáčková et al., 2008b). Sac fry of vimba bream are reared in pond conditions usually in monoculture in smaller ponds up to 0.5 ha with the possibility of their pond harvesting under the dam. These ponds are stocked in an amount of 400000–1000000 pcs.ha^{-1} of sac fry. Rearing takes place until the autumn and the losses are not higher than 20%. The reared vimba bream reach a size of 4–5 cm and the weight of 0.7–0.9 g. It is also possible to rear the fattened fry in a pond environment after they have been reared for 20 days in controlled conditions in monoculture as well. From the technological point of view, it is the same system of rearing as the previous method. However, a smaller amount of fish (100000 pcs.ha^{-1}) is stocked and the reared vimba bream achieve larger sizes (5–9 cm, or 1.2–2.5 kg). The losses do not exceed 10% (Hamáčková et al., 2008b).

Rearing of older stock of vimba bream can also be conducted in controlled conditions in larger flow-through reservoirs under the same conditions as the rearing of fry. The stock ranges in such case from 15–20 kg.m^{-3}, depending on the size of stock and the feeding intensity. If such method of rearing is used, it is necessary to secure the reservoirs against the fish's escape, or more precisely, against fish jumping out (Hamáčková et al., 2008b). The pond rearing of stock can be conducted in monoculture or polyculture, in most cases with carp. If reared in monoculture, an amount of 50000–100000 pcs of fish are stocked per 1 ha, depending on the age category of the reared stock. If reared in polyculture with carp, yearling are stocked in an amount of up to 2500 pcs.ha^{-1}, one-year-old fish are stocked in an amount of 1000 pcs.ha^{-1}, three-year-old fish are stocked in an amount of 800 pcs.ha^{-1} and four-year-old fish are stocked in an amount of 500 pcs.ha^{-1} (Hamáčková et al., 2008b; Łuszczek-Trojnar et al., 2008).

4.8.18. Eurasian minnow (*Phoxinus phoxinus*)

Brood fish (2–3 year-old fish with the weight of 3–10 g) are obtained in the spawning period by catching from open waters directly in the spawning grounds or they can be reared in pond conditions. The reproduction itself is conducted by artificial or semi-artificial spawning. Artificial spawning is conducted by the classical dry method, after both genders have been hormonally stimulated. Minnows are hormonally stimulated with carp pituitary that is injected into females in two doses and males are injected with one dose (Stalmans and Kestemont, 1991). The relative fertility ranges around 100 pcs.g^{-1} and the average size of unswollen eggs is around 0.3 mm. The eggs are incubated in Zug jars of a smaller volume or in horizontal incubation apparatuses, at a water temperature between 11–15 °C. Semi-artificial spawning is the most common method of minnow reproduction that is conducted in small rearing ponds (Stalmans and Kestemont, 1991; Stráňai, 2010), or more often in reservoirs situated in a hatchery (Kestemont and Stalmans, 1992; Krupka, 1999), onto the so-called spawning nets, which are basically mats, baskets or ceramic containers filled with gravel. Brood fish in an amount of 500–1500 pcs.m^{-2}, or up to 3000 pcs.m^{-3} are placed into such reservoirs. After spawning, eggs are relocated with the substrate onto incubation apparatus where their incubation at a temperature of 16 °C is conducted. The fry hatch approximately after 6 days and yolk sac is absorbed for 14 days. Immediately before the yolk sac is absorbed, fry are relocated onto subsequent rearing (Stalmans and Kestemont, 1991; Krupka, 1999).

Sac fry are reared in monoculture in small rearing ponds with the volume of up to 0.1 ha, usually until autumn, or in the case of rearing in controlled conditions in hatchery, it is for 1–2 months in troughs. If reared in ponds, an amount of 15–200 pcs of sac fry are stocked per 1 m^2, depending on the pond quality. The losses until the autumn range from 38–52% (Stalmans and Kestemont, 1991). If reared in troughs, an amount of 20–50 pcs of sac fry are stocked per 1 litre at a water temperature of 20 °C. The losses during rearing are between 10–20% on condition that the fry are fed live or combined feeding (live + dry). If only a dry diet is applied, the losses amount up to 56–70% (Kestemont and Stalmans, 1992; Krupka, 1999).

4.8.19. Wels catfish (*Silurus glanis*)

Catfish reproduction itself is conducted by artificial or semi-artificial spawning. With respect to artificial spawning, brood fish of an age of 4–10 years and individual weight of 5–25 kg are usually used (Linhart et al., 2001), however, in order to ensure easier manipulation with fish, it is advisable to use brood fish with a weight of 4–8 kg (Kouřil et al., 1992). The stripping itself is conducted in a hatchery at a water temperature of 22–25 °C after the fish have been anaesthetized and hormonally stimulated. The anaesthesia is induced with clove oil or 2-phenoxyethanol. Brood fish are hormonally stimulated with a one-time dose of carp pituitary, while males are injected 24–48 hours before the scheduled stripping. The use of synthetic preparations (Kobarelin, Ovopel) is not recommended for catfish due to the prolongation and increase in time span of ovulation. Milt that is released by massaging with urine, is removed by suction into test tubes that are filled with immobilisation solution (Kouřil et al., 1992; Linhart et al., 2001). If there is an insufficient amount of milt, dissection of gonads is conducted and they are consequently sieved through a fine fabric (fine synthetic web called uhelon, gauze) directly onto eggs (Horváth et al., 2002). The relative fertility of catfish ranges from 10000–48000 pcs.kg^{-1} and the average size of unswollen eggs is around 2.0–3.0 mm. The eggs are greyish yellow to greyish green and sticky. Desticking is conducted by means of alcalase enzyme for about 2 minutes (Linhart et al., 2001), or by clay suspension for about 5–10 minutes (Kouřil et al., 1992). The eggs are incubated in incubation jars (Zug) at a temperature of 22–24 °C and fry start to hatch approximately after 3 days. Hatched fry are 8.0–10.0 mm large and they absorb the yolk sac for 3–4 days. Another method of catfish reproduction is semi-artificial spawning. This method is conducted mostly in storage tanks or small ponds onto nests that have been prepared beforehand from roots of willow, alder or sedge. Storage tanks are stocked with a pair of brood fish of the same size and the stripping itself is conducted at a water temperature of 20–22 °C within a short time period. Spawned eggs are protected by males. Nests with eggs are relocated to a hatchery onto troughs or ponds, where their subsequent rearing should take place. It must be conducted 12 hours before the scheduled hatching at the latest (Čítek et al., 1993; Stráňai, 2000; Horváth et al., 2002).

Sac fry can be reared in natural or controlled conditions. In natural conditions, Wels catfish are reared in monoculture or polyculture, mostly with tench, carp, herbivorous fish or other commercially preferred fish species. The rearing itself is conducted in trench ponds or in classical fry-ponds on the basis of natural food over a period of 1–1.5 months, or until the end of the growing season. Better results are achieved if reared in polyculture, where an amount of 1000–8000 pcs.ha^{-1} of sac fry are stocked, however, the losses during the rearing are relatively high and they amount up to 80% (Čítek et al., 1993; Stráňai, 2000; Horváth et al., 2002). On that ground, it is advisable to stock Wels catfish sac fry for subsequent rearing no sooner than they start the initial feeding and after they have reached a minimum size of 1.5 cm (Kouřil et al., 1992; Linhart et al., 2001). This initial rearing of Wels catfish fry is conducted in a hatchery in closed (darkened) troughs from the start of exogenous nutrition over a period of 3–6 weeks at a temperature of 26–30 °C on the basis of the natural food (assorted zooplankton, later on fry of cyprinid fish species as well) or dry feeding mixtures. Depending on the duration of rearing and the type of feed provided, an amount of 10–200 pcs.l^{-1} of sac fry is stocked, while the losses during this period are between 10–30% and the reared advanced fry Wc_a reach usually the size of 2–5 cm, or 0.1–1 g (Hamáčková et al., 1992; Jamróz et al., 2008; Zaikov et al., 2008). Fattened fry can be further reared either in natural or controlled conditions. With respect to natural conditions, Wc_a are stocked into smaller ponds in an amount of 2–10 pcs.m^{-2} if reared in monoculture; if reared in polyculture with carp or herbivorous fish, the amount is 1–5 pcs.m^{-2}. The losses during the rearing are between 30–60% and Wels catfish yearling Wc_1 grow to the size of 10–20 cm and the weight of 20–80 g (Čítek et al., 1993; Stráňai, 2000). Rearing in controlled conditions is conducted in flow-through, or recirculation systems usually on the basis of a dry diet. The initial stock Wc_a amounts up to 4000 pcs.m^{-3}, however, in the course of all-year rearing, it reduces down up to 160 pcs.m^{-3}. Individual phases of rearing, the size of the final product as well as the feeding technique are elaborate on in the study of Talpeş et al. (2009).

Rearing of older stocks is conducted mostly in pond conditions in polyculture with carp, tench or herbivorous fish, where 50–150 pcs.ha^{-1} of Wc_1 are stocked (Čítek et al., 1993; Stráňai, 2000). If granular feeding is used, the stock can be increased up to 50–100 kg.ha^{-1} of Wc_1, or if reared in monoculture, up to 150–200 kg.ha^{-1} of Wc_1.

4.8.20. Northern pike (*Esox lucius*)

Brood fish for reproduction purposes originate almost solely from pond rearing. Artificial spawning is conducted in a hatchery at a temperature of 8–10 °C (Fig. 4.8.10.). Hormonal stimulation is usually not necessary, and if required, carp pituitary or synthetic preparations Ovopel, Ovaprim or Dagin can be applied (Čítek et al., 1993; Stráňai, 2000; Muscalu-Nagy et al., 2011). Before the stripping itself, fish are anaesthetized with 2-phenoxyethanol. The relative fertility of females amounts to 15000–45000 pcs.kg^{-1}. The eggs are sticky, of a yellowish-orange to orange colour and their average size is between 1.5–2.5 mm. Desticking is conducted by rinsing in water several times or classically by means of clay emulsion (Čítek et al., 1993; Stráňai, 2000; Horváth et al., 2002). The eggs are incubated in Zug or Chassé jars at a water temperature of 8–12 °C. Hatching starts within 8–14 days. Hatched fry are about 8.5–9 mm large and they absorb the yolk sac fry for 5–10 days. Hatched fry are carefully relocated into nursery tanks until they start to swim.

Sac fry is most commonly reared in monoculture until the stage of advanced fry (P_a) either in natural or controlled conditions in a hatchery. In both cases, they are fed by natural food (plankton, fry of prey fish). If reared in controlled conditions, sac fry are reared in flow-through reservoirs of different shapes at a water temperature of 14–18 °C for the usual duration of 2–3 weeks. The stock recommended for such rearing method is 6–7 pcs.l^{-1}. After this period, reared fry are about 2.5–4 cm large and the losses during this rearing are 50–60% (Čítek et al., 1993, Stráňai, 2000; Horváth et al., 2002). Rearing in natural conditions is conducted in small ponds or storage tanks with a volume of 0.1–1 ha where up to 80000 pcs.ha^{-1} of P_0 are stocked and after 2–3 weeks of rearing; the advanced fry reach a size of 3–4 cm. The losses during the duration of rearing are not higher than 50%. Another alternative is rearing of P_0 in trench ponds where 200–250 pcs are stocked per 1 m. The rearing lasts approximately 3–4 weeks and the final product measures 5–6 cm with a survival rate from 20–40% (Lusk and Krčál, 1988; Čítek et al., 1993). Sac fry can also be reared in cages for a duration of 2–3 weeks. The initial stock is 3000 pcs.m^{-3} of P_0. At the end of rearing, the fry measure between 2–2.5 cm (Čítek et al., 1993; Žiliukiene and Žiliukas, 2006).

Fig. 4.8.10. ***Stripping of northern pike*** *(photo: J. Andreji)*

4.8.21. Silver carp (*Hypophthalmichthys molitrix*)

Brood fish for reproduction purposes are reared solely in pond conditions. Artificial spawning is conducted in a hatchery at a water temperature of 22–25 °C. Brood fish are hormonally stimulated with carp pituitary, or in combination with choriongonadotropin or synthetic preparations (Ovopel, Ovaprim) in one, respectively, two doses (Schoonbee and Prinsloo, 1984; Brzuska, 1999; Stráňai; Horváth et al., 2002). All operations connected with artificial spawning are conducted after application of anaesthesia with the use of 2-phenoxyethanol. The relative fertility of females ranges between 60000–92000 pcs.kg^{-1}. The eggs are pelagic, transparent, light yellow coloured and their average size in an unswollen state is 0.7–1.3 mm. If they come into contact with water, they swell up massively and they increase their volume up to 30–50 times. The eggs are incubated in Zug jars at a water temperature of 23–25 °C. Hatching starts approximately within 1–1.5 days. Hatched fry measure around 5 mm and the yolk sac is absorbed for approximately 3 days. Hatched fry are stocked into nursery tanks or special incubators until they start swimming. After the fry start swimming, they are stocked for the subsequent rearing in ponds.

4.8.22. Bighead carp (*Hypophthalmichthys nobilis*)

Brood fish for reproduction purpose are also reared in pond conditions only. Artificial stripping is conducted in a hatchery at a water temperature of 24–26 °C. Brood fish are hormonally stimulated with carp pituitary, or alternatively, in combination with choriongonadotropin or synthetic preparations in one or two doses (Schoonbee and Prinsloo, 1984; Stráňai, 2000; Horváth et al., 2002; Meddour et al., 2005). Fish should be manipulated only after application of anaesthetic with the use of 2-phenoxyethanol or MS-222

Sandoz. The relative fertility of females ranges from 40000–60000 pcs.kg^{-1}. The eggs are pelagic, light grey coloured and their average size in an unswollen state is 0.9–1.2 mm; after becoming swollen, they reach a size of 3.2–5.3 mm. The eggs are incubated in Zug jars at a water temperature of 22–26 °C (Čítek et al., 1993). Hatching starts approximately after 1.5–2 days. Hatched fry measure 7–8 mm and they absorb the yolk sac for about 3 days. Hatched fry are stocked into nursery tanks or special large-capacity incubators until they start swimming. After the swim-up, fry are stocked into ponds for the subsequent rearing, similarly to the above-mentioned species.

4.8.23. Grass carp (*Ctenopharyngodon idella*)

Similarly to silver carp and bighead carp, brood fish of grass carp are also reared in a pond environment. Brood fish are hormonally stimulated with carp pituitary, or it can be combined with choriongonadotropin or synthetic preparations (Ovopel, Dagin) in two, or alternatively, one dose (Schoonbee and Prinsloo, 1984; Brzuska, 1999; Horváth et al., 2002). Anaesthesia with 2-phenoxyethanol or MS-222 should precede this. The artificial stripping itself is conducted in a hatchery at a water temperature of 20–24 °C. The relative fertility of females ranges from 60000–123000 pcs.g^{-1}. The eggs are greyish, pelagic and their average size in an unswollen state reaches 0.9–1.5 mm. If the eggs come into contact with water, they become swollen quickly and after few hours, they grow to a size of 4–5 mm. The eggs are incubated in Zug jars at a water temperature of 21–22 °C (Čítek et al., 1993). Hatching starts approximately within 1–1.5 days. Hatched fry measure 6–7 mm and yolk sac is absorbed for about 3 days. Hatched fry are stocked into nursery tanks or special incubators until they start swimming. After the fry start swimming, they are stocked for the subsequent rearing in ponds.

Rearing of stocks of herbivorous fish species – Sc, Bhc, Gc

Sac fry are reared in the Czech conditions mostly in monoculture in natural conditions, but it is also possible to rear the fry in controlled conditions. If reared in natural conditions in monoculture, an amount of 1000000–2500000 pcs.ha^{-1} of sac fry are stocked into the fry-pond of the I. order for the duration of 3–5 weeks. After this period, advanced fry grow to the size of 2–4 cm while the losses range from 20 to 70%. Advanced fry of herbivorous fish are stocked for subsequent rearing into the fry-pond of the II. order in an amount of 100000–150000 pcs.ha^{-1} until the end of the growing season (Čítek et al., 1993; Stráňai, 2000). If the sac fry of herbivorous fish species are reared directly in the fry-pond without re-stocking, an amount of 25000–50000 pcs.ha^{-1} of sac fry are stocked. The losses are as high as 90 %. If reared in polyculture with carp, which represents a less common method, an amount of 50000–200000 pcs.ha^{-1} of C_a are stocked with 15000–80000 pcs.ha^{-1} of advanced fry of herbivorous fish at the ratio of 50% of Sc_a, 25% of Bhc_a and 25% of Gc_a. The losses until autumn with respect to herbivorous fish are around 50–70% (Čítek et al., 1993; Stráňai, 2000). Rearing of sac fry is also conducted in controlled conditions in a hatchery where fry are reared in flow-through reservoirs for the duration of 2–4 weeks at a water temperature of 25–30 °C on the basis of natural food, however, cereal meal or commercially produced starter mixtures can be used as well. The initial stock of 100–400 pcs.l^{-1} is gradually reduced down to 25–50 pcs.l^{-1}, depending on the duration of rearing and the type of feeding. The losses during this rearing do not exceed 35% and advanced fry measure 2.5–3 cm (Prinsloo and Schoonbee, 1986; Čítek et al., 1993; Stráňai, 2000).

The rearing of older stock is conducted in polyculture (Milstein et al., 2006; Afzal et al., 2007) with carp in stock-ponds or main ponds where the main carp stock is completed with up to 50% of one-year-old stock of herbivorous fish, or alternatively, up to 30% of two-year-old stock of herbivorous fish (Stráňai, 2000).

4.8.24. European eel (*Anguilla anguilla*)

Due to the fact that eel are catadromous fish, their reproduction is not conducted in the Czech Republic. The artificial spawning of eel has been conducted abroad, however, only under experimental conditions so far (Boëtius a Boëtius, 1980). Both genders are hormonally stimulated with natural or synthetic preparations in 12–25 doses (Palstra and Van den Thillard, 2009), or alternatively, by means of cellular implants (Spaink et al., 2005). Relative fertility reaches on average 1600000 pcs.kg^{-1} and the average size of the eggs is around 1 mm. This method has not been used in practise until now, probably because of problems with fertilization, incubation, hatching and initial rearing which have not been clarified yet.

Rearing of fish for stocking in the Czech conditions depends on the import of glass eel from abroad (Spain, France, and Great Britain). The average size of the imported glass eel is usually from 60–80 mm, or 0.3–0.5 g. The rearing itself is conducted solely in controlled conditions. Reservoirs and troughs of different shapes and volumes are used for this purpose. At present, plastic reservoirs of rectangular shape with a volume of 1 m^3, gradient bottom and outlet secured against the glass eel escape have proved suitable. The water column height in this reservoir should be around 50 cm and the top edge of the reservoirs must be provided with a moulding that is 4–5 cm large and that run perpendicularly to the inside, in order to prevent the glass eel's escape (Peňáz and Wohlgemuth, 1988). These reservoirs are stocked with approximately 30–40 pcs.l^{-1} or 12–15 g.l^{-1} of glass eel (Appelbaum et al., 1998), in some cases it can be even up to 30 g.l^{-1}. Such high initial stocks are necessary for the creation of intensive feeding reflexes. In the case of diluted stock, glass eel take in the feed in a worse manner and they also grow more slowly (Peňáz and Wohlgemuth, 1988). At present, the glass eel rearing itself is conducted usually for a duration of 3 months at a water temperature of 22–25 °C. The initial feeding of glass eel begins with cod eggs, plankton (live or frozen), or eggs of cyprinid fish species, depending on the time of import (usually February – May). After 1–2 weeks, the feeding continuously changes over to mash of granular feeding and after another two weeks, solely dry granular feed is provided. Eel reared under such method double their weight within approximately one month and at the end of the rearing, they reach a size of 15–20 cm, or 1.5–3 g. The losses during the rearing period do not usually exceed 20%. Such reared eel are stocked into fishing grounds and their survival is much higher (up to 60%) than with respect to glass eel stocked immediately after their import (survival around 1–2%).

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4.9. Protection of fish and lampreys in Europe and in the Czech Republic *(J. Musil)*

The river network of continental Europe comprises the river basins of the Arctic Ocean in the north, the Mediterranean Sea in the south, the Atlantic Ocean in the west, and the Black and Caspian seas in the east. This geographical area is distinguished by its diverse climate and habitats and great diversity of fauna and flora. Above all, the area of the Mediterranean Sea belongs to one of the most important biodiversity regions of the planet from the number of species point of view, and is known as a "biodiversity hotspot" (an important area with occurrence of endemic species) (Mittermeier et al., 2004).

The Czech Republic represents a relatively small territorial unit, however, due its location in the centre of Europe and the river network, that includes three international river basins (the Elbe, Danube and Odra Rivers), the Czech Republic's diversity of freshwater fish species is relatively rich.

4.9.1. Species diversity

The term species diversity expresses species richness and as is evident from the term, species is considered the basic unit. Species diversity represents a subordinated term to biodiversity (called also biological diversity) that distinguishes forms of organisms at all known levels – molecular, population, species and ecosystem, and it thus expresses better the unique biological diversity (Magurran and McGill, 2011).

Species diversity of freshwater fish in Europe

Freshwater fish represent approximately 1/4 of the world's vertebrates and they are the most abundant group of European vertebrates from the species point of view. They comprise 546* native fish species and lampreys (Kottelat and Freyhof, 2007; Freyhof and Brooks, 2011). Freshwater fish include various taxonomic and ecological groups and lampreys are ranked among freshwater fish for this publication purpose. The European continent represents for this relatively small group (42 species) the centre of diversity with 14 species present (Kottelat and Freyhof, 2007). Sturgeons represent another group of "European importance". Similarly to lampreys, their species diversity in Europe is high and eight out of the total 26 species are found in Europe (Billard and Lecointre, 2001; Pikitch et al., 2005).

The lower part of the Danube River (delta) is from the global view the most significant reproduction area for three species of sturgeon, including the largest living representative of the planet – beluga (*Huso huso*), which can be over 8 metres long and weigh over 3.2 tons (Kottelat and Freyhof, 2007). The majority of sturgeons belong to a group of long-lived fish (these species are distinguished by long juvenile periods, with the first reproduction at the age of 10 or even later). They belong to diadromous (species that are dependent during their life cycle on freshwater as well as the sea environment), anadromous (species that spend the majority of their life cycle in the sea environment but migrate to freshwaters in order to reproduce) and polycyclic species (species with repeated spawning that is often conducted, with respect to sturgeons, at intervals of several years). The representatives of anadromous fish species are known from several families, including lampreys (Kottelat and Freyhof, 2007). The majority of European fish species belong to the Cyprinidae family (cyprinid species) which achieves the highest species richness in the temperate zone and in the south of Europe. The representatives of the families Coregonidae (whitefish), Salmonidae (salmonids) and Thymallidae (grayling), that were classified into one family, Salmonidae, in the past, i.e., salmon, trout, grayling and whitefish, are dominant and the most abundant representatives of the mountain areas and the north of Europe. Another significant group are spiny-rayed, perch-like fish (the family: *Perciformes*) (Freyhof and Brooks, 2011). Although they do not represent a large group from the species point of view, they have significant ecological roles in the freshwater ecosystems. Some representatives, for example, ruffe (*Gymnocephalus cernua*) and some gobies (*Neogobius* sp.) are, unfortunately, also known as invasive species, be it within Europe or worldwide (Kornis et al., 2012). Over 80% of all European species of freshwater fish are endemic and many of these species inhabit delimited localities encompassing one or several rivers or lakes (Kottelat and Freyhof, 2007).

Species diversity of freshwater fish in the Czech Republic

The current number of native fish and lampreys that occurred or occur in the Czech territory is about 61* in total. With respect to lampreys, two species out of this number represent resident species (Ukrainian brook lamprey *Eudontomyzon mariae;* European brook lamprey *Lampetra planeri*) and two species are anadromous (river lamprey *Lampetra fluviatilis;* sea lamprey *Petromyzon marinus).* Similarly to Europe, the Czech Republic was a significant natural area for diadromous fish species. According to Béguer et al. (2007), 11–15 diadromous species occur in Western Europe, with the highest number (11–12 species) in Central Europe (this study does not include the Danube river basin where this number can be even higher). In the Czech Republic, the occurrence of nine species in the Elbe River basin, five species in the Odra River basin and three species in the Danube River basin was documented on the basis of historical records and literary sources (Musil et al., 2009). With respect to the Acipenseridae family (sturgeons), European sturgeon *Acipenser sturio* (the Elbe and Odra River basins) and beluga *Huso huso* (the Danube River basin) demonstrably historically occurred in the Czech territory. Starlet *Acipenser ruthenus* (the Danube River basin) are still found in the territory. Questionable but possibly feasible (there is historical evidence of catches that do not tie with any description of the above-mentioned species, but no documented evidence has been preserved)

Fig. 4.9.1. ***The alluvial area of the meandering Odra River*** *is one of the valuable locations not influenced by human activity to a large extent, and characterised by high species diversity (the protected landscape area Poodří, Bohumín, photo: J. Musil).*

is the historical occurrence of other species of sturgeons (the Russian sturgeon *Acipenser gueldenstaedtii*; ship sturgeon *Acipenser nudiventris;* and stellate sturgeon *Acipenser stellatus)*. These species are known from the adjacent and hydrologically connected Danube River basins (Musil et al., 2009). Although even if the above-mentioned species really occurred in the Czech territory, then there were only few individuals recorded, therefore, their occurrence could not be considered regular.

The majority of fish species and lampreys occurring in the Czech Republic belong to the Cyprinidae family (32 species, 53% of ichthyofauna). Other species belong to the families Percidae (percid – eight species), Petromyzontidae (lampreys – four species), Acipenseridae (three species), Cobitidae (spined loach – two species and one hybrid complex *Cobitis* sp.*), Salmonidae (two species and the species *Salmo trutta*, that is further classified into sea form – *S. trutta* m. *trutta*, brook form – *S. trutta* m. *fario* and lake form – *S. trutta* m. *lacustris*), Cottidae (sculpin – 2 species), *Anguillidae* (eels – the only species, eel, *Anguilla anguilla*, which occur in Europe), Clupeidae (shad – 1 species), Balitoridae (stone loaches – one species), Esocidae (pike – one species), Lotidae (burbot – one species), Pleuronectidae (righteye flounders – one species), Coregonidae (whitefish – one species), Thymallidae (grayling – one species), Siluridae (catfish – one species). There are no endemic species in the territory of the Czech Republic.

4.9.2. The most significant anthropogenic pressures endangering freshwater fish

Agricultural activity, such as deforestation and soil cultivation belong to the first human activities dating back to the Bronze Age. These activities have resulted in considerable modification of the landscape, and subsequently, changed flow-rates, nutrients and sediments flows have also altered the aquatic ecosystems. Similarly, the consequences of excessive fishing, their translocations and introductions have been known since ancient Rome. The first regulations of water streams (Roman aqueducts) were introduced at that time but only reached considerable intensity in the 19th and 20th centuries due to

*Note: There are 300–500 new fish species being described each year by scientists across the world. In Europe, there are about 5–10 new freshwater fish out of this number. At present, it is assumed that about 18 out of the 564 species have not been described satisfactorily and it is also expected that entirely new species would be described. The estimate of the total number of native freshwater fish ranges from 700 to 800 species, in comparison with 160–270 species recorded in the 19th century. The centre of the species diversity in Europe is the Mediterranean Sea area, where the majority of new species have been located. Most of the newly described species are, however, listed among endangered species (Freyhof and Brooks, 2011). Due to the development of molecular methods, several taxonomic changes have occurred also in the Czech Republic recently, respectively, the original genus *Gobio* was divided into two genera – the *Gobio* sp. genus with the species *G. gobio*, *G.obtusirostris* and probably also other species *G. carpathicus,* and the genus *Romanogobio* with the species *R. belingi*, *R. vladykovi, R. banaticus* and probably one other species (Mendel, personal information, 2012). On the other hand, Kessler's gudgeon *(R. kessleri)* does not occur on Czech territory (Mendel et al., 2008). The taxonomic situation of the *Cobitis* sp. genus is rather complicated since probably only Danubian spined loach (*Cobitis elongatoides*) is the genuine species occurring on Czech territory, and in dependence on river basin, there are the so-called hybrid diploid polyploid complexes (Ráb and Bohlen, 2001) which share the genome, apart from *C. elongatoides,* also with other species *C. taenia* and *C. tanaitica* (Ráb and Lusk, 1998; Hanel and Lusk, 2005). The overall determination of species number of Czech ichthyofauna is also very difficult, and varies according to individual authors. This publication does not consider three-spined stickleback (*Gasterosteus aculeatus*) as a representative of native species, in accordance with other authors (Lusk et al., 2010; Musil et al., 2010). Neither tubenose goby (*Proterorhinus semilunaris*) is considered native as its expansionary character of spreading from one area and other biological characteristics correspond to an expansionary invasion phase that is typical for invasive non-native species (Musil et al., 2010).

the use of new technologies. With the industrialization of Europe in the 19th century, another negative factor was added to the existing problems of the aquatic ecosystem's degradation, which was the aerial (non-point) and point source pollution. The 20th century is characterized by, above all, the mass construction of water works, that have often served for hydroenergetic and water management purposes (Fig. 4.9.2.), and general stream regulations, which is a phenomenon known as river network fragmentation. Fragmentation has reached extraordinary dimensions especially in the Western Europe and in the Czech Republic and it has continued basically to the present day. The original riverine environment (lotic) has been considerably modified by the construction of artificial obstacles (weirs and dams) in the standing (lentic) environment. The native river communities (rheophilous) have been gradually substituted by eurytopic, often non-native, more tolerant, species.

Although there are many anthropogenic pressures (some of which, for example, water contamination, are elaborated on in chapters 3.3., 3.4. and 5.5.) from the current European point of view, the most significant pressures endangering the biodiversity of aquatic ecosystems are uncontrolled water off-takes, fragmentation and hydroenergetics, non-native species and recreational fishery.

Water off-takes

Uncontrolled, often illegal, water off-take for agricultural purposes represents a considerable threat in the Mediterranean Sea area, which is, from the point of view of the biodiversity of fish, the most valuable part of Europe (Freyhof and Brooks, 2011). These water off-takes are characterized by the fact that water does not return back to the river system, and although the off-takes are often seasonal, they still represent a fundamental factor limiting the existence of fish populations. Commercial use of water, in comparison with biodiversity conservation, is often given preference, which is a phenomenon not only confined to southern Europe. In the Czech Republic, water off-takes, which are typical with the fact that water is returned to the system, represent a considerable threat and these are often connected with activities of hydroelectric power stations (HPS) and they are thus discussed below.

Fragmentation and hydroenergetics

The possibility for organisms to spread freely is an essential condition for their natural behaviour, realisation of the life cycle and their occurrence in time and space. With respect to migrations between different types of aquatic ecosystems (sea and inland streams) and their environments (lower and middle stretches of streams, headwaters), organisms are limited by artificial obstacles.

The construction of weirs, locks and reservoirs has a very long history, dating as far back as the Middle Ages, not only in Europe but especially in the Czech Republic. For example, the oldest reservoir in Europe – the Jordán Reservoir in Tábor – was built in the Czech Republic back in 1492. Similarly, the Czech river network was interrupted by the massive construction of pond systems in the Middle Ages, which was especially common in the Pardubice region, southern Bohemia and Moravia. In the course of the 19th century, much more significant factors were gradually added to the construction of weirs with raceways for mills and wood processing – which used water gradients for electric power production, and the construction of water works for the water management and hydroenergetic purposes. The outcome of the above-mentioned activities in Europe was considerable fragmentation, and in the Czech Republic an absolutely impassable river network. In connection with the increasing fragmentation, a considerable decrease in migrating fish populations was already observed in the last century.

It was not only in the Czech Republic, where the increasing fragmentation of rivers (construction of artificial obstacles and water works) has led to a considerable decrease to the populations of most rheophilic species (Lucas and Baras, 2001) and to the partial to almost total disappearance of specialised diadromous species (Béguer et al., 2007). Although such status has resulted from several anthropogenic pressures (fishing, fishery management, pollution, climate changes, modification or loss of native habitats as a result

Fig. 4.9.2. ***The fragmentation of the river network in the Czech Republic is the cause of one of the most significant anthropogenic pressures.*** *River barriers on the main migration corridors influence, among others, the natural distribution area of diadromous species that once inhabited the environment in abundant numbers in the past (regulated stretch of the middle Elbe River, the Dolní Beřkovice weir in Mělník; photo: J. Musil).*

of regulation and alteration of stream beds), the essential impact on the reduction or limitation of free migration is utterly evident on the example of the current area of occurrence of diadromous species that are limited by the presence of the first reservoir on a stream (Fig. 4.9.2.). Diadromous (anadromous and catadromous) species require within their life cycle periodic migrations in both directions and over long distances. Therefore, they currently belong to the group of organisms that are the most endangered by the fragmentation. There are many species in Europe (e.g., houting *Coregonus oxyrinchus*; lamprey of the *Eudontomyzon* sp. genus in their anadromous form) and in the Czech territory (e.g., Allis shad *Alosa alosa*; flounder *Platichthys flesus*; European sturgeon and beluga) that have already disappeared or whose existence is entirely dependent on artificial stocking (sturgeon, eel, Atlantic salmon). Also, river fragmentation negatively affects many other species including potamodromous fish and on a global scale is a threat to all aquatic organisms.

Ecological effects associated with the construction and operation of hydroelectric stations represent an important negative factor that is connected to fragmentation. Their operation causes mechanical injuries and direct mortality of migrants when passing through the turbine, which is known as "turbine mortality". Although there is a wide range of possible technological corrective measures that represent prerequisites for hydroelectric power stations' (HPS) operation in many countries, they are not common in the Czech Republic. Besides, no measure that would entirely eliminate the mortality has yet been established. For example, hydroenergetics, which has received political support under the title "green energy", absolutely ignores the real ecological impact of turbine mortality on the European eel, which regularly exceeds the level of 60% with small hydroelectric power stations (SHPS). If we consider the cumulative effect of all hydroelectric power stations on a river which an adult fish has to pass through during its migration to the Sargasso Sea in order to reproduce, its chances of survival (= migration success rate) are minimal. It is no surprise that this species, which was common in the past, has been added to the Red list of critically endangered species. Turbine mortality does not relate only to eel, but also represents a threat to all migrating organisms. In addition to the above-mentioned direct impacts, hydroenergetics is also connected to water off-takes from rivers, which have often been planned at their maximums (and often even exceeded), in order that several corporations gained profit. Alterations to the natural hydrological regime can thus considerably influence not only the abiotic and biotic parameters of the riverine environment but also the functionality of the corrective measures themselves, such as, for example, fishways.

Negative impacts of river fragmentation connected to the existence of artificial obstacles, however, extend well beyond the issue of the free migration of aquatic organisms, including spatial isolation of populations, since they change irreversibly the native habitats (transport and depositing of sediments, quality and flow-rates in rivers) and they limit the availability of species-specific environment (reproduction areas, shelters for wintering, preferred habitats for foraging for food). These changes, among others, create frequently suitable conditions for the development of biological invasions (Leprieur et al., 2006) and they are connected with the subsequent ecological impacts in the form of the considerable changes to the level of individual populations, species and communities (Musil et al., 2012). The negative impacts of river fragmentation by artificial obstacles should thus be viewed as a complex, since they have an essential influence on the ecological functionality and biodiversity of aquatic ecosystems.

The anthropogenic pressure of fragmentation, in relation to climatic changes and planned measures related to them (extensive construction of reservoirs and the development of hydroenergetics), is currently, together with non-native species, the most significant threat to the sustainability and maintenance of the biodiversity of aquatic ecosystems. European legislation thus requires the restoration of migration passability and aims to improve the ecological status of rivers by means of several legislative measures, such as, for example, Directive 2000/60/EC, which defines the EU's strategy framework when it comes to water policy (The Water Framework Directive); Council Regulation (EC) No. 1100/2007 Coll., establishing measures for the recovery of the stock of European eel; Council Directive No. 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, etc. In order to fulfil the above-mentioned legislation and solve the current poor situation within the Czech rivers, the concept of river network restoration in the territory of the Czech Republic has been established and approved. The first phase is orientated on the construction of fishways (Birklen et al., 2009; Ministry of the Environment, 2010). The accompanying negative factors – hydrologic alterations on the general level have been solved in the Czech Republic via the Ministry of the Environment of the Czech Republic by means of the so-called minimum residual flow-rates. A very promising conceptual strategy, the so-called Ecological limits of hydrologic alteration (ELOHA), has been developed on a global scale (Poff et al., 2010).

Non-native species

The negative impact of non-native species and biological invasion connected with invasive species is currently considered to be one of the most significant factors destroying biological diversity on the planet (Williamson, 1999). Non-native species influence biodiversity and thus a large number of native populations and species of freshwater fish by a wide range of mechanisms out of which the spatial and food competition, direct predation, transfer of new parasites and diseases as well as, e.g., alterations in genetic composition of native populations, are the most significant (Gozlan et al., 2010a). The consequences of

Fig. 4.9.3. ***Amur sleeper, Perccottus glenii, a fish originating from the Far East and North-East of China, is a new invasive species in Europe that has been spreading through the Danube River basin further to the west.*** *Its arrival in the Czech Republic is highly probable (photo: J. Musil).*

the arrival of non-native species have often been more significant in areas where native piscivorous fish are missing or in communities with low species diversity. In these cases, the native species are often very quickly replaced by non-native species better equipped for competition than the fish communities in lower stretches of large rivers that are rich with species. Control over the introduction of non-native species is thus an important task (Fig. 4.9.3.), and its successful implementation is also a necessary prerequisite for the conservation of the current biodiversity.

The importance of monitoring can be demonstrated by the successful invasion of the topmouth gudgeon *Pseudorasbora parva*. This species, originating from the South-East Asia (Mongolia, China, Korea, Japan), was introduced into Europe with herbivorous fish by the pond aquaculture sector in Romania. Over the next 40 years it has spread across the entire European continent due to the non-existence and/or non-functionality of control mechanisms, and has had a negative impact on native fish communities (Gozlan et al., 2010b). However, the majority of non-native fish and, above all, the most dangerous species from the biodiversity conservation point of view, do not originate from the Far East or exotic countries, but from Europe (Fig. 4.9.4.). Recreational fishery represents a significant introduction vector – "legal" as well as illegal stocking by anglers (Rahel, 2004). Classical examples are pike (*Esox lucius*), European catfish (*Silurus glanis*) or pikeperch (*Sander lucioperca*) – attractive "large piscivorous fish" that have become a subject of many introductions across Europe, such as, for example, in Spain or Italy. At present, these species (their fishing above all) have been popularized and publicized in those areas in which they are non-native. The main reason is that due to their better competitive abilities and the characteristics of the non-native area (warmer climate) they have occurred in large numbers and considerable sizes. However, forage (prey) species, often notoriously known as invasive species, such as gibel carp (*Carassius bigelio*), have been introduced together with them to provide ideal bait. The Ebro River currently represents the most drastic example of the impact of

Fig. 4.9.4. ***The most dangerous fish species, in the context of the conservation of biodiversity, do not originate from the Far East or exotic countries, but Europe.*** *Recreational fishing represents a significant introduction vector – "legal" as well as illegal stocking conducted by anglers. A classical example is the European catfish (Silurus glanis), which has been introduced across Europe due to its appeal to humans. In Spain and Italy, its introductions have had profound ecological impacts (photo: J. Musil).*

introductions conducted for recreational fishing purposes in Europe, since only after a few years, the local ichthyofauna have comprised fish communities of the Central Europe, including invasive representatives, that are attractive for anglers, however, the native fish species are totally absent (García-Berthou, 2007).

Non-native species represent a considerable threat in Czech waters. In the Czech Republic, where a large number of introductions (42 introduced species*) were carried out in the past mainly by the aquaculture and recreational fishery sectors as well as for the purpose of bio-manipulation (Fig. 4.9.5.), 29 non-native species were documented in open waters. Moreover, 20 non-native species have remained in open waters until now, out of which 14 have become established and two are invasive species (topmouth gudgeon *Pseudorasbora parva* and gibel carp *Carassius gibelio*). The number of non-native species, that reproduce naturally, ranges around 27% of the current ichthyofauna of the Czech Republic (Lusk et al., 2010; Musil et al., 2010).

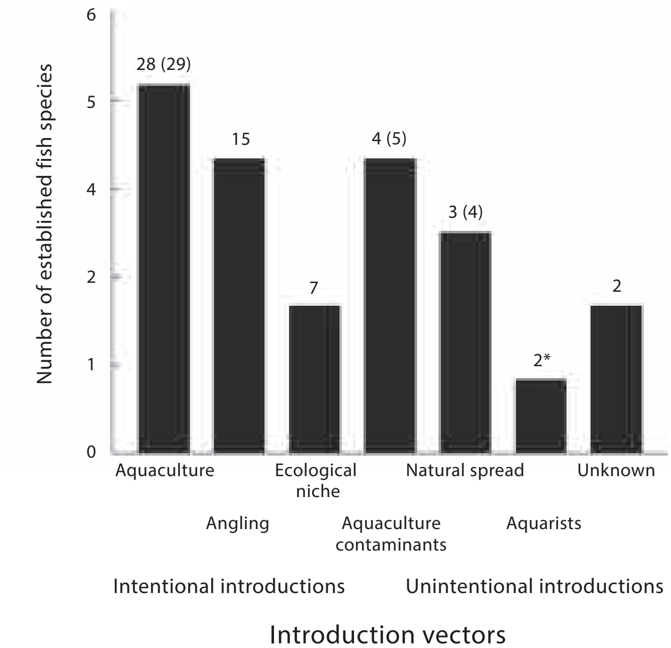

Fig. 4.9.5. ***Introduction vectors of non-native freshwater fish with the number of introduced*** *(number of species are given above the bars and probably introduced species are in brackets)* ***and established species*** *(adapted according to Musil et al., 2010).*

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*Note: Similarly to native species, the determination of the total number of non-native species in the Czech waters has not been unified with respect to individual authors (Adámek and Kouřil, 1996; Lusk et al., 2010; Musil et al., 2010). For example, sturgeon species, that have been known as native from adjacent and hydrologically connected Danube River basins, are not considered as non-native by Musil et al. (2010). However, they have not been classified among native species either as there is not currently enough information concerning their nativeness (Russian sturgeon *Acipenser gueldenstaedtii*; thorn sturgeon *Acipenser nudiventris*; starry sturgeon *Acipenser stellatus).* Discussions and certain ambiguities concerning nativeness to the Czech territory have related also to other species, such as, for example, tubenose goby (*Proterorhinus semilunaris*), as well as common carp (*Cyprinus carpio*) or three-spined stickleback (Froufe et al., 2002; Kottelat and Freyhof, 2007; Musil et al., 2010). Bitterling, *Rhodeus amarus,* have not been ranked among non-native species either which belong, on the contrary, to the protected species under European and international legislation, although, this species is most probably non-native to Czech territory (Van Damme et al., 2007).

The most significant introduction vector of non-native species not only in the Czech Republic is pond aquaculture (intensive aquaculture, as a closed system, is considered safe in relation to biodiversity and therefore, it is not discussed in this chapter) (García-Berthou et al., 2005; Rahel, 2007; Musil et al., 2010). In general, the aquaculture is responsible for many introductions, and is currently dependent on non-native species on a global scale (Gozlan et al., 2010a) as well as in the Czech Republic. However, non-target (undesirable) species have also been introduced by this sector together with intentional introductions and they have typically represented contaminants of fish stocks (e.g., topmouth gudgeon, gibel carp, black bullhead *Ameiurus melas*) (Fig. 4.9.7.). These accidentally introduced species often have a large number of invasive characteristics that lead to a fast adaptation and an increase in their competitive ability, hence the survival success as well (species with a short generation cycle, often with repeated reproduction within one season and parental care, food generalists or piscivorous species, etc.).

Therefore, in many cases, these intruders are able to acclimatize quickly (species acclimatized to local conditions that have not reproduced naturally so far) and have the ability to establish populations (species that reproduce naturally in new territory). If they get into open waters they can become naturalised (species showing ecological qualities of wild organisms) or invasive species. Naturalised species are considered invasive as they have negative influences due to biotic interactions on native organisms on the level of population, species, community, and/or they participate in important ecosystem alterations, for example, in energy flow by influencing the food base, etc. Thus, aquaculture represents a significant vector of non-native

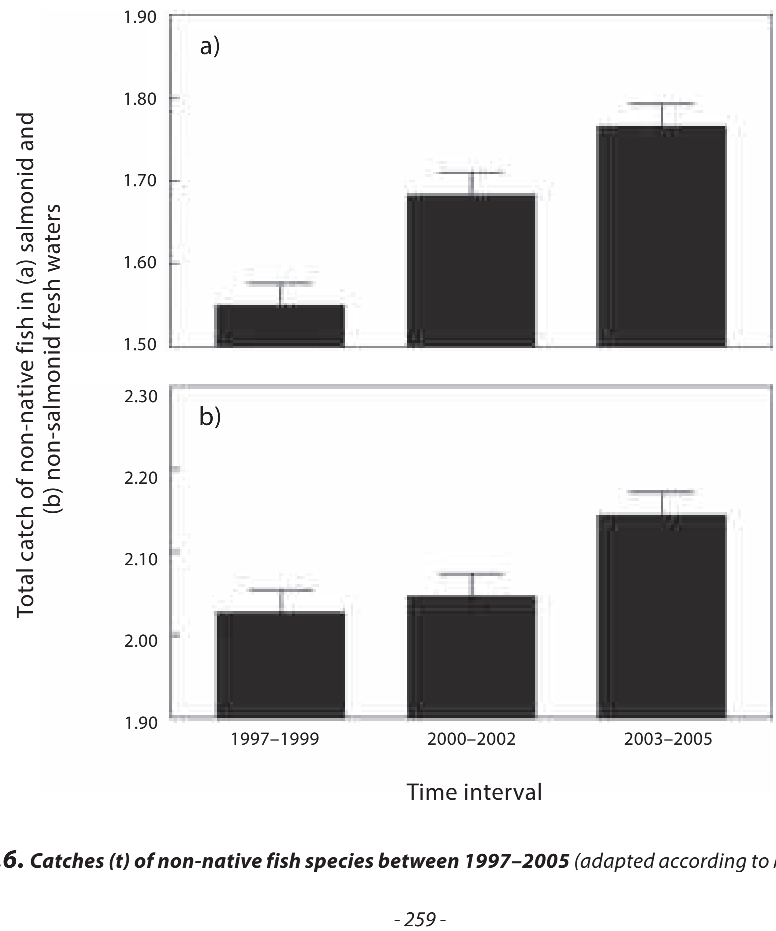

Fig. 4.9.6. ***Catches (t) of non-native fish species between 1997–2005*** *(adapted according to Musil et al., 2010).*

organisms transport. As the aquaculture is logically connected with frequent transfers of fish stocks, these non-target species might spread quickly. The mechanism of introducing non-native species (introduction vector) into open waters are mainly aquaculture escapees (Musil et al., 2007) or their intentional stocking.

The second most significant vector for the introduction of non-native species in the Czech Republic is the recreational fishery. Apart from own production of stocks in ponds or stocking of fish originating from aquaculture involving identical risks as pond aquaculture, the target non-native species have been stocked in open waters intentionally in order to increase the attractiveness and the species richness of catch species. Although the majority of these introductions have not been successful or it has concerned the acclimatized species (Table 4.9.1.) that do not reproduce naturally under regular circumstances, it is clearly evident from the Fig. 4.9.6. that the catches of non-native species have increased considerably due to the mass stocking. This fact is alarming especially in salmonid fishing grounds (rainbow trout *Oncorhynchus mykiss*; brook trout *Salvelinus fontinalis*). Apart from stocking itself, recreational fishery represents a dangerous vector of introductions and the spread of non-native species by using non-native organisms as bait that are released alive into the wild nature after the fishing is over.

Another introduction vectors and methods of non-native species spreading comprise mainly targeted introductions for the purpose of bio-manipulation through the so-called "top-down control" – influencing various trophic positions in the food chain in order to modify the nutrient flow (silver carp *Hypophthalmichthys molitrix*; bighead carp *Hypophthalmichthys nobilis*; grass carp *Ctenopharyngodon idella*) and reduce the undesirable vegetation (grass carp) or organisms (black carp *Mylopharyngodon piceus*) in aquaculture. Next, it comprises the spread of non-native species through hydrological systems, which is often accompanied by other human activities (navigation), escape of non-native organisms from ornamental or aquarium farms, etc.

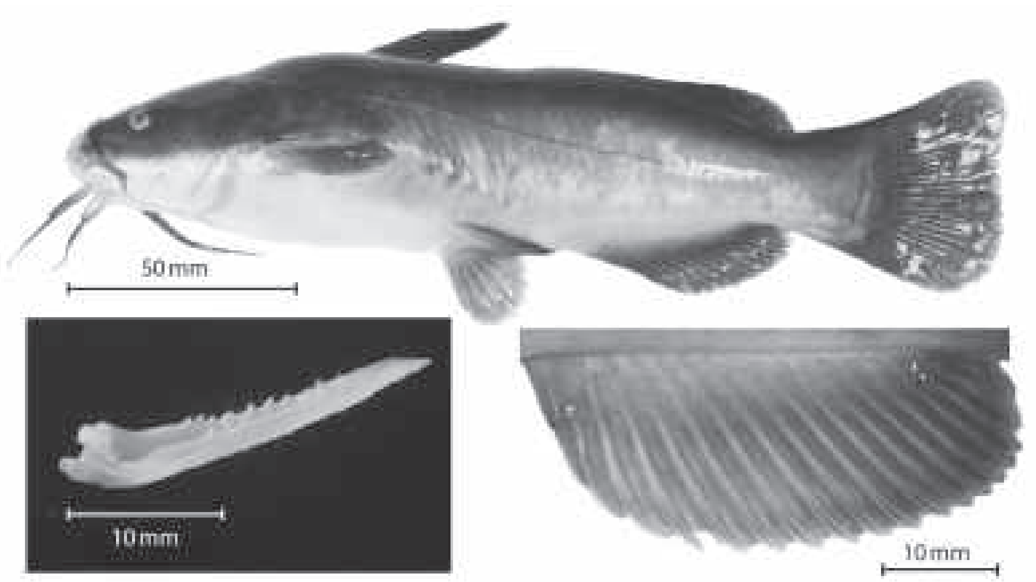

***Fig. 4.9.7.* In 2007, another catfish (Ictaluridae) native to North America – black bullhead, Ameiurus melas, was noticed in Czech open waters (Musil et al., 2008a).** *This species resembles to a great extent its closely related species on the basis of the external morphology – brown bullhead (Ameiurus nebulosus) which also inhabits Czech waters. In order to secure safe identification, it is advisable to use the geometric morphology methods and/or analysis of m-DNA (Musil and Petrtýl, unpublished, photo: M. Bláha).*

A considerable dependence on demographic, socioeconomic and political factors has been evident from the detailed analysis and chronological order of non-native species' introductions, and the general level of biological invasions (with respect to invasive species) (Lockwood et al., 2009). It is also typical that the majority of non-native species and especially invasive species have been introduced and spread by a combination of many factors and methods. As an example, we can look at two invasive fish species, the gibel carp and the topmouth gudgeon, whose successful invasion was caused by two significant introduction factors (aquaculture escapees, contaminant of fish stock during stocking, forage/bait fish), however, their invasion was considerably accelerated also by their spread within the hydrological system (Lusk et al., 2010; Musil et al., 2010). Nowadays, crucial factors influencing the species-specific ability to establish, and thus become a potentially invasive species, have been described (García-Berthou et al., 2005; Jeschke and Strayer, 2006).

Our current knowledge on what threats and risks the non-native species represent for biodiversity is still very limited. The majority of work on this the issue of the ecological effects of non-native fish species in the Czech Republic (summarized by Adámek and Kouřil, 1996; Lusk at al., 2010; Musil et al., 2010) have focused until now on the spatial and food competition, predation, transfer of new parasites and diseases, hybridization, etc., which means the mechanisms with which the non-native species can influence biodiversity. It must be stated that many native fish species that are stocked from the aquaculture, can have similar effects. The studies that would really demonstrate the negative impacts of non-native species on the biodiversity through population decrease, limitation/disappearance of a concrete species or alterations within a community, structure or the ecosystem functionality , have been missing for the time being. The study of ecological impacts of non-native species is, in addition to that, complicated by the considerable synergic influences from other anthropogenic pressures (Didham et al., 2007).

To understand the process of how non-native species are introduced into open waters, what are their abilities to establish and how they spread (Rahel, 2004, 2007), a risk assessment including knowledge of the causal ecological impacts (Didham et al., 2007; Gozlan et al., 2010a), play a crucial role in the successful prediction and control of biological invasions. The basic steps leading to effective conservation of biodiversity are paying increased scientific attention to the topic of biological invasion, and the development of control mechanisms, management measures (eradication, education, etc.) and the necessary legislative support. These factors are basically missing in the Czech Republic. In addition to that, a mental shift in society from the current preference and classification of desirable species (stocked and introduced species), undesirable (species that are necessary to be eliminated) and commercially non-valuable species (species left to their own destiny) is required.

Table 4.9.1. ***Non-native species of the Czech ichthyofauna.*** *The status comprises information relating to the naturalization process (Ex – extinct; A – acclimatized, E – established, N – naturalised species, NA – not applicable due to absence of relevant information), population trend (with respect to established or naturalised species) (L – local population, W – widespread or occurrence) and invasive species (In – invasion, NA – not applicable due to absence of relevant information). Further information is provided in Musil et al. (2010).*

Species in Latin	Species in English	First introduction	Naturalisation	Population trend
Acipenseridae[0]				
Acipenser baerii[1]	Siberian sturgeon	1982	A	
Polyodontidae[0]				
Polyodon spathula	American paddlefish	1995	A	
Catostomidae[2]				
Ictiobus cyprinellus	Bigmouth buffalo	1986	A	
Ictiobus niger	Black buffalo	1986	A	
Centrarchidae				
Ambloplites rupestris	Rock bass	1892	Ex	
Enneacanthus sp.		1914	Ex	
Lepomis gibbosus[3]	Pumpkinseed	1929	E	L, NA
Lepomis auritus	Redbreast sunfish	?	Ex	
Micropterus dolomieu	Smallmouth bass	1889	Ex	
Micropterus salmoides[4]	Largemouth bass	1889	A, ?E	NA
Cichlidae[2,5]				
Oreochromis aureus	Blue tilapia	?		
Oreochromis urolepis	Wami tilapia	?		
Oreochromis mossambicus	Mozambique tilapia	?		
Oreochromis niloticus	Nile tilapia	1985		
Clariidae[2,5]				
Clarias gariepinus	North african catfish	1986		
Coregonidae				
Coregonus albula	Baltic cisco	1889	Ex	
Coregonus autumnalis	Arctic omul	1959	Ex	
Coregonus maraena[1]	Maraene	1882	A, E	W
Coregonus peled[1]	Peled	1970	A, E	W
Cyprinidae				
Carassius auratus	Goldfish	?	NA	NA
Carassius gibelio[3,6]	Prussian carp	1961	N	W, In
Carassius langsdorfii[6]	Ginbuna	?	NA	NA
Ctenopharyngodon idella[4]	Grass carp			
Hypophthalmichthys molitrix[1,4]	Silver carp			

Species in Latin	Species in English	First introduction	Naturalisation	Population trend
Hypophthalmichthys nobilis[1,4]	Bighead carp			
Mylopharyngodon piceus	Black carp			
Pseudorasbora parva[3,6]	Topmouth gudgeon	1982	N	W, In
Rhodeus amarus[3,6]	Bitterling	?	N	W, NA
Gasterosteidae				
Gasterosteus aculeatus[6]	European three-spined stickleback	?	N	L
Gobiidae				
Neogobius melanostomus[6]	Round goby	2008	E	L, NA
Proterorhinus semilunaris[6]	Western tubenose goby	1994	N	W, ?In
Channidae				
Channa argus	Snakehead	1956	Ex	
Ictaluridae				
Ameiurus melas[3]	Black bullhead	2003	E	L, NA
Ameiurus nebulosus	Brown bullhead	1890	N	L, NA
Ictalurus punctatus	Channel catfish	1985	A	
Salmonidae				
Oncorhynchus clarkii	Cutthroat trout	1905	Ex	
Oncorhynchus mykiss[4,7]	Rainbow trout	1888	A, E	W
Salvelinus alpinus	Arctic charr	1581	Ex	
Salvelinus fontinalis[4,7]	Brook trout	1883	A, E	W
Salvelinus namaycush	American lake trout	1972	Ex	
Thymallidae				
Thymallus arcticus	Siberian grayling	1959	Ex	

[0] breeding in intensive and pond aquaculture, ornamental fish and stocking for the purpose of recreational fishery in private fishing grounds
[1] species occurring mainly in the form of hybrids
[2] species that are no longer regularly bred in the Czech Republic but have been kept individually
[3] non-target introduced species, contaminants of fish stocks (species whose path of introduction is known are listed in brackets)
[4] species that are stocked in open waters (whose existence in the wild is dependent on stocking)
[5] thermophilic species bred solely for intensive aquaculture
[6] species with a known "natural spreading" (species whose path of introduction is known are listed in bracket)
[7] local established populations are known, however, extensive area of occurrence results from stocking

Recreational fishery

Recreational fishery (= sport fishing) has become a globally expanding sector owing to improving standards of living and growing demands for relaxation and free-time activities. In the Czech Republic, where it has been historically well-organised, recreational fishery fulfils a wide range of functions far greater than just maintaining the productivity of water by fishing. It directly involves activities that are connected with the conservation of some fish species, such as the return of the Atlantic salmon to the Czech Republic (Fig. 4.9.8.).

Fig. 4.9.8. Artificial spawning of the Atlantic salmon pair (Salmo salar) caught in the spawning ground *on 2nd November 2011 (total length of male = 72 cm, weight = 3.02 kg; total length of female = 84 cm, weight = 4.20 kg; the Kamenice River; photo: M. Trýzna).*

At present, recreational fishery is generally distinguished also by an intense management representing the reaction to the fast development of this sector and a considerable increase in numbers (for example, in the Czech Republic, there are about 350000 anglers who belong to the Czech and Moravian Anglers Union). The introductions of "attractive" sport non-native species represent a frequent management measure (Cambrey, 2003; Cowx et al., 2010) risk rate of which has been discussed above. In a similar way, the negative impact of the current mass stocking of typically sport attractive species on the diversity and structure of fish communities (due to the spatial and food competition, predation, transmission of diseases and parasites, hybridization, etc.), thus on aquatic ecosystems in general, have also been known and documented (Cambray, 2003; Cowx et al., 2010; Welcomme et al., 2010). The risk rate considerably increases if the stocking of fish is accompanied by transfers of fish from other river basins (loss of genetic identity and variability of populations) or aquaculture (transmission of diseases and parasites, spatial competition, hybridization) (Muhlfeld et al., 2009), and if stocking plans do not respect natural fish communities and are not derived from them (do not support natural reproduction of fish). Also if there are no so-called "quiet zones" that represent important areas especially for those species that are not subjected to fishing (Cowx et al., 2010).

4.9.3. The Red list of endangered species

The status of endangered plants and animals serves as one of the most used ecosystem indicators and it provides current information about issues of endangerment and the necessity of conservation. The status of endangerment is thus an important tool to determine the priorities of species conservation. Hence, this system is used within a whole range of legislative framework dealing with species conservation and diversity around the world. Globally, the best information source of information about endangered plants and animals is the database of the International Union for Conservation of Nature (IUCN), the so-called Red List of endangered species (www.iucnredlist.org). This list has been compiled in order to determine the relative risk of species extinction, with the main aim to catalogue and identify the most endangered taxons. At the same time, the list provides the basic taxonomic information, status of endangerment and information about how many times the target species has been subjected to assessment (IUCN, 2001). The Red List comprises in total nine categories ranging from "least concern" for those species that are not currently under threat, to "extinct" for those species that no longer inhabit the earth. This categorization is based on a set of quantitative criteria that are in relation to population trends, size and structure of populations, including geographical area of occurrence. The species, that are classified as "vulnerable", "endangered" and "critically endangered" are considered endangered in general.

The risk of species endangerment can be assessed on a global, regional or national level. One species can be assessed in a different category, for example, on the global or national Red List of endangered species. The classical example represents species globally assessed in the category "least concern" (LC), however, a large number of which are endangered by several anthropogenic pressures not only on the regional, but also national level, and therefore, they are assessed, for example, in the national Red List of fish and lampreys of the Czech Republic (Lusk et al., 2004) as endangered species (Tab. 4.9.2.). The rules and criteria for the classification of the individual categories were set down in the IUCN methodical instructions (2003), but they have been, for example, in the case of the national Red list of fish and lampreys, modified due to the lack of relevant data (Lusk et al., 2004). The classification of endemic species is naturally identical to the global level as well as the regional level. However, in the case of regional or national red lists, there are two other categories that are used – "regionally extinct" and "not applicable" (IUCN, 2003).

Table 4.9.2. ***Native species of the Czech ichthyofauna.*** *Information includes the terminology used by Kottelat and Freyhof (2007), the status of species endangerment according to the IUCN, international species conservation within the Bern Convention, Council Directive 92/43/EEC on the conservation of natural habitats and CITES, including the national legislation – the Decree No. 395/1992 Coll. and the Decree No. 166/2005 Coll. Old species' names that are no longer current are in brackets.*

Species in Latin	Species in English	IUCN Europe	IUCN CZ	Decree 395/1992 Coll.	Decree 166/2005Coll.	Bern Conven-tion	Directive on Natural Habitats	CITES
Acipenseridae								
Acipenser ruthenus	Sterlet	VU	NE		appendix 2C	III	V	II
Acipenser sturio	European sturgeon	CR	RE			II	II, IV	I
Huso huso	Beluga	CR	RE			II, III	V	II
Anguiilidae								
Anguilla anguilla	European eel	CR	NT					II
Clupeidae								
Alosa alosa	Allis shad	LC	RE			III	II, V	
Balitoridae								
Barbatula barbatula	Stone loach	LC	LC					
Cobitidae								
Cobitis elongatoides[2]	Danubian spined loach	LC	EN		appendix 2A	III	II	
Cobitis taenia[2]	Northern spined loach	LC		ST	appendix 2A	III	II	
Cobitis tanaitica[2]	Don spined loach	NA			appendix 2A	III	II	
Misgurnus fossilis	Weather loach	LC	EN	EN	appendix 2A	III	II	
Sabanejewia aurata[0]	Golden spined loach	LC		CR	appendix 2A	III	II	
Sabanejewia balcanica	Balkan golden loach	LC	CR		appendix 2A	III	II	
Cyprinidae								
Abramis brama	Common bream	LC	LC					
Alburnoides bipunctatus	Spirlin	LC	VU	ST		III		
Alburnus alburnus	Bleak	LC	LC					
Aspius aspius	Asp	LC	LC		appendices 2A,C	III	II,V	
Ballerus ballerus (Abramis ballerus)	Blue bream	LC	VU			III		
Ballerus sapa (Abramis sapa)	Zobel	LC	CR	EN		III		
Barbus barbus	Barbel	LC	NT		appendix C		V	
Blicca bjoerkna	Silver bream	LC	LC					
Carassius carassius	Crucian carp	LC	VU					
Chondrostoma nasus	Nase	LC	EN			III		
Cyprinus carpio	Common carp	VU	CR	EN				

Species in Latin	Species in English	IUCN Europe	IUCN CZ	Decree 395/1992 Coll.	Decree 166/2005Coll.	Bern Conven-tion	Directive on Natural Habitats	CITES
Gobio gobio	Common gudgeon	LC	LC					
Gobio obtusirostris[1]	Danube gudgeon	LC						
Leucaspius delineatus	Sun bleak	LC	EN					
Leuciscus idus	Ide	LC	VU	EN				
Leuciscus leuciscus	Dace	LC	LC					
Pelecus cultratus	Razor fish	LC	CR	ST	appendices 2A,C	III	II,V	
Phoxinus phoxinus	Minnow	LC	VU	EN				
Rhodeus amarus[3] *(Rhodeus sericeus)*	Bitterling	LC	LC	EN	appendix 2 A	III	II	
Romanogobio albipinnatus	Volga whitefin gudgeon	LC	VU		appendix 2 A	III	II	
Romanogobio belingi[1]	Northern whitefin gudgeon	LC				III	II	
Romanogobio vladykovi[1]	Danube whitefin gudgeon	LC				III	II	
Romanogobio kessleri[0]	Sand gudgeon	LC	CR	CR	appendix 2 A	III	II	
Romanogobio banaticus[1]								
Rutilus pigus	Pigo	LC	RE	EN		III	II,V	
Rutilus rutilus	Roach	LC	LC					
Scardinius erythrophthalmus	Rudd	LC	LC					
Squalius cephalus (Leuciscus cephalus)	Chub	LC	LC					
Tinca tinca	Tench	LC	LC					
Vimba vimba	Vimba	LC	VU			III		
Esocidae								
Esox lucius	Pike	LC	LC					
Lotidae								
Lota lota	Burbot	LC	VU	EN				
Percidae								
Gymnocephalus baloni	Danube ruffe	LC	CR	ST	appendix 2A,B	III	II,IV	
Gymnocephalus cernua	Ruffe	LC	LC					
Gymnocephalus schraetser	Yellow pope	LC	CR	EN	appendices 2A,C	III	II,V	
Perca fluviatilis	European perch	LC	LC					
Sander lucioperca (Stizostedion lucioperca)	Pikeperch	LC	LC					
Sander volgensis (Stizostedion volgense)	Volga pikeperch	LC	NT			III		
Zingel streber	Streber	LC	CR	CR	appendix 2A	III	II	
Zingel zingel	Zingel	LC	CR	CR	appendices 2A,C	III	II, V	

Species in Latin	Species in English	IUCN Europe	IUCN CZ	Decree 395/1992 Coll.	Decree 166/2005Coll.	Bern Conven-tion	Directive on Natural Habitats	CITES
Petromyzontidae								
Eudontomyzon mariae	Ukrainian brook lamprey	LC	CR	CR	appendix 2A	III	II	
Lampetra fluviatilis	European river lamprey	LC	RE		appendix 2A,C	III	II, V	
Lampetra planeri	European brook lamprey	LC	EN	CR	appendix 2A	III	II	
Petromyzon marinus	Atlantic sea lamprey	LC	RE			III	II	
Pleuronectidae								
Platichthys flesus	Flounder	LC	RE					
Coregonidae								
Coregonus oxyrinchus	Houting	EX	RE		appendix 2C	III	V	
Salmonidae								
Hucho hucho	Huchen	EN	RE		appendix C	III	II,V	
Salmo salar	Atlantic salmon	NE	CR		appendix 2A,C	III	II, V	
Salmo trutta m. *trutta*	Sea trout	LC	RE					
Salmo trutta m. *fario*	Brown trout	LC	LC					
Thymallidae								
Thymallus thymallus	Grayling	LC	NT		appendix C	III	V	
Cottidae								
Cottus gobio	Sculpin	LC	VU	EN	appendix 2A		II	
Cottus poecilopus	Siberian sculpin	LC	VU	EN		III		
Siluridae								
Siluris glanis	European catfish	LC	LC			III		

0 species that are subject to national legislation but not occurring on Czech territory, according to the latest available information
1 newly described native species that are not subject to national legislation yet
2 species that occur in the form of hybrid diploid-polyploid complex
3 very probably non-native species

Note: In the Decree No. 166/2005 Coll., all species of loach are defined as loach of genus *Cobitis* contrary to the Decree No. 395/1992 Coll., where only one species, northern spine loach, is stated, but this species does not occur in the Czech Republic. Similarly to that, the Golden spined loach, that is defined in the Decree No. 166/2005 Coll. as *Sabanejewia aurata/balcanica* is not subject to the Decree No. 395/1992 Coll., where the Balkan golden loach is defined. There are also other inconsistencies, mainly in connection with the changes in taxonomic classification.

Endangered freshwater fish species in Europe

At the European level, 37% of freshwater fish species have been classified as endangered, out of which 12% are "critically endangered" species, 10% are "endangered" species and 15% are "vulnerable". At the same time, 4% of species are classified as "near threatened". Thirteen species are globally assessed as "extinct", out of which 10 occurred only in Europe (Fig. 4.9.9.). The problem of assessment is the unavailability of objective, relevant data relating, above all, to population trends (IUCN requires data lines for the last 10 years, i.e., at least three generations). On that ground, the use of other available data, for example, from monitoring within the Water Framework Directive, are being considered because it is probable that by specifying the population data of individual species, more endangered species would be identified than at present. The most dramatic population decreases were recorded in the Western Europe between 1890–1990. The population decrease has slowed during the past two to three decades and with respect to some populations, they have become stabilized, although they have not achieved the same levels as before the impact of anthropogenic pressures.

As far as individual taxonomic groups are concerned, the most endangered group are sturgeons, whose existence is today dependent exclusively on artificial reproduction and stocking. With respect to Adriatic sturgeon (*Acipenser naccarii*), European sturgeon (*A. sturio*) and Persian sturgeon (*A. persicus*), no natural reproduction have been recorded over several decades and these fish would be soon classified as extinct without human assistance. Regarding other representatives, such as stellate sturgeon (*A. stellatus*), Russian sturgeon (A. *gueldenstaedtii*) or beluga (*Huso huso*), only residual populations and a few reproduction areas have been recorded, which have all been localized in the lower stretch of the Danube River, i.e., within the European Union. European eel (*Anguilla anguilla*) belongs among other highly endangered species which is currently classified in the category of "critically endangered" and it is the only representative of the Anguillidae family in Europe (Freyhof and Brooks, 2011). From the individual taxonomic groups point of view the current endangerment of freshwater fish (37%) is the second highest after freshwater molluscs (44%), followed by amphibians (23%) (Cuttelod et al., 2011). Just for comparison, the number of endangered species of reptiles, mammals or birds ranges "only" around 13–19% (Temple and Terry, 2007; Cox and Temple, 2009).

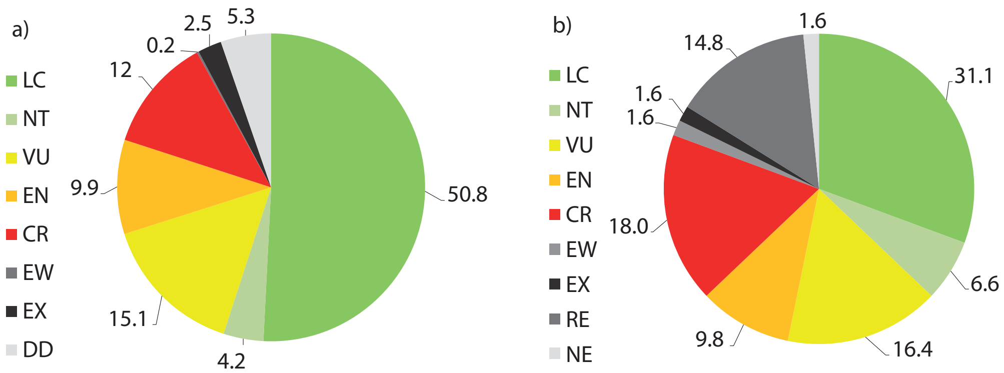

Fig. 4.9.9. Degree of species endangerment within the so-called Red Lists of endangered freshwater fish species *(a) in Europe (adapted according to Freyhof and Brooks, 2011) and (b) in the Czech Republic. (EX – extinct, EW – extinct in wild nature, RE – regionally extinct, CR – critically endangered, EN – endangered, VU – vulnerable, NT – near threatened, LC – least concern, DD/NN – not evaluated/not applicable.*

Endangered freshwater fish species in the Czech Republic

In the Czech Republic, 44% of ichthyofauna is classified as endangered, out of which 18% are "critically endangered" (11 species), 10% are "endangered" (six species) and 16% are "vulnerable" (10 species). At the same time, 7% of species are classified as "near threatened" (four species). 16% of ichthyofauna is assessed as "regionally extinct" (10 species). Due to an unavailability of data, one species, sterlet *Acipenser ruthenus,* has not been assessed (Tab. 4.9.2., Fig. 4.9.9.).

As far as individual groups in the Czech Republic are concerned, potamodromous species requiring both directional free migration for medium distances and species with a biological cycle dependent on river alluvials represent the most endangered species due to river network fragmentation and regulation. Most species from the diadromous fish are already extinct in the Czech Republic and with respect to the last two remaining species (Atlantic salmon *Salmo salar* and European eel *Anguilla anguilla)*, their existence is wholly dependent on stocking. In addition to that, the current Atlantic salmon, which is assessed as "critically endangered" (Lusk et al., 2004, 2011), has been the subject of a reintroduction program, and comes from Swedish populations because the native populations of the Elbe salmon were exterminated in the past by people. The classification of the European eel in the national Red List as a "vulnerable" species (Lusk et al., 2004) does not respect the IUCN population criteria (2003) since its population is fully dependent on stocking without which the eel would probably become extinct in the Czech Republic. The statistics of endangered freshwater fish species clearly document the high bio-indication value of fish towards anthropogenic pressures and the alarming rate of endangerment on the one hand, and insufficient conservation of freshwater ecosystems and their biodiversity on the other hand. This fact obliges each state to be responsible and to protect populations that represent our natural heritage.

4.9.4. Legislative framework relating to the conservation of freshwater fish

National legislation

The development of legislation relating to freshwater fish (ichthyofauna) and their conservation is, in a historical context, and particularly in the Czech territory, very interesting. The first legislation – the Act on Fishery that originated in the 1880s – was adopted thanks to a significant scientist Prof. Antonín Frič. National legislation is the subject of another chapter of this book, and it was last elaborated on in detail by Hanel and Lusk (2005). In brief, it can be summarized that freshwater fish and their conservation in the Czech Republic are primarily subjected to the following legal regulations: the Act No. 114/1992 Coll., on the Conservation of Nature and Landscape, as amended by later regulations, which is the most important protection tool not only of ichthyofauna, including the Decree No. 395/1992 Coll., that implements certain provisions of the above-mentioned Act. Concretely, it comprises a nominal list of specially protected species categorized as critically endangered, endangered and vulnerable. Next, it is the Decree No. 166/2005 Coll., implementing certain provisions of the Act, as amended by later regulations, in connection with the creation of the NATURA 2000 system (Table 4.9.2.). Other legislation relating to ichthyofauna and its environment include: the Act on Fishery No. 99/2004 Coll. and its implementing Decree No. 197/2004 Coll.; the Act No. 254/2001 Coll., on water and amendments to some acts (the Water Act), Government Regulation No. 61/2003 Coll., on indicators and levels of permissible pollution of surface and waste water, requisites of a permit to discharge wastewater into surface water and sewerage system and on sensitive areas; Government Regulation No. 71/2003 Coll., on the determination of surface waters suitable for life and reproduction of indigenous species of fish and other aquatic animals and about the assessment of the water quality; the Decree No. 21/2009 Coll., amending the Decree No. 296/2003 Coll., on animal health and its protection, on the movement and transport of animals, and on the authorisation and professional competence to perform certain professional veterinary activities, as amended, and many others.

Since 1996, when the Czech Republic applied for membership in the European Union, European law has been binding in the Czech Republic, and was incorporated into national legislation during the accession period (1996–2003) as well as in the subsequent periods and the implementation process has been basically in progress until today. Therefore, the current national legislation is based to a large extent on the European Union legislation and international conventions and agreements, if the Czech Republic or the European Union are signatories.

Important international conventions and agreements

The Czech Republic is a signatory of many international conventions and agreements. With regard to the conservation of the biological diversity of freshwater fish, the following conventions are particularly essential:

Convention on Biological Diversity

The Convention on Biological Diversity is one of the most important international conventions in the field of the environment, and it was adopted at the UN conference on environment and development on 5th June 1992 in Rio de Janeiro by 188 states. For the Czech Republic, it came into force on 3rd March 1994. The main objectives of the convention are the conservation of biological diversity at all levels (genetic, species and ecosystem), the sustainable use of its components and access to genetic resources, including fair and equal share of benefits arising from its use. The convention identifies the environmental conservation *in situ* (in the place of occurrence) and *ex situ* (including rescue measures outside the area of occurrence). However, as mentioned by Hanel and Lusk (2005), the convention is only partially guaranteed under Czech legal order and, for example, the issue of genetic diversity, i.e., the conservation at the population level, has not yet been satisfactorily resolved.

(important links:

official website of the Convention on Biological Diversity – http://www.biodiv.org; Information system on the Convention of Biological Diversity of the European Community – http://biodiversity-chm.eea.europa.eu;

Conservation strategy of biological diversity of the Czech Republic – http://chm.nature.cz/cooperation/fol362718).

Convention on the Conservation of European Wildlife and Natural Habitats – Bern Convention

This convention was concluded in Bern, Switzerland, on 19th September, 1979. The Czech Republic acceded to the convention with a number of sometimes curious objections on 27th August, 1997. The Bern Convention Secretariat is based in Strasbourg, in the seat of the Council of Europe. The convention comprises more than 50 contracting parties both from the European and African continents and the European Union is also a contracting party. The objective of this convention is to conserve wild flora and fauna and their natural habitats, urge cooperation among states, lay particular emphasis on the protection of endangered and vulnerable species, including migrating species. Appendices concerning the conservation of the significant European species and sub-species of wild flora (Appendix No. 1) and wild fauna (Appendix No. 2) (Fig. 4.9.2.) are part of the convention. Those are prohibited to be collected, disturbed, damaged, captured from nature, held, traded in the internal market and deliberately killed. Appendix No. 3 refers to animals that may not be strictly protected by parties but these animals should be used in a reasonable way in order that their existence is not endangered. Appendix No. 4 contains a list of prohibited means of hunting or killing animals. This convention has a special control mechanism where citizens or organizations of a state which is a contracting party of the Bern Convention, can notify the Secretariat (managing authority), that, according to their opinion, the government of a particular country does not fulfil, in a particular case, its obligations taken on by the accession to the convention. The permanent Committee shall hear this complaint, if it is justified, and ask the government of the relevant country to provide an official explanation.

If the Committee agree with the complainer, it will suggest concrete recommendations for correcting the matter and ask the state to fulfil them. The case is closed only when the permanent Committee acknowledges that the relevant contractual party has fulfilled adequately these recommendations.

(important links: official websites of the Bern Convention – http://www.coe.int/t/dg4/cultureheritage/nature/bern/default_en.asp)

Convention on International Trade in Endangered Species of Wild Fauna and Flora – CITES

It is also known as the Washington Convention as it was concluded in the capital city of the U.S. at a conference of 80 countries on 3rd March, 1973. The CITES Convention entered into force on 1st July, 1975, and today, more than 175 countries including all 27 EU Member states are signatories of this document. The Czech Republic affiliated to this convention as the former Czechoslovakia on 28th May, 1992 and it was one of the last European countries to do so. Currently, the CITES is a global international agreement under the auspices of the United Nations Environment programme (UNEP) and is considered an important tool for the World Nature Conservation Strategy. It is a government contract which is strongly supported by major international conservation non-governmental organizations, such as the World Conservation Union (IUCN), World Wildlife Fund (WWF), and many others. From the financial and political point of view, the Convention has significant support from the European Union, the USA and other countries. The main objective of this convention is to protect biological diversity and contribute to its sustainable use by ensuring that no species of wild fauna or flora would become, or remain, a subject to unsustainable exploitation owing to international trade, and thus contribute to a significant reduction in the loss-rate of biological diversity. More than 5000 animal species and approximately 28000 plant taxons are subject to the CITES protection. This convention applies not only to live but also dead species, including all ontogenetical stages, body parts and products made of them. According to the degree of endangerment to its existence in nature, they are divided into three lists stated in Appendix I, II and III:

Appendix I. Species directly endangered by extinction, which are or could be endangered by international trade. International trade in these species is prohibited (prohibition of import and export) and is allowed only in exceptional cases. Export permits of an exporting country and also import license of a country where the species is to be imported to must be submitted to custom authorities (in this Appendix, European sturgeon, *A. Sturio*, is included in the list of fish that occurred in the Czech territory).

Appendix II. Species whose situation in nature is not critical but which could be endangered if international trade in them is not regulated in accordance with the principles of the sustainability of renewable natural resources. The main emphasis is laid on permits from an exporting country that confirms that the species being exported is not endangered. Scientific authorities evaluate data on the extent of trade, according to issued permits, and compare them with data on the status of the animal and plant populations. If the trade has caused an excessive decrease in the population they would recommend trade restrictions. In this list, there are also species that are easily interchangeable for endangered species from the Appendix I and II, which simplifies the work of customs and other control authorities (in this Appendix, all sturgeon species and European eel, *Anguilla anguilla*, are included on this list of fish present in the Czech territory)

Appendix III. This Appendix includes species that are endangered by international trade only in certain countries, and that are protected upon request by these countries. For species coming from these countries, it is necessary to submit an export permit granted by the executive authority of an exporting country to the custom authorities. In other cases, the trader shall submit a certificate of origin of these species.

(important links: the CITES Secretariat – www.cites.org;
the CITES in the EU – http://ec.europa.eu/environment/cites/home_en.htm
Ministry of the Environment – www.mzp.cz/cites;
Red list of endangered species – www.redlist.org)

Subsequent selected legislation of the European Union

The Water Framework Directive 2000/60/EC

This Directive of the European Parliament entered into force on 23rd October, 2000 and has established a Union framework action in the field of water policy. The Directive has two main objectives: conservation and enhancement of the ecological status of aquatic ecosystems (it requires, for example, the restoration of the river continuum, therefore, the natural fish environment), and the support of sustainable, balanced and legitimate water usage (including anti-flood protection, etc.). A wide range of significant activities have been implemented within this legislation, for example, plans of river basins, monitoring of bioindicative organisms and the development and evaluation of methods for the assessment of ecological status (at the time of publication of this book, the integration of other indicators, above all, of non-native species, is being considered). The results shall be handed over by each Member State at regular intervals to the managing authority of the EU (more details to be found in chapter 3.3.).

(important links:

Water policy of the EU – http://water.europa.eu/policy;

Common Implementation Strategy – http://ec.europa.eu/environment/water/waterframework/objectives/implementation_en.htm; European Environmental Agency – www.eea.europa.eu/themes/water;

WISE – Water information system for Europe – http://water.europa.eu)

Habitat Directive 92/43/EEC and Natura 2000

The nature conservation policy within the European Union, apart from the above-mentioned Water Framework Directive and international conventions, is established, above all, by two legislative frameworks. The oldest European common legislation on the environment and nature conservation are: the Bird's Directive 2009/147/EC, established in 1979, and the Habitat's Directive 92/43/EEC which has the objective to protect habitats and species occurring in the territory of the EU. The most important for fish vertebrates is the Habitat's Directive, which establishes habitat conservation and the protection of species other than birds, not taking into account whether freshwater, terrestrial or sea ecosystems are concerned. One of the main requirements of this Directive is to identify the "special areas of conservation", their scientific assessment (the scope of anthropogenic pressures) including a proposal of measures to be taken and preparation of suitable management, which should be conducted in connection with the strategy of sustainable development. These areas together with the areas that are subject to conservation, according to the Bird's Directive, represent the essential platform of the current Natura 2000 system – the cornerstone of a common European nature conservation policy. Identification of important localities and species by individual Member States has been implemented under the Habitat's Directive on the basis of the appendices of this Directive, which define the types of habitats and species of European importance. Each Member State is obliged to propose individual Natura 2000 areas for all species listed in the Appendix II and IV (the Appendix IV identifies species requiring strict protection). As far as freshwater fish species are concerned, 202 species are currently listed in the Appendices II and IV (Freyhof and Brooks, 2011), out of which, for 16 species Natura 2000 areas were proposed in the territory of the Czech Republic (Nature Conservation Agency of the Czech Republic, Hanel and Lusk, 2005). The delimitation of areas of "natura species" within the Natura 2000 system is targeted at the maintenance or enhancement of the natural environment (habitats) and thus the conservation of target species. Individual Natura 2000 areas should thus comprise localities that are highly vulnerable owing to occurrence of endangered species, localities inhabited by species having an endemic or limited area of occurrence, or localities representing important reproduction habitats. In the Czech Republic, these localities have been in the majority of cases delimited as independent aquatic biotopes with the occurrence of populations of "natura species" of fish and lampreys. The process of their selection can be found in several publications (e.g., Lusk et al., 2002; Dušek et al., 2004).

Important links:

Natura 2000 of the EU – http://ec.europa.eu/environment/nature/natura2000/index_en.htm; The Ministry of the Environment of the Czech Republic – http://www.mzp.cz/cz/natura_2000; Nature Conservation Agency of the Czech Republic – http://www.nature.cz/natura2000-design3/hp.php;

The Czech Environmental Inspectorate – http://www.cizp.cz/;

State Environmental Fund of the Czech Republic – http:// www.sfzp.cz.

Council regulation No. 708/2007 concerning the use of alien and locally absent species in aquaculture including the Regulation No. 304/2011 amending Council Regulation No. 708/2007

This Directive identifies invasive alien species as one of the main anthropogenic pressures leading to damage to biological diversity, in connection with the Convention on Biological Diversity, which the EU is the contracting party. Each contracting party, if possible and applicable, shall prevent the introduction of alien species which endanger ecosystems, natural habitats or species, and shall control and exterminate such species. The objective of this Regulation, within the European Community, is thus not only to optimize the benefits connected with stocking and transferring of non-native species within aquaculture, but also to minimize or prevent alterations to ecosystems, prevent negative biological interactions with native populations, including genetic alterations, and to eliminate the spread of non-target species (escaped from aquaculture) and the harmful impact on natural habitats.

The Directive strictly differentiates between the closed and open aquaculture with respect to the potential risks of the escape of non-native species from aquaculture (the Regulation of the EU No. 304/2001, amending Council Regulation No. 708/2007), it details the methodical procedures of screening and risk assessment of introductions in accordance with the permission (or prohibitions) governing the introduction of non-native organisms for aquaculture purposes. This Directive relates to all reared alien and locally absent (non-native) aquatic organisms, with the exception of species listed in the Appendix IV. This Directive is the strategic legislation with respect to the control of the most significant introduction method of non-native species in aquatic ecosystems – aquaculture (Musil et al., 2010), however, it has not been incorporated into the national legislation yet.

(important links – Legislation in the EU: http://europa.eu/legislation_summaries/environment/nature_and_biodiversity/l28179_en.htm)

Council regulation No. 1100/2007/EC establishing measures for the recovery of the European eel stock

A considerable population decrease in the European eel, *Anguilla anguilla,* has been observed during the past decade, and has even reached the critical level of more than 1% of their historical abundance. The decrease has resulted from several anthropogenic pressures and their impacts (turbine mortality, trade in the glass eel for intensive aquaculture purposes, introductions and areal spread of non-native parasitic swimbladder nematode *Anguillicola crassus*, fishing, climatic changes and fluctuations in the Gulf stream related to that, predation pressure exerted by the great cormorant *Phalacrocorax carbo,* etc.) (ICES, 2004). These facts have led the European Union to adopt measures (this issue is discussed in detail below), aimed at halting the decrease and restore the European eel population. The objective of this regulation is a guarantee that catadromous (downstream) reproduction migration shall be enabled beyond the territory of each member states for at least 40% of eel populations, with respect to their historical abundance in a given territory before the negative human-induced impact took effect. It is to be implemented by the so-called management plans, under which each member state has suggested measures leading to the fulfilment of the objective of the Directive on the level of international river basins or within their own territory (CZ). Each management plan shall be approved by the managing authority of the EU. Each plan shall contain, apart from the proposal and the prediction of the effectiveness of individual measures, a time schedule stating when the target shall be reached. The management plan of the Czech Republic is managed by the Ministry of Agriculture and can be read in Musil et al. (2008b). In connection with the Council Regulation, the sphere of eel management has been delimited on the basis of the presence of large water works that represent for eels an impassable migration barrier, and so influence eel populations considerably due to the high turbine mortality. This plan comprises also other corrective measures, such as a decrease in turbine mortality, directed stocking in the least risk river basins and the main migrating corridors (stocking is conducted by the Czech Anglers Union). The significant control mechanism is the monitoring of the migration success rate (Musil et al., 2008b), which shall assess the effectiveness of individual measures, including their alterations, in order to fulfil the targets of the Council Regulation. This regulation ensures, apart from conservation of this species, that the glass eel is stocked in open waters of the EU. If the stocking is in connection with the management plan, it is financially supported by means of operational programmes.

(important links: Legislation in the EU – http://eur-lex.europa.eu/cs/index.htm;
Ministry of the Agriculture – www.mze.cz;
Czech Anglers Union – www.rybsvaz.cz)

4.9.5. International Action plans for important diadromous species

At present, there is officially no fish species in the Czech Republic for which an action plan has been established (Hanel and Lusk, 2005; Agency for Nature Conservation and Landscape Protection of the Czech Republic). The only exception is the European eel, which represents the subject of the Management Plan of the Czech Republic in connection with the Council Regulation No. 1100/2007. Another species that is subjected to international action plans and that occur in the Czech territory is the Atlantic salmon (*Salmo salar*).

European eel (*Anguilla anguilla*)

The European eel (Fig. 4.9.10.) occurs along the Atlantic coastline of the European continent southward to the Canary Islands, in estuaries of the Mediterranean, North and Baltic Seas and very rarely also in estuaries of the White and Barents Seas. Small numbers of glass eel migrate also to the Black Sea. This species has been intensively stocked in open waters (for recreational fishery) due to its attractiveness. Part of the population stay permanently in the sea environment. Considerable population decrease has been observed during the past decade that reached the critical level of less than 1% of the eel's historical abundance (ICES, 2004). It is an important commercial species and caught glass eel from brackish waters have been introduced into several continents for aquaculture purposes (mostly in Asia), since the technology of spawning and subsequent rearing of viable offspring has not been managed until today. In the Czech Republic, eel occur in all major river basins only due to the long-term stocking of glass eel conducted by the Czech and Moravian Anglers Union (and also by the aquaculture sector in the past). In the Danube River basin, eel represent non-native species (Kottelat and Freyhof, 2007).

The European eel is catadromous species which mature after several years of growth in the freshwater environment (solely females, because males remain permanently in the sea or brackish waters) as the so-called "yellow eel", which is usually about 60–110 cm long and at the age of 10–13 years (Tesch, 2003). Maturing is accompanied with metamorphosis until the stage of the so-called "silver eel," which is distinguished by several morphological and physiological changes. Adult eels undertake catadromous reproduction migration into the spawning area in the Sargasso Sea which has still not been precisely located (at present, this issue as well as ocean migration of the eel has been investigated by an international team under the Alliad project). The time of catadromous (downstream) migration probably differs with individual genders and in the freshwater environment (females) it is different in various geographical latitudes (Tesch, 2003). This migration is typically synchronous for a large number of individuals and in Central Europe it is characterized by two migration peaks between March – May and August – October. Migration is considerably dictated by water temperature and it is usually bigger in autumn (Tesch, 2003, Tábor local organization of the Czech Anglers Union, unpublished data). At this period, in some countries (e.g., Holland or Germany), eels have often been caught by mass fishing methods with fish traps or pots. In Czech territory, the last eel traps on the Lužnice River were terminated in 2009 (Tábor Local organization of the Czech Anglers Union, personal information, 2008). Catadromous migration in the freshwater environment is considered the most critical period since there is enormous mortality rate due to mechanical injuries as a result of being hit by the turbines of the hydroelectric power stations. The final mortality rate (direct as well as a result of internal injuries) is highly dependent on the type of turbine, its gradient, number of revolutions, size and capacity flow. In general, it ranges from 15–100%. Reproduction migration of eel is influenced mainly by the water temperature, flow-rate, turbidity, light intensity, lunar cycle and barometric pressure (Matthews et al., 2001; Tesch, 2003). Migration is never undertaken during the day and it is the most intense during the dark nights at the first or last phase of the moon, with the highest activity at dusk and in the middle of the night (Deelder, 1984). Eel are known as sensitive indicators of barometric pressure changes, seismic activity and the use of magnetism for navigation (Durif et al., 2011). Similarly to that, eel are also sensitive to the sounds of different frequencies, not only negatively, but also positively (Patrick et al., 1982).

Fig. 4.9.10. ***The life cycle of the European eel (Anguilla anguilla) is dependent on the freshwater and sea environment.*** *During the catadromous reproduction migration to the sea, eel are endangered mainly by the operation of hydroelectric power stations as they suffer mechanical injuries and high mortality. At present, the population decrease in eel has reached the critical level of 1% of its historical population, which is partially caused by the invasion of non-native parasitic swimbladder nematode (Anguillicola crassus), excessive fishing and other anthropogenic pressure (the Elbe River, photo: J. Musil).*

Glass eel are transparent larvae that come towards the coastline and enter the brackish waters depending on geographic position. As far as Ireland and England are concerned, it is usually from October to December and glass eel begin to actively migrate as late as during spring (Matthews et al., 2001). In spring, the most intensive catching of glass eel is conducted, for example, on the Ern Shannon and Severn Rivers (Solomon and Beach, 2004). Some individuals remain in the brackish environment, even for several years or for the whole freshwater stage of their life cycle. Most of them, however, migrate upstream, mainly in warm months and this migration can also be interrupted, and can last up to several years. Migration of juvenile individuals of different age and size has been recorded at the same localities (Naismith and Knights, 1988). The most significant factor influencing the anadromous migration of glass eel is the water temperature, with the optimum ranging from 9–16 °C (Matthews et al., 2001; Tesch, 2003). Flow-rate does not represent a significant factor with glass eel and 1+ juveniles, and conversely, with respect to older individuals, increased flow-rate acts as a considerable stimulator to migration and as an attractant. Other factors influencing anadromous migrations comprise tides, and probably also the lunar cycle, however, it is not so noticeable when compared to catadromous migration of adult eel. Similar situation occur in the diurnal migration activity when glass eel do not show significant preferences, in comparison with considerable night activity of 1+ and older eels (Tesch, 2003). The distance of upstream migration in the first year of life is considerably influenced by the relatively short suitable period, small size of individuals and their limited speed, therefore, it does not exceed a few kilometres. On the other hand, distances of upstream migration from lowland, little or not at all fragmented streams, where glass eel migrated for 200 km from the tidal zone have been recorded. In natural conditions, the number-age relationship is evident in which with the increasing distance from the sea, the abundance is decreasing and the age of eel is increasing. Opinions about the maximum distance of upstream migration of eel vary and usually range between 250–300 km. The distance of historical migration in the territory of the Czech Republic belongs to the longest known migrations (Musil et al., 2009).

In connection with the rapid decrease in population of European eel, this species has been ranked in the IUCN Red List among the critically endangered species. Concurrently, this species was inserted in the Appendix II of the CITES in June 2007, in connection with the glass eel export for aquaculture purposes. The most significant step towards its conservation is, however, the Council Regulation (EC) No. 1100/2007, which has established measures for the restoration of European eel populations implemented in the form of the European Action Plan. This regulation allocates part of the caught glass eel for stocking into open waters, which is in connection with the eel management plans of Member states that have clearly defined individual factors of eel mortality and that require each state to implement the effective corrective measures (see above). The issue of restoration of both directional migrations has been implemented on the general level by the related legislation (the Water Framework Directive, the Concept of river network restoration in the territory of the Czech Republic, etc.). European eel, however, show considerable migration specificity so the restoration of their migration in the longitudinal gradient requires a very individual approach (this issue and various technical solutions have been elaborated on in the publication that is being currently prepared by Slavík et al., 2012) which has not been established in the Czech Republic until now.

Atlantic salmon (*Salmo salar*)

Atlantic salmon (*Salmo salar*) occur virtually along the entire Atlantic coastline of the European continent, in estuaries of the North, Baltic, White and Barent Seas, in Iceland, Great Britain as well as Scandinavia. Isolated populations have been known in Finland, Sweden, Russia and Norway. Salmon have been introduced in almost all continents as it represents an important commercial species. Large populations occur also in New Zealand, Chile and Argentina (Kottelat and Freyhof, 2007). In the Czech Republic, as rich historical sources have documented, this commercially valuable species, which was common in the past, occurred in many waterways of the Elbe River basin and it was also documented in the Odra River basin

(Frič, 1893). In the Vltava River, salmon migrated up to the Teplá and Studená Vltava River, in the Otava River, they migrated to the headwaters of the Vydra, Křemelná and Losenice Rivers. Important spawning grounds represented also the Ohře, Kamenice, Ploučnice and Tichá and Divoká Orlice Rivers, while other tributaries were not usually sought by salmon (Ulrych, 2007).

The construction of weirs in Bohemia dates back to the 13th century, and although at this time, the weirs were not utterly impassable for salmon, these constructions were used for the installation of very effective salmon catching devices. More than 20 devices were installed in the migration corridors of salmon in Bohemia in the 18th century (Andreska, 2010a). Salmon populations have been gradually decreasing and in the 1870s, salmon became already very rare in Bohemia (Ulrych, 2007). At this time, Professor Antonín Frič attempted to save the salmon by means of the first artificial spawning and by establishing 30 salmon hatcheries (Frič, 1893). However, this activity did not manage to stop the decreasing population trend owing to the increasing stream fragmentation and regulation for the water transport, continuing fishing and increasing pollution. The construction of the Střekov lock chamber (1923–35) definitely terminated the migration of salmon and all diadromous fish species and lampreys in general to Bohemia. The last salmon in Bohemia was caught in 1948 close to Lovosice (Ulrych, 2007; Andreska, 2010a,b). Similarly to the situation in Bohemia, salmon was also exterminated in the German part of the Elbe River in the half of the 20th century (Monnerjahn, 2011) and the native populations of the Elbe salmon perished for ever.

Atlantic salmon is an anadromous species whose life cycle is dependent on the freshwater (juvenile stage) and sea environment (adult stage). Similarly to sea trout *Salmo trutta* m. *trutta*, it is a species with a wide range of phenotype forms including resident and non-migrating populations (Fleming, 1996; Klemetsen et al., 2003). The main reproduction anadromous migration starts usually in summer for typical migration populations. This migration has a typical seasonal character and can last from several days up to several months (Klemetsen et al., 2003). The time of migration is different for individual genders and the size of the migrants, and is mainly dependent on the flow-rate and water temperature. Large females migrate usually the first and they are followed by large males. Small individuals migrate the last. Anadromous migrations of salmon can comprise several phases that considerably differ in the movement activity rate. Although migration is very demanding, salmon, just as sea trout, do not take in any food during the migration (Klemetsen et al., 2003). After salmon have spawned in the autumn period and survived (they are known as "kelts") they migrate back, and the whole cycle can repeat after several years (salmon, similarly to sea trout, belong to polycyclic species with repeated spawning). After the hatching, juveniles spend from one to several years in the freshwater environment (Klemetsen et al., 2003). These individuals are called "parr." After the so-called "smoltification", parr cluster into shoals and they start synchronous catadromous feeding migration to the sea (Eriksson and Lundqvist, 1982). This migration starts usually in spring, continues until the beginning of summer and is dependent on many external stimuli (Lundqvist et al., 1988). After one to several years, depending on the environmental conditions and population characteristics, young salmon mature and they migrate back to the place of birth in order to reproduce (Klemetsen et al., 2003).

The native population of the Elbe salmon was exterminated in the half of the 20th century. The first efforts to re-introduce salmon in the Elbe River basin started in Germany in 1976 in Lower Saxony (the lower Elbe River). In 1980, the first fry and parr that were imported from the Sweden's Lagan River to the Stör River (Schleswig-Holstein) were stocked. Introductions of salmon originating from several areas (Sweden, Norway, Denmark, Ireland; today, Swedish and Danish populations are used) have been conducted from 1983 also in other river basins of the lower (Lower Sachsen, Hamburg, Schleswig-Holstein) and the middle Elbe River (Sachsen-Anhalt, Brandenburg) (Monnerjahn, 2011). The salmon management plan is implemented by several states along the lower Elbe River only indirectly, for example, by restoration of migration corridors and revitalization programmes, because at present these river basins appear unsuitable for salmon reproductive habitats due to considerable ecosystem alterations (dams). In the middle Elbe River valley, the Sachsen and Anhalt re-introduction programme does not relate solely to salmon, it comprises also sea trout and European sturgeon, and it is coordinated by the Freshwater Fishery Institute Postdam-Sacrow in Brandenburg (Monnerjahn, 2011).

In 1994, the Salmon management plan was adopted in Saxony and extensive re-introduction program "Elbelachs 2000" was initiated also in the upper Elbe River in order to restore independently reproducing communities. This program, which is funded for the German part of the Elbe River partly by Saxony, the European INTERREG project and Saxony Angling Unions, was joined also by the Czech Anglers Union in 1998 – the North Bohemia regional board and from 2000, the Bohemian Switzerland National Park Administration (activity known as "Salmon 2000"). This re-introduction programme is co-funded by the Nature Conservation Agency of the Czech Republic in participation with the Czech Anglers Union and the public. The re-introduction of salmon on the German part of the upper Elbe River into the selected Saxony river basins was initiated in 1995 (Monnerjahn, 2011) and from 1998, it was also conducted in Czech territory along the Kamenice River and its tributaries Chřibská Kamenice River, Ještědský Brook on the Ploučnice River, and the upper stretch of the Libočanský Brook under the Doupovské Mountains on the Ohře River (Kava, 2007). In total, during 1998–2011, the amount of 2910000 salmon swim-up fry and 53000 fry at the size of 8–10 cm were stocked into these localities. This stock originated from the incubation of eggs in hatcheries in Germany, Děčín or Jablonec nad Nisou (Kava, 2007), and recently from the artificial spawning of caught brood fish in Czech territory. In compliance with the re-introduction programme of the upper Elbe River, all salmon come from a Swedish population in Lagan. The outcome of the re-introduction programme is that from 2002 (information about a salmon catch comes already from 2001), the return of first

Fig. 4.9.11. ***Catch of Atlantic salmon female (Salmo salar) (total length = 104 cm, not weighed) from the non-fragmented stretch of the Elbe River in Hřensko (The Elbe 1 fishing ground)*** *– first outcomes of salmon repatriation in Bohemia? (angler L. Mervínský, photo: archive of T. Kava).*

adult individuals (4 pieces) in the Kamenice River has been recorded. Between 2002–2011, the amount of 100–150 of adult fish was recorded on the basis of random catches, targeted electrofishing and monitoring. Although this estimate is not reliable, there were 4 salmons recorded in the Kamenice River in 2002, in 2008 it was 8 individuals and in 2011, there were already 12 adult salmons. Apart from one exception (caught in the Ohře River in 2004), all adults salmon were registered solely in the non-fragmented stretch of the Elbe River under Střekov (Kava, personal information, 2012) (Fig. 4.9.11.).

Comparing the re-introduction programmes of salmon between Germany and the Czech Republic, it is evident, that in Germany it represents an important Action Plan. Salmon have been deliberately chosen in Germany as the so-called flag species, because this species is sufficiently attractive and known to general public, it is a great species indicating the quality of the environment (migration passability, quality of water and substrate), therefore, salmon represent a suitable indicator of the ecological status of waterways, including the effectiveness of revitalisation measures. The re-introduction programme of salmon has thus been implemented across the Elbe River basin, in connection with the Water Framework Directive. Apart from the re-introduction of salmon itself, another objective is to enhance the ecological status of the river network and re-introduce other species that became extinct in the past. The re-introduction of salmon is therefore considerably supported in Germany by legislation (the Salmon management plan), it is coordinated by research institutes and its funding guarantees the project's sustainability. It is the sustainability that is probably the key factor in re-introduction of salmon, because even Germany has not succeeded so far to restore independently sustainable salmon population either in the Elbe or Rhine River basins (Monnerjahn, 2011). Conversely, in the Czech Republic, the re-introduction programme has been implemented as an environmental activity of the Czech Anglers Union with the participation of the Nature Conservation Agency of the Czech Republic. Although the role of salmon as the "flag species" is generally understood even in Czech territory (Andreska, 2010b), re-introduction of salmon in Bohemia has been supported only partially by the legislative classification of salmon on the Red List as a critically endangered species (Hanel and Lusk, 2005) and in the Decree No. 166/2005 which ranks salmon among "natura species" (even if salmon do not represent native and independently reproducing population). Although some positive signs have appeared already (the concept of river network restoration in the territory of the Czech Republic), the direct continuation onto the Water Framework Directive and restoration of the Czech river network connected to it, including the necessary revitalization of the riverine environment, Action Plan (comprising professional monitoring and evaluation of compensatory measures) and financial sustainability have been missing in the Czech Republic for salmon re-introduction. Despite the fact that several streams, that represented historically significant spawning grounds of the Elbe salmon, are probably lost for ever for re-introduction (irreversible ecosystem changes connected with construction of water bodies), the fulfilment of the above-mentioned conditions represents at least a certain hope that Atlantic salmon could return to the Czech territory in future.

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4.10. Marking fish *(J. Turek)*

Marking and tagging fish are the main techniques to conduct detailed and highly objective studies on fish in all aspects. It is possible to obtain a wide range of information by marking fish. Some methods of marking allow to monitor fish in order to better understand their migration behaviour, whereas other methods based on re-capturing marked fish provide information on the composition of populations in open waters, as well as growth and survival of fish in natural conditions. Marking fish also represents a necessary prerequisite for fish distinction and keeping records on breeding activity (the Act No. 154/2000 Coll., on Breeding, Stirpiculture and Record Keeping of Farm Animals and on Amendments to Certain Related Laws (the "Breeding Act"), as well as breeding manipulation, as it enables to identify individuals of different strains or geographic origin.

The basic requirements for marking fish are (Kelly, 1967; Wydoski and Emery, 1983) as follows:

- the possibility to identify individuals or groups of fish
- no influence on the growth, survival, behaviour and probability of catching the marked fish
- the lifespan of the mark for the time required for the purpose of marking
- easy application and subsequent identification of the mark
- economic effectiveness

Marking fish can be divided into two basic methods on the basis of its use: group and individual.

Group marking is used, above all, in order to identify groups of fish of different origin (strain, geographical origin, method of breeding or feeding, treatment) that are to be stocked together in open waters or for subsequent breeding. With respect to the fact that group marking is used for abundant groups of fish (hundreds of fish and more) that are usually of small size (yearling), it is advisable that the method of marking is not demanding from the technical, time as well as financial point of view. Identification of marked fish during the consequent sampling should also be fast and unambiguous.

Individual marking is used for identifying particular fish and individual parameters, such as growth, migration, etc., of each individual which can be monitored. This type of marking is also used for marking breed (parent) fish within the breeding activity or preservation and restoration of genetic fish resources. The method is usually based on implanting a mark with a unique code. These marks or the method of their application usually represent a higher stress load for fish, in comparison with group marking. In addition, individual marks are of a certain size and can thus be used only for individuals of a certain size (depending on the type of fish). Expenses connected with individual marking are usually higher than those with the group marking.

With respect to both marking methods, other techniques can be further characterized. Below the most frequent marking methods are described, including their advantages/disadvantages and most often use.

4.10.1. Use of differences in morphological traits

The most reliable differences are, for example, different type of scaling (scaly x scaleless for common carp), or coloration (regular x ornamental for tench, ide, rudd, rainbow trout, European catfish, sturgeon and other fish species which are distinguished by colourful mutation). The use of this method is based on a comparison of different breeding parameters, the physiology or biology of these dissimilar groups within a species during their breeding in a common environment, which is very important (Flajšhans et al., 2008). The main advantage is its ease of application, easy identification of fish and the possibility to use it for annual ontogenetic stages. Its disadvantage is, mainly during fry breeding, the necessity to precisely identify the brood fish from the genetic point of view due to the phenotype manifestation of offspring.

4.10.2. Amputation (perforation) of fins

This method is used solely for group marking. It is based on amputating one of the paired fins, which does not cause fish any serious health or movement problems. Perforation of fins, most often the upper or lower lobe of the caudal fin, is carried out by pliers or piercers. It is necessary to treat the affected area with a suitable disinfectant (e.g., $KMnO_4$). These methods of marking are most often used for identifying young breeding fish or within breeding while testing the yield of fish in ponds. This method is quick and inexpensive. The limitations are the possibility of a negative impact on the health status of fish (fungal infections), as well as the fact that fins grow back and regenerate after some time, which complicates the identification of fish after a longer period. This method can only be used in the artificial breeding of fish or for scientific purposes (the Act No. 246/1992 Coll., on the Protection of Animals Against Cruelty, as amended).

4.10.3. The cryogenic method (marking by liquid nitrogen)

The method is used for group, or alternatively, individual marking of fish which have solid skin and small scales or scaleless. In the Czech Republic, it is commonly used for marking tench, scaleless carp, and occasionally brood trout or catfish. The principle of the method rests in injuring innervation of melanophores in the fish skin by attaching metal (aluminium) dyes chilled in liquid nitrogen to the temperature of -196 °C. Such treated place is colour distinguishable from the surrounding tissue and for approximately two years, with visible patterns on the skin in the shape of the dye used (alphanumeric symbols, dots, lines, etc.). The affected skin has to be sterilized as well. It is possible to mark a group of fish with the same dye or individual fish by a unique combination of symbols. This method is advantageous due to its affordable price and quick marking technique. The breeder needs a dye, a container with liquid nitrogen, some liquid nitrogen and protective devices. The disadvantage is the gradually deteriorating identification of the mark and the possibility of fungal infection if the marking is carried out unprofessionally. Application is also dependent on the size of the marked fish as there is a higher risk of injury for smaller fish.

4.10.4. Attached tags, discs, etc.

Tagging by means of attached tags fastened with a string, most often to dorsal fins, or alternatively, various discs attached to fins was very common in the past; however, nowadays it is used very rarely. This method can be useful mainly for breeding sturgeons since their pectoral fins are anatomically suitable for this type of marking. It can be used not only for group, but also for individual identification. This method is cheap, however, there is a high loss rate of the marks with respect to all fish species (if the mark snags on an obstacle in the aquatic environment or during manipulation with fish) and the marking process itself is also rather time-consuming.

4.10.5. Visible implant elastomer (VIE) tags

These tags are internal colourful marks made of biocompatible, bicomponent elastomer. They are used mainly for group marking of fish. By placing more marks (tags) on one individual, identification of an individual fish can be achieved; however, it is more time-consuming. This method can also be used for juveniles from the size of approximately 5 cm. Before use, it is necessary to mix both components (elastomer and hardener) in the ratio defined by the manufacturer. The principle consists in injecting liquid elastomer beneath the transparent skin of fish, most often on the head (especially around the eye), or alternatively in the fins. Within several hours, or days at maximum, the elastomer hardens into a firm, elastic substance. It is advisable to perform the application of marks under anaesthesia by using a suitable anaesthetic (see Kolářová et al., 2007). Application is carried out with a needle with a very small diameter (insulin syrette); therefore, the marked fish is only injured to a minimum extent (Fig. 4.10.1.). The implanted mark does not affect the surrounding tissue in any way and the application site quickly regenerates. There are no recorded instances in the available literature about any negative impact of VIE marking on the survival and growth of fish. The marks are available in ten colours, of which some are fluorescent. The marks can be seen with the naked eye for two years or more, depending on the changes of colouring and transparency of skin in the application area during fish growth. It is easier to identify the fluorescent tags by using a UV lamp. The loss rate of VIE tags is influenced by the application area, the degree of injury of the tissue during application and the experience of the sampler. McMahon et al. (1996) recorded losses of VIE tags with four species of salmonid fish in the course of 30–430 days from application, which ranged from 2–50%, while the most significant losses occurred during the first 100 days of the experiment. Bolland et al. (2009) discovered with cyprinid species (roach, chub and ide) in the first month after marking that the VIE retention was higher when the tag was applied on the head (96–98%) than on the fins (78–90%). After six months, the retention was, conversely, higher with tags placed on fins (77–89%) than on the head (21–58%). In the case of simple group marking (different colours for each group) the loss rate of marks can be eliminated by applying more tags of the same colour on each fish.

Fig. 4.10.1. **The set for marking with VIE tags and an example of the location of the tag in roach** *(photo: J. Turek).*

4.10.6. Visible implant alpha (VIA) tags

These tags consist of multi-coloured flat plastic plates 1.2 x 2.7 mm with an imprinted black code consisting of two letters and two numbers. The tags come in four colours and each colour has 2500 different alphanumeric codes. This system is used for individual marking of fish sized approximately 10–15 cm. Marks are applied with a special injector, which consists of a flat, hollow needle into which the tag is inserted. The tag is then placed under the transparent tissue of the fish (usually on the head) using the tip of the injector and is left in place as the needle is withdrawn (Fig. 4.10.2.). Tags are visible with the naked eye. Identification of the VIA tags can also be enhanced under UV-lamp. The impact on the tagged fish, similarly to impact on changes in skin transparency on identification, is the same as with VIE tags. Anaesthesia is required to achieve successful application of the VIA tag. The loss rate of this type of marking is usually approximately 20% (e.g., Rikardsen et al., 2002) and is highly dependent on the experience of the sampler. Losses usually occur shortly after their application, due to injury to the skin around the tag.

Fig. 4.10.2. ***Application of a VIA tag to grayling*** *(photo: J. Turek).*

4.10.7. Coded wire tags (CWT)

These tags are pieces of magnetized stainless steel wire 0.25 mm in diameter containing a printed numerical code. They are applied with a special injector (based on the same principle as the VIA tag injector) usually in the rostrum, cheek muscle or other muscles of the fish. The manufacturer also offers automatic injectors. Tag length ranges from 0.5–2.2 mm. The tags can be detected by readers working on the basis of metal detectors. Groups of fish can be marked and subsequently distinguished by application of marks in different places. Individual identification of the code is possible after removal of the tag with a binomagnifier when magnified 20–40 times. The advantages of the CWT system are use in very small fish, minimum biological impact and almost zero loss rate. The disadvantages of CWT system are the high purchase price of the injector and, in particular, the tag detector, as well as the necessity to remove the tag in order to identify the fish individually.

The VIE, VIA and CWT tagging systems are produced by the American company Northwest Marine Technology (www.nmt.us).

4.10.8. Radio frequency identification systems (RFID)

These consist of systems of individual marking based on contactless interaction between the transponder ("chip") and the reading device using radio waves. Passive transponders (tags, incorrectly chips), called Passive Integrated Transponders (PIT), are applied for marking fish (Fig. 4.10.3.). They comprise a memory chip with a miniature coil and condenser encased in a biocompatible glass into a roller with a diameter of 2 mm and length of 11–15 mm. If the transponder passes through the electromagnetic field of the aerial (reader), the coil induces voltage and energizes the condenser. This enables to send the information saved in the memory tag to the reading device, which then decodes the signal and sends it to the communication interface. The tag code is represented by numeric or alphanumeric combinations of different lengths (usually 10 or 15 symbols). The code is displayed not only on the reader, but it can also be displayed directly on the computer (e.g., in an Excel programme), which can be interconnected with the reader via cable (e.g., USB). In order for the computer to communicate with the reading device it is necessary to install a programme in the PC supplied by the manufacturer along with the reader.

Implantation of tags in the fish body is conducted using the applicator based on the principle of an injection needle with an internal "piston" which pushes the transponder out of the needle into the tissue. If sterilized or disinfected, these applicators can be repeatedly used to implant more tags.

The PIT tag is most often applied to the dorsal muscles at the base of the dorsal fin at an acute angle (approximately 30°) 1–1.5 cm deep. The applicator must be placed between the scales because the scales of larger fish (carp, grass carp) cannot be pierced through. Conversely, as far as fish with smaller scales (salmonid) are concerned, there is a risk of denting the scales into the wound after injection and subsequent infection. It is advisable to use anaesthetic during application and the puncture mark should be treated with a suitable disinfectant.

The use of PIT tags is suitable mainly for tagging breed fish of larger sizes. The advantages of this system are almost a zero loss rate and the long tag lifespan. The limitations are initial investment in the reading device and the higher price of the tags. This system is thus mainly used by breeders intending long-term fish breeding, including reproduction.

RFID systems are produced by various manufacturers (e.g., www.trovan.com; www.aegid.de).

Fig. 4.10.3. ***Set for application and identification of the PIT tags*** *(photo: J. Turek).*

4.10.9. Radio telemetry

Radio telemetry enables active monitoring of movement of marked fish in current time. The principle consists of implanting a telemetric transmitter into the fish's body, most often in the abdominal cavity. Implantation should be carried out by a veterinary surgeon. The transmitter emits individually coded signals regularly, which are displayed on the telemetric receiver. The system can use two models of signal transmission. In dam reservoirs and lakes, the acoustic model is successful where the signal is emitted into the transmitter on one frequency for each fish. The acoustic signal is suitable for the environment with deep waters and alternatively high conductivity. Conversely, the digital coded model that was developed later, provides the possibility to monitor up to several hundred fish on one frequency. This method is, however, limited to environments with shallow water columns (approximately to 4 m) and low conductivity (500–600 μS), such as rivers and brooks. Fish location is determined by so-called triangulation. The principle of the method is based on measuring the relative signal strength from the place where the signal is the strongest and then from two other positions. The current location of the monitored fish defines the intersection of the lines drawn from the three mentioned positions of the observer. The observer's position is specified by geographical coordinates which are subsequently processed by special programmes. Special transmitters enable to record whether a fish is moving or how much energy it consumes at that moment, as well as the depth where the fish occurs (by pressure measuring) or current temperature. Receivers (aerials and decoders) can be installed firmly in the surroundings of the test reservoir or stream, or they can be transferred manually or by boat. This marking method is used only for specialised scientific studies focusing on research of migration characteristics and other types of fish behaviour (Lucas and Baras, 2001). Its use is limited by the high purchase cost of devices and transmitters, the possibility to only tag fish that are large enough (from approximately 12 g) and the transmitter's battery capacity. Transmitters can be used for approximately 20 days (the smallest transmitters weighing 0.25 g for up to four years).

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5

ADVERSE HUMAN IMPACTS UPON FISH COMMUNITIES IN OPEN WATERS AND THE POSSIBILITIES OF THEIR ELIMINATION

Z. Adámek, P. Dvořák, J. Andreji, T. Randák

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5.1. Hydrotechnical interventions into biological processes in open waters *(Z. Adámek)*

5.1.1. Alterations of the hydrologic regime in streams

Stream regulations represented the preferred technical solution to unfavourable changes in flow regimes not only in the past but even today. These changes have been caused by fluctuating outflow regimes in river drainage areas that differ mainly within short-term seasonal periods or occur episodically. However, they have also been recorded from the long-term point of view in connection with climatic changes. Regulations are most often implemented by interventions to longitudinal and cross profiles by channelization and by construction of weirs and dams, respectively. The necessity to influence the hydrologic regime of streams is multiplied by increased consumption of water and hydro-power energy, use of waterways for navigation, sports and recreation, which have led and still leads to construction of reservoirs as well as minor structures directly on streams. All interventions to the hydrologic regime of streams disrupt the natural course of physical, chemical as well as biological processes in streams and have a negative impact on their ecosystems.

Outflow regime

The essential large-scale impact on outflow regime is the human-induced change of surface outflow rates in the landscape. If the intensity of rainfall precipitations exceeds infiltration (absorption) of water in soil, **surface outflow of excess water** occurs. This results in **water erosion** which causes damage not only in the source area but subsequently also in the whole basin where physical degradation of the aquatic environment and deterioration of water quality appear. A well-known example resulting from water erosion is silting of reservoirs, including ponds, with soil washes which decreases their production volume and increases overgrowing with emerged littoral vegetation. If the removal of excessive layers of sediments is not conducted in time, the pond ecosystem might transform into wetland. Erosion causes surface soil washes that can be long-term, connected with the creation of erosion furrows and gullies concentrating surface outflow and local soil deposits. Vast washing and runoff of soil endanger mainly agricultural land during extreme rainfall where relevant agrotechnical procedures have not been performed (Fig. 5.1.1.). As a consequence, the upper soil layers are flushed away, soil is deprived of nutrients and water absorbing capacity is reduced, which multiplies the problems even more. Repeated occurrences of erosion increase losses of soil particles from the upper soil layer. These phenomena and interventions in river basins alter the so-called **specific outflow** which is defined as the volume of water outflow per unit of river basin area, usually in $m^3.km^{-2}$.

***Fig. 5.1.1.* Soil flush caused by inappropriate agrotechnical procedures during potato growing across surface contours** *(Stonařov, August 2011, photo: Z. Adámek).*

Water abstractions

Human activities are fundamentally reflected in the impact on the ecology of surface waters. The most significant manifestation of human activities is water management, which offers two points of views – quantitative (influencing the water quantity in ecosystem) and qualitative (water pollution and recipient ecosystem quality). From the quantitative point of view, the basic scheme of water management is generally acknowledged (Fig. 5.1.2.), which defines the basic terms, such as **water need** – comprising water taken from the source and water that is recycled (returned to technology) and **water consumption** – water which is not returned back to the system after its abstraction in the source locality, but it can be returned somewhere else, or it evaporates, or is permanently incorporated into a product. In the site of abstraction or in its surrounding (in the same stretch of a river or at least in the same river basin), it is **waste water** that is returned. According to the above mentioned scheme, it is thus theoretically possible to elaborate an overall result of water need for each human activity (production).

Water abstractions are conducted mainly for industry, waterworks, irrigation and hydroelectric power station purposes. They result in water level fluctuations in reservoirs and decreases in discharge in streams under the sites of abstractions, be it by its diversion into raceways, derivation channels or technological operation. In these cases, an altered hydrologic regime occurs that can be from several tens of metres up to tens of kilometres long. The diverted water never returns back to a stream in its original volume, but it is usually less.

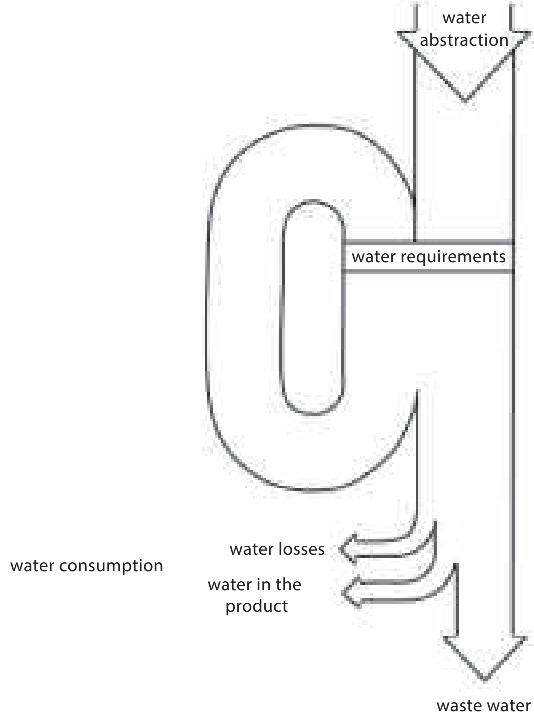

Fig. 5.1.2. ***The basic scheme of water treatment*** *(adapted from Adámek et al., 2010).*

Water abstractions from reservoirs cause water level fluctuations in different scope and duration. While water abstractions for irrigation or water works purposes induce continual, short-term, rather insignificant decreases in water level, the consequences of water abstractions for hydroenergetic purposes usually cause a sharp decrease in water level connected with draining the littoral zone, which eliminates the most important bottom areas from the production point of view. Because these drops occur regularly, the littoral bottom is not re-colonised more substantially (often not at all). A similar phenomenon occurs during regular lowering of the water level in the majority of dam reservoirs before winter in order to create a spare volume for water retention and equalise discharges under reservoirs due to spring snow melting. In such cases, the inundated littoral bottom is then again re-colonised during the growing season mainly with early developmental instars of water insect larvae (midge fly larvae and mayfly nymphs of the *Caenis* genus) while older developmental stages or permanent benthic fauna (tubificids) are totally missing (Fig. 5.1.3.). Benthic fauna is able to respond to slow continual decrease in the water level caused by water abstraction for irrigation or water works, which occurs mainly in drier periods of the year by migration with the water level, however, bivalves can be endangered as they cannot move fast enough. As far as fish are concerned, a decrease in the water level and exposure of the littoral zones represents, above all, the reduction of the food base and shelters, or a threat to the reproduction success rate due to drying of spawned eggs.

Water abstractions from streams for the purposes of water works, irrigation or industry can have a negative impact during a long-term dry season when decreased discharges and depths, increased water warming, lowered oxygen concentration, reduced dilution of pollutants and enormous overgrowing of bottom

Fig. 5.1.3. ***Littoral of the Brno reservoir drained before winter allowing water retention during spring snow melting*** *(photo: Z. Adámek).*

with filamentous algae occur. More considerable, however, is the decrease (fluctuation) in discharges caused by stream derivation due to the water works activities (mills and small hydroelectric power stations).

Maintaining the **discharge regime** within values close to natural is fundamental for the functioning of the riverine ecosystem. Fish react to discharge alterations with their whole life cycle, including spawning and food migrations (Lusk et al., 2011). A radical decrease in discharges during the growing season results in a decrease in fish growth and condition, while during the winter time, it causes increased cooling or even over-freezing, including the bottom. In the affected streams, the situation when the temperature of flowing water drops below 0 °C can occur. This induces the creation of an ice crust of different thickness on the bottom with fatal consequences for the life of fish as well as benthic animals. Running water does not freeze even at temperatures below freezing point due to the continual current; however, slow running layers near the bottom can freeze (Fig. 5.1.4.). Maintaining the required discharge is thus vital for spawning upstream migrations of, e.g., brown trout, and for the functionality of fish by-passes.

Apart from the direct impact of human activities on discharge alterations by manipulation with discharges, there is also indirect impact comprising stream bed modifications that contribute to fast diversion of water from areas of human interest (residences, constructions, agricultural areas, etc.). As a consequence, water outflow in stream basins has been considerably accelerated which supports the occurrence of extreme discharge episodes with fast subsiding and subsequent prolongation of periods of low discharges with the above-mentioned negative impact for stream biota.

Fig. 5.1.4. Freezing of the bottom and water column during extreme frosts *– Zděchovka, February 2005 (photo: Z. Adámek).*

Fish as well as benthic organisms are well adapted to **high discharges** including extreme discharge situations and in unmodified river beds they survive basically without any consequences. In channelized streams, however, shelter availability on the bottom or shorelines is limited and the organisms are drifted downstream. Zoobenthos respond to extreme discharges by escape into the aquiferous subsurface (hyporheal) where they survive the period of high discharges connected with increased flow velocity with no harm. Extreme discharges are also often connected with the transport of solid particles which causes changes in the bottom structure and its silting up.

In order to preserve the functionality of running water ecosystems, it is important to maintain the so-called minimum discharges. Determination of **ecologically acceptable minimum discharges**, that are to be maintained in a modified stream, is essential for preservation of sustainable development of the stream ecosystem. Under the conditions of the Czech Republic, this need is even accentuated by low water capacity of most water courses and a large number of constructions (mainly small hydroelectric power stations) that have been built on them, or their construction is under consideration. Qualitative as well as quantitative indicators of individual communities in a stream are considerably influenced by the decrease in discharges – reaction of fish to physical degradation of the environment is significantly stronger than the reaction of zoobenthos (Adámek and Jurajda, 2001). Lowered discharge, which is also connected with smaller depth, and flow velocity lead to increased warming and light penetration, which supports overgrowing with filamentous algae and submerged as well as emerged macrophytes. It is known that even if the discharge is

Q_{330} (the minimum discharge that is kept for 330 days during the year), species diversity decreases and the composition of plant and animal species alters as well. Therefore, this discharge must be maintained as the **minimum residual discharge** in streams with Q_{355} lower than 50 l.sec^{-1}. In streams with higher discharges, the requirements for the minimum residual discharge values are lower (Table 5.1.1.).

Increased warming and light penetration supporting plant overgrowing of smaller salmonid brooks often enable the occurrence of other fish species – mainly juvenile rheophilic cyprinids (Eurasian minnow, common dace, chub, barbel, etc.) which paradoxically increases the biodiversity of the fish assemblage (Adámek and Jurajda, 2001). Nevertheless, such status is neither natural nor desirable, since, on the one hand, populations of species typical for this type of stream (brown trout, bullhead, and stone loach) survive, but on the other hand, their density and biomass are considerably reduced.

5.1.2. Impact of water constructions

Cross barriers on streams

Cross barriers – weirs and dams represent very serious interventions into the functioning of stream ecosystems. The negative impact of weirs is usually increased by the fact that they are mainly built on channelized streams with the aim, among others, to increase water retention for energetic use, navigation, water abstractions, etc.

Weirs create a permanent impoundment of water – the weir reservoir that is gradually silted up with suspended solids and debris. A weir reservoir is silted up gradually on the basis of current velocity with coarse material in the upper parts up to particles smaller than 2 mm in bigger depths nearby the weir body, where the current velocity is minimal. Construction of weirs creates an utterly new environment for the ecosystem – a large area and volume of lentic water with completely different organisms. While in the original, unaffected stream, rheophilic (requiring running waters) organisms demanding high oxygen content usually dominate,. in weir reservoirs, organisms of lentic waters (e.g., planktonic crustaceans, tubificids, etc.) with lower demands for oxygen and water quality, that would not be able to survive in a stream at all, appear. Increased sedimentation of suspended organic solids in the weir reservoir leads to increased consumption of dissolved oxygen which can lead towards a critical decrease in oxygen concentrations in case of a heavy load caused by organic pollution. Mechanical aeration and diffusion of oxygen from the air is very low in a weir reservoir due to still water level. Sometimes, increased aeration of water at the weir overfall is considered positive, however, it must be emphasised that this aeration cannot usually compensate for the loss of oxygen due to respiration of the weir reservoir ecosystem, since, especially in the case of higher organic loading, the subsequent absorption of oxygen in the stream under a weir is higher than the benefit of aeration at the weir and it usually occurs within a very short stretch. In addition, the stretch of a stream under weir is threatened by the disturbance and flushing away of the sediments during increased discharges or manipulation with the weir dam.

Table 5.1.1. ***Determination of the minimum residual discharge (MRD) according to the methodical procedure ZP16/98*** *(Balvín and Mrkvičková, 2011).*

Q_{355} of stream (m^3.sec^{-1})	MRD (m^3.sec^{-1})
< 0.05	Q_{330}
0.05–0.5	$(Q_{330} + Q_{355})$. 0.5
0.5–5.0	Q_{355}
> 5	$(Q_{355} + Q_{364})$. 0.5

The most significant negative impact of construction of artificial cross barriers is the alteration of stream character from a running ecosystem to the system of successive weir cross barriers with lentic water, which causes considerable destruction of communities of dominant rheophilic species. This factor has destroyed a large number of rivers, as e.g., the Vltava River in the Czech Republic and the Váh River in Slovakia.

If weirs are constructed in the form of low barriers, their impact is not substantial and conversely, they can even have a positive effect on fish stock (higher depth, shelters). Fish typical for lower zones occur often in weir reservoirs, for example, roach, perch, pike and nase in salmonid and grayling zones or carp and bream in barbel zones. Typical fish species of these zones (brown and rainbow trout, grayling, burbot) are less abundant in weir reservoirs; however, they often reach a trophy size at these sites. Generally, it is true that in channelized streams, weir reservoirs represent sites with increased density of fish of all age categories, however, is the are also an insuperable migration barrier (Fig. 5.1.5.), especially if they are not provided with a functional fish by-pass ways. Construction of weir and dam reservoirs causes fragmentation of a stream and disruption of the **river continuum** (Vannote et al., 1980). This is characterized as a continual gradient of physical conditions from headwaters up to estuaries, which induces continual succession of biological reactions and characteristic course and changes in loading, transport, use and sedimentation of organic substances along the whole length of a stream. It is thus logical that water retention as well as artificial structures themselves cause essential disruption of the river continuum.

Specific conditions are created in ecosystems that have emerged due to the construction of dam (valley) reservoirs. By damming a stream with a dam body, a large volume of water is impounded, the biota of which is close to lake ecosystems, however; there is a wide range of specifics that are given mainly by the purpose for which a reservoir has been built. In most cases, this is the water management function

Fig. 5.1.5. ***Weirs without fish by-passes represent an insuperable migration barrier not only for fish but also for other aquatic species – weir on the Morava River at Bolelouc*** *(photo: Z. Adámek).*

(retention or balancing discharge ratios). However, it is usual that several other functions, such as energetic, water works, recreational, irrigation, etc., are applied as well. These specifics, with respect to fishery management, are detailed in chapter 4.

Artificial regulations – weirs and dams – cause a wide range of essential alterations to the ecosystem of running waters due to:

- unnatural annual and daily hydrologic regime;
- unnatural annual and daily temperature regime;
- altered regime of transportation and sedimentation of suspended solids and debris which is connected with altered morphology and granulometry of bottom and shoreline sediments;
- controlled outflow respecting the minimum discharges.

These alterations then have an essential impact on stream life, however, to some extent, even upstream the reservoir. Discharges under the weir have different annual distribution – while in unmodified streams, the maxima in the Central Europe are in March and April and the minima in September (August to October). Spring discharges increased up to flood values are equalized under the reservoir and are extended over a longer period. The minima basically do not occur and if yes, they are higher and spread over several months. The temperature regime of a stream under the reservoir is fundamentally influenced by the depth profile from which the water is discharged from the reservoir. If the water is discharged via an upper overflow, the river water gets warmer. When discharged from hypolimnion, it causes, on the contrary, considerable cooling down with the absence of the high temperatures in July and August. The stream under the reservoir does not freeze over in winter, which eliminates other natural ecological disturbance – ice drifting, and fish are exposed to predation pressure exerted by piscivorous predators (cormorant). Discharge of water from hypolimnion is also connected with problems with saturation of water with oxygen. Cold water with high oxygen deficit is discharged into a stream, where it is consequently intensively additionally saturated with gasses. Microbubbles of dissolved gasses occur thus in water which emerge mainly during intensive warming up and the so-called supersaturation occurs. Microbbubles then appear on bodies and mainly in vascular systems of fish which may lead to their injury, which is called "gas-bubble disease". This diseased status manifests itself by gas embolism in vessels – mainly in gill capillaries and by increased fry mortality, in particular of salmonid fish, under reservoirs (Fijan, 2006).

A specific problem is the operation of energetic dam reservoirs in the so-called **peaking regime**. This represents the episodic operation of hydroelectric power station, usually twice a day, when a sudden increase of discharge from minimum (sometimes zero) up to discharge given by the maximum capacity of turbines occurs (Fig. 5.1.6.). Almost all large hydroelectric power stations in the Czech Republic operate in a peaking regime. When the operation is ended, discharge decreases and the water runs off through the stream bed. This process is already slower and it is considerably influenced by the bottom morphology.

Peaking causes several disturbances that are subsequently also reflected in fishery management possibilities. These are, above all:

- fast transportation of small particles – there are no sediments, the stream bed is constantly being washed out;
- the top layer of sediment contains only a few organic material due to permanent washing which creates specific conditions mainly for macrozoobenthos, since the feeding base for detritivorous organisms is heavily reduced;
- fluctuation of the oxygen concentration in the bottom connected with movement of the anoxic–redox zone towards the bottom surface;
- permanent and massive erosions of shorelines where the sloping gradual zone with riparian vegetation is not formed and shorelines are thus permanently uncovered.

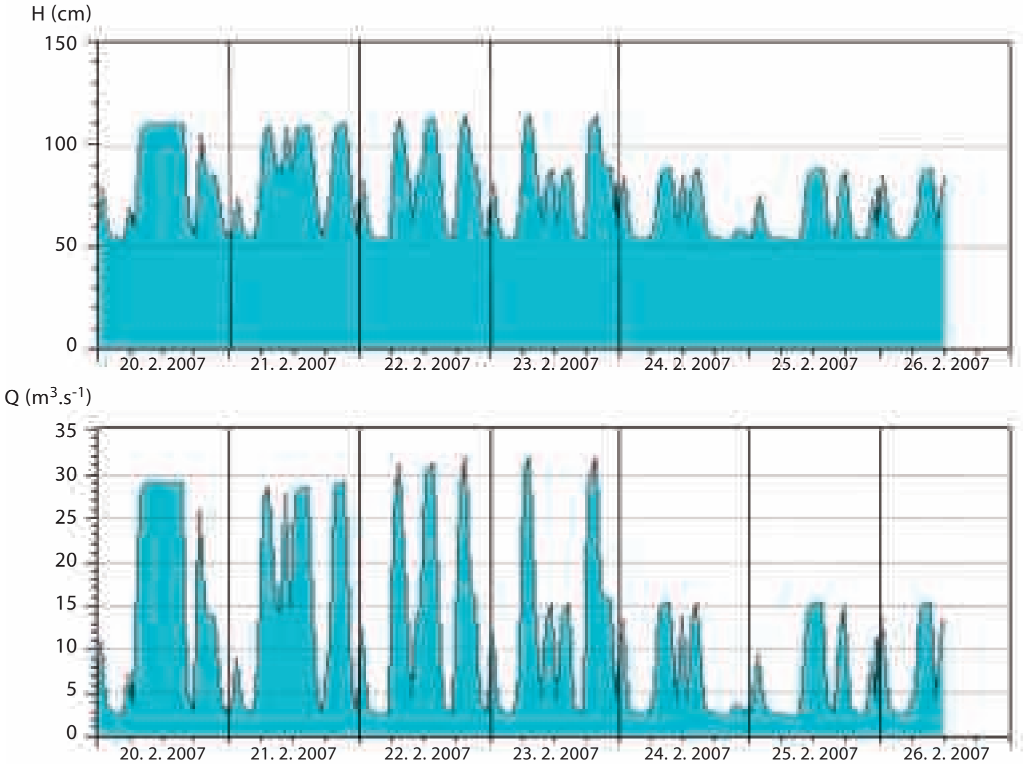

Fig. 5.1.6. ***Peaking of the Vranov reservoir, the Dyje River, Hamry monitoring point*** *(adapted from Adámek et al., 2010).*

It is necessary to realize that peaking – sudden changes in discharge –represents basically an unknown phenomena for aquatic organisms. In natural unmodified systems, even catastrophic flood arises gradually and only spring flood discharges after breaking the ice barriers can closely resemble peaking. Such discharge, however, occurs only once and after that the regime stabilizes. The sudden rapid decrease in discharge, which is a part of peaking, never occurs in nature.

The peaking regime of discharges under hydroenergetic structures resembles sudden changes of discharges that are excessively increased for the purpose of water boat sports. The main trouble is, similar to peaking, the sudden increase and especially the sharp decrease of discharges, which is, however, multiplied by the fact that it occurs several times per year at maximum, and not on a daily basis with respect to peaking. The ecosystem of a stream is not adapted to such phenomenon anyhow. The danger of being moved away by increased discharge does not seem to be essential either for fish or macrozoobenthos. More problematic, however, is the fast decrease and outflow of water from the riparian part of the river bed (often newly inundated surfaces in riparian zone) to which aquatic species are not able to react in time and they subsequently die in small isolated puddles or pools, or in dry places.

Stream channelization

Longitudinal modifications (channelization) of streams represent frequent phenomena in the cultural landscape; however, these activities cannot always be fully justified. Generally, they comprise modifications of the longitudinal geometry of a river bed connected with various forms of shoreline fortification. Channelization most often substantiated by the necessity to protect various agglomerations, including industrial premises, communications and agricultural land against extreme (flood) water discharges, less often represents a requirement to make a stream navigable, or to modify a piece of land. Channelization of the streams flowing through urban areas is rather common.

A natural stream in the landscape creates a floodplain – **flooded area** where meanders, oxbow lakes and pools (river arms) are created. These are essential for the functioning of natural ecosystems. Oxbow lakes communicating with the main stream, be it permanently or only during floods, serve as reproduction areas for the riverine fish species and nursery areas for their fry. The main stream is interconnected with its arms into one unit mainly during floods. Newly inundated areas enlarge the space for development of natural food and provide suitable spawning substrate to phytophilous and indifferent fish species. During the subsequent water level drop, the majority of fry and juveniles remain in arms, from where they consequently migrate back to the main stream where they mature (Jurajda et al., 2001). On the Czech territory, there is only an insignificant part of water streams that function this way, the majority of them being in protected areas. The most common approaches to channelization (longitudinal regulations) of streams are illustrated below in Fig. 5.1.7.

The A and B modification types appear as the least suitable from the stream ecology and its floodplain point of view (these are, however, the most common) – this causes considerable shortening of a stream and active enlivening of bottom and shoreline zones. Outflow from the area is accelerated and exposes a stream to higher differences in discharge. On the one hand, sudden flood discharges with fast subsiding and on the other hand, even considerably lower minimum discharges can be expected. Outflow in such a straightened stretch is thus usually slowed down by artificial structures (weirs) which induce all the above-mentioned

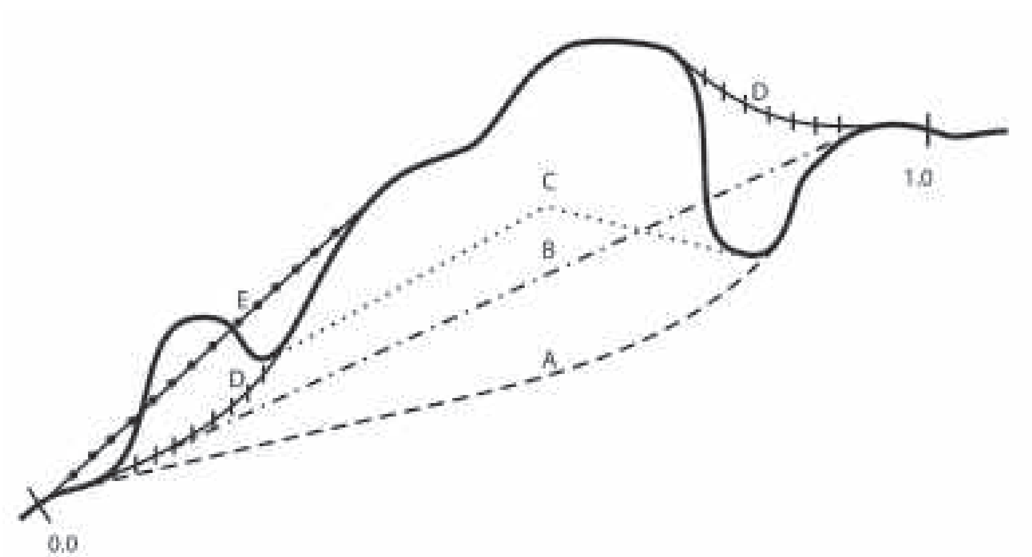

Fig. 5.1.7. ***Possible alterations to longitudinal geometry of a stream*** *(according to Zelinka and Kubíček, 1985, adapted from Adámek et al., 2010). Note: A–E represent various options of solution (see the text).*

consequences. The remaining modification types (C, D and E), that are conducted in shorter stretches of streams, enable at least partially for some curvatures to remain (meanders), therefore, to create convex and concave shorelines with gravel beds, islands and erosion areas. The unfavourable impact of longitudinal stream regulations is most obvious in case of smaller streams with higher slope.

Channelization of a stream represents an intervention which has very unfavourable impact on ecosystem functioning. The water course is shortened, the number of active elements (gravel beds and islands) in a stream is lowered, overall ecological diversity is decreased and communication of river water over shoreline and bottom with hyporheal and underground waters is reduced. Channelization of streams also shortens riparian zones and reduces water surface and volume. From the hydrological point of view, outflow of water from the landscape is accelerated, deficit water discharges are prolonged and the risk of fast and sudden culmination of high water levels is increased. Channelization of streams also causes extinction or considerable reduction of riparian vegetation. The self-cleaning ability of a stream is also significantly reduced and pollution thus reaches larger distances from the source. Unnatural transport of suspended solids and debris occurs, the effect of which is even multiplied in case that channelization is combined with weirs.

Fish communities in channelized streams are, in comparison with natural conditions, substantially poorer from the qualitative as well as quantitative point of view, which is not only due to a reduction of natural reproduction and the possibility of fry to ongrow, as mentioned above. In a channelized stream, the diversity of habitats and sheltering possibilities are also considerably reduced. The food base (periphyton and macrozoobenthos) is not influenced in a modified stream due to habitat degradation to such a considerable extent, on the contrary, increased development of tolerant organisms along with the decrease in species diversity may occur (Adámek and Jurajda, 2001). The fish community is also unfavourably influenced by extremely increased discharges in periods of high water levels, when the possibility to survive this period beyond the main stream bed is eliminated. Nevertheless, it appears that the ability of fish to survive periods of extreme discharges is higher than expected and fish manage to stay relatively easily in places of original occurrence or in their vicinity, while they use the limited availability of sites with lower flow velocity, probably in the immediate vicinity of shorelines or bottom.

Stream channelization is often connected with different modifications of shorelines and bottom. The most frequent technical solutions are illustrated in Fig. 5.1.8.

Stream piping (Fig. 5.1.8.a.) is unacceptable from the ecological point of view. The stream is wholly removed from the surface, be it under or above the terrain level, which makes it impossible to communicate with surface water courses and underground waters, there is no light access and stream aeration is very limited. This is thus a totally inconvenient modification, excluding life of fish, green plants and higher aquatic animals.

Hard fortification of bottom and shoreline (Fig. 5.1.8.b.) comprises strengthening with concrete slabs that are usually attached tightly to each other. In such a stream, there is almost only laminar flowing with considerable transportation ability, the bottom has very low hydraulic roughness, there is no diversification of current velocities and bottom, and there are almost no shelters. Communication with sub-riverine and underground waters is also considerably eliminated and bottom and shorelines are impenetrable for organisms. In addition, the gradient of such channelized streams is often ideally constructed in such a way that the water can run off as fast as possible. Due to this fact, these streams are rather shallow for almost the whole year. In summer, water is warmed up intensively and temperatures higher than 27 °C are not exceptional, which represents a lethal temperature for the majority of riverine organisms, regardless of the fact that water usually lacks dissolved oxygen. In frosty winters, these streams freeze over wholly up to the bottom and because organisms cannot escape into the hyporheal, they consequently die. In these modified streams, the bottom is often overgrown with filamentous cyanobacteria and algae, especially in streams with high nutrient loading. Zoobenthos is very poor from the qualitative as well as quantitative point of view and it is basically limited only to small oligochets and midge fly larvae, or leeches that they feed on.


a
b

Fig. 5.1.8. Different types of longitudinal regulations of streams *(a – piping – the Bílina River under Jirkov, b – hard fortification – the Bílina River in Jirkov, c – riprap fortification of shorelines – the Bílina River above Most, d – fortification of the convex shoreline – the Vlára River in Bylnice) (photo: Z. Adámek).*

If the current velocity in these streams is not higher than 0.1–0.2 $m.s^{-1}$ there are also abundant mayfly larvae (*Cloeon, Baetis*) that profit here from the preferred microhabitat (filamentous algae) and absence of fish. Fish in these streams occur very rarely, solely in connection with migration activities, and often they are completely missing in a stream. In a limited extent, they can survive in such stream in the form of 0+ category (fry) in the immediate vicinity of shorelines or vegetation.

Shoreline riprap fortifications (Fig. 5.1.8.c.) or those with coarse gravel or wood lining are already much closer to nature. The bottom is preserved with the original substrate and it enables communication with sub-riverine and underground water. However, natural stretches with pools, gravel beds and undermined shorelines are removed. In order to reduce this matter, small weirs (stony or wooden) are built in a stream bed, which create, at least partially, diversity of water currents, sedimentation and depth conditions in a stream as well as diversity of bottom substrates. A negative phenomenon during these regulations is the use of sharp quarry stone and lately, it has also been strengthening by wire constructions (gabions – wire stone cages). In these streams, fauna is preserved from the most part, however, phytophilous organisms dependent on vegetated shorelines, which live in exposed shorelines and roots of trees of riparian vegetation, that regularly reach water, are limited. If a stream is not covered with riparian shrub and tree canopy, then the water is intensively warmed up by sunshine during summer months. Increased temperature with a large portion of exploitable photosynthetic radiation enables the development of filamentous algae and cyanobacteria, especially in streams with higher nutrient loading. These streams often become overgrown with higher plants, mainly with water *Batrachium* and *Potamogeton*. Zoobenthos is developed without any considerable limitation. Riprap shoreline fortification serves as refugium mainly of fry (0+), or also adults of some benthic fish species (bullhead, gudgeon and burbot). Ripraps in the lower Morava and Dyje Rivers have been colonized by representatives of Gobiidae family in recent years – tubenose goby (*Proterorhinus semilunaris*) and also newly round goby (*Neogobius melanostomus*). The production potential of such modified smaller streams, mainly salmonid brooks, has been considerably increased by the construction of small weirs. Nevertheless, such status is neither natural nor desirable and is permissible only in urban areas.

The type of **stream regulation with fortification of a convex shoreline** due to erosion reduction (Fig. 5.1.8.d.) is the most closest to the nature. The fortification is conducted by riprap, lining with tree trunks, combination of tree branches and rock filling. These modifications, especially if riparian vegetation is preserved, have almost no detectable impact on the life of a stream.

A purposeful measure which minimizes the negative impact of stream and shoreline modifications is the use of emerged plants to strengthen shorelines or bottom (so-called **vegetation fortification**). Suitable vegetation fortification resists flow velocity up to 0.5 $m.s^{-1}$, episodically even considerably higher. The advantage is the maximum possible approximation to natural status, creation of shelters for fish (mainly fry) and substrate for the development of natural food. Almost all species of emerged hard vegetation are suitable to be planted in bottoms or shorelines (e.g., *Calamus*, *Butomus*, *Typha*, *Glyceria*, *Phragmites*, *Sparganium*, and *Phalaris*), the shrubby willow trees (*Salix* sp.) being particularly advantageous due to the fact that they resist occasional inundation and high flow velocity.

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5.2. Restoration of damaged aquatic ecosystems *(Z. Adámek)*

5.2.1. Determination of ecologically acceptable minimum discharges and alterations to hydrologic regime

The minimum discharges and alterations to hydrologic regime represent one of the most negative factors influencing stream biota. There has been an increased effort in recent years, however, not always successful, to implement necessary corrective measures. The factors which contribute to alterations to hydrologic regimes the most, as already mentioned above, are:

- peaking – often down to zero values between increased discharges,
- derivative hydro-power stations and mills with raceways – modified stretch of a river;
- water abstractions – drinking and industrial water;
- manipulation with water management systems – e.g., pond filling and draining.

The minimum discharge (MQ) is a balance value that represents the preferentially secured entitlement to water source; it respects the preservation of conditions for **biological balance in a stream and its immediate surroundings** and enables general use of water that does not require permission of water management authorities.

A large number of criteria regarding determination of such discharge have been published, which were summarized by B. Statzner et al. (1990):

The determination should be based on bottom morphology (cross-section of the stream bed, i.e., shape of watered profile, bottom slope and hydraulic roughness – substrate granulometry).

The level of technical modifications in a river bed, the greater they are, the higher residual discharge is to be ameliorated.

- Depth is a less critical variable for invertebrates than for fish for which a certain type and current velocity are necessary to be respected. Fish thus represent the most suitable indicator group for the determination of minimum necessary discharges.
- The minimum discharge should be "close-to-nature", including relevant impact on composition and distribution of overall fauna of the bottom or important species.
- The minimum discharge must be comfortable not only for fish but also for their food organisms.
- Discharge conditions that are comfortable for protected species should be preferred to other criteria.
- Minimum discharge should be established individually for each case.

Water managers consider the discharge Q_{364} as the minimum from the hydrologic point of view, i.e., the discharge which occurs only within the long-term monitoring once a year and all the other discharges are always higher. The discharge Q_{355} has been suggested as ecologically acceptable several times, i.e., the value which occurs only for 10 days per year and all the other discharges are higher.

However, all these values are based only on hydrology, and do not take the stream ecology into account, which is an attitude which has started to change at present. Objective determination of the minimum discharge that would not have any essential impact on populations and communities of aquatic organisms represents a rather difficult task from the methodical point of view. Usually, it is established that MQ should correspond to the values that lead to a maximum 20% decrease in values of macrozoobenthos density and biomass, which corresponds to the values between Q_{330} and Q_{300}, i.e., the value that is necessary to be adhered to in salmonid and grayling zones. Methodical instruction of the Ministry of the Environment explicitly defines that these values are recommended and initial and minimum discharges should be established individually according to the above-mentioned principles. It regularly occurs that in a trapezoidal stream bed of large cross-section, the minimum discharge is required to be several times higher than in a natural meandering stream.

The minimum discharges are not the only matter caused by artificial and longitudinal constructions. Peaking and zero flow-rates can be eliminated by constructing a reservoir with sufficient volume directly

Fig. 5.2.1. ***Deflectors on the Dyje River in the National Nature Reservation Soutok, Pohansko area*** *(photo: P. Jurajda).*

under a dam. Compensatory reservoirs are built with large water works. These structures are distinguished by controlled outflow which should eliminate the peak as much as possible and protect the stream from extremely low discharges.

Next, it is possible to modify the stream bed by so-called deflectors which are inclined or vertical walls in a stream (Fig. 5.2.1.) that increase water retention and decrease the flow. They can be either impermeable (rather unsuitable from the ecological point of view) or permeable, made of stone blocks, often supported with timbering.

5.2.2. Restoration of outflow rates

A significant future task within all river basins in the cultural landscape is alteration to outflow rates. Alterations to outflow rates in the landscape can be achieved by changing the extent of forested and grassed areas, elimination of ill-considered regulations and restoration of wetlands in the landscape.

Restoration and revitalization of streams degraded by regulations is extremely demanding and consists of restoration and modification of the longitudinal and cross-section geometry of a stream bed and modification of the whole flood area. It is always necessary to proceed in a complex manner, i.e., if a river bed itself is revitalized, it is necessary also to modify the shorelines and optimally the whole floodplain – flooded area. Weir dams represent a considerable obstacle for migrations of aquatic organisms, mainly fish, and an overflow ray is often not able to fully saturate water with oxygen (see chapter 5.1. Hydrotechnical

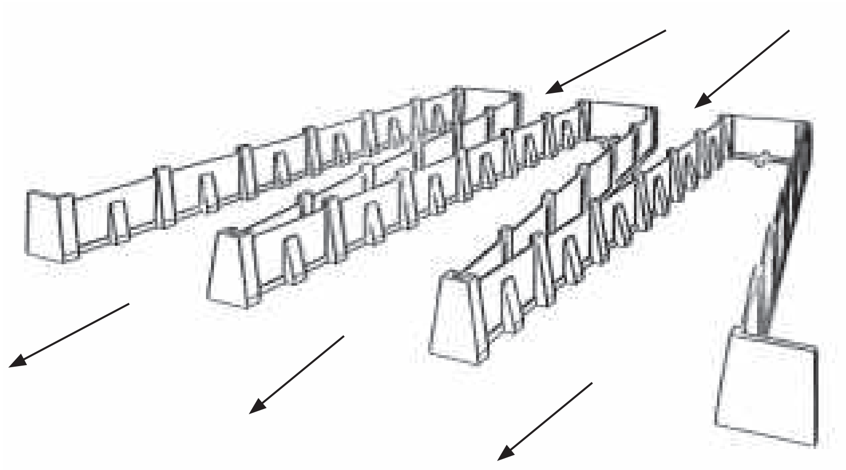

Fig. 5.2.2. ***Possible modification of a weir dam – elongation of the weir top with increased aeration*** *(adapted from Adámek et al., 2010).*

interventions). Several technical modifications can be conducted for such purpose. One of the simplest modifications is to lower the height of the weir dam and to elongate the overflow edge (Fig. 5.2.2.).

Another solution that has often been used recently is a fully-manipulable bag weir which enables total draining of a weir reservoir. Weir dams made of wire blocks filled with stones (gabions) have also been used very often, or a weir formed by a riprap – Fig. 5.2.3.). These riprap weirs can also serve as fishways enabling fish and other aquatic organisms to overcome artificial obstacles in a stream.

Fig. 5.2.3. ***Riprap weir on the Morava River near Lanžhot*** *(photo: Z. Adámek).*

All corrective measures and interventions should be accompanied by the monitoring of the effects – biomonitoring focusing on key communities and taxa. Monitoring of a fish community should be aimed at key species in particular, preferentially predators and protected species (Adámek et al., 2010). In upper stretches of streams, the key species are considered to be: brook lamprey, bullhead and Alpine bullhead and brown trout. In lower situated profiles, these are, above all, rheophilic species – barbel, common carp, chub, bleak and piscivorous species. As far as predators are concerned, it is rather disadvantageous that they are exposed to considerable angling pressure which radically decreases their applicability for the meaningful monitoring purposes.

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5.3. Protection of migrating fish *(P. Dvořák, J. Andreji)*

Global as well as local ill-considered interventions in the aquatic environment have caused alterations in fish communities. The large base of knowledge of these alterations has led to an effort to effectively protect not only fish but also other living organisms. In the 19th century when water in streams started to be intensively used for technological purposes, numerous water constructions emerged which interrupted free migration routes for aquatic organisms that had been existentially dependent on them. Hydroelectric power stations have had a considerably negative impact on fish as well as other organisms.

5.3.1. Impact of operation of hydroelectric power stations on fish

The operation of small hydroelectric power stations (SHPS) has a negative impact on fish populations in a water stream. Due to water off-take from a stream the number of species usually decreased and the abundance of 1–2 species, which prefer shallow water (e.g., common gudgeon, stone loach), increased enormously. Weir storage basins alter the original mesohabitats of fish in running waters and create conditions for lentic water species (e.g., roach, common bream, and gibel carp). Derived stretches of SHPS streams are distinguished by demonstrably lower abundance and biomass. The cycling operation of a power station (peaking) prevents stabilization of aquatic biotope, which is less settled by fish, natural reproduction is decreased and in some cases, it can even cause the death of fry eggs and fish. Artificial obstacles prevent fish from freely migrating through a stream and re-settling in its upper stretches (Otterström, 1931).

Fish thrown by water flow against bodies of small hydroelectric power stations (SHPS) are injured by getting stuck on screens and when passing through turbines. Half of the fish that get stuck on a screen are ill or injured individuals which are not able to resist the water suction pressure which throws them on the screen due to their illness or injury. The number of fish that get stuck on SHPS screens increases in the spawning periods and during post-spawning migrations. In early ontogenetic stages, fry and fish of a size of up to approximately 15 cm are injured only to a small extent and reversibly while passing through SHPS turbines. As far as fry of the cyprinid species are concerned, the losses caused by passage through SHPS turbines are around 10% (Adámek and Jurajda, 1997).

Turbine blades cause migrating fish external as well as internal injuries, haematoma, fractures or chop their bodies into pieces (Monten, 1985; Davies, 1988). Davies (1988) monitored the impact of different turbine types on passing fish and described 4 basic reasons for their injuries:

- collision with a hard or rotating part of the turbine;
- sudden change in pressure;
- centrifugal force and turbulence;
- hydrodynamic cavitation.

With respect to fish passing through reaction turbines, it is possible to record considerable exophthalmos, bleeding eyes, ruptured eyes and bleeding fins. There are also internal injuries, such as ruptured air bladders, internal organs and tissue haemorrhage or external injuries caused mainly by hydrodynamic cavitation (Davies, 1988). Mechanical injuries are usually less dangerous for live fish that have passed through water turbines; however, fish usually die due to sudden pressure changes and hydrodynamic cavitation (Donaldson, 1960; Cada, 1990). As far as small fish and insect larvae are concerned, increased injuries and higher mortality rates are observed due to sudden pressure changes during passage through turbines (Marcy, 1975; Collins, 1984). Injuries of fish that have passed through turbines are of different sizes. If an injury affects more than one fourth of the body surface, the injured fish usually die (Kostecki et al., 1987; Bernoth, 1990).

5.3.2. Fish barriers and their function

Extensive research focusing on enhancement of living conditions of fish that are dependent on migrations was initiated at the end of the 19th century. Enhancement of upstream fish migration is ensured by fishways (see chapter 3.8.). Technical or natural bypass systems ("bypasses") that are equipped with fish barriers protecting fish against being sucked in at water off-take sites support downstream migrations. Fish barriers started to be used at the beginning of the 20th century especially to protect young salmon smolts and adult eel migrating to the sea (Lundbeck, 1927; Baar, 1903; Otterström, 1931).

Fish barriers have two fundamental functions:

- **- to prevent fish and other aquatic organisms from entering technical devices** (hydroelectric power stations, filling stations, irrigation systems, refining stations, breeding facilities, etc.);
- **- to guide fish away from technical devices to an original stream bed that is affected by the water off-take,** e.g., through a bypass (Fig. 5.3.1.).

Before installation of fish barriers, it is important to:

- know the data concerning the hydrotechnical system;
- know information about the hydrologic flow-rate and topography of the stream's bottom;
- conduct biological assessment of the affected stretch of a stream;
- map fish communities in an affected stream, or other possible species migrating through a stream, so that suitable barrier types and parameters can be chosen;

Suitable placement of fish barriers in front of the water off-take from a stream raceway is a precondition for its proper functioning. The efficiency rate of the protective device is influenced also by the flow velocity in a stream. Protective systems are installed in front of turbines or supply bodies (raceways) and they are always connected to the bypass which helps migrating fish to get away from the working area of the turbines back to a stream under hydroelectric power station.

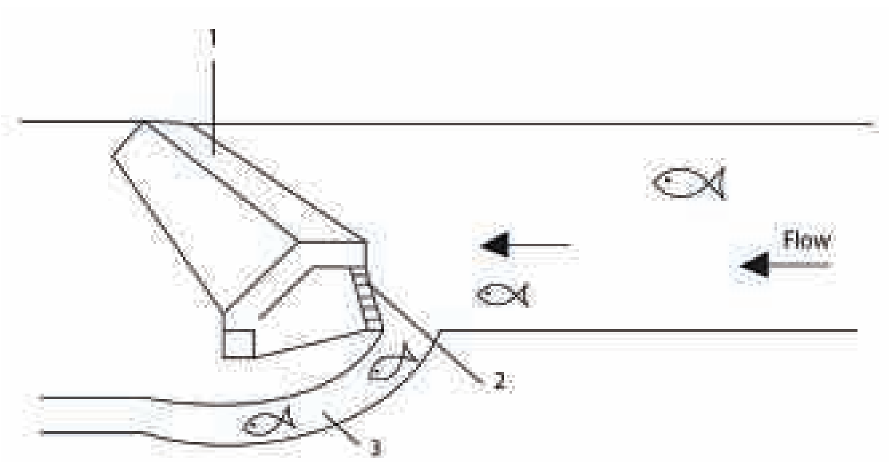

Fig. 5.3.1. ***Scheme of weir with installed SHPS bypass for fish migrating downstream.***
Weir body – 1 creates artificial obstacle for migrating fish. Intake into SHPS is protected against fish entering by a barrier – 2 which guide fish into the bypass 3 (scheme: P. Dvořák).

Possibilities to decrease negative impact of SHPS on aquatic biota

Decisive prerequisites for the successful reduction of the negative impact of water works on aquatic biota involve adherence to the relevant legislation and the proper attitude of state administration bodies to construction of new or the operation of existing water works and SHPS. Most importantly, it is necessary that the construction and operation of SHPS are based on a global assessment of the relevant territory and river continuum. Such attitude will prevent devastation of a stream and preserve its ecological stability and function as a significant landscape element. Adherence to the below-mentioned measures can lead to a decrease in the negative impact of SHPS on aquatic biota:

- ensuring continual regulation of the water off-take in order to maintain the minimum residual flow-rate
- prevention of water accumulation and cyclic modification of river flow-rates
- installation of technical devices reducing the entry of aquatic organisms into a power station body
- construction of alternative migration pathways over artificial obstacles (weir, dam, etc.)
- minimization of leakage of substances decreasing the water quality (substances connected with the SHPS operation – oils, lubricating grease, paint, varnish, disinfectants and detergents, waste sewage water, etc.)

Current systems focusing on direct protection of migrating fish (so-called fish barriers) are divided into:

- mechanical;
- optical;
- acoustic;
- electric;
- other.

a) Mechanical fish barriers

Screens

Screens represent one of the oldest and still the most used fish barriers. They are used mainly as protection against fish entering places that are determined for consumption of technological water, against entering undesirable fish species and other organisms into fish breeding facilities, or against escape of fish during draining (fitting) of ponds before the harvest. Screen bars are oriented horizontally or vertically. They are of a streamlined shape (which puts up little resistance to water flowing through) and they are rounded in order not to injure fish. Based on the fish community type, it is necessary to select an appropriate screen pitch (Adam, 1998; Hartvich and Dvořák, 2002). The flow velocity in front of the screens should not exceed 0.2 $m.s^{-1}$ which increases the barrier protective effect and fish can easily avoid it and are guided to the bypass. Increasing the flow-rate by way of a screen curtain, which is required by the technological off-takes, enables suitable placement of the screen field, e.g., by inclined adjustment of the screens and a pointed screen curtain in the shape of the V or U letter with the point oriented against the flow (Hartvich and Dvořák, 2002).

Revolving flat screen

Revolving flat screens (Fig. 5.3.2.) guide migrating fish into the bypass away from working area of SHPS turbines. Screens are fixed in the middle on a swivel joint which enables the washing away of collected impurities. When turned over, they are cleaned with flowing water and they can again work and guide fish properly. Revolving screens are recommended for installation in smaller streams (or on the edge of a raceway) in front of the off-take of technological water (Hofer and Riedmuller, 1996). The gaps between the bars should be at least 20 mm. The bypass for fish migration around the water off-take site is connected to the back base of the screen curtain (pipe of 300 mm diameter is sufficient). It results from the Rathke and Kuhlmann's (1994) observation that by installation of a barrier with a bypass, damages to migrating eel have been decreased by up to 62%.

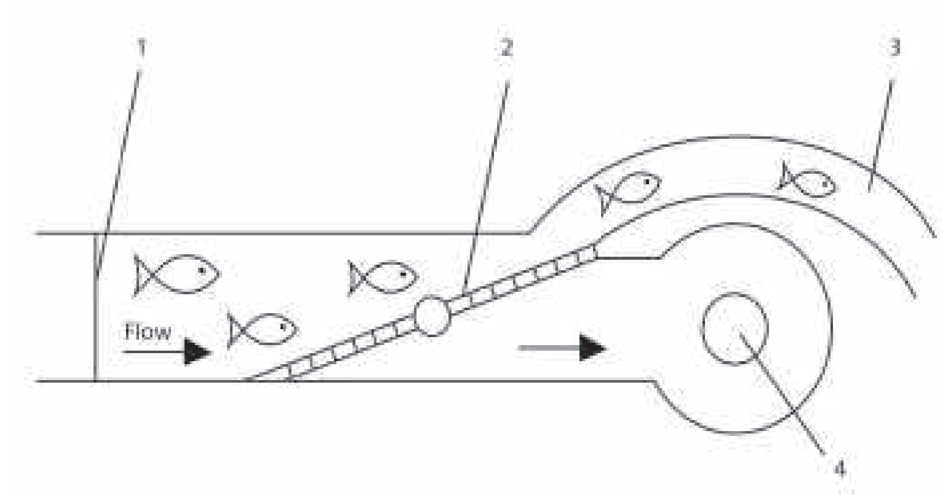

Fig. 5.3.2. ***Revolving screens*** *are installed in a raceway – 1, screens – 2 are attached onto a swivel joint which enables turning over of the screens and rinses them with flowing water, the fish are guided by the screens to the bypass – 3, away from the SHPS turbine – 4 (scheme: P. Dvořák).*

Wedge-wire screens

Wedge-wire screens are constructed in a different way and directed with the broader base against the flow (Fig. 5.3.3.). The gaps between the bars are usually 5.3 mm; therefore, they are effective even for juveniles (Otto et al., 1981; Ehrler and Raifsnider, 1999). The screens are installed in a slight slope towards the bottom in the direction of the stream, which increases their protective effect, facilitates automatic cleaning, increases the surface of flowing water and prevents heaving (Weisberg et al., 1987). The screens are connected with their top edge to the transverse bypass which guides fish away from a technical body under an artificial obstacle. Trapezoidal screens in the form of cylindrical barrels (Fig. 5.3.4.) are used for bottom off-takes which function as a suction basket of the pumps and which provide very efficient protection.

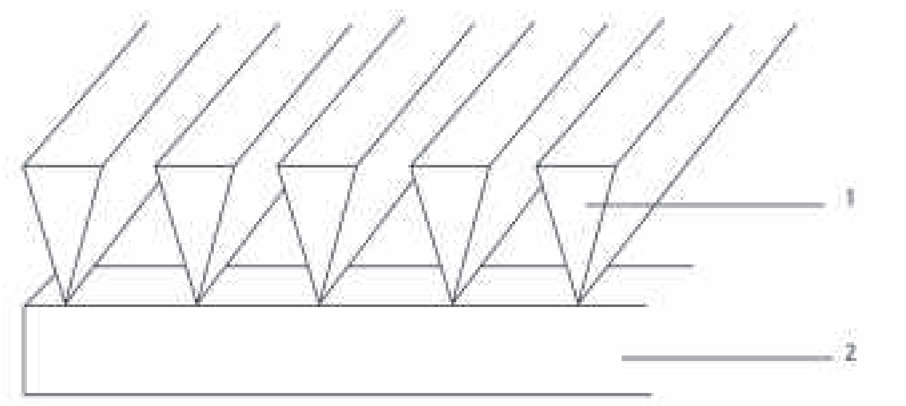

Fig. 5.3.3. ***Wedge-wire screens.*** *Screens are formed by trapezoidal bars – 1, the base is directed towards the water inflow and the bars are reinforced by crossbeams – 2 (scheme: P. Dvořák).*

Fig. 5.3.4. ***Cylindrical barrels made of trapezoidal bars installed as a protective filter on piping taking off technological water*** *(photo taken from http://www.bdiscreens.com/fishdiversion.htm used with the approval of Industrial Screen Products, Inc., P.O. Box 366, Placerville, CA 95667 USA).*

Louver

The louver roll-up shutter is a screen barrier developed in order to protect young salmon (smolts) that migrate to the sea (Fig. 5.3.5.). The barrier consists of up to 15 cm large iron vertical slats and the spacing between the slats is up to 10 cm (optimally 4 cm). The screens are installed at an angle of 65–80° against the direction of water flow which creates a repelling turbulent flow for fish (Fig. 5.3.6.). Migrating salmons, which also use their eyesight for orientation, see no free migration pathway ahead. Therefore, they avoid the barrier and migrate along it up to the bypass (Scruton et al., 2002). The barrier is installed on the inlet of the side off-takes from the river bed. The efficiency is highly influenced by the flow-rate and water cleanliness (Bates and Vinsonhaler, 1956; Bates and Jewett, 1961). Skinner (1974) assessed the Louver barrier adjusted to the V-shape with the 15° gradient towards streamline. The monitoring proved a reduced protective effect for migrating fish of smaller sizes. The efficiency of this barrier for migrating eel was monitored in Germany, however, in these tests, it did not prove effective (Goosney, 1997).

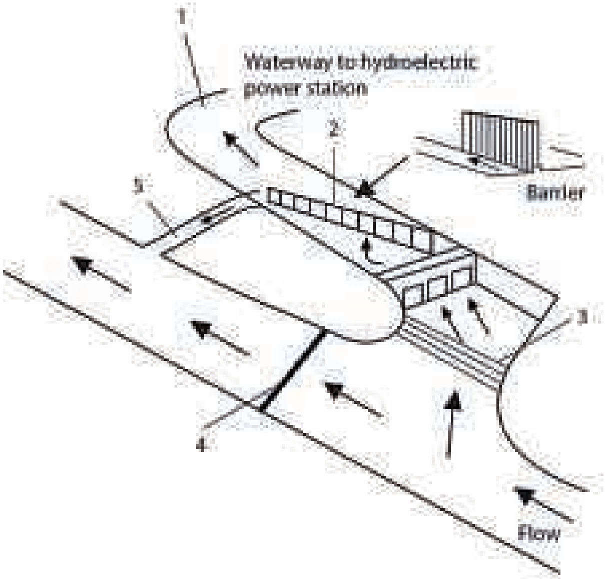

Fig. 5.3.5. ***Installation of the Louvre barrier into the raceway for the SHPS.*** *Water is flowing through the raceway – 1 into the SHPS, fish are guided by the barrier – 2 back to the main stream under the weir – 4. Coarse impurities and water debris are caught by pre-screens – 3 (scheme: P. Dvořák).*

Fig. 5.3.6. ***View of the stream of the irrigation channel – inclined position of the barrier – Louver*** *(photo taken from http://www.usbr.gov/pmts/hydraulics_lab/pubs/manuals/fishprotection/ used with the agreement of the U.S. Department of the Interior Bureau of Reclamation Denver, Colorado 2006: Fish Protection at Water Diversions, A Guide for Planning and Designing Fish Exclusion Facilities 2006, pp. 480).*

Rotating meshes

Mobile screens in the form of differently arranged flat rotating meshes supplemented with a bypass system for diverting migrating fish represent a relatively new fish barrier (Fig. 5.3.7.). Maintaining the required flow-rate is dependent on the cleanliness of the meshed barrier. High-pressure water jets are usually used for cleaning. Meshes can also be cleaned by mechanical brushes that move on the mesh and clean them at regular intervals. A high protective efficiency for migrating fish is achieved by the slow rotation of the metal mesh whose individual meshes are 8 x 15 mm in size. This barrier should be used in small and medium streams where its efficiency is higher than 70% (Matthews et al., 1977; Hartvich et al., 2008). If installed correctly (gradient up to 30°), it represents suitable protection for juvenile fish and grown-up fry. This barrier is used also in production fish breeding, during harvesting of pikeperch yearling under the dam of ponds when it continually harvests fish migrating with drained water.

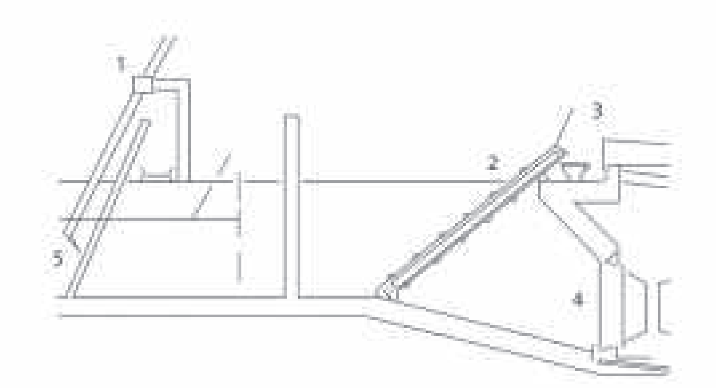

Fig. 5.3.7. ***Scheme of installation of the barrier in the form of a rotating mesh for derivative SHPS in Hadamar, Germany.*** *Technological water from the raceway (5) flows through rough screens (1) onto rotating screens (2) that carries fish and minor impurities into the bypass (3). Water is subsequently taken off by the SHPS (4) (scheme: P. Dvořák).*

Rotating cylinder

The barrier comprises a cylinder of wedge-wire screens; water flows through these cylinders and migrating fish are diverted from the side off-take back to the stream (Fig. 5.3.8.). The downstream rotation enhances the protective function of the cylinder which also ensures its draining and cleaning. Water off-take can be conducted from the inside space of a cylinder or behind the cylinder. If this barrier is installed into raceways, it is necessary to ensure the fish migration through a suitable bypass, closely to the intake side of the cylinder. The barrier is especially suitable for off-take of water from smaller streams (Höfer and Riedmüller, 1996; Holzner, 1999).

b) Optical barriers

These types of barriers require sufficient water transparency (Fig. 5.3.9.); therefore, the protective effect of a light barrier is considerably decreased due to turbidity in eutrophic and hypertrophic streams or during floods. The effect of light barriers (of different colours) influences riverine species selectively. Photophobic fish species avoid the barrier; conversely, photophilous species are attracted by the barrier (Betge et al., 1965). New mercury discharge tubes have slightly increased the efficiency of the barrier, but migrating eel have managed to overcome this barrier after a short-term interruption of the migration. It was the increased flow-rate in the bypass that diverted migrating eels from the main streamline to the bypass (Berg, 1985; 1994; Seifert, 1998). A light barrier equipped with a mercury discharge tube filled with helium and stroboscopic lamps has proved highly effective with migrating salmon (Nemeth and Anderson, 1992).

Fig. 5.3.8. Wedge wire screen cylinder *(photo taken from http://www.bdiscreens.com/fishdiversion.htm and used with the agreement of B. Deo-Volente, Inc. 1255 Monmouth Blvd., Galesburg, Illinois 61401).*

Fig. 5.3.9. Installation of underwater floodlights *(photo: Bruijs, 2010).*

Air bubble curtain

These protective systems use freely floating gas of minor air bubbles that create a curtain several centimetres wide. Fish react visually to the barrier, moreover, the noise which is released by the compressed air into water has also a repelling effect. Trefethen (1968) described the deterring effects and impenetrability of these barriers with migrating herrings.

Chain curtains

This is a curtain consisting of metal glistening chains installed in front of the side inlet (raceway) into the power station. Fish perceive the curtain as an optical barrier and avoid it. The efficiency of this barrier is enhanced by the sound that is produced by the movement and friction of the mutually interconnected chains (Holzner, 1999). This chain barrier can be used stationarily or it also functions very well as endless rotating belt.

c) Acoustic barriers

Generation of repelling noise

Generation of noise or sound under water influences fish behaviour. Some sounds can allure fish (stimulating) while others can repel them (repelling). A sound projector (Fig. 5.3.10.) generates sound by way of a flexible membrane (Filčagov et al., 1988; Hartvich and Dvořák, 2002). Enger et al. (1993) monitored the reaction of young salmon – parr to different sound frequencies and discovered that the frequency of 10 Hz has a strong repelling effect. He verified his laboratory finding even in practice and parr in fact avoided localities in front of SHPS where the sound (10 Hz) was generated. Other frequencies (e.g., 150 Hz) did not show any considerable repelling effect on salmon. Nedwell et al. (2003) studied the reaction of fish to the level of a sound barrier and they improved its efficiency in combination with an electrical barrier. Its efficiency has been confirmed even by some salmon stock breeders in Germany who mentioned a decrease in losses of up to 96%.

"Popper"

This is a sound-pneumatic barrier operating on the principle of producing sound by means of compressed air released from jets under the water level. This creates a repelling noise or pressure waves that deter fish permanently and keep them at safe distance from the water off-take site. The disadvantage is

Fig. 5.3.10. ***An underwater sound projector and sound generator with control unit*** *(photo: Bruijs, 2010).*

that the efficiency of the barrier is decreased during intensive migration activity and also the operation of such barrier is very demanding from an energy point of view (Holzner, 1999).

d) Electrical barriers

It is possible to exert a repulsive effect on migrating fish by means of an electrical pulse field or constant direct field. The efficiency of the electrical barrier is influenced by a wide range of physical and chemical water qualities (flow-rate, temperature), species and size of migrating fish as well as their physiological status (Hartvich and Dvořák, 2002). Eel have proved to be the most suitable for the testing efficiency of electrical barriers and the effect of electrical fields on fish (Rommel and McCleave, 1973). Eel were able to recognize even the smallest changes in an electrical field after which they escaped. The deterring effect of an electrical field on rheophilic fish species was increased, in comparison to the constant electrical current effect, by alternating the voltage and change in frequency of electrical impulses (Halsband, 1955a,b; 1956). An electrical barrier consists of the source of the electrical energy, the pulse generator, wiring and electrodes installed in a stream (Fig. 5.3.11.). These basic components of the barrier can also be equipped with a device that evaluates the deterring effect of the electrical field on migrating fish and subsequently changes the frequency and intensity of electrical pulses. Electrodes can be installed on one or more levels. The efficiency of one-level electrodes on migrating eel is the highest when the flow velocity is up to 3 $m.s^{-1}$ and temperature above 9 °C (MeyerWaarden, 1956; Adlmannseder, 1986). Although the deterring effect of electrical barriers has been modified and enhanced, their efficiency, however, is only temporal (mainly for eel), and if the barrier is not connected with a functional bypass, fish can overcome it (Rauck, 1980).

Arrangement of electrodes on two and more levels

These systems are used mainly in Russia and are highly effective due to their arrangement. They are installed in slow flowing waters to enable migrating fish to escape in time from a considerably greater electrical field (Holzner, 1999). These systems are also used in fish breeding facilities to prevent from entering of undesirable fish species and other aquatic organisms.

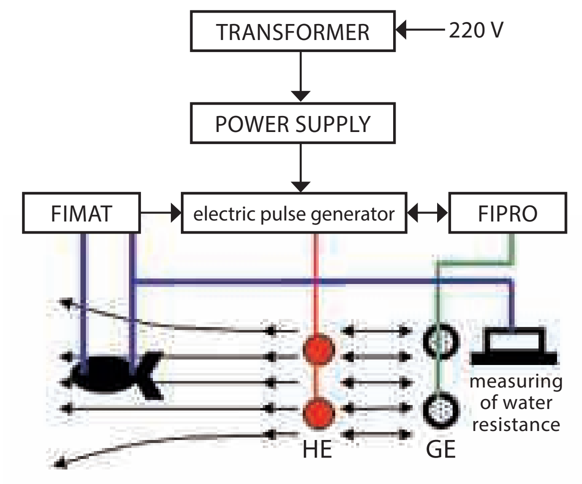

Fig. 5.3.11. ***Scheme of electronic barrier Geiger.*** *The pulse generator changes the frequency and intensity of electrical pulses, the Fimat device monitors the efficiency of the repelling zone and adjusts the alternation of frequencies of electrical pulses, the Fipro device monitors selected physical and chemical water qualities, the repelling electrical field is produced between electrodes (HE and GE) which repel fish (scheme: P. Dvořák).*

e) Other types and possibilities to protect migrating fish

Use of chemical repellents

Chemical repellents were used experimentally in tested bodies with technological water off-takes. Effective substances were applied by batching units on intakes into raceways of derivative SHPS continually or at intervals. Biodegradable chemical substances which were neither addictive nor residual were used to repel fish. Chemical substances used for repelling fish had an effect on the mucosal surface of fish – the eyes in particular (Holzner, 1999). At present, chemical repellent preparations for repelling fish in streams are not used.

Fish pumps

The construction and operation of fish pumps are fish-friendly and they suck in fish together with water. Fish pumps are operated in a slow manner and consist of rounded blades of a conical rotor that enlarges in the direction of the flowing (Fig. 5.3.12.). They are used mainly in localities with regular and abundant migrations of smaller fish species where it is not possible to build effective bypasses, or where several water levels in a short distance are situated from each other and fish are loaded, transported and released after a unit of insuperable obstacles (e.g., Columbia River, USA). The effectiveness and efficiency of the pumps are directly dependent on the proper functioning of the harvesting fish trap that is to catch fish before their transportation (Holzner, 1999).

Safe operation of hydroelectric power stations and water off-takes – water turbines not injuring fish

McKee and Rossi (1995) described a turbine based on a Kaplan turbine which alters internal hydraulic rates that considerably decreases the damage to migrating fish. It was successfully tested during spring downstream migration of salmon parr. It is possible to minimize the danger for fish passing through turbines by means of targeted measures and modifications to turbines (Bernoth, 1990). New types of low-speed rotors, rounded blades and changes in operation conditions decrease cavitation and mainly turbulent flow. Ideally the users of hydroelectric power stations should reduce their operations during the increased migration activity of fish.

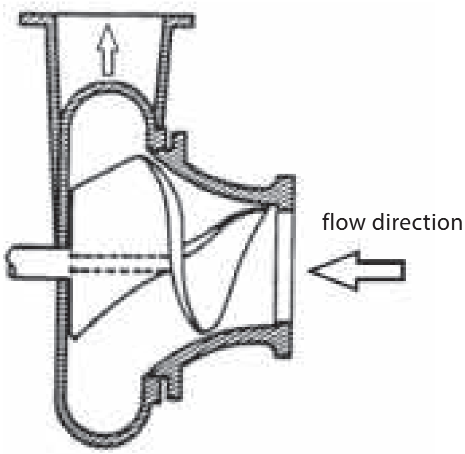

Fig. 5.3.12. **Scheme of a fish pump** *(scheme: Clay, 1995).*

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5.4. Piscivorous predators and their impact on fish populations in fishing grounds *(Z. Adámek)*

Damage caused by piscivorous predators is permanently persisting on the territory of the Czech Republic. It can be stated that beyond doubt the seriousness of the conflict between fishery and the protection of overabundant protected predators has been constantly emphasized by social as well as economic aspects. Alterations in human use of the landscape connected with enhanced water quality, as well as relatively highly effective conservation of protected fish predators over the past two decades have resulted in an increasing spread of predators not only in Europe but also on Czech territory. Alterations in human use of the landscape have contributed to an enormous increase in the number of cormorants throughout European territory, however, their contribution to increased numbers of otters is smaller and their relation to the numbers of herons and kingfishers is rather insignificant. American mink represents a separate chapter which has spread into the wild mainly as a consequence of the liquidation of breeding facilities or through their escape during the past decades. The most significant factors that have influenced the spread of fish predators in the Czech territory are (apart from the intensified legislative protection):

- rich and easily accessible food offer of fish in ponds;
- increased trophic level of Czech water bodies;
- non-freezing of the streams under the valley reservoirs;
- reduced application of pesticides;
- channelization and regulation of streams connected with the loss of ecological diversity (shelters, shallow riffles, etc.);
- stocking of open waters with hatchery-reared fish with weaker anti-predatory behaviour and poor escape reactions.

5.4.1. Great cormorant (Phalacrocorax carbo sinensis)

The abundance of great cormorant (Fig. 5.4.1.) has increased rapidly within a relatively short time span. It is stated that approximately 3500–4300 breeding pairs nested on the territory of the North-Western and Central Europe at the beginning of the 20th century, while at present, as many as 340000 breeding pairs have been recorded, which represents approximately 1400000 birds together with the non-nesting individuals (Fig. 5.4.2.). They have caused serious damage to fishery which has even forced some fish farms in the north of the European continent to close down. Cormorants have caused the highest losses in salmonid waters, especially in grayling populations, as grayling do not shelter and fully correspond to the feeding requirements of cormorant from the size as well as morphological and behavioural point of view. Grayling populations have decreased so dramatically in some well-known grayling grounds in Germany, Switzerland and Austria that they almost no longer occur there. Fatal decreases in catches has also been recorded in the Czech territory in some salmonid fishing grounds under dam reservoirs, such as on the Dyje River downstream of the Vranov reservoir, the Vltava River downstream of the Lipno reservoir or the Ohře River downstream of the Nechranice reservoir. In non-salmonid fishing grounds, large damage caused by hundreds of hunting cormorants have been reported mainly in the winter period, e.g., from the Radbuza River in Pilsen, the Elbe River near Ústí nad Labem or the Vltava River in Prague.

Cormorant flocks cause the largest damage in autumn (October – November) from north to south and subsequently, during the return of these flocks in spring (March – April), the damage is slightly smaller. A considerable number (9000–14000 cormorants by estimation) stay within the Czech territory over the whole winter (Fig. 5.4.3.). Outside the nesting period, permissions to cull cormorant are granted and approximately 4000 cormorants are culled in the Czech territory each year. In other countries (e.g., France, Germany), these numbers are several times higher.

Fig. 5.4.1. ***Great cormorant*** *(photo: P. Vrána).*

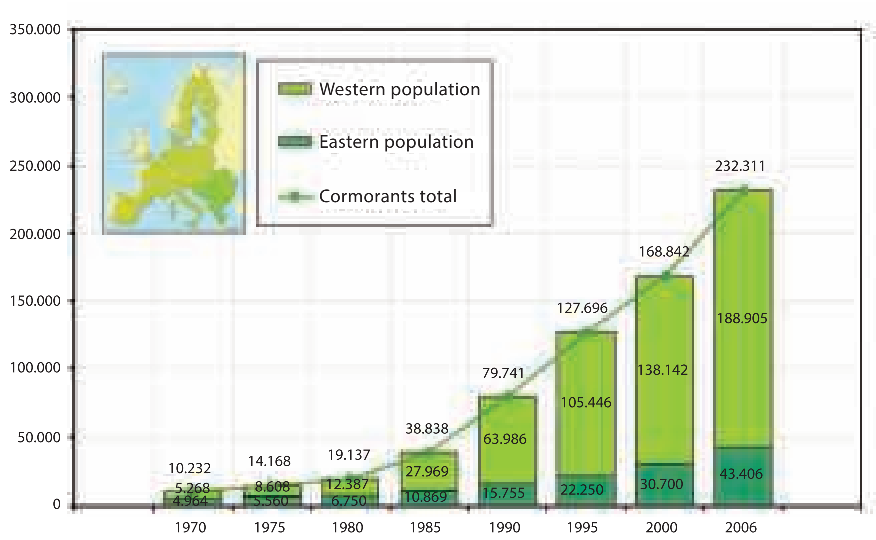

Fig. 5.4.2. ***Increase of the number of great cormorant nests in Europe between 1970–2006*** *– adapted according to P. Musil (unpublished).*

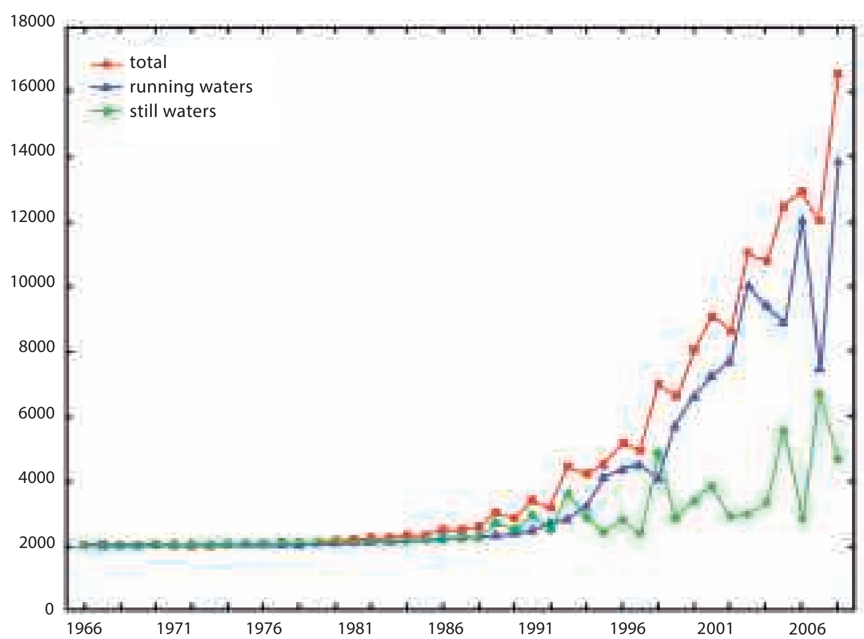

Fig. 5.4.3. ***Estimation of the number of wintering cormorants within the Czech territory (January)*** *– adapted according to P. Musil (unpublished).*

During spring and autumn migrations, cormorants occur within the Czech territory in all places where they find suitable feeding conditions, i.e., at ponds, usually in periods without ice cover, and after lentic waters have frozen over, they occur at large rivers and open streams under reservoirs. Nesting populations do not usually represent a serious problem. At present, nesting colonies can be found in four sites in the Czech Republic and the number of nesting pairs ranges at around three hundred. When young cormorants are fed in a nest (from the end of May till the beginning of July), parent cormorants fly for food over 25 km. Nesting trees in colonies and their surroundings, as well as places where up to hundreds of birds rest overnight, are covered with their droppings and are dying (Fig. 5.4.4.).

Hunt for food

Cormorants hunt for prey fish by diving from water level. When swimming under water, they simultaneously use both legs and their long tail (up to 15 cm), which is used as a depth helm. The position of wings slightly apart from the body enables them to dive up to 16 m; however, they most often hunt in depths from 1 to 3 m and remain under water for 15–30 seconds (in some cases up to 70 seconds).

Cormorant hunting for fish is based on visual foraging for prey from water level by submerging the head up to behind the eyes. The hunting strategy comprises two approaches – hunting within the vicinity of shorelines or hunting on open water level. During collective hunting conducted close to shorelines, fish are pushed and concentrated into littoral zones. This strategy is mainly applied in lentic waters with higher concentration of prey fish (ponds) and other piscivorous birds (mostly heron and gull) often feed on such hunt as well. Cormorant flocks create semi-circular or line formations during hunting on open water level and their aim is to encircle fish. They swim forward, dive after their prey and run the fish shoal ahead. Individuals delayed by hunting and swallowing prey fly up and take position again at the front of the formation

Fig. 5.4.4. ***Resting sites of cormorants with trees burnt by their droppings in the Kopacki Rit Nature Reserve (Croatia) at the confluence of the Danube and Drava Rivers*** *(photo: Z. Adámek).*

while cormorants that have already eaten stay at the back. The phase of active hunting lasts for around 15 minutes and each cormorant dives approximately 30 times within this period. As far as the diurnal feeding rhythm is concerned, it is possible to observe two activity peaks – two to five hours after sunrise and one hour before sunset until sunset. During the nesting period, they hunt throughout the whole day.

Cormorant exert mainly group hunting to catch shoal fish, however, it can also be an adaptation to hunting in water with lowered transparency. The group hunting strategy has been observed with cormorant in Europe relatively recently and is connected with the adaptation to conditions of decreased visibility. A change in strategy from individual to group hunting was observed in Holland in the 1970s when water transparency in lakes considerably decreased due to eutrophication. Group hunting is more efficient in water with lowered transparency, within which cormorant push the fish shoal up towards water level where fish are easier to catch due to enhanced light conditions.

Cormorants catch fish with the sharp tip of their beak (Kortan and Adámek, 2010) and attempt to hit the area behind the operculum (Fig. 5.4.5.). Afterwards, they swim up to the water surface and swallow the fish head first. Fish which cormorant have not managed to catch, because they have escaped from their beak or could not be swallowed due to their size, suffer from various wounds (Fig. 5.4.6.) which cause infections and subsequently death (Adámek et al., 2007). Other damage (apart from direct predation and wounds) that they cause to fish in open waters is connected with, similarly to ponds, stress responses of fish exposed to hunting cormorant flocks, deterioration of physical condition and decrease in innate immunity (Kortan et al., 2008; Kortan and Adámek, 2011; Ondračková et al., 2012).

Fig. 5.4.5. ***The most common way cormorant catch prey*** *(photo: Z. Adámek).*

Fig. 5.4.6. ***Typical wound of fish that managed to escape cormorant*** *(photo: Z. Adámek).*

Diet composition

Cormorant feed almost exclusively on fish. Frog femurs have been found in cormorant regurgitates only in one case (Adámek, 1991). Although great cormorants are able to basically catch any fish corresponding to their size, they are mainly food opportunists, which means that they preferentially hunt for such food that is the most available in a given period. Cormorant's preference to feed on weak or ill fish, which has been mentioned rather often, is insignificant from the factual argumentation point of view, since the share of these fish in the cormorant diet is negligible and the cormorant is such an efficient predator that they are not dependent on such prey at all. The positive effect of eliminating weak and ill fish is inconsiderable in comparison with the extent of weakening and injuring healthy fish by hunting cormorants. It seems that the more preferred prey are silver coloured and non-hiding fish, such as grayling and silver carp, and especially shoaling species (whitefish, bleak, roach, etc.). Selective behaviour is not necessarily based only on cormorant preference for certain fish species, but it mostly reflects the different availability of prey, which is connected with species-specific behaviour, anti-predation responses or depth distribution. Shoaling fish are more often found in the diet of cormorants on lentic waters, while fish species selectiveness on rivers corresponds mainly to the density of a concrete species.

Species and size preference for prey is closely related to the quality of the environment. The majority of fish species that are caught due to cormorant group hunting in natural conditions belong to species which increase the density of their populations due to eutrophication processes. Medium turbid water represents the optimum transparency for hunting cormorants. Excessive turbidity in the water limits detection of prey due to decreased visibility, conversely, in clean water, fish are able to escape easier from predators. Fish sized from 15 to 20 (25) cm are hunted the most often. Cormorants, however, can catch and swallow even fish larger than 30 cm with a weight of around half a kilogram. Even considerably larger fish can be wounded by unsuccessful attempts – the most documented fish with an obvious wound caused by cormorant were carp (53 cm and weight of 2 kg – Davies et al., 1995) and catfish with the weight of 2.2 kg (Adámek et al., 2007).

Cormorant daily consumption of food varies throughout the year and the most frequent estimations range around 0.5 kg, which is also the value that is respected by the methodology for determining the amount of damage caused by cormorant (see below).

In dam reservoirs, the most abundant and easiest accessible fish species, such as roach and bleak, usually dominate in the cormorant diet. Common bream, which cannot be swallowed by cormorant too easily due to their body size, are consumed, according to Čech (2004), to a limited extent, even though their populations are also abundant (e.g., Želivka Reservoir).

The diet composition of cormorant hunting in running waters differs on the basis of stream character. In faster flowing rivers, the most common prey are salmonid fish, including grayling, while in lower, slowly flowing stretches, cyprinid species predominate, roach and bream up to the size of 30 cm being the most common. If cormorant diet composition and composition of ichthyofauna of streams visited by hunting cormorants are compared, obviously zero selectivity in the choice of prey in rivers is suggested. However, the majority of authors have accentuated in this context a considerable share of salmonid fish in the cormorant diet, especially grayling, which was already mentioned in the introduction to this chapter. As resulted from extensive studies conducted in Switzerland during 1974–1992, roach (55%) and chub (23%) represented the most frequent cormorant diet in large channelized and regulated streams. However, 65% of salmonid fish, out of which grayling represented the highest share with 49%, were discovered in the cormorant diet in larger unregulated rivers. Only in several cases, barbel, chub and other rheophilic cyprinid species dominated in smaller streams (Sutter, 1997).

It is almost impossible to protect fish in open waters against cormorant predation. Culling and scaring the protected bird are forbidden. Nevertheless, the effect is solely short-term as scared cormorants only move to another locality, where they continue in their hunting with the same intensity. Moreover, fish that they caught before they were scarred away are usually regurgitated in order to be able to fly up easier from water level and understandably, cormorants are forced to catch the required food biomass again. The localities that cormorants were forced to leave are consequently occupied by birds from other, less suitable feeding sites. To cover the critically endangered river sites by wires that would prevent cormorant from descending on the water level is not acceptable from the nature conservation point of view, since it could cause injury to other protected birds.

At present, after serious discussions at the level of competent Czech ministries, the cormorant was removed from the list of protected species and this species is now classified as a game bird.

5.4.2. European otter (Lutra lutra)

In the Czech Republic otter cover more than 40% of the territory and their abundance is estimated to range between 2000–2500 individuals. The highest occurrence is in the areas of the South Bohemia and the Bohemian-Moravian Highlands. These two populations, which were originally separated, have increased in numbers and have mingled with the Polish otter population on the north. Otter populations from Slovakia and Poland have expanded to North-East Moravia to the Beskydy Mountains, smaller populations can also be found in Bruntál and Jeseník areas and in the north of Bohemia.

Otter (Fig. 5.4.7.) is an animal which displays mainly nocturnal activity and inhabits virtually all types of waters within the Czech territory. Otter spend the predominant part of their life in the aquatic environment,

Fig. 5.4.7. **European otter** *(photo: Z. Kadlečíková).*

however, they also need safe places on dry land in order to rest and breed offspring. Burrows and resting sites are usually within the shoreline, among the roots of riparian trees, and they can also be found in reeds, piles of stones, alluvial sediments and thick bushes. Their territory always comprises several burrows. Each one is used for a certain period while burrows used for breeding offspring are usually farther away from the shore than resting burrows. The male leaves the female soon after mating and usually in May to August, one to three offspring are born, which leave their burrows in September to December and stay with their mother for approximately one year.

Studies of otter social behaviour have found that female territory is divided into an internal part, which is defended by females, and peripheral zones, which overlap with neighbouring territories. Overlapping of territories is more apparent in areas where still water bodies are centred than with individuals inhabiting riverine ecosystems. Male territory is much larger and comprises the territories of several females among which males migrate. The area of the territory can be highly variable, depending on the size and distribution of water bodies in a given locality and mainly on the amount of food. The extent of female and male territory is usually 20 km and 40 km of a stream, respectively. If converted to the size of water surface this is approximately 34 ha and 63 ha, respectively. An otter can have two to four main activity areas within its territory where it always spends several days and the distance that an otter covers during one night can reach as much as 15 km. In winter months and in periods with decreased food availability, otters can accept close contact and tolerate hunting by individuals from surrounding territories in their territory in places with water access and a sufficient amount of food (Roche, 2001).

The presence of otters can be recognized on the basis of site signs. Otters mark their territories with excreta which they leave on visible places, such as stones, tree trunks or sand. Favourite places for leaving their excreta include boulders or small rocks extending into water or places under bridges. Particularly in winter, it is possible to find typical five-fingered tracks, burrows in the shore or slides into water on snow-covered or muddy shorelines. In winter, it is often possible to notice the unconsumed remains of fish on the shore or ice as otter usually only eat the abdominal part especially of larger fish or leave only fish heads on the ice.

Diet

The otter diet mainly comprises fish, with non-fish components occurrence being influenced by seasonal availability. Apart from fish, they also hunt mammals, birds, reptiles, crayfish, molluscs, insects and amphibians. Amphibians can represent a considerable part of the otter diet in some areas during the spring period. The fish component represents approximately 75–85% of prey and increases during winter months when the availability of other food is limited. The proportion of individual fish species in the otter diet is dependent mainly on their availability and susceptibility to predation. It has been proved that slow-moving fish species and fish living at the bottom are caught more often. This was also the case, for example, in the Kamenice River in North Bohemia where salmon fry have been regularly stocked. Bullhead and grayling were caught in considerably higher proportion than was their representation in the stream, conversely, trout and salmon parr were caught at a slightly lower success rate (Kortan et al., 2010).

It has been stated that smaller fish dominate the otter diet – the majority of studies mention that the average length of fish caught is up to 15 cm, however, with respect to methodological limitations, the share of large fish can be considerably undervalued. Remains of large fish are not retained in otter excreta on which the analyses are based. The negative role of otter with respect to consumption of larger fish is thus often undervalued. If otter catch a large fish, they usually eat only the soft throat parts and also fish viscera partially (Fig. 5.4.8.). In order to reconstruct the original length and weight, regression relationships between the fish vertebra diameter and its length and weight are used. The reconstructed weight of some carp from Czech ponds that were not completely consumed and remained left by otter, corresponded to up to 7 kg (68 cm). The largest documented catch of otter was carp from a small river between two Finnish lakes with the length of 88 cm, the left remains of which

Fig. 5.4.8. ***Carp remains left by otter*** *(photo: Z. Adámek).*

weighed 14.5 kg (Adámek et al., 2003). A negative feature of the food behaviour of otter, as an intelligent and "playful" predator, is the excessive hunt "for fun" or teaching offspring how to hunt.

Otters' daily prey intake is dependent on the size of the individual and its energy output. Conducted studies have mostly agreed that the daily intake represents 12–15% of body weight, i.e., around 1 kg of prey (Carss et al., 1990). In winter months, the amount of prey can be higher because during hunting in cold water, otters' energy requirements to maintain body temperature are increased which they compensate with by increased food intake and hunting for more suitable prey from the energy point of view (Kruuk, 1995).

Impact of predation on fish communities

Studies concentrating on the impact of otter predation on fish communities have concluded that otter predation suppresses fish populations considerably (e.g., Alexander, 1979). In the Scottish salmonid Dee River and its tributaries, otters consumed 9.6–12.0 g of salmonid fish per m^2, which represented 53–67% of annual production (Kruuk et al., 1993). This study discovered a positive relationship between fish biomass, i.e., their productivity, and use of the river by otters which was expressed as a number of nights that an otter spent on one hectare of water surface. The use of the stream also decreased with increasing breadth of the river, which was explained by higher productivity of the fish community in narrower streams. Otters play an important role in the relationship between fish populations and environment, however, at the same time fish density is probably a limiting factor for otter's occurrence (Kruuk, 1995).

The above-mentioned study represents an example of research on food relationships within natural conditions where relationships between predator and prey have evolved for a long time and ecological balance has probably been reached between both populations. The situation in waters where artificially reared fish are stocked is completely different. If fish density is high and food resources are often supplemented, the predator is not limited by food which allows maintaining higher numbers and smaller territories (Roche, 2001). This situation is reflected in increased predation pressure on fish and higher financial losses caused to fishery management.

A significant share on losses is also attributed to the so-called indirect impact of predation on fish stocks, which is mainly mentioned in connection with ponds. Such phenomenon is manifested mainly in the winter period when hunting otters are suspected of the disturbance of wintering fish which rise up from the bottom and lose energy necessary for wintering. In spring, fish die due to their weakening and reduced resistance to diseases. In otter migration pathways, such as smaller streams and connecting lines between ponds, fish are forced out of these localities. However, the indirect impact of predation on fish stocks and the actual share of these indirect losses on production have not been verified by any study until now with respect to limited methodological opportunities.

Fish in open waters cannot be protected against otter predation anyhow. Fish farms with a high concentration of fish (trout farms, storage ponds, etc.) can be protected by careful fencing and installation of an electric repeller on the inlet (Halada et al., 2011).

5.4.3. American mink (Mustela vison)

Mink are carnivores of the mustelid family occurring in the wild within Czech territory as a consequence of escape or uncontrolled release from fur farms. They feed on minor mammals, snakes and frogs, as well as larger terrestrial invertebrates. However, the mink diet also comprises fish and crayfish to a considerable extent. Not only stone crayfish (*Austropotamobius torrentium*) but also noble crayfish (*Astacus astacus*) have been largely eliminated due to mink predation in some smaller streams. They occur throughout the whole territory of the Czech Republic and are considered as an invasive non-native species which has neither important competitors nor enemies in Czech nature.

5.4.4. Common kingfisher (Alcedo atthis)

Kingfishers are strictly territorial birds and live in solitude for almost the whole year. They feed mainly on smaller fish up to 12 cm long which represents 60–70% of their diet. They also consume aquatic insects or minor amphibians to a smaller extent. Although they also hunt the fry of commercially valuable fish species (trout) and have a relatively high consumption of food (up to 60% of their weight daily), their negative impact on fish communities is rather insignificant, because despite their common occurrence their populations are not abundant and in most cases these are mainly individual birds which cannot be unnoticed due to their bright coloration. They mostly hunt fry of minor cyprinid species with low-deep bodies (gudgeon, chub, topmouth gudgeon, etc.) due to their easier swallowing.

5.4.5. Black stork (Ciconia nigra)

Black storks are large, predominantly black birds, the numbers of which have also increased in recent years. They live mainly in forests at higher altitudes; however, they also occur in low floodplain forests. As they mainly feed on fish and other minor organisms that they catch mostly in smaller streams, they are able to exert a relatively high predation pressure especially on ranching brooks upon one and two-year-old brown trout where they can cause considerable damage.

Fish are also caught by other piscivorous predators, mainly birds, such as grey heron (*Ardea cinerea*) and great white egret (*Ardea alba*), white stork (*Ciconia ciconia*), gulls (black-headed gull *Chroicocephalus ridibundus* and less often also some other gulls), great crested grebe (*Podiceps cristatus*) and many others. However, the negative impact of their predation pressure on fish communities in open waters is rather insignificant and mostly applies to ponds.

5.4.6. Assessment and compensation for damage caused by piscivorous predators

The amount of compensation paid out on the basis of the Act No. 115/2000 Coll. on compensation for damage caused by selected specially protected animals (in the case of fishery, currently only by otter) has currently reached several tens of millions of Czech crowns per year and only direct losses due to predation on fish breeding facilities have been covered. It has been estimated that individual fish predators contribute to damage to the Czech fishery as follows: cormorant 70%, otter 23%, heron 5% and mink 2%. Secondary damage caused by death and injury to fish as a consequence of being wounded by predators and induced panic stress responses are not covered, with some exceptions, although the Act on compensation for damage caused by selected specially protected animals provides for it. This is mainly due to the complicated process of the proof of evidence for the damage, which discourages the majority of applicants. In open waters, compensation for damage caused by protected piscivorous predators is not possible in terms of the current interpretation of the law, since the attitude according to which fish in fishing grounds are so-called "*res nullius*", which means "no one's property", is applied as a matter of principle and fish become property only at the very moment that they are caught.

The Act No. 115/2000 Coll. enables, if the statutory conditions on selected subjects of compensation for damage are fulfilled, as stipulated by this Act, to pay for the damage caused by selected specially protected animals, but this applies exclusively to fish breeding facilities (ponds, storage reservoirs, trout farms). In the case of damage caused by European otter, it is necessary to prove the amount of damage by expert opinion and to respect the relevant methodology (Nature Conservation Agency of the Czech Republic, 2010). With respect to the fact that these compensations do not apply in the sense of the present wording of the Act in open waters, we will mention only the basic principles of their calculation.

The application is submitted to the relevant local regional authority department of the environment. In accordance with the Act No. 115/2000 Coll., compensation for damage only applies to fish bred for commercial purposes in ponds, storage reservoirs, fish hatcheries and breeding facilities, cage culture and trout farms. With respect to less valuable fish species (mainly small cyprinids), it is possible to cover the damage only if the fish were stocked by an applicant in the relevant period and the applicant is thus able to provide evidence of the cost of this stock. The amount of the loss must be proved by an expert opinion. The author of the expert opinion works on the data obtained from an applicant demanding compensation for the damage. The expert opinion should contain, above all: an overview of the assessed ponds of the applicant with a record of plot delimitation, cadastral area, area of all afflicted ponds, time of the stocking, species composition, the amount and size categories of stocked fish, current price of the fish in Czech crowns per kg and a record of predator abundance.

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5.5. Pollution of aquatic environment and its impact on fish *(T. Randák)*

Extraneous substances in the aquatic environment have a significant influence on the health status of fish inhabiting open waters, their reproduction as well as hygienic quality. The amount of chemical substances contaminating the environment has dramatically increased during the 20th century as a consequence of industrial development. At present, almost 100000 chemical substances have been regularly used.

In the past, industrial production contributed the most to the pollution of aquatic environment. A wide range of chemical compounds entered streams due to draining of waste waters from industrial plants. The most significant pollutants were the so-called toxic metals (mercury – Hg, cadmium – Cd or lead – Pb) and organochlorine compounds (polychlorinated biphenyls – PCBs, hexachlorobenzene – HCB and dioxins). After enhanced sewage treatment technologies and the ban on production and use of several dangerous substances have been established, the supply of pollutants from these sources into water has not been so substantial. However, most of the compounds have persisted in the environment and can also influence the organisms. It is, above all, contaminated sediments in streams and reservoirs and also old ecological loading occurring in the vicinity of water streams that cause the main problems. Extraneous substances from sediments and waste dumps are constantly being released into the aquatic environment and they contaminate food chains, of which fish represent an integral part.

In the past, intensive agricultural production using industrial fertilizers and persistent pesticides (e.g., hexachlorocyclohexan – HCH, dichlordifenyltricholrethan – DDT) contributed considerably to chemical pollution of waters as well. In this respect, the situation has improved in connection with the decrease in intensity of the agricultural production and also due to the use of pesticides with relatively fast decomposition. Nevertheless, it is the occurrence of pesticide residues in waters which represents presently a relatively significant issue even in drinking water-supply reservoirs. Intensive agricultural production is often conducted even in the immediate vicinity of these reservoirs (Fig. 5.5.1.).

Fig. 5.5.1. ***Application of pesticides in the immediate vicinity of the drinking water-supply Reservoir Švihov (Želivka) – the key source of drinking water for Prague and middle Bohemia (2011)*** *(photo: T. Randák).*

Municipal waste waters belong to other significant source of contamination of the aquatic environment. After extensive construction of sewage treatment plants (STP) have been implemented recently, the water quality in the Czech streams has improved considerably, mainly from the organic substances and nutrient loading point of view, nevertheless, several scientific studies have proved that the current sewage treatment technologies cannot eliminate a wide range of biologically active compounds. These compounds enter the aquatic environment through "purified" waste waters drained from STPs and can influence the present organisms. These compounds consist mainly of pharmaceuticals (hormonal preparations, high blood pressure medication, antibiotics, anti-rheumatics, antiepileptics, etc.), perfumes, cosmetic preparation constituents, detergents and their degradation products, or pesticides. Some of these substances can affect organisms exposed to their effect much more than continually decreasing concentration of the most monitored industrial contaminants, especially if substances interfering with hormonal functions of organisms are concerned. Their occurrence in the environment is considered the most serious cause of the reproductive disorder of organisms, including human beings.

Different abiotic (e.g., water, sediment) and biotic (e.g. fish, benthos, biofilm, macrophytes) components of the aquatic environment are used to assess contamination of aquatic ecosystems with extraneous substances. The most important contamination indicators are fish, which represent the final link in the food chain in the aquatic environment. As far as several extraneous substances (e.g., mercury and persistent organochlorine pollutants) are concerned, they are virtually not biodegradable and accumulate in tissues of fish. It means that their concentration in tissues increases with aging and trophic level of fish. In order to objectively assess the contamination of the aquatic environment with extraneous substances, it is necessary to select the so-called indicator species of aquatic organisms. The main requirements for these species are their availability in the majority of monitored localities and sufficient time of their occurrence in an assessed environment. Next, also behaviour of monitored substances in organism of fish must be taken into account when selecting suitable indicator species. In general, it can be stated that the most suitable bioindicators for assessment of the contamination of the aquatic environment with metals are older categories of piscivorous fish species, e.g., pike, pikeperch, European perch and asp. With respect to assessment of the contamination of the aquatic environment with persistent organochlorine pollutants that accumulate mainly in fat, the most suitable bioindicators are fish with higher fat content in muscles (e.g., European eel and catfish). However, to obtain the representative amount of the above-mentioned fish species is almost impossible in several localities. Within the monitoring of open water contamination, 4 (indicator) fish species in particular have been used over a long period in the Czech Republic:

- chub (*Squalius cephalus*) – species which is relatively easy to catch occurring virtually in all types of running waters in the Czech Republic, apart from mountain stretches, it is a polyphagous fish species;
- common bream (*Abramis brama*) – representative of benthophagous species;
- European perch (*Perca fluviatilis*) – representative of piscivorous species;
- brown trout (*Salmo trutta*) – species occurring in upper stretches of streams.

Common carp (*Cyprinus carpio*) is used for monitoring of contamination of production ponds in the Czech Republic.

Fish species that are stocked in catchable sizes (lengths) (e.g., common carp) have rather insignificant indicator ability in open waters' conditions. A considerable disadvantage of analyses of older fish categories is the fact that the discovered values of the content of extraneous substances in tissues of these fish must not necessarily correspond to the locality loading they have been sampled from due to migrations undertaken during their life. Another way of comparing different localities is to use juvenile fish (fish fry) as another component of the aquatic ecosystem indicating loading with extraneous substances (Randák et al., 2006). The advantage of this methodology is the easy catch of the representative sample. Juveniles of most species occur along shorelines during the first months of exogenous nutrition, hence they are easier to catch than adults which occur mainly in deeper stretches of streams. Capturing of juveniles can be conducted with simple gear. Catchability is more difficult when fish grow older which is due to their enhanced abilities to move actively. During the juvenile stage, migrations are heavily limited during summer months, which means, that juveniles stay in most cases during their first months of life in the locality where they have hatched. Conversely, older fish migrate regularly throughout the entire season (Slavík and Jurajda, 2001). It can be assumed that the community of juvenile fish of different species intake natural food of similar composition (plankton, biofilm) during the first months of exogenous nutrition, which implies that they intake similar content of extraneous substances. Analyses have discovered a very low interspecific variability in the case of concentration of extraneous substances in body homogenate of juvenile fish (Fig. 5.5.2.). Based on present findings, it is not necessary to separate caught juvenile fish from the species point of view and subsequent treatment is not necessary either (disembowelling, muscle sampling, etc.). On the contrary, it is important to keep fish guts in their body. Higher accumulation of most metals occurs in guts when compared to muscles (Svobodová et al., 2002), remains of natural food can be found here and guts also contain more fat as opposed to muscles.

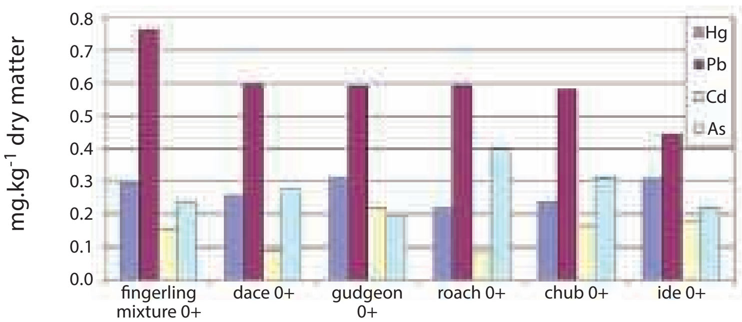

Fig. 5.5.2. ***Content of toxic metals in samples of juveniles in the Děčín locality (2005).***

As far as extraneous substances in fish are concerned, mainly those substances that have been limited by the Czech or European legislation are monitored – i.e., toxic metals Hg, Cd, Pb and persistent organochlorine pollutants (PCB, HCH, HCB, DDT). As an illustration – the Commission Regulations (EC) No. 396/2005, 1881/2006, 629/2008, 1259/2011 determine presently the hygienic limits and the maximum admissible quantities (MAQ) of contaminants in foodstuffs (Table 5.5.1.).

5.5.1. Toxic metals

Mercury, cadmium and lead are the most monitored toxic metals within monitoring of contamination of the aquatic environment. Mercury is undoubtedly the most problematic in terms of the contamination of fish muscles. This metal is able to accumulate in organisms, i.e., the highest concentrations are found in older fish (Žlábek et al., 2005; Jewett et al., 2003). With respect to the loading of individual tissues, the highest concentration in commonly loaded localities are usually detected in muscles, in heavily loaded localities in livers (Havelková et al., 2008). In general, the highest values of mercury content in muscles can be found in species occurring at the end of the food chain, i.e., piscivorous fish species (e.g., pike, asp, European catfish, pikeperch, European perch) (Svobodová et al., 1987). Mercury in the aquatic ecosystems can be found in several forms encompassing elementary mercury (Hg^0), inorganic and organic forms of mercury, monomethylmercury (CH_3Hg^+; MeHg) and dimethylmercury ($(CH_3)_2Hg$) in particular. The dominant form of mercury (up to 100%) in the tissues of the majority of fish species is MeHg (Maršálek et al., 2006). It is considered the most toxic form of mercury due to its neurotoxic qualities.

Table 5.5.1. Hygienic limits for content of contaminants in fish.

Pollutant	HYGIENIC LIMITS		
	Fish muscles	Units	Source
Hg	0.5 (eel, pike 1.0)	$mg.kg^{-1}$ of muscles	EC No. 1881/2006
Pb	0.3	$mg.kg^{-1}$ of muscles	EC No. 1881/2006
Cd	0.05 (eel 0.1)	$mg.kg^{-1}$ of muscles	EC No. 629/2008
Σ PCB (6 congeners)	0.125	$mg.kg^{-1}$ of muscles	EC No. 1259/2011
Σ DDT	1	$mg.kg^{-1}$ of muscles	EC No. 369/2005
γ-HCH	0.02	$mg.kg^{-1}$ of muscles	EC No. 369/2005
HCB	0.2	$mg.kg^{-1}$ of muscles	EC No. 369/2005

Fish are the main source of human exposition to methylmercury (WHO, 1990), therefore, they are the main objective of monitoring of contamination of aquatic ecosystems not only from ecological but also hygienic point of view.

The content of the total mercury in fish muscles originating from the polluted environment does not exceed in the Czech conditions the value of 0.2 $mg.kg^{-1}$ of muscles (Kružíková et al., 2008). In ponds, the values of mercury content in fish muscles are usually lower than 0.1 $mg.kg^{-1}$ (Svobodová et al., 2002). The highest concentration of this metal in fish within the Czech Republic are found in fish occurring in the middle stretch of the Elbe River (between Pardubice and Mělník) and in the Skalka Reservoir near Cheb. The hygienic limit for mercury content in fish muscles stipulated by the European Directive EC No. 1881/2006 has been often exceeded in these localities.

Apart from mercury, concentrations of cadmium and lead have often been discovered in the tissues of fish as well. The contamination of the aquatic environment with these metals is usually of anthropogenic origin. These substances are highly persistent contaminating the food chains and accumulating in organisms. These metals show high toxicity for organisms already at very low concentrations (Fianko et al., 2007). In contrast to mercury, the highest concentrations of these pollutants are found in kidneys and livers. Concentrations in muscles are usually low (Čelechovská et al., 2007).

5.5.2. Polychlorine biphenyls (PCB) and organochlorine pesticides (OCP)

Polychlorine biphenyls (PCBs – the sum of 6 indicator congeners – K28, K52, K101, K138, K153, K180), hexachlorocyclohexane (HCH), hexachlorogenzene (HCB), and dichlorodiphenyltrichloroethane (DDT) are the most monitored pollutants, apart from toxic metals, within monitoring of contamination of aquatic environment.

PCBs became significant contaminants of the environment in the second half of the past century. PCBs belongs to the most stable organic compounds, the water solubility is low, and it can be easily dissolved in non-polar solvents and fats.

PCBs were used mainly in the electrical engineering industry as filling of condensers and transformers, in mechanical engineering as non-flammable liquids for heat transfer, filling of hydraulic devices and in the chemical industry for the production of synthetic varnishes, paints and plastics. In the 1970s, their production was reduced due to warning findings concerning their harmful effects in the environment and in the 1980s, PCB was completely banned (Svobodová et al., 1987). These substances have been currently released into the aquatic environment from old ecologic loadings. PCB enters food chains and accumulates in plant as well as animal organisms. Their persistence rises with the increasing level of chlorination. PCBs are lipophilic compounds and their accumulation in organisms is considerably influenced by the fat content in tissues (Niimi and Oliver, 1989).

Pesticides based on DDT were used in the past as highly effective insecticides that were used in agriculture, forestry as well as within human hygiene. Troubles connected with the massive DDT use emerged at the end of the 1940s. Carson (1962) pointed out for the first time the risks connected with DDT persistence in components of the environment and its ability to accumulate in living organisms. Subsequently, several negative impacts of DDT on wild living organisms connected with presence of the pollutant in food chains were described. DDT and its metabolites (DDE in particular) were consequently classified as Endocrine Disrupting Chemicals (EDCs) (Keith, 1997), i.e., compounds interfering with endocrine systems in organism, including reproduction. DDE and PCB have been labelled as widespread contaminants of the environment representing serious risk for the health of not only wild living animals but also human beings.

In the 1940s, lindane (HCH gamma isomer) started to be used as effective insecticide. This compound was also used as fungicide and antiparasitics. Technical lindane was usually accompanied by 5 other isomers, out of which the most significant were alpha and beta isomers. Negative features of lindane were described simultaneously with its spreading, which was especially persistence in the environment, contamination of food chains and high toxicity for fish (Duffus, 1980). The U.S. Environmental Protection Agency then labelled lindane as potential carcinogen. HCH alpha and beta isomers have been currently considered widespread environmental contaminants (Saunders and Harper, 1994).

HCB was used in the past as fungicide for seeds and it was also produced within chemical production. Similarly to the above-mentioned contaminants, HCB is also highly persistent in the environment and shows high bioaccumulation ability (Augustijn-Beckers et al., 1994).

The presence of persistent organic pollutants (POPs), DDT and its metabolites, HCH and HCB in particular, has started to be monitored systematically in the Czech Republic at the end of 1970s. Attention was focused on streams (e.g., Svobodová et al., 1993), reservoirs (Hajšlová et al., 1997) as well as pond and farm breeding facilities (Svobodová et al., 2003). The results of these studies pointed out the increased contamination of fish inhabiting open waters with DDT and its metabolites (mainly DDE) and HCH. The highest values were found in fish with high fat content in muscles (chub, catfish, eel) and in fish that were food-dependent on a stream's bottom (barbel).

5.5.3. Extraneous substances in fish meat in important fishing grounds in the territory of the Czech Republic (Červený et al., 2014)

A study with the objective to assess meat loading with selected extraneous substances in fish inhabiting important Czech fishing grounds and to assess the edibility of fish was implemented between 2006–2010 with the financial support of the Ministry of the Agriculture of the Czech Republic. Concentrations of toxic metals (Hg, Pb and Cd) and POPs (PCB, HCH, HCB and DDT) were investigated. 31 important fishing grounds in the territory of the Czech Republic were monitored in total (Fig. 5.5.3.).

Bream (*Abramis brama*) was selected as a reference species for the comparison of individual localities. Next, samples of muscles of 5 other fish species that occurred in the monitored localities the most often and that were caught and consumed by anglers were also analysed. Fish in regular catch lengths were analysed, i.e., fish usually exceeding the minimum size limit. Determination of the content of mercury, lead and cadmium was conducted individually with all sampled species of bream, with regard to other species, it was conducted in pooled samples. The results of analyses of fish muscles were compared with the above-mentioned hygienic limits.

Fig. 5.5.3. ***Monitored fishing grounds (2006–2010).***

In addition to that, in the case of individual pollutants, assessment of health risks for consumers using toxicological limits adopted by the World Health Organization (WHO) was conducted (Table 5.5.2.). Limit exposure values (toxicological limits) of monitored chemical substances and concrete concentrations of the pollutant in the muscles of indicator fish were used for the calculations.

Limit exposure values: ADI (acceptable daily intake), PTWI (provisional tolerable weekly intake), PMTDI (provisional maximum tolerable daily intake). $\mu g.kg\ b.\ w.^{-1}.week^{-1}$ – microgram per kilogram of body weight and week.

Table 5.5.2. *WHO toxicological limits.*

Pollutant	TOXICOLOGICAL LIMITS			
	Exposure limit		Units	Source
MeHg	1.6	PTWI	$\mu g.kg\ b.\ w.^{-1}.week^{-1}$	WHO
Pb	25	PTWI	$\mu g.kg\ b.\ w.^{-1}.week^{-1}$	WHO
Cd	7	PTWI	$\mu g.kg\ b.\ w.^{-1}.week^{-1}$	WHO
Σ PCB	0.4	PMTDI	$\mu g.kg\ b.\ w.^{-1}.day^{-1}$	WHO
Σ DDT	20	ADI	$\mu g.kg\ b.\ w.^{-1}.day^{-1}$	WHO
γ-HCH	8	ADI	$\mu g.kg\ b.\ w.^{-1}.day^{-1}$	WHO
Σ α+β HCH	–	–	–	–
HCB	0.17	ADI	$\mu g.kg\ b.\ w.^{-1}.day^{-1}$	WHO

Comparison with toxicological limits was conducted on the basis of the following formula:

$$D = \mathbf{EL} \times \mathbf{W} \qquad NTL = \frac{\mathbf{D}}{\mathbf{C}} \qquad PP = \frac{\mathbf{NTL}}{\mathbf{P}}$$

D – acceptable (tolerable) daily, weekly, monthly intake of the pollutant (mg/person)
EL – exposure limit of ADI, TWI, PTWI, PMTDI (WHO, ESFA)
W – average body weight of a consumer (70 kg)
c – content of pollutant in fish muscles ($mg.kg^{-1}$ of fresh matter)
NTL – weight of fish muscles to reach the toxicological limit (kg/day, week, month)
PP – number of portions a consumer can eat during a given period (portion/day, week, month)
P – weight of one portion (0.170 kg)

The concrete output of this assessment was the number of portions (portion = 170 g) of fish defined from the species, size and weight point of view, that a consumer (angler) could eat from a given locality per month. Consumption of this amount of fish meat for a man with the average weight of 70 kg does not represent health risk according to the present knowledge. The data concerning the number of portions for given fish species and concrete localities were clearly arranged in tables. The tables with briefly, however comprehensibly for lay public, explained values are available to the fishery public in information leaflets published by the Ministry of the Agriculture of the Czech Republic and also on the websites (www.bezpecnostpotravin.cz).

The most significant contaminant found in the fish muscles sampled from the Czech open waters within the monitored period was unequivocally mercury. The highest values were detected in the Skalka Reservoir, which was severely contaminated with industrial waste waters with high concentrations of mercuric compounds in the past. In this locality, the discovered concentrations of the total mercury often exceeded considerably the value of 1 $mg.kg^{-1}$of muscles, mainly with piscivorous fish. The value of the hygienic limit of 0.5 $mg.kg^{-1}$ was exceeded in almost all cases. For example, the value of mercury content of 3.57 $mg.kg^{-1}$ was discovered in the sample of asp muscles (piscivorous representative). The results proved permanently high contamination of the Skalka Reservoir with mercury and pointed out the high hygienic risk connected with consumption of mainly piscivorous fish caught in this reservoir which corresponded to the previous data (Maršálek et al., 2005). Other localities, where increased mercury concentration in fish muscles were recorded, were located in the middle stretch of the Elbe River (locality near Neratovice), in Odra River 1 (near Ostrava) and in the Dalešice, Kořensko and Vranov Reservoirs. The values of the content of this metal in muscles of analysed fish in these localities exceeded several times the value of 0.5 $mg.kg^{-1}$. The limit was exceeded the most often with piscivorous fish species. The values of the mercury content in fish muscles ranged under 1 $mg.kg^{-1}$, with the exception of the asp sample from the Elbe 15 locality in Neratovice (2.18 $mg.kg^{-1}$). In other monitored localities, the concentration of the total mercury usually did not exceed, or only in a moderate level, the value of 0.5 $mg.kg^{-1}$ of muscles. The comparison of average mercury concentrations in muscles of the reference species – common bream – is illustrated in the Fig. 5.5.4.

The values of Cd and Pb content in fish muscles sampled in the monitored localities were low and in most cases, they ranged around the detection limit of used analytical methods. The hygienic limit for the Cd content in muscles was exceeded only once, which was the pikeperch from the Těrlicko locality (0.058 $mg.kg^{-1}$).

As far as edibility is concerned, i.e., the limit number of portions, there was limiting concentration of mercury in all cases except 1 (eel sample from the Těrlicko locality, where PCB was limiting). Large (old) specimen of piscivorous fish appeared the most problematic from the consumption point of view. The lowest level of loading showed usually common carp – the most frequently caught species in the Czech Republic. This species is usually stocked in open waters in catchable size and it thus comes from generally

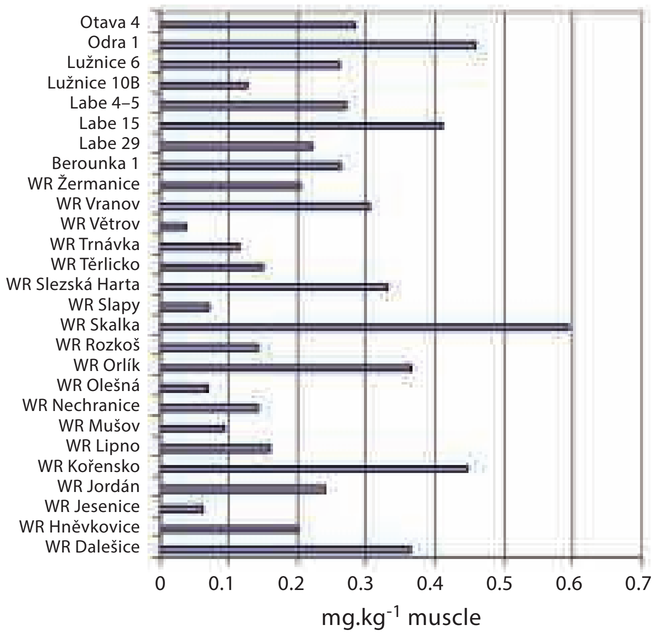

Fig. 5.5.4. ***Comparison of average mercury concentrations in common bream's muscles in fishing grounds monitored between 2006–2010*** *(WR – water reservoir).*

uncontaminated pond breeding facilities. Other potential sources exposing a man to monitored chemical substances were not taken into account within the assessment.

The highest values of the content of the set of 7 indicator PCB congeners in common bream's muscles were revealed in the Odra River near Ostrava, Elbe River close to Ústí nad Labem and Mušov locality (Fig. 5.5.5.). Nevertheless, the determined concentrations were in general very low and ranged deep below the hygienic limit. The highest PCB concentration in fish muscles was found in the Žermanice locality with European eel (1.67 $mg.kg^{-1}$ of muscles). However, if the PCB levels in samples of the main indicator species – common bream were compared, it was the Žermanice locality that belonged to less loaded ones. This concentration was extreme with respect to approximately other 180 values measured within this study. It was caused by the several times higher fat content in eel's muscles (in this case, it was 18%) in comparison with other analysed species (in this locality, e.g., common bream – 3.2%). In general, PCB and POPs accumulate mainly in fat. Therefore, PCB concentrations in muscles of fish with higher fat content in tissues are often even several times higher than species with lower fat content caught in the same locality. It is advisable to state POPs contents converted into fat in order to compare the level of locality loading more precisely (Randák et al., 2009). Similar dependences were also observed with other monitored POPs.

DDT content concentrations (expressed as the sum of DDT, DDD and DDE) in pooled samples of common bream are illustrated in the Fig. 5.5.6. The highest values were discovered in the Dalešice, Elbe River near Ústí nad Labem and Mušov localities. In general, the values of DDT content in fish muscles ranged deep below the hygienic limit in the monitored localities.

HCH and HCB concentrations ranged in most cases below the detection limit of used analytic methods. Concentrations of these compounds were detectable only in some localities and it applied mainly for fish with higher fat content in muscles.

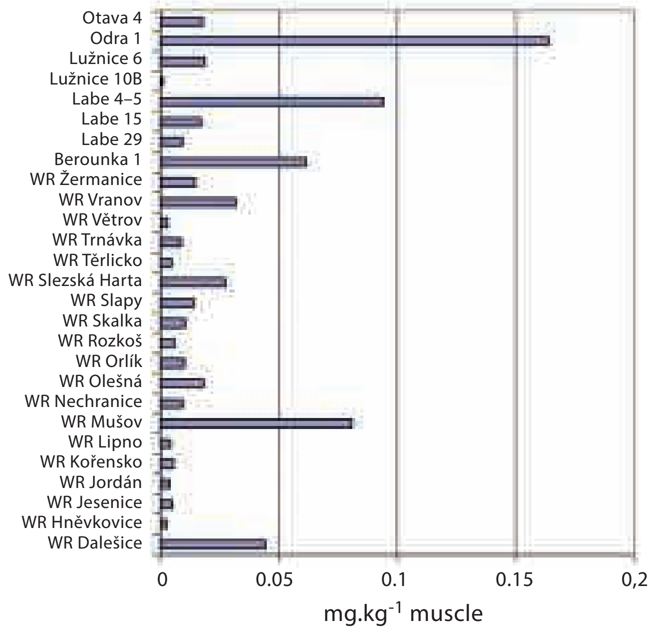

Fig. 5.5.5. **Comparison of PCB content (sum of 7 indicator congeners) in muscles of common bream in fishing grounds monitored during 2006–2010** *(WR – water reservoir).*

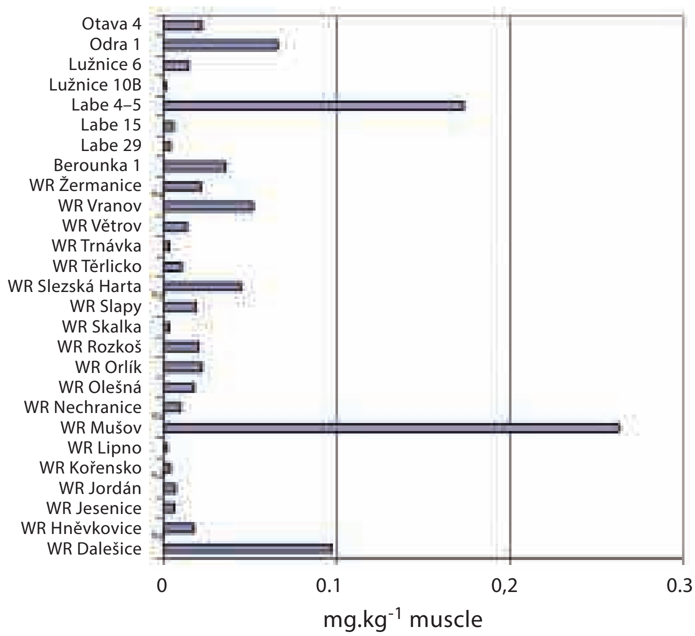

Fig. 5.5.6. Comparison of DDT content (sum of DDE, DDD and DDT metabolites) in muscles of common bream in fishing grounds monitored between 2006–2010 *(WR – water reservoir).*

As far as fish edibility is concerned, the monitored POPs do not represent, apart from only one exception of eel from the Žermanice locality, any considerable problem within the monitored fishing grounds. Theoretical acceptable number of portions calculated by means of exposure limits with respect to these compounds ranges usually between tens to thousands of portions per person and month. In the case of limiting mercury pollutant, it is ones to tens of portions per month.

The consumption of common carp's meat, which is the most often caught fish in the Czech fishing grounds, **does not represent any health risk** as far as content of extraneous substances is concerned, which also applies to heavier loaded localities (Skalka Valley Reservoir, the Elbe River near Neratovice). It is due to the fact that carp are stocked in fishing grounds in catch lengths (usually as three-year-old fish) and until then they grow up in pond breeding facilities. Most carps are caught shortly after their stocking and potential negative impact of a given locality is thus insignificant. Relatively low concentrations of extraneous substances have been also discovered in meat of other frequently caught cyprinid species (bream and roach). As far as piscivorous species are concerned (pike, catfish, pikeperch, asp, perch), the situation seems rather worse as they are situated at the end of the food chain and the largest amount of extraneous substances accumulate in their organisms. It is especially meat of larger and older fish caught in polluted localities that cannot be recommended for regular consumption.

5.5.4. Impact of common municipal sources of environmental pollution on fish

The probability of the occurrence of new environmental loadings caused by these "classical" pollutants has decreased as a consequence of the enhanced level of waste water treatment of industrial plants and prohibitions of production of some problematic substances in the past (e.g., PCB and DDT). However, people still surround themselves with new and new chemical compounds that could potentially negatively influence not only their health but also stability of entire ecosystems.

Pharmaceuticals, personal care products, bactericides, etc. are currently considered the most significant. Part of these substances is included into the group of endocrine disrupting chemicals (EDCs). EDCs are synthetic or naturally occurring chemicals that influence already in the minimum concentrations the balance of normal hormonal functions of animals. Damage to the endocrine system of fish can even cause reproductive disorder (Tyler et al., 1998). This group of substances comprises mainly classical chlorinated insecticides, synthetic pyrethroids, active ingredients of herbicides and industrial chemical substances (PCB, PAH, phthalates, styrenes, Hg, etc.) (Keith, 1997), steroid medicaments and their metabolites (Kolpin, 2002), degradation products of non-ionic surfactants (alkylphenols) (Bennie et al., 1997), musk compounds – synthetic analogues of musk used widely as fragrant essences within a wide range of consumer goods (Rimkus, 1999), etc. In general, there has been minimum information concerning effects of these "new" compounds occurring in the environment. Their presence in the environment is connected with reproduction disorders of animals, including human beings, carcinogenicity, (Fig. 5.5.7.), etc. Most of these compounds enter the environment through municipal waste waters.

Results from the present world research studies show that pharmaceutical products play a significant role in the contamination of the environment and in the potential impact on organisms (Heberer, 2002; Li and Randák, 2009; Corcoran et al., 2010). At present, risks connected with the presence of wide spectrum of pharmaceutical products in the environment have been subjected to an intensive research. Pharmaceutical products represent the risk group of environmental contaminants especially due to their wide use in human as well as veterinary medicine. Worldwide consumption of active compounds has been estimated to be more than 100000 tonnes per year (Kummerer, 2004). This amount includes approximately 3000 of different substances that are used in medical practice in the EU countries. Natural and synthetic pharmaceuticals used by people or animals, such as prophylactics, therapeutics and diagnostics, contain almost always biologically active substances. A large group of pharmaceuticals comprises of natural substances

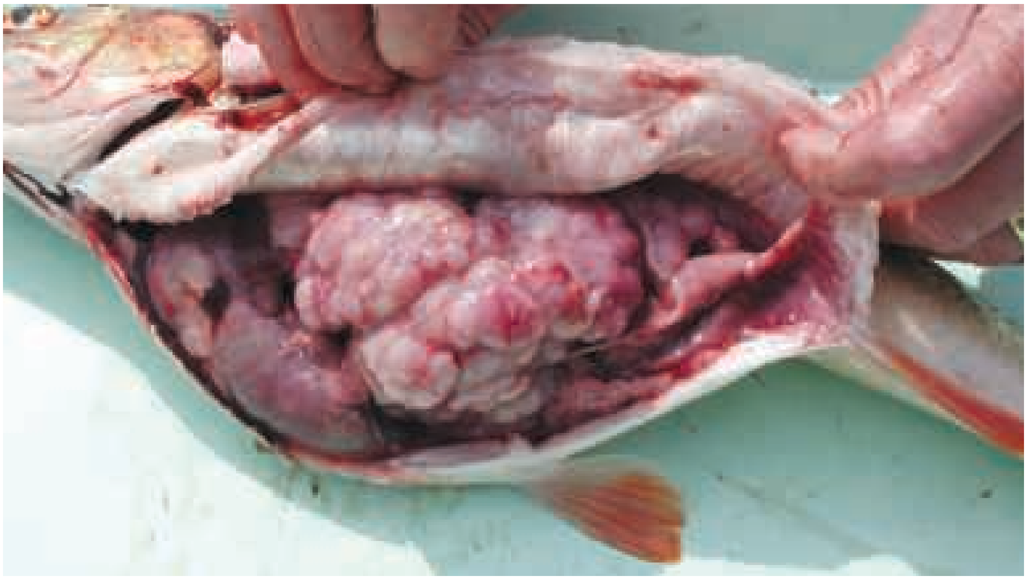

Fig. 5.5.7. ***Gonad tumour of chub male caught at the confluence of the Elbe and Bílina Rivers*** *(photo: T. Randák).*

(antibiotics, alkaloids, steroids, amino acids, enzymes, proteins and vitamins). The largest and constantly expanding group of medicaments constitutes synthetic pharmaceuticals. Apart from artificially produced natural substances, these are various modifications and structural analogies as well as substances that have no parallel in the nature. Pharmaceuticals are discharged from organisms in the original form or in the form of metabolites. Subsequently, these compounds enter the aquatic environment mainly through municipal waste waters. Pharmaceuticals are not completely degraded within the sewage treatment plant process, which means that they enter the aquatic environment even through "treated" waste waters. After that, they influence aquatic organisms occurring in these localities (Heberer, 2002; Corcoran et al., 2010).

Pharmaceuticals are generally highly effective substances from the biologic point of view, which means that they influence organisms already in very low concentrations (Gunnarsson et al., 2008). The most biologically effective are steroid medicaments (e.g., 17a-ethinylestradiol (EE2), 17b-estradiol (E2), diethylstilbestrol (DES), etc.). These pharmaceuticals are classified as EDCs substances, i.e., substances that interfere with the synthesis, secretion, transport, binding, action or elimination of natural hormones in the body that are responsible for the maintenance of homeostasis, reproduction and development. In human medicine, steroid hormones are used for treatment of hormonal disorders mainly of sex organs. Synthetic steroids are also commonly prescribed as oral contraception (EE2, etc.).

The largest concentrations of steroid substances are mainly found in influents (inflow) and effluents (outflow) from the sewage treatment plants, in sewage treatment sediments and they are regularly detected in low concentrations (in units of $ng.l^{-1}$) in surface waters (Kolpin, 2002). After entering the aquatic ecosystem, steroid hormones can have a negative impact on aquatic organisms and marginal manifestation of their presence can even result in feminizing of males and occurrence of hermaphroditism. According to the Swedish study of the STP effluent, synthetic ethinylestradiol originating from contraceptive preparations and natural estrogenic steroids, estradiol and estrone were defined as the main source of estrogenity (Hanselman et al., 2003). Common accessible technologies of waste water treatment reduce to a large extent the levels of steroid substances, however, the final concentration of these substances can still easily exceed concentrations which can be supposed to exert negative impact on aquatic organisms, fish in particular. As far as 17-β-estradiol is concerned, feminization symptoms have been observed already at concentrations lower than 1 $ng.l^{-1}$ (Dorabawilla and Gupta, 2005).

A large number of studies describing the negative effects of pharmaceuticals' occurrence in the environment have been published until today. The obtained data have documented that effluent treated water from common STPs represents a significant source of pollution of the aquatic environment – especially with pharmaceuticals and personal care products (PPCPs). It is obvious that even seemingly insignificant sources of pollution, such as STP of regular municipalities, burden considerably the aquatic environment with biologically active extraneous compounds.

The impact of these compounds on aquatic organisms increases with the decreasing dilution of drained waters from STPs with water of the stream where they flow into. As results from the previous monitorings – the worst situation is not – as could seem at first sight – in lower stretches of large rivers, however, it is in smaller streams with lower flow-rates because water drained from the STPs becomes less diluted here (Li et al., 2011) (Fig. 5.5.8.). These streams are often used for production of brown trout stocks or also for capturing brood fish for artificial spawning purposes. In some localities, considerable deterioration of fish production has occurred due to contamination of the aquatic environment (Kolářová et al., 2005).

The effect of different non-monitored biological active groups of substances entering the aquatic environment through regular municipal waste waters has been subjected to an intensive research in the world. It is probable that these neglected groups of substances have even more considerable impact on the aquatic organisms than the constantly decreasing concentrations of regularly monitored industrial pollutants.

***Fig. 5.5.8.* Pipe inlet of treated municipal waste waters from the Prachatice sewage treatment plant into the Živný Brook.** *These waters represent approximately 30% of the recipient flow-rate. Fish occurring under this STP show reproduction disorders as well as other significant physiological changes in organisms (photo: T. Randák)*

5.5.5. Accidental pollution

Accidental pollution is considered to be exceptionally serious deterioration or endangerment of quality of surface or underground waters that is of temporary character. Accidental pollution causes damage to the environment, fish as well as other aquatic organisms, disruption of self-cleaning processes in water, the deterioration of water chemistry including decrease in oxygen, alterations in smell, taste and colour of water and taste of fish and sometimes also the accumulation of extraneous substances in the aquatic environment's components. Accidental pollutions cause considerable economic losses in fish stocks and require expensive rehabilitation of the affected areas. In the Czech Republic, 200–300 accidental pollutions are recorded each year out of which only less than one half is clarified. Detailed information relating to accidental deaths, their reasons, clarification procedures including the legal framework are described in the methodology written by Svobodová et al., (2011).

Accidental pollutions are connected with the **death of fish** in most cases. The most frequent causes are increased concentrations of organic substances in water, usually connected with the decrease in oxygen content which is absorbed during their decomposition. Accidental death caused by insufficient amount of oxygen in water occur usually in summer in the low flow-rates periods, in spring and summer in reservoirs rich in nutrients or in stretches of streams with excessive development of plant plankton when there are oxygen deficits in night and morning hours before sunrise due to the breathing of these organisms, and also in trophic reservoirs where coarse zooplankton become overabundant which eliminate plant plankton producing oxygen.

Pollution with organic substances is usually connected with increased concentrations of ammonia. This element occurs in water in dependence on acidity or alkalinity (pH level) and on temperature in two forms – bound and free. Free ammonia is highly toxic for fish and its share (out of total amount of ammonia) grows with the increasing pH level. The optimum pH values for the majority of freshwater fish range between 6.5 to 8.0. The pH level lower than 4.8 and higher than 9.2 causes damage and death of salmonid fish species. Cyprinid fish die when the pH level is below 5 and above 10.8 (Svobodová et al., 1987). Reduced pH values in the aquatic environment is caused by acid rain, snow thaw in the area of peat bogs or accidental pollution, during which strong acids or silage juices leak. Increased pH level occurs in reservoirs rich in nutrients where carbon dioxide, which serves as a pH stabilizer, is absorbed due to intensive photosynthesis in heavy vegetation turbidity. The pH level can be increased after leakage of waste waters containing alkaline substances or after accidents related to some construction works (e.g., cement infusion).

A large number of accidental deaths of fish is caused by pollution of the aquatic environment with various chemical substances (pesticides, cyanides, chlorine, oil substances or metals). Pesticide intoxication occurs the most often due to washes of freshly applied spraying from fields. Cyanides can enter water due to accidents in some industrial plants. The typical symptoms of cyanide intoxication of fish is a bright red colour of the branchial arch – cyanides prevent the transport of oxygen from blood into cells. Chlorine intoxication is caused usually by water pollution with disinfectants which contain this chemical. Chlorine compounds are often also contained in drinking water, which can cause the death of fish kept in reservoirs freshly filled with drinking water (e.g., Christmas carp in a bathtub). If we want to place fish in such an environment, we have to leave the water stand at least for several hours after filling a reservoir. However, this measure may still not be sufficient if the water is disinfected with more stable chlorine compounds, e.g., chloramine. Oil substances create a thin layer on water level preventing diffusion of atmospheric oxygen into the water, hence during large accidental pollutions fish die of asphyxiation. Oil and oil products have a toxic effect on water and besides, it negatively influences the sensorially perceptible qualities of fish meat, especially its taste and smell, already at very low concentrations (in milligrams per litre). The main source of pollution of the aquatic environment with metals is industrial production. Toxicity of individual metals varies and it is dependent also on the chemical form of their occurrence in water. Some metals, e.g., mercury, can accumulate in an organism. The most significant metals from the contamination point of view, are mercury, cadmium, lead, iron, arsenic, nickel, copper, aluminium, chromium and zinc (Svobodová et al., 1987).

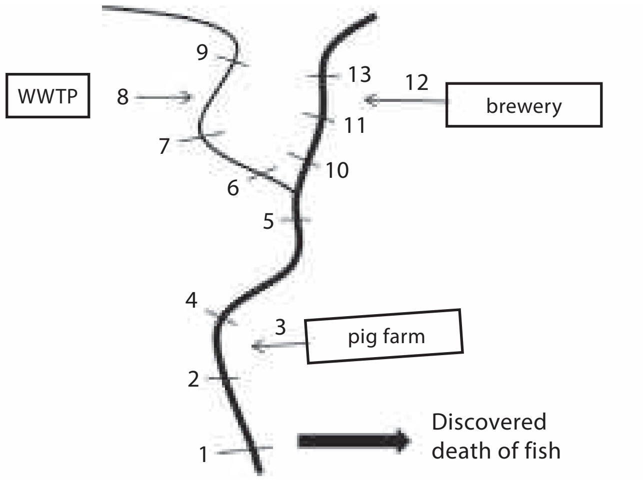

Fig. 5.5.9. ***Sketch map of water sampling places after death of fish has been discovered*** *(Svobodová et al., 2011).*

In order to **investigate the causes of accidental pollution** and to impose a penalty on party at fault, it is essential to conduct a thorough **local investigation** and **samplings**. It is necessary to announce an accidental pollution to the police immediately, or to a relevant fishery manager, fire fighters, sanitary inspectors or persons involved in environmental protection. Samplings of water, fish or sediment, minor organisms, biofilm and plankton must be conducted as soon as possible and delivered to specialized laboratories as fast as possible. If there is a suspicion of concrete or potential source of pollution it is necessary to conduct sampling above and under all of these sources.

It is advisable to measure the temperature, water transparency and oxygen content in the sampling place. If there are still living fish (preferably with symptoms of damage), it is ideal to catch several of these fish and transport them alive, if possible, to a specialized laboratory. It is not advisable to examine fish in the state of decomposition. It is very important to mark legibly and indelibly the samples, keep them in a cool place and to transport them as fast as possible to laboratories. It is also advisable to sketch the sampling places and to add the time of sampling and potential sources of pollution (Fig. 5.5.9). Water samples can be taken into plastic bottles from unflavoured water, sediment into polypropylene bags, samples of minor organisms, scabs and plankton preferably into clean glasses.

If there is a suspicion that the decrease in oxygen was caused by excessive development of plant plankton, it is necessary to measure the oxygen content during night hours. Phytoplanktonic organisms do not produce oxygen in night, but they consume it. The first sun rays start the photosynthesis again and the oxygen in water starts increasing again rapidly.

It is important to fill in the sampling statement which shall be signed by all participants. Svobodová et al. (2011) suggest the following statement's pattern:

Statement of samplings if accidental death of fish is suspected

Day, hour of accidental pollution:

Participants of the investigation (organization):

Locality:

Owner/Managing organization:

Length (area) of the affected stretch:

The scope of death (species, categories and amount of deceased fish):

Description of the behaviour and macroscopic changes in fish:

Potential sources of pollution:

Water samplings (place and time of sampling, marking of samples):

Identification conducted on site (temperature, colour, transparency, smell, O_2, pH, or other; place and time, locality):

Fish samplings (deceased, living, time and place, locality, species, categories, number):

Samples sent to (place): a) water
b) fish
c) other

Other important facts (flow-rate, weather at the time of sampling and in the previous period, results of the last control examination of water quality and health status of fish, etc.):

Statement of participants of the investigation:

Signatures, date, time:

Attached sketch map indicating significant localities of samplings, sources and other facts (e.g., course of toxic wave):

The scheme illustrated in the Fig. 5.5.10 can help to decide on which to focus during samplings and investigation of accidental pollution.

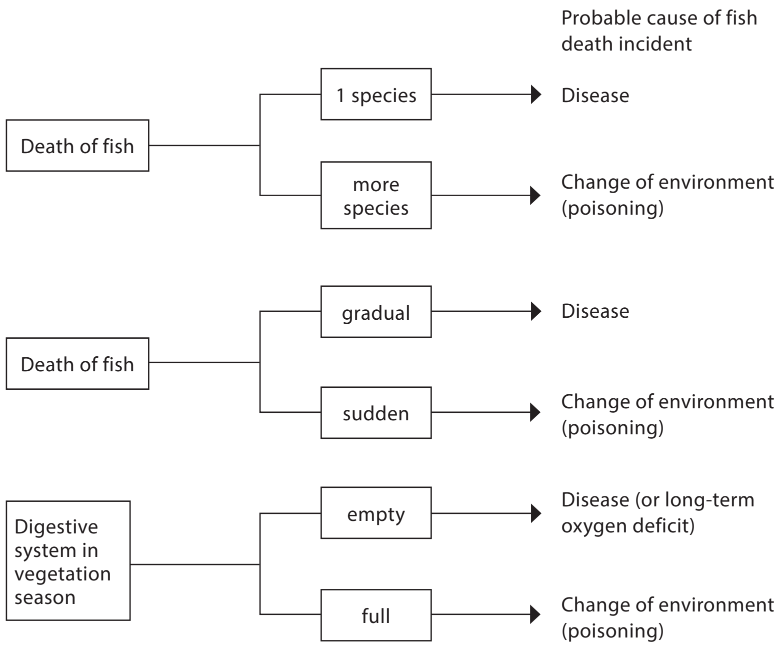

Fig. 5.5.10. ***Decision-making scheme for investigation of fish accidental kills*** *(Svobodová et al., 2011).*

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FISH CAPTURE METHODS IN OPEN WATERS

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6

FISH CAPTURE METHODS IN OPEN WATERS

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6.1. Electrofishing *(J. Turek, M. Kratochvíl)*

The first attempts to catch fish using electric current were carried out as early as at the turn of the 19th and 20th century, whereas this method has been used in the Czech Republic in operating conditions since the 1950s. Currently, there are electrical aggregates with various drives and power allowing fishing in all types of waters.

6.1.1. Importance and use of electrofishing

The use of electrofishing is especially justified when we need to catch various fish, of various age categories, while maintaining the requirement for mobility in the field and the efficiency of fishing. In some types of waters electrofishing is the only possible method of fishing. Its main advantages are due to its simplicity, availability and efficiency. It is also a physically undemanding method, which when carried out properly is friendly to the fish that are caught. Electrofishing is used:

- to catch yearling and brown trout stocks from rearing brooks,
- to obtain brood stocks,
- in regulatory catches of overabundant fish,
- to fish scarce species for the purpose of their transfer to other localities or for the purpose of further breeding,
- in control catches,
- in accidental situations in fishing grounds,
- for scientific purposes and biomonitoring,
- rarely in commercial catching of fish for the market.

6.1.2. The legislation of electrofishing

Electrofishing is subject to several legal regulations. Under **Act No. 99/2004 Coll.** on Fisheries, it is a forbidden method of fishing (§ 13, paragraph 2c), whereas exceptions to this prohibition may be authorized by the competent fishery authority. Exceptions may relate, for example, to fish breeding, fish rescue in accidental situations, for scientific purposes or in individual specially justified cases (§ 13, paragraph 5). Paragraph 6 of the same section states that electrofishing is only permitted upon compliance with safety regulations. A person operating an electrical aggregate should carry a permit for such fishing and documents authorizing its use, established **by the Decree No. 50/1978 Coll.** on expertise in electrical engineering with him/her.

The implementing **Decree No. 197/2004 Coll.** of the Fisheries Act then provides that exceptions to the ban on electrofishing can only be given to a user of a fishing ground to provide fish stocks, to catch brood fish, to move fish stocks to another location, for scientific or educational purposes, during floods, due to extraordinary and life threatening to fish water pollution, at reduced flow-rates, at reduced oxygen content in water or for the needs of the regulation and control of fish stock composition in a fishing ground. Fish farmers may be allowed an exception for the needs of pond fishing practices (§ 9, paragraph 2). At the same time a maximum period of two years is determined by the decree, to which an exception may be granted (§ 9, paragraph 3).

The Decree No. 50/1978 Coll. on proficiency in electrical engineering specifies requirements for the qualifications and experience when working on electrical equipment. The most important concepts include the staff qualification (in this case members of the electrofishing team). The head of catching, the catcher and the electrical aggregate operator must be qualified educated persons (§ 4), i.e., they must be holders of the **Certificate on electrical qualification pursuant to § 4 of Decree No. 50/1978 Coll.** It is issued on the basis of training conducted by an employee with higher qualification specified in § 5–9 of the Decree. The validity of the certificate can be extended on the basis of re-examination, at a maximum interval of 3 years from the date of the examination, or a previous examination. The other members of the electrofishing team (auxiliary function) must have the qualifications of people familiar with the method. This qualification can be obtained by completing training (conducted in the form of a collective interview), carried out by an employee with the minimum qualifications pursuant to § 4 of the **Decree No. 50/1978 Coll.** At the training workers become familiar with the basic organizational and technical information (organization of catching), electrical (especially safety) information and principles of the first aid. The training is recorded and signed by all the participants and the trainer.

Another important piece of legislation is **CSN 331500** – The revision of electrical devices, setting out the obligation to maintain the electrical equipment (including the electrical aggregate) every 12 months. The review must be performed by a knowledgeable person with higher qualifications in accordance with Decree No. 50/1978 Coll., and after the repair of a serious defect by an inspection engineer in accordance with § 9 of this Decree. Other standards govern the requirements for the design of the electrical aggregate.

6.1.3. Basic components of the electrofishing gear and the types of used devices

Generally, the electrofishing device consists of several basic parts: As **energy source** either a generator or battery kit is used in practice. The latest **battery** types are used due to their technical maturity and low weight as a suitable power source for electrical aggregates. Mostly small sources with voltage of 12 V and a capacity of up to 10 Ah are used whereas more powerful battery units are equipped with rechargeable batteries with a capacity larger than 20 Ah. Batteries should be protected against acid leakage and designed for frequent charging. Modern, so-called gel batteries meet both conditions at minimum maintenance requirements. The second energy source for electrofishing devices is the **generator system,** consisting of a suitable combustion engine with speed control and power mostly between 1.5 to 15.0 kW and a power generator. Most often, it is a suitable type of alternator, producing alternating current. It is further adjusted in the **control box.** It is a device used to adjust power and to control the operation of the electrical aggregate. In it the supplied AC power is adapted to DC pulse current (typically 10 to 120 pulses per second). The control box of some types of electrofishing devices also allows switching output voltage (typically 2 degrees, app. 230/400 V). On the control box are also sensors (mostly informational lights), indicating the current operation of the device (the presence of the current on electrode outlets, the voltage on the electrodes as well as the voltmeter and ammeter). The adjusted output current is then supplied to the connection points for the connection of **lead in electrode wires.** It is formed by a well insulated pliable cable (min. cross section of 1.5 mm^2), which is used to supply power energy from the source to the electrodes. Catching electrodes are used for direct induction of the power into the water. Electrodes are always at least two – **catching electrode** (positive – **anode)** and opposite (return) electrode (negative – **cathode).** When immersed in water and upon the switch of the control button, an electric field is established around the catching electrode. A negative electrode is needed to generate an electric field in the water. It is usually placed near the electrical resource. It can also be towed behind a boat (when a boat is used for fishing, see chapter 6.1.7.) or pulled by the catcher behind him (when using a portable aggregate). The **catching rod** of the anode should be made of a good insulating material and the ends are adapted for the connection of the catching electrode and for the connection of the supply line. The control button used by a catcher for switching the power supply on and off as necessary is an important part of the rod.

With stationary types the electrofishing device frame is made of steel profiles, which are attached to the main part of the device. Often the frame is fitted with a chassis and drawbar. For stationary aggregates all parts of the frame must be electrically connected and grounded. This is done by a grounding spike – a metal rod with a wire, which connects the rod to the device assembly. Once stuck into the ground the rod serves as a protection against the contact voltage in case of failure of the electrical aggregate. Modern power units are equipped with handles for easy carrying. With mobile types of electrofishing devices the frame is designed as a structure with straps, allowing the carrying of the device on a person's back. Some battery units with a small and lightweight battery are placed in special bags together with the necessary accessories. The battery gear accessories also include a special charger used for charging used batteries.

6.1.4. Occupational safety while electrofishing

Compliance with the safety regulations and the security of the catching team is the responsibility of the head of the team. Before the start of fishing he/she informs members of their obligations, distributes tasks, instructs them on safety at work and makes entries in the aggregate operation logbook. The head of the team is also responsible for organizing and running the fishing and the inspection of the protective equipment. The entity, which appointed the team, equips the electrofishing team with the protective equipment. The use of protective devices is given by a function of the member of the electrofishing team. Members of the team operating in a dangerous zone must be equipped with high fishing boots, whereas dielectric gloves are used for hand insulation. Landing net handles (sacks) and containers for keeping caught fish must be made of non-conductive material whereas fishing rods of the anode must be completely isolated from the electrode itself.

6.1.5. Effect of electric current on fish

By immersing both electrodes in the water and connecting the electric current, the electric field created is characterized by field lines going in all directions from one electrode to the other. The field lines near electrodes are thicker per unit of area and with increasing distance from the electrodes their density decreases. However, during electrofishing a pulsating direct current is used which is much less dangerous for fish than alternating current. The electric field in the water acts on the nervous system of fish and makes them react in various ways. The fish that enter the electric field of low voltage feel the weak effect of the electric field, which manifests restlessness and causes them to try to escape from the field. This condition is called **excitation.** At higher voltages the fish put their head towards a positive pole and swim in the direction to it **(anodic effect, positive galvanotaxis, positive electrotaxis)** and close to the positive electrode, where there is a further increase in voltage, it leads to muscle contraction (in extreme cases to tetanic muscle contraction) followed by the muscle relaxation – fish get into a state of narcosis **(galvano-narcosis).** In this state, the fish lose mobility, turn on their sides and sink to the bottom. After transfer to the oxygenic clean water the restoration of the body's physiological functions occurs within a few minutes. The time of recovery of bodily functions is dependent on the conductivity of the water, the fish species, the size of the fish, the period of time of the power impact and the voltage. The body is affected by the voltage that is directly proportional to the length of the body. This so-called physical (gravity) voltage is generated between the head and the tail. Larger fish are more susceptible to electrical current than younger and smaller fish. For smaller fish the number of pulses should be increased. Cyprinid species are more sensitive than salmonids. For cyprinids the galvano-narcosis is generated by a voltage of about 1.0 V, compared to 1.5 to 2.0 V with salmonid fish.

6.1.6. Electrofishing – wading and fishing from the bank

Equipment

Portable aggregates allow intense electrofishing in segmented sections of running and lentic waters, as they are transmitted during the fishing by the source operator. Therefore, they are less demanding for the preparation of electrofishing and as regards the number of catching team members (minimum 2 members). Battery aggregates (Fig. 6.1.1.) are usually very light and mobile; after connecting, the electrodes are immediately ready for electrofishing. The aggregate weight ranges from 6.5 kg (LENA, SEN made by Bednář company) to about 16 kg (IG200, AGK-Kronawitter company). Their operation is limited by lower power and battery capacity. This varies depending on the conductivity of water and the operator experience from around 5 hours for smaller types (LENA, SEN) to about 10 hours for more powerful types. Since the aggregates are usually supplied with two batteries, which can be easily replaced during electrofishing, it is possible to use them even during all-day fishing. Another advantage of battery units consists in their quietness. This is particularly important when fishing at larger locations where fish are able to escape from the catcher's range. The anode itself is either formed by a plate or conductive mesh frame that allows the lifting of caught fish.

Fig. 6.1.1. ***Battery electrofishing devices of Czech and foreign production*** *(left LENA, SEN – Bednář company, right IG200 – Kronawitter company) (photo: J. Turek).*

Backpack engine electrofishing device, manufactured abroad, combine the advantage of higher performance and mobility while fishing. Their weight ranges according to the type and power from 13 to 30 kg (Fig. 6.1.2.). Especially lighter types are perfect for all-day electrofishing in all types of localities. Types used in the Czech Republic are equipped with gasoline combustion engines (mostly Honda) with an output of 1.5 to 3.0 kW and an alternator of adequate performance. When fishing, they are only limited by the need to refuel and in some cases their noise level may be a disadvantage. The engine is turned on with a retractable cord and is equipped with a gas lever with a switch, located within the range of the sampler. In terms of safety, it features a dip slip switch that can only be operated in a vertical position with slight fluctuations. For larger and longer lasting (about 5 seconds) deflection, the aggregate's engine turns off automatically.

Fig. 6.1.2. ***Backpack engine electrofishing device produced by EFKO (Germany) with accessories*** *(photo: J. Turek).*

Stationary units are located on the shoreline of a catching area, while a catching electrode is equipped with a long connecting wire, allowing its use at a considerable distance (up to 500 m) from the unit itself. These are motor generator sets with a power output of 2–4 kW and output voltage of 300–600 V. In the Czech Republic, Bednář company offers a device consisting of a Honda engine power with output of 2 kW for the BMA PLUS control box or 160 NB. The device is suitable for small and medium-sized streams with a depth of up to 1.5 m and its weight is 40 kg. The whole device is attached to a tubular frame and equipped with an easily detachable towbar chassis with wheels. It can be used in all types of the conductivity of the catching area (100–1500 microseconds). The mean output current is indicated by an ampermeter. The operation of the control box only regulates output (www.r-bednar.cz). Devices of ML 3 type of a similar design are quite frequently operated; they are driven by an internal Briggs & Stratton combustion engine with a power output of 3.6 kW and an output voltage of 250/500 V. Older types – ML 1 and ML 2 – no longer meet applicable technical and safety standards. The main disadvantage of these aggregates consists of the considerable length of the cable, hampering their use in segmented and overgrown terrain. Stationary devices also include powerful generators delivering output of up to 15 kW, used mainly for fishing from a boat. These devices are described in the section on electrofishing from boats.

Other facilities used in wading fishing (or fishing from the bank) include various types **of sacks** that are selected according to the expected size of fish. It is important that their handles are made from a non-conductive material. Also, **collecting containers** (e.g., buckets) made mostly of plastic and fitted with a non-conductive handle are necessary. If a higher quantity of caught fish is expected, a **live box** must be used, the structure of which should allow for a sufficient flow-rate of fresh water to the retained fish. Wicker baskets or large perforated plastic containers are often used as live boxes.

Organization of electrofishing by wading and fishing from the bank

The planning and preparation of electrofishing is the responsibility of the head of catching team. He/she is responsible for inspecting the functionality of the aggregates and other equipment needed for fishing. The equipment must include a first aid kit. Before the fishing, the head of the team should instruct other members on the relevant occupational safety, he/she checks the protective equipment used and determines the functions of individual members of the catching team as well as the signals used in the actual fishing. Team members must be familiar with the purpose and procedure of the fishing as well as with the target species and categories (age or size) of the fish. The training is recorded and the record should be signed by all members of the catching team. The head of the team also makes an entry in the operating diary of the electrofishing device. The instruction to start electrofishing can only be given by the head of the team and the fishing should be suspended on the signal of any member of the team (especially in case of an emergency), as well as due to rain or other adverse weather conditions, due to modifications or repair of the aggregate, refuelling or relocation of the stationary device. The fishing is terminated on the signal of the head of the team, who consequently records the number and species of caught fish.

During **wading fishing,** which is the most common electrofishing method in running waters, catchers usually proceed upstream. Advantages of this fishing method include both the runoff of the turbid water behind the catching team and thus the easier capture of stunned fish and the possibility of forcing the fish to the closest obstacle in the flow (weir, gravel beds, stone threshold, etc.) where they can be caught more easily. The advance rate is governed by the catcher, who progresses upstream, and systematically fishes the whole area of the stream. In streams with plenty of shelters, the catcher alternately turns the current on and off in front of the expected shelter. This is a very effective method, which forces fish to leave their shelter due to the induced electrotaxis. The catching electrode is always directed toward the sacks, making fishing easier. The catcher is closely followed by collectors with sacks. Their task is to take the fish collected in the sack at the end of the fishing rods and in that order to actively catch all guided and stunned fish the catcher does not manage to collect. The collectors further pass the fish to a person carrying a container with a non-conductive handle. After accumulating more fish, the carrier takes the fish to a storage container (live box, tub and transport box). If he/she is not replaced by another carrier, the fishing will be interrupted until his/her return. In wider streams (over 5 m) it is also appropriate that two catching groups (two catchers) proceed along the stream; in this case also the number of auxiliary members should be increased accordingly. To make the fishing effective, the catchers should move at the same level (Fig. 6.1.3.).

When electrofishing for the purpose of the quantitative evaluation of a stock, the sampled section must be dammed at the upper end (unless it has a fixed barrier there) using nets or other electrical aggregate. This prevents fish forced by catchers upstream from leaving the examined section. The section must be

Fig. 6.1.3. ***Electrofishing using two backpack electrofishing devices in a medium size stream*** *(Blanice River, Vodňany; photo: M. Bláha).*

sampled several times and the population estimation itself is made through a calculation (e.g. Zippin, 1956; Cowx, 1983) based on the decline of catches in repeated catchings.

When sampling by way of a backpack device aimed at catching fewer fish (sampling, etc.) fishing can only be conducted by two persons where the first person operates as the catcher and source operator and the second person is head of the catch, who at the same time also acts as a carrier (or collector).

When a stationary device is used it is followed by a person operating the supply source (a cable leading to the catching electrode). His/her mission is to release the cabling depending on the progress of the catcher. In segmented terrain another person can be assigned to this activity to prevent cable breakage or its tearing out from the handle. The person operating the electrofisher should be permanently present at the device and in the direction of the head of the catching to ensure its shutdown.

Electroishing **from the bank** is done on very narrow salmonid streams or in places with deep water or obstacles in the stream. The catcher proceeds first along the bank, followed by persons with landing nets, who walk through the stream or along the shoreline catching the fish.

6.1.7. Electrofishing in running and lentic waters with boats

Basic characteristics of electrofishing from a boat

Electrofishing from a boat is most often used where due to the size of a water body, its depth or other limitation, it would be impossible to catch fish by wading with the use of small portable units. The use of boats is justified in large rivers and almost in all lentic waters. In larger rivers fishing from boats is carried out everywhere where wading is not possible or may be dangerous. In upper parts of larger rivers and stronger flows, electrofishing can also be performed from a floating boat or raft equipped with oars. Electrofishing from such a device is effective when the boat or raft floats along the shoreline at a speed slightly higher than the speed of the flow (Curry et al., 2009). In quieter parts of streams or in the lower stretches of rivers a motorboat is mostly used. If the depth and nature of a stream allows so, also the riparian zone and the river bed can be fished. An ideal place for such fishing includes shallower parts of a river above a weir and lower stretches of rivers with slow flow-rates, where it is possible, within a relatively short period of time, to fish longer stretches of a river by motorboat. As in the case of lentic waters, electrofishing is most effective for catching those species of fish that occur in shallow or riparian zones.

Electrofishing in lentic waters has its specifics and also should be engaged in differently depending on the morphological nature of a particular reservoir. Lentic waters where electrofishing is commonly used include ponds, valley reservoirs, lakes, as well as blind or dead channels and oxbows. The downside of electrofishing is its limited sampling bound only to the shallowest parts; catching is mostly conducted in a depth of 1.0 to 1.5 m. Below a depth of 1.5 m electrofishing efficiency is very limited. In deeper lentic waters it is therefore only possible to fish a narrow riparian zone, which only occupies a very small part (volume) of the total area (volume) of the body. Deep canyon-shaped reservoirs are a typical example of these bodies. In shallow lakes or ponds there is a chance to conduct fishing almost on the whole area of the reservoir with the electrofishing boat passing across the water body.

The main advantages of electrofishing from a boat include the ability to sample all types of riparian habitats that are inaccessible for fishing using seine nets, gillnets, or even wade fishing. These habitats include dense vegetation of emerged and submerged aquatic plants, continuous reed belts, submerged trees, bushes, areas with lots of roots, stumps or boulders, steep scree slopes and rocky shorelines. When used appropriately and subject to a correct set up, electrofishing is one of the most economical methods particularly suitable where it is important to maintain the welfare of fish, such as at catching, when the fish are caught for the purpose of transfer to another reservoir, brood stock catching and if fish are only caught for scientific purposes and are released back into the water after data recording or sampling.

For electrofishing from a boat, usually 3–4 persons suffice. It only is in cases of mass catching of fish, such as during spawning, or an accumulation of fish at low water level, when more people are needed to cooperate to ensure fast and efficient processing of the catch and shortening the stay in stressful conditions. Electrofishing in larger running or lentic waters should not be conducted in extreme temperature conditions. The ideal temperature for electrofishing of common species of fish is 10–20 °C; if also salmonid fish are present in the water, electrofishing should be conducted at temperatures of 10–15 °C (Beaumont et al., 2002). Since electrofishing especially from a boat is a demanding and hazardous activity, it is necessary to consider the time of the day that should be chosen for fishing. Daytime has a great influence on the distribution and behaviour of fish, or even on their escape responses, which are substantially reduced at night. Night catches of fish can provide us with very different results than catches during the day; however at night, the visibility is very limited and the fishing is therefore more difficult and less safe. Night catches can be performed in lentic water bodies, which are inaccessible (e.g., water-supply reservoirs, reservoirs in military areas, etc.) and where there is a reduced risk of an electrical accident to an accidental nocturnal visitor. It is not recommended to electrofish from a boat at night in faster running waters, where the risk may be disproportionately high and catches are therefore carried out only during the day.

Equipment for electrofishing from a boat

Floating devices used for electrofishing carry all the equipment, including the electrical aggregate, electrodes, tubs with water for fish placement and a place for the team. At present, boats made of conductive and non-conductive materials are used for the purpose of electrofishing, most often there are fibreglass boats (England) or boats made of aluminium alloys (USA, Czech Republic). An important property of the boat is that it should have adequate size, stability and also easy manoeuvrability. The size of the boat must be designed so that there is sufficient space to accommodate all the necessary equipment and it must also be comfortable enough to allow for the crew to move around in the boat. The boat's stability is one of the most essential safety requirements and must meet such criteria so that even with an extreme load on either side, the boat does not overturn. The manoeuvrability is very important in rivers with increased flow-rate as well as anywhere where the vessel moves in an environment full of obstacles and in segmented riparian areas of lentic or running waters. These requirements are best complied with by boats 4–6 m long, 1.5–2 m wide, with two closed chambers in the bow and the stern (Miranda and Boxrucker, 2009; Kubečka et al., 2010). In the front part of the boat should be a suitable safety element consisting of a railing at least 1 m high that would serve as a support for a catcher and as protection against falling into the water (Fig. 6.1.4.) (Kubečka et al., 2010). The engine and curtains on the oars are essential parts of the boat. For catches in large lentic waters or in stretches of rivers with increased flow-rate it is recommended to use a more powerful engine that can also be used in shallower parts (short leg motor or the shallow drive mode).

Fig. 6.1.4. ***An electrofishing boat with a safety railing and a system of two anodes placed obliquely in front of the vessel's hull*** *(Smith-Root, USA) (photo: M. Kratochvíl).*

The powerful electrofishing device is composed of three main parts – the petrol unit (engine) itself, the generator and power unit (control box). The petrol engine gets its fuel supply from an external tank. For the output of an electric power unit used for catching with an electrofishing boat a minimum output power of at least 5 kW is necessary (Kubečka et al., 2010). Furthermore, in waters with higher conductivity, analogically an even more powerful electrical aggregate should be used. The generator can be a part of the whole device (Fig. 6.1.5.) or can be a separate unit connected to the rest of the equipment only with cables (Fig. 6.1.6.). The generator also includes outputs for electrodes and safety switches or outputs for lighting. The generator should be equipped with an output voltage control so that the total applied power output can be maintained at constant values in waters with various concentrations of salt. The equipment provides the option of selecting the types of current used – direct current, commonly known as DC or pulse direct current, commonly known as PDC. For pulse direct current, the control of pulse frequency, and other possible settings, if the generator is equipped with them (e.g. length of time) are an integral part of the equipment. A built-in voltmeter and ammeter are a suitable part of the power aggregate providing a general overview of the output parameters of voltage and current (Fig. 6.1.7.).

Fig. 6.1.5. ***An electrofisher commonly used for catching fish from boats in European running and lentic waters. The equipment also includes a power unit with outputs for connecting electrodes and an auxiliary fuel tank*** *(Hans Grassl, Germany) (photo: M. Kratochvíl).*

Fig. 6.1.6. ***A stand-alone power unit with options of setting parameters of the type of electrical current, settings of voltage, frequency, working cycle,*** *etc. (Smith-Root, USA) (photo: M. Kratochvíl).*

Fig. 6.1.7. ***Detailed view of the voltmeter and ammeter to measure the output voltage and current of the electrofisher*** *(Hans Grassl, Germany) (photo: M. Kratochvíl).*

A system of electrodes forms an essential part of the electrofishing assembly. For catches from boats various types of electrodes (of different shapes, sizes and materials) can be used depending on the conditions and focus of catching. Cathodes copper tapes that freely flow behind the boat are commonly used and in places heavily overgrown with aquatic vegetation also floating cathodes are used. Recently, the use of the hull has appeared as the most appropriate solution for grounding when the whole vessel becomes a negative electrode. This solution has many advantages; for example, it avoids the risk of getting stuck in aquatic vegetation, obstacles or even the risk of wrapping the tape around the propeller engine, which may occur with freely flowing cathodes towed behind a boat. Another advantage is the constancy of the shape of the electric field. If freely flowing strips towed behind the boat are used there are changes in the position of one or more anodes and often also uncontrolled touching of the boat hull. The assembly and use of positive electrodes (anodes) depend on the fish which the catching is focused on. During catching we primarily focus either on fish fry (0+ fish) or on fish older than fry (1+ fish and older). For catching fish fry a system of one anode is used most often, which has a different size and shape, and is a part of a fibreglass rod (Fig. 6.1.8.). This rod can be equipped with an integrated safety switch. For catching older fish the best way is to use a system of two anodes that are placed on fibreglass poles directed obliquely against the hull (Fig. 6.1.9.). Rods are finished with metal rings, to which the electrode system is connected. It has a star shape and is mostly equipped with six steel cables, which are immersed in water during the fishing itself (Miranda and Kratochvíl, 2008). Electric safety switches (12 V) form an integral part of the electrical aggregate assembly; they are used to activate the electric field. Mostly a system of two switches is used including a foot-operated (manual) switch, which is controlled by a catcher standing on the bow of the boat. Another hand (foot)-operated switch is controlled by the driver of the boat sitting on the stern of the boat, who has a sufficient view of all persons on board and in case of danger can switch off the switch immediately (Kubečka et al., 2010). To activate the electric field both switches must always be turned on simultaneously.

Fig. 6.1.8. ***Catching of fry from boats using point sampling.*** *The positive anode (circular shape) at the end of the fibreglass rod is placed into the water in front of the boat and at the same time the electric field is activated. All stunned fish are then collected by a catcher with a landing net (photo: M. Kratochvíl).*

Fig. 6.1.9. ***Catches of older and adult fish are carried out by electrofishing with two anodes fixed before boats and equipped with steel cables, which are immersed in the water during catching*** *(photo: M. Kratochvíl).*

The methodology of electrofishing from a boat in running and lentic waters

In slow running and lentic waters a similar methodology of electrofishing from a boat is used. Catching of fry is done mostly by spot sampling methodology commonly used in riverine systems (Copp, 2010) and its modification in lentic or running waters from the boat (Fig. 6.1.8.). Catching is conducted with the boat moving with the help of oars along the coast. At certain intervals the anode is immersed in the water in front of the vessel and the electric field is activated simultaneously, while all stunned fish in the activated electric field are collected. At this moment the boat is not moving. After collecting all stunned fish the boat moves forward again to another, randomly pre-specified point. The quantity of caught fish (abundance) is calculated per number of achieved points and is expressed as a catch per unit of effort (CPUE).

For catching of older fish than fry, the system of two anodes placed obliquely against the hull is used (Fig. 6.1.4. and 6.1.9.). The boat moves using the engine in a forward motion parallel to the bank at 0.5–3 km.h^{-1} depending on the amount of fish, shoreline segmentation, obstacles in the water, etc. (Kubečka et al., 2010). The electric current can be activated continuously or can be activated every 3–5 m of the boat track. Temporarily stunned fish are collected by catchers standing on the bow of the boat and placed in a tub with water. The quantity of caught fish (abundance or biomass) is calculated as a catch per unit of effort (CPUE) and most often relates to the units of the shoreline length or the time period during which the electric field is activated.

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6.2. Fish sampling using nets *(T. Jůza, J. Kubečka, M. Prchalová, J. Peterka)*

This chapter provides an overview of fishing net techniques commonly used to fish in various types of mainly lentic and partially also running waters. The standardization and development of many net fishing tools used in conditions of dam reservoirs and lakes have been undertaken by the Fish ecology group (FISHECU, www.fishecu.cz) at the Institute of Hydrobiology BC AS CR, v.v.i., in České Budějovice; thus the size and design of fishing net tools described in this publication are primarily based on years of experience and research of members of this group. Globally, the latest summary of the net fishing methods was prepared by Gabriel et al. (2005). As effective fishing by way of certain complex net methods entirely depends on careful net preparation, the proper setting of the net in the water and also on the synchronization of the work of more workers, the treatment and handling of nets is described in more detail.

6.2.1. Active fishing tools

Active fishing tools include lift nets, falling gears, bagnets, dragnets, beach seines, purse seines, trawls and push nets. These are methods where fish are caught by way of active net movement, which is induced either by pulling, lifting or throwing the net (lift nets, falling gears, beach seines, bagnets and purse seines) or by dragging or pushing the net by using motor power (trawls and push nets, large seines).

Lift nets and falling gears

Lift nets are nets consisting of a horizontal wall made of netting or bag in a shape of prism, pyramid or cone open towards the surface (Fig. 6.2.1. – left). After being immersed in the desired depth, the nets are hauled by hand or machine to the bank or the boat. Fish that are located above the net during the pulling out are detained in the net and caught. To increase the efficiency of lift nets fish can be lured by the light or bait fish (Vácha, 2002).

Fig. 6.2.1. ***Sketch of a lift net on a stationary device located on the bank with a mechanized lifting system*** *(left, according to Vácha, 2002)* ***and fishing with a falling net*** *(right, photo: FISHECU).*

Falling nets are nets thrown into the water from the bank, from the shallow water or from a boat that catches fish during the descent (Fig. 6.2.1. – right). After reaching the bottom, falling nets are closed through various complex mechanisms. Their use is generally limited to shallow waters (Vácha, 2002). Both lift nets and falling nets are typically used for catching small fish with limited escape reactions. In the Czech Republic, these methods are not usually used for the routine monitoring of water bodies and are considered rather marginal.

Bagnets

A bagnet consists of a net with a deep core, an upper line with floats (75 cm apart), lower line and two maces (Fig. 6.2.2.). Maces are two short wooden poles on which two short strings (braces) are fixed with meshes to tie-up towing ropes. They are mainly used to catch fry and stocks in riparian zones and at harvesting of ponds when bagnets are distributed along the part of the bank and workers on each side pull the net toward the bank at first by towing ropes and later with the help of maces. When maces approach the bank the fished area is closed and the caught fish remain in the core of the bagnet. Bagnets are also used in running waters of brooks and rivers, where one proceeds with them downstream and thus disturbed fish are caught after fleeing upstream to the net. Fry bagnets tend to have a width of 3, 6 or 10 m and a mesh size of 6 or 10 mm. Bagnets for catching fish older than 0+ are manufactured in widths of 5, 7, and 12 m and the mesh sizes of 20, 25 and 30 mm. The height of bagnets is 50–75 cm and the depth ranges from 2 to 7 m (Adámek et al., 1995).

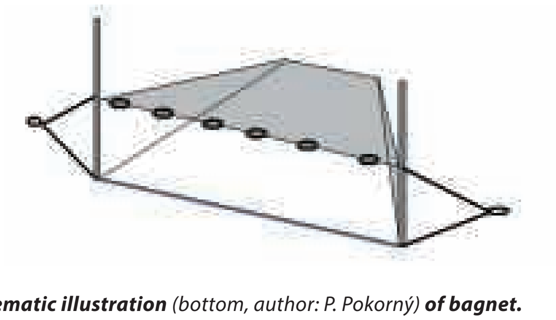

***Fig. 6.2.2.* Photo** *(up, photo: P. Pokorný)* **and schematic illustration** *(bottom, author: P. Pokorný)* **of bagnet.**

Beach seines

Beach seines consist of a net fence fitted with floats (max. 1 m apart) on the upper line and loads on the lower line (similar to bagnet). However, they often lack maces, do not need to be equipped with a core (simple net fence) and the float and the load line are connected by ropes at both ends (the same principle as braces with a bagnet, Fig. 6.2.3.). The net may also be supplemented with pulling ropes attached to both ends. Generally, we can divide them into fry beach seines with the length of 10–20 m, a height of 2–3 m and mesh size of 1–2 mm and adult (intended for catching fish older than 0+) with a length of 30 to 1000 m or even more, up to a height of 3 to 10 m with a mesh size of 6–50 mm (Fig. 6.2.4.). Říha et al. (2008) recommend at least a 50 m long adult beach seine for routine fish sampling in dam reservoirs (depth 4 m, mesh size 10 mm). Currently beach seines are widely used in all types of waters, both for commercial and fishery purposes and for scientific monitoring.

The main advantages of beach seines especially include their simplicity, affordability and speed of seine, during which no excessive damage and exhausting of fish occur. When using beach seines of larger sizes much of the littoral areas can be sampled within a relatively short period of time. This area is clearly defined and the catch can be easily related to the sampled area (Kubečka et al., 2010). The efficacy in relation to various kinds and different size groups of fish is very high. As with any fishing techniques also with adult beach seines we encounter size selectivity, when the smallest fish that pass through meshes of the net are usually not caught in any significant quantity (in an amount equivalent to the actual representation in the reservoir – to catch these fish we use the fry beach seines). From a certain size the catchability grows almost exponentially and soon equals nearly 100% (Fig. 6.2.13.). At the recommended 10 mm mesh size nets are non-selective in late summer for all fish older than 0+. Speaking about the selectivity of beach seines, it is necessary to mention also fish that are able to jump over the upper line and thus significantly reduce the likelihood of their capture. This is especially the case with larger individuals of such species as carp, asp, grass carp or silver carp. The disadvantage of beach seines consists primarily in their limitations to use in a shallow littoral area usually to a depth of 4–5 m with a low bottom slope (30°) without large unevenness (boulders, branches, stumps). Pulling can be conducted at any time during the day and night. Night catches usually have more valuable notice capability (Říha et al., 2008, 2011).

The seine itself starts with the preparation of the net. An adult beach seine is usually carefully loaded on the bow of a flat bottomed boat (the back of the boat is equipped with an engine) and is thus ready to be used. The boat subsequently floats (using paddles and stern first) along the perimeter of the area to be sampled and the net from its bow is laid in the water. The part of the bank which is to be consequently sampled is thus bordered. The net is pulled out so that at both its sides there are at least two workers. On each side one worker pulls the upper line and the other one pulls the lower one. During the seine the lower should be in permanent contact with the bottom, so that the fish cannot pass underneath. When pulling out the net the staff at both ends slowly move towards each other until the moment when the net is cored and pulled out from the water. The entire catch is then gently shaken down to the part of the net with the largest number of fish and later processed (Kubečka et al., 2010). Fry beach seines, which are relatively short, are set along the shoreline on oars from the boat; in case of sampling a site with a shallow depth of water the net can be set in the water by an employee in high boots (Slavík and Jurajda, 2001). Then the catching procedure will be the same as with the adult net; however, one person on each side of the fry net would be enough (Fig. 6.2.4.). The guidebook by Slavík and Jurajda (2001) also contains a procedure for using fry beach seine in localities with increased flow-rate.

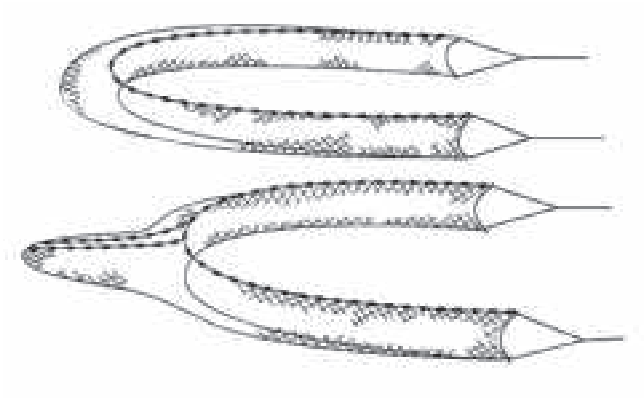

Fig. 6.2.3. ***Beach seine, simple net fence*** *(upper image)* ***and net with core*** *(lower image, Kubečka et al., 2010).*

Fig. 6.2.4. ***Fry sampling using the fry beach seine*** *(up)* ***and adult sampling using the adult beach seine*** *(bottom, photo: FISHECU).*

Purse seines

A purse seine is basically a beach seine adapted to fishing in open waters of deep water bodies. Originally, it was a sea technology that was also successfully transferred to freshwater conditions. A purse seine consists (like the beach seine) of a belt of netting with floats on the upper line (max. 1 m apart) and steel rings hanging on the lower line (max. 1 m apart). Purse seines can be similar to beach seines classified into fry and adult ones. The length of fry purse seines used in fresh waters is usually 60 m, their height is 6 m and they have mesh size of 1–2 mm. Adult freshwater purse seines are over 100 m long and over 10 m high with a mesh size of 6–10 mm.

The main advantage of the purse seine is the relatively low purchase cost compared to the cost of other active methods used in open waters, as well as care for the fish and the opportunity to express the catch per fished volume or area. The main disadvantages especially include the need for considerable experience of staff performing catches and also relatively small fished volume in relation to the total volume of open water of water bodies. Another disadvantage is the lower ability to catch larger fish that may escape from the fished area during the seine setting (Charles-Dominique, 1989; Říha et al., 2012).

The catches are preceded by a very thorough preparation of the purse seine on the purse seine vessel (Fig. 6.2.5.). It is a long narrow flat-bottomed boat equipped with an outboard engine, on which the net is laid so that the upper line with floats lies on the back and the lower line with steel rings on the bow of the boat. The boat is equipped with an electric motor and a pulley and at the bow there is also a hand drum winch with a coiled rope passing through the rings on the bottom line of the seine. This relatively long and narrow boat is rather unstable while working with the purse seine, so the auxiliary float is attached to the port for increased stability. Before laying the net on the water, one side of the purse seine is anchored outside the purse seine boat (another boat with a worker who, when distributing the seine into the water, hinders the movement with oars, can serve as an anchor). When distributing the purse seine the purse seine boat starts to move and distributes the net clockwise into the water so that it makes a circle on the water surface. During circling the net is thrown away into the water while the upper line is held by floats on the surface and the lower line with steel rings decreases rapidly, and thus closes the sampled area from the sides. At this stage a shape of a cylinder is formed in the open water (Fig. 6.2.5. above). The closure of the cylinder is achieved by the winding of the rope passing through rings to the winch pulling the rings together and closing the lower part of the cylinder. At this point, the fish that were encircled by the purse seine are trapped in the middle of the cylinder made of the netting. During the next stage the lower line with circles is lifted into the boat using an electric motor via a pulley with the upper line remaining on the surface. The workers on the purse seine boat then begin to put also the netting into the boat (Fig. 6.2.5. middle). After collecting all the netting into the boat, the catch remains in the last pocket. The catch is then removed to the tub for further processing.

Fig. 6.2.5. ***Set adult purse seine*** *(above),* ***putting the net into the boat during working with purse seine*** *(middle)* ***and a boat with special modifications for handling purse seine*** *used by the Hydrobiological Institute of the AS CR, v.v.i. – patent no. 302159 (below, photo: FISHECU).*

Trawls

Trawls are active fishing gear with a cone shape usually tailored from 4 panels (facing panels are identical) ended with a core or tapered sleeves. It was originally a sea method that has in recent decades also been successfully transferred to the freshwater environment. These nets are used either for bottom (benthic trawls) fish sampling or for fish sampling in open waters (pelagic trawls, Gabriel et al., 2005). Due to the many obstacles on the bottom of water bodies, benthic trawls are in the Czech conditions only rarely applicable and therefore, pelagic trawls are more likely to be used. Like most net fishing techniques, trawls can also be divided into fry trawls and adult trawls. For the earliest stages of the fry, so-called ichthyoplankton trawls are used (Fig. 6.2.6.).

Ichthyoplankton and fry trawls are much smaller compared to adult ones (Fig. 6.2.6.). In the conditions of Czech reservoirs a trawl with a square mouth opening of 2 x 2 m for ichthyoplanktonic trawl (Jůza et al., 2010) and 3 x 3 m in case of fry trawl (Jůza and Kubečka, 2007) has proven to be sufficiently effective for fry sampling. The netting made of sewn tulle (mesh size 1 x 1.35 mm) is sewn to the fixed metal frame in the case of ichthyoplanktonic trawl. A fry trawl has in its front part netting with a mesh size of 6 mm, and 4 mm at the rear, where the catch is accumulated (core, so-called cod end). On the transition between these two parts a funnel of netting (funnel) is sewn, which prevents the escape of fish from the end part of the trawl when the tow stops. At the end of the mesh work of the ichthyoplanktonic trawl the removable metal cylinder (collector) is attached, which accumulates the catch. In the centre of the upper part of the frame of both types of the trawl, the float is attached that keeps the trawl on the surface. Alternatively, by inserting the rope between the float and the frame of the trawl it is possible to change the depth of sampling (Fig. 6.2.6.). In the lower corners of the trawl frame the balance weights are fixed of the weight corresponding to the size of the float. The ichthyoplanktonic and fry trawls of these dimensions must be towed by a vessel with the power of at least 25 horse power in order to achieve an optimal speed of 1 ms^{-1}. The optimum duration of tow in the conditions of Czech reservoirs is 5 minutes (ichthyoplanktonic trawl) or 10 minutes (fry trawl). The towing boat should also have on the stern a sufficiently large working area on which the trawl can be laid after the end of the run and where the catch will be processed. Night time is suitable for sampling open water by means of the fry trawl, due to the significantly reduced activity of the fish and movements of the fry from the bank to the open water for the night (Gliwicz and Jächner, 1992). Ichthyoplanktonic trawls are used both during the day and night. The minimum number of workers for ichthyoplanktonic and fry trawling is 3 people.

Adult trawls used in the Czech reservoirs are 15 to 40 meters wide, approximately 10 meters high and 40 to 100 meters long. Thus unlike ichthyoplanktonic and fry trawls, they have no metal frame but are also equipped with a funnel. The mesh size in the rear part of the trawl, where the caught fish is accumulated, is 10 mm and towards the front part the mesh size becomes larger (at the input the mesh size is typically 100 to 400 mm, see Figure 6.2.7.).

The main advantages of using trawls include the fact that it is possible to sample large volumes and different depths of open waters within a relatively short period of time, and the catch can be easily adapted to the unit of area or volume (Kubečka et al., 2010). The range of species and sizes, which are able to be sampled, is very wide. Even with trawls, the size selectivity occurs that has a similar course as the seines (Fig. 6.2.13.). By using trawls, also much of the fish biomass at the observed location can be caught and therefore can be used for biomanipulation (removal of unwanted fish species, see chapter 4.7.). The disadvantages mainly include the fact that the price of trawling nets is relatively high and the towing nets in open water requires powerful and specially equipped towing boats with high purchase costs and relatively high fuel consumption during trawling. As in the case of purse seine catches, adult trawling in particular requires a well trained crew. Adult trawling is effective both during the day and night, but for exploratory purposes night trawling is definitely recommended, when the reactions of the fish approaching the trawl net are much weaker (Rakowitz et al., 2012).

Adult trawling can be, with regard to the number of towing vessels, divided into single-boats and double-boats. In single-boat trawling the trawl is towed by only one boat and its opening is maintained through expansion boards that are hung on towing ropes in front of the trawl (Fig. 6.2.7.). With double-boat trawling the trawl is towed by two towing vessels, each of which pulls one side of the trawl (Fig. 6.2.7.). The boats maintain a constant distance from each other during the trawl, thereby providing an optimum opening of the trawl inlet. For fishing of adult fish in freshwater the boats are usually not as efficient as those available at sea, so double-boat trawling has proven to be much superior (Gabriel et al., 2005). The basic parameter of the towing vessel (trawler) is its towing power. With double boat trawling it is necessary to have two towing boats, each with a minimum towing power corresponding to half of the total power required for trawl towing. With adult trawling it is also necessary for one of the towing boats to be equipped with a hydraulically operated trawl drum for the rolling of the ropes and trawl (Fig. 6.2.7., Kubečka et al., 2010). The towing speed of the adult trawl should be at least 1.2 ms^{-1} and the duration of the trawl is chosen with regard to the quantity of fish caught between 15 to 30 minutes.

***Fig. 6.2.6.* Frame ichthyoplanktonic trawl used for catches of the earliest stages of fry in open waters of dam reservoirs** *(above, photo: P. Pokorný)* **and fry trawls used for catching juvenile fry later in the season** *(below, photo: FISHECU).*

The tow is preceded by the trawl entanglement including towing cables to the drum of one of the towing vessels (Fig. 6.2.7.) and arrival at the location of the first tow. During the setting of the trawl into the water one worker under the constant slow forward movement of the boat unwinds the net from the drum of the trawl and two other workers ensure that the net is well distributed out from the deck. When almost the entire net is in the water and only the inlet opening is left on the board (the end portion is put into the water first) the workers attach floats holding the trawl on the surface to the upper corners of the trawl (or at the desired depth using a rope between the float and trawl) and in the bottom corners a balance weight is fixed corresponding to the weight ensuring the proper vertical opening of the trawl. After distributing the whole trawl net into the water both towing ropes are unwound from the drum and consequently the other towing boat arrives and ties up its towing rope. The boats move away from each other and if the trawl on the surface opens properly (floats get away from each other) the run can start. A fitting part, which makes adult trawling easier and faster, is the so-called handling boat with at least 3 workers. It is a barge with a tub, dipnets, ventilation, and other facilities necessary for the processing of caught fish. After the end of towing the boat arrives at the end of the trawl (marked float), and its crew releases the catch to the prepared tub. Then it closes once again the end part of the trawl and another run may follow. After the last run the net is wound on a drum on the towing boat in a procedure opposite to its setting into the water (Kubečka et al., 2010).

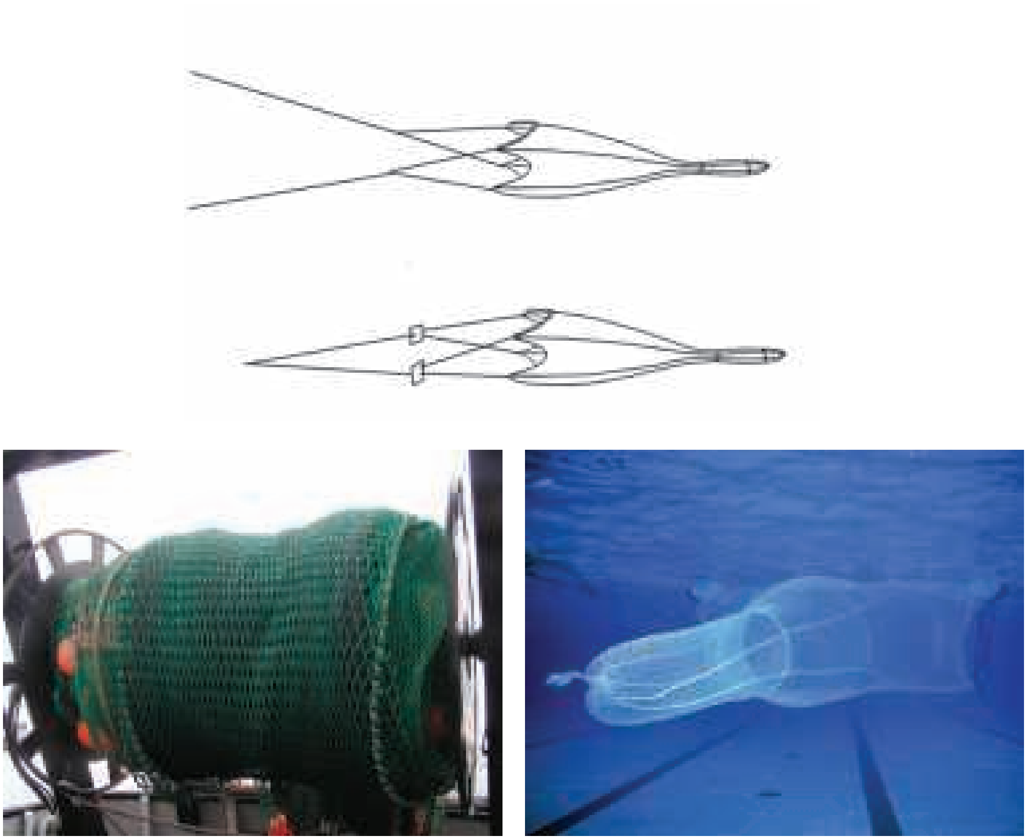

***Fig. 6.2.7.* The scheme of the trawl for double-boat trawling** *(top scheme)* **and single-boat trawling with space plates** *(bottom scheme, Kubečka et al., 2010)* **the model of adult trawls** *(bottom right, photo: FISHECU)* **and the adult trawl wound on the drum of the towing boat** *(bottom left, photo: FISHECU).*

Push nets

In terms of its function, a push net is very similar to a towing net; however it is not towed on a rope behind the vessel, but pushed on a fixed structure just in front of the boat or at different depths under the boat (Fig. 6.2.8.). The main advantage of the push net compared to the towing net consists in not affecting the areas sampled by the vessel (the net samples ahead and the vessel only arrives afterwards to already sampled space). The major disadvantages of push nets include the small maximum size (the net must be a solid structure comparable in size to the width of the vessel) and limited depth availability (usually within 4 m, Fig. 6.2.8.). Because of sizes of vessels used on lakes and dam reservoirs, the usual dimensions of push nets are at most 1 x 1 m, which in combination with the use of tulle netting (mesh size of 1 x 1.35 mm) only allows for fishing of fish in the earliest stages (larvae and early juveniles) similarly to the ichthyoplanktonic trawl. Quantitative fishing of older fry and adult fish is not possible using a push net.

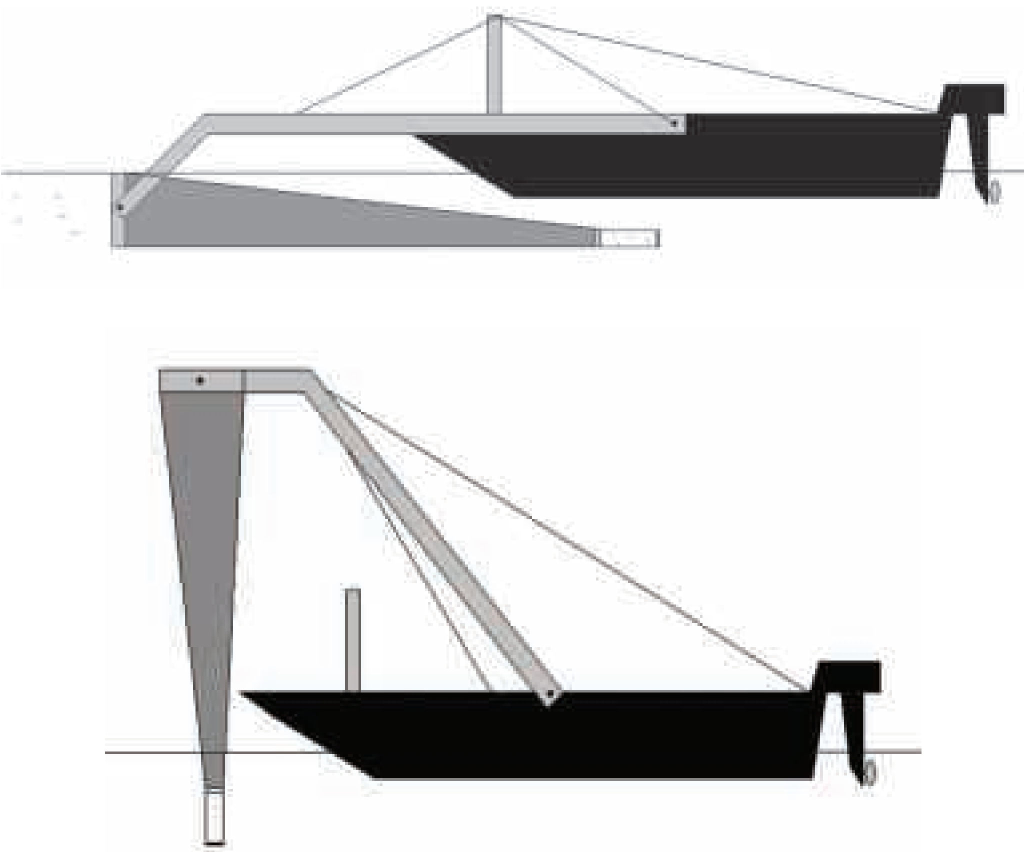

Fig. 6.2.8. ***Sketch of a net pushed in front of a vessel during sampling*** *(top)* ***and positions of the push net after sampling completion before emptying the catch*** *(below, according to Herzig et al., 1994).*

6.2.2. Passive fishing tools

Passive net fishing tools especially include automatic traps such as gillnets, pots, fyke nets, traps and nets adjustable in the stream (stow nets). These are methods by which fish are caught passively, i.e. the net is not moving, but waiting in the water for a fish to be caught in it on the basis of their own physical activity (gillnets, pots, traps) or to enter it by way of the water flow (stow nets).

Gillnets

Gillnets consist of fine mesh and lower load and upper float lines (Fig. 6.2.9.). The lines and netting are balanced so as to provide a vertical position of gillnets in the water. Fish are caught in gillnets in various ways, most often at the body behind the head, gills, teeth or other body protrusions (Fig. 6.2.9., Prchalová et al., 2008). Gillnets can be used as benthic, pelagic, vertical or drifting nets. However, the last two types have not recently been used in the monitoring of freshwater systems. The size of meshes of used gillnets vary according to the target species and sizes of caught fish. Gillnets may consist of the netting of one size of meshes or sections of netting (so-called panels) of different size of meshes – so-called multi-mesh gillnets (Kubečka et al., 2010).

Gillnets are divided, according to the habitats for which they are intended, into the benthic (bottom) and pelagic (open waters, Kubečka et al., 2010). **Benthic gillnets** are balanced so that the lower load line copies the bottom and the upper float line provides the vertical position of the net in the water column. Their height is usually 1.5 m and at each end the net is equipped with a float on the strap of a sufficient length that after the installation locates the gillnet in the water (Kubečka et al., 2010). **Epipelagic gillnets** are installed directly from the surface thanks to the floats on the upper line (Fig. 6.2.9.). Their height is between 4.5 and 6 m and they sample the surface layer of open water. In shallower sites (e.g. at the inflow areas of reservoirs or in ponds) epipelagic gillnets of the height of only 3 or 1.5 m can be used (Kubečka et al., 2010). **Mesopelagic gillnets** sample the depths below the epipelagic gillnets, i.e. usually from 5 to 9.5–11 m, thanks to the slowly submerging lines. The depth of the upper line is determined by the length of the string between the surface floats and the upper line (Fig. 6.2.9.). The minimum safe depth at the installation site is 12 m. **Bathypelagic gillnets** are of the same design as epipelagic ones (the net is buoyant thanks to holding up the upper line sufficiently), but are intended for fishing in significant depths near the bottom. The installation depth is provided by a string between the balance weights and lower line (Fig. 6.2.9.). The minimum depth at the installation site is 20 m.

All these types of gillnets have the same structure: they consist of 2.5 m wide gillnet panels of partial size of meshes. The panels are firmly sewn to each other along the entire height. In each net there are meshes of 12 sizes – 5 mm; 6.25; 8; 10; 12.5; 15.5; 19.5; 24; 29; 35; 43 and 55 mm (so-called standard gillnet – it corresponds to the requirements specified in European and Czech standards for sampling using gillnets, EN 14757, 2005; CSN 75 7708, 2005; the size of the meshes is specified from knot to knot). If it is reasonable to assume that in a given water body there are fish of a larger size (> 30 cm length of body size), it is important to add panels with the sizes of meshes of 70, 90, 110 and 135 mm. Panels with large meshes constitute separate gillnets (so-called big mesh gillnets), in which the length of individual panels is 10 m and they are installed according to the same sampling schemes as standard gillnets (Kubečka et al., 2010).

The main advantages of using gillnets include the possibility to sample in all depths and habitats of monitored water bodies and the wide catchability of the various types of species and sizes of fish. The broad size spectrum is secured merely by combining different sized meshes in the panel. Gillnets formed by panels with only one mesh size are very selective (so-called single peak selectivity), where the only fish caught are fish which size corresponds to the mesh size used and bigger or smaller fish are not sampled or are caught very rarely (Fig. 6.2.13.). The main disadvantages include the fact that gillnets only provide data on the relative abundance and biomass of fish by means of catch per unit of effort (relative catch CPUE and BPUE, see chapter 4.2.) and currently no conversion is known between the catch per unit of effort and absolute numbers of fish in water bodies. Other disadvantages include the possibility of damaging gillnets especially in places with submerged obstacles (trees, stumps, rocks, etc.), underestimation of fewer moving species or size classes of fish (e.g. territorial pike or small 0+ fish), undervaluation of fish with an atypical morphology of the body (eel), overestimation of more active species that are more likely to be caught (perch), the possibility of the saturation of the gillnets when the fish already caught reduce the likelihood of further catches and, last but not least, the destructiveness of the method when part of the fish is killed after the overnight installation (Kubečka et al., 2010).

The setting of gillnets into the water is carried out from the boat, in a direct line, which follows the given depth or the depth range in the case of benthic gillnets. The epipelagic and mesopelagic gillnets should be anchored or moored to the shore or to another stable element (buoys, bridge piers, etc.) to prevent the net flowing away. The installation is carried out 2–3 h before the sunset and gillnets are removed from the water 2–3 hours after sunrise the next day. This time period is determined by the activity peaks of fish that are for the majority of our species at dusk and dawn (Prchalová et al., 2010), to maximize the catch. The basis for the effective installation of gillnets is their careful storing in cases. After pulling the gillnets to the boat the case with the catch is labelled and the legend should be supplemented by any valuable fish catches that were released during the collection back into the water. The sampling with benthic gillnets is done by two workers (one worker handles the nets, and the other one operates the vessel). With higher pelagic nets it is optimal that two persons handle the nets, i.e. the number of crew members increases to three (Kubečka et al., 2010).

While reaching the end of the chapter on gillnets, we should also mention a similar type of levelling nets – so-called double wall nets or trammel nets. They consist of two external nets, called mirrors made of a stronger material with a mesh size of 100 to 150 mm, and the inner net called the core, which in turn is made of a very fine material with a mesh size of 15–30 mm. This internal net is much longer and higher than both mirrors. All three (or two) of the network are folded on each other, whereas the inner net is loosely folded and they are connected by the upper and lower lines. The upper line has floats and the lower line has the lead load or the load cord. The net height is 3–5 m. The advantage of this net is that it enables the catching of fish that are less damaged and usable for the next stocking or breeding. The fish tries to break through the net barrier, comes through the mirror, creates a fold in the dense core of the fine mesh, which is drawn through the opposite mesh of the other mirror and thus creates a kind of pocket in which it gets stuck (Prášil and Reiser, 1976). Collecting fish from these nets is very time consuming and therefore they are used very rarely for monitoring of fish communities.

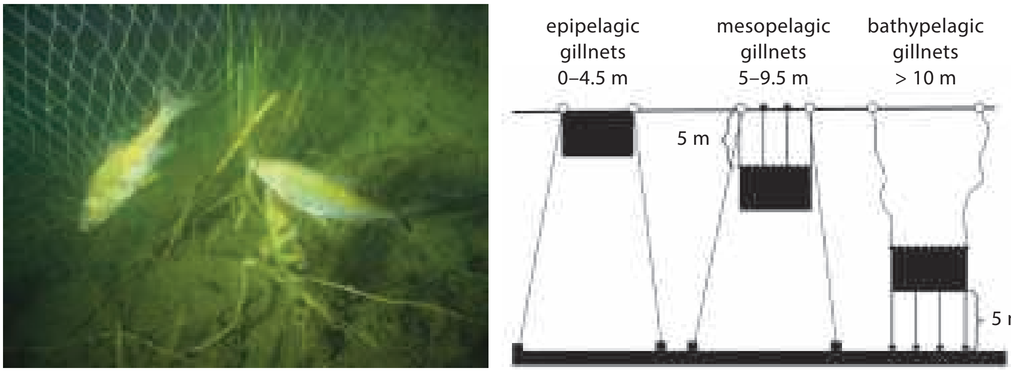

Fig. 6.2.9. ***Fish caught in benthic gillnets*** *(left, photo: FISHECU)* ***and the design of the installation of pelagic gillnets in the open water of the reservoir*** *(right, Kubečka et al., 2010).*

Pots

Pots are hunting tools of a cylindrical or square cross-section, now usually made of corrosion-resistant metallic material coated with mesh tissue (Fig. 6.2.10.). In the front part there is an enhanced entry or two wings guiding fish into the main chamber of the pots. In the direction from the inlet into the space in the chamber of the pots there is a tight net funnel. The function of fishing by way of pots lies in the fact that a fish guided through enhanced input or wings through the funnel to the main chamber is no longer able to re-locate and find the narrow mouth of the funnel and remains trapped in the chamber of the pot. The length of pots including wings ranges from 0.8 to 2 m, with the width of the chamber being 25 to 50 cm. So-called Breder traps are a special type of pot; their size is about 40 cm, including wings, and they are used for fry sampling.

The main advantage of pots consists in their simple and inexpensive construction, as compared with, for example, gillnets that release the caught fish much easier, and the ability to install them into very structured bottom habitats. Fish from pots remain in appropriate frequency of collecting in a good condition. The disadvantage is their low efficiency outside periods of major fish activity and the high degree of species selectivity. They are therefore mainly used successfully during mass migrations or for catches of selected species of fish in periods of increased activity during spawning at spawning grounds.

Pots are usually placed on the bottom from the boat by a rope tied to one end of the structure of the pot. At the other end a float is tied, making it easier to find the pots when they need to be emptied. Pots are collected daily and in the case of a small quantity of fish the interval of the collection can be extended.


Fig. 6.2.10. ***The so-called Klíčavská fish pot with a solid metal frame*** *(left, photo: P. Pokorný)* ***and a photo of the stretched Římov pre-chamber fyke nets*** *(Kubečka, 1992)* ***with an antechamber of 1.5 x 1.5 m, with a chamber diameter of 0.9 m and a mesh size of 20 mm*** *(right, photo: FISHECU).*

Fyke nets

The principle of sampling by fyke nets is the same as in the case of fish pots. Their structure is formed by hoops of a circular or square shape (Fig. 6.2.10. and 6.2.11.). Stretched netting is located on the frame. Compared to pots, fyke nets have larger dimensions, with the inlet opening into the chamber bigger than 1 m. The wings sewn from the sides to the inlet opening are usually several meters long and the total length of the fyke net is several dozens of meters. For mass spawning migrations of fish, fyke nets are used; their wings partition the full width of the stream or the water body, and the fyke net itself is then anchored to the structure made of scaffolding (Fig. 6.2.11.; Hladík and Kubečka, 2003). The entry into the fyke net consists, as in the case of pots, of a funnel in the shape of a conical sleeve having an opening through which the fish pass through to the chamber. A fyke net can have more funnels (two, three), and hence it is referred to as one-, two- or three-chambered (Fig. 6.2.11.). As in the case of pots, fyke nets use their wings to guide fish to the inlet opening and further on through the funnel into the chamber, where they remain trapped.

The main advantage of fishing through fyke nets consists in the relatively easy catching of large quantities of fish at the time of their mass runs and their being in a good condition. The main disadvantage is the particularly low efficiency of fyke nets during the periods outside the fish runs. The success of fishing with traps also depends on good knowledge of local conditions, particularly in the location of fish habitats and migrations and knowledge of the bottom relief. A catch of smaller fyke nets is species selective.

Fyke nets are installed on a flat bottom or on a bottom with a slight slope from the boat and are stretched between poles or by using sufficiently heavy weight loads attached to the start of the top of the wings and also to the end of the fyke net behind the last chamber. During the fish collection, we do not usually remove the whole fyke net but rather use a rope with a float attached to the structure of the inlet opening of the fyke net and only chambers with the catch are lifted into the boat, while the wings remain in the water. After releasing the fish from the chambers the fyke net is again stretched to its original position. Fyke nets are collected approximately twice a week; in case of a large number of fish the interval is shortened.

Fig. 6.2.11. ***Giant fyke net stretching across the whole inflow zone of the reservoir*** *(left)* ***and the sample of the bi-chambered trap with bands of the circular shape*** *(right, photo: FISHECU).*

Stow nets

Stow nets are used for the sampling of early stages of fish (ichthyoplankton) that are passively carried by the flow (drift). They are mainly used for sampling in rivers or in outlets of water bodies. Such net has a rectangular frame structure (typically 0.5 x 1) to which 2 m long tulle netting with a mesh size of 1 x 1.35 mm is sewn (Peterka et al., 2004; Fig. 6.2.12.). The underside of the frame is equipped with two spines which serve for attaching the frame to the bottom, and the side part of the structure is equipped with metal struts maintaining the net in a vertical position, or the frame in the upper part is attached to the stretched rope (Fig. 6.2.12.). Nets usually sample throughout the whole water column from the surface to the bottom. The main advantage of these nets is their simple and inexpensive design. The main drawback is their tendency to get clogged during longer exposures and their applicability only in smaller flow-rates.

Fig. 6.2.12. ***Stow nets installed in a river bed*** *(photo: FISHECU).*

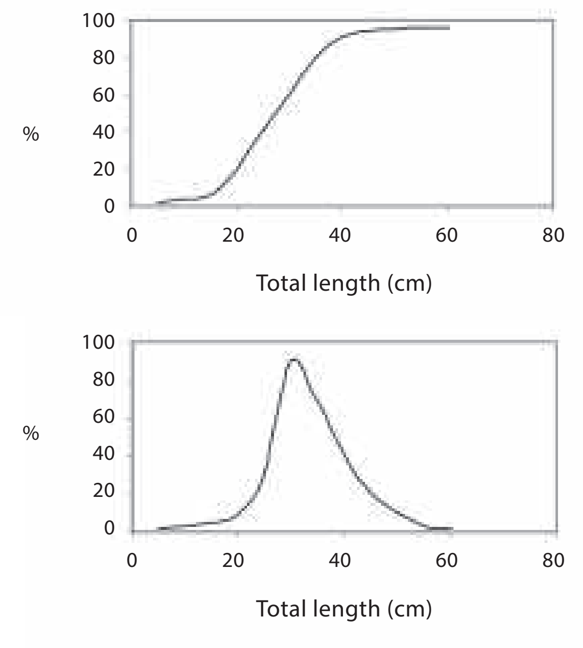

Fig. 6.2.13. ***Hypothetic selective curves typical for active*** *(top, beach seines, trawl with uniform size of meshes)* ***and passive sampling tools*** *(bottom, gillnet with uniform size of meshes). Percentage on the Y-axis represents relative effectiveness (according to Pivnička, 1993).*

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ORGANISATION OF ANGLING

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The organisation of angling is the main objective of the management in fishing grounds. Since the fishing grounds are mainly state-owned, the state has provided users of fishing grounds pursuant to § 13 of the Act No. 99/2004 Coll. on fishpond management, the execution of angling rights, angling inspection, protection of marine fisheries resources and amending certain laws (Fisheries Act) and its implementing regulations, with fairly fundamental constraints, within which it is possible to conduct the sport of angling. These rules are given both historically, as they have undergone certain evolution, and next, they are influenced, for example, by requirements for the protection of nature and partially also by modern elements in sport angling. Furthermore, users of fishing grounds are provided with the possibility to amend, change and specify the angling rules provided by the law within specific rules connected with a given fishing ground or to make the general rules stricter. Legal opinions diverge on this provision, whereas some lawyers, including some representatives of the Ministry of Agriculture, interpret this provision in such way that users of fishing grounds are free to specify the rules of angling in fishing grounds managed by them, whereas they cannot break the rules laid down by the law and the decree. For example, the minimum size cannot be reduced but it can be increased. On the other hand, some lawyers conclude that in this way only local angling conditions can be specified and that for any fundamental changes to fisheries rules (either tightening or easing), it is always necessary to apply for an exemption at the relevant angling authority. Unfortunately, no official interpretation is available and thus individual users act according to their capabilities and their opinions and experience. So, we encounter both various local arrangements concerning the definition especially where angling is permitted and where it is not, as well as, for example, increased size limits, extension of the closed season of individual species, prohibitions of certain angling methods, and the like.

In the fishing grounds it is prohibited to catch fish other than by way of angling, and only under certain conditions is it possible to be exempted from this prohibition (see the chapter on the management in fishing grounds). Furthermore, places from which it is not possible to fish (such as bridges, dam reservoirs, sluices, fishways, etc.) are defined. The owners of riparian lands shall not hinder the exercise of angling rights and must accept the designation of fishing grounds (§ 11 of the Act, paragraph 8 and 9), even though they are entitled to compensation for any losses caused to them by users due to exercising angling rights.

Anyone who wants to fish in a fishing ground shall at first obtain a state angling license, whereas the conditions for obtaining and issuing the license are again determined by the law and the decree. Furthermore, it is necessary to get (actually purchase) an angling permit for a given fishing ground to be allowed to fish there. Within Czech Anglers Union (CAU), so-called regional annual permits, i.e., permits valid for all salmonid or non-salmonid fishing grounds of individual regional angling unions are most frequently used. It is also possible to buy permits of a short duration (one day, three days, one week) as well as union-wide permits, i.e. applicable to all districts of CAU. There is also so-called nationwide permit, valid in the grounds of CAU and Moravian Anglers Union (MAU).

The major general rules of angling, which provide statutory regulations, include legal minimum sizes of selected species of fish (a minimum length of fish must be achieved so that an angler can keep it), time of day to fish in a calendar year (varies by month and between non-salmonid and salmonid fishing grounds; plus it is not allowed to fish at night) and closed periods of individual fish species (the period when anglers cannot keep the fish and if they catch it, it must be carefully and immediately released). In its annex, the regulation defines a template of the form for angling permit and permitted angling methods.

Angling rules vary between salmonid and non-salmonid fishing grounds. Major differences include the prohibition to use any bait of animal origin in salmonid waters. In addition, each salmonid fish caught in salmonid fishing grounds in other way than by fly fishing or by spinning must be released. Spinning is

***Fig. 7.1.* Salmonid fish require special care and protection** *(beautiful grayling from the Vltava 33 fishing ground; photo: M. Hladík).*

permitted from April 16th to the end of August only. Year round angling is permitted by the legislation, but within the detailed conditions applicable to fishing grounds of the CAU and MAU, angling is permitted from April 16th to November 30th only. In non-salmonid grounds, spinning, live bait fishing and using of baitfish nets is allowed from 16th June to the end of the year, whereas in the non-salmonid fishing grounds, year round angling is permitted.

Basic methods of angling are defined in the Annex 7 of the decree; we present here a summary of these definitions:

Bottom fishing and float fishing is the basic type of angling when angling with no more than two rods is permitted with no more than 2 single hooks or 1 double- or triple hook (only in fishing grounds). For angling with live bait in fishing grounds, also multiple-hook systems may be used with three hooks as a maximum (single, double or triple). During bottom fishing, the movement of angling bait is not actively influenced by angler. When float fishing, an angler may actively influence the movement of the bait.

Spinning consists in the active leading of the bait where only 1 rod may be used which must be held in hand while angling; no other rod is baited. As bait, 1 artificial or natural bait can be used. The bait, depending on its design has no more than 3 hooks (single, double or triple hooks). Spinning also includes fishing with an artificial fly equipped with accessories increasing the excitability of fish, such as a metal sheet or a little propeller.

Trolling is fishing from a boat using 1 angling rod, behind which one piece of bait is dragged at any water depth; no other rod is baited. Artificial or natural bait is used. The bait, according to its design mostly has 3 hooks (single, double or triple hook). For the propulsion of the vessel it is also possible to use an electric engine according to the conditions determining navigation in a given fishing ground. However, in some fishing grounds (Lipno and Orlík Valley Reservoirs) trolling is allowed from vessels propelled by human power only.

When fly fishing, only one rod can be used which is held by hand during angling; no other rod is baited. On the leader there are no more than 3 flies tied to single hooks. The fly cannot be equipped with accessories that increase the excitability of fish through their movement, such as a rotating metal sheet or propeller. In some regions, it is prohibited to use additional floating elements or weight outside of the body of the fly.

The live bait net must have an area not exceeding 1 m^2. While fishing with a live bait net, no rods may be baited.

Thanks to the development of angling, at a time when the production of angling equipment and bait has already become a separate industry and with the possibility of exchanging information, the current definitions of angling methods are now already outdated and inadequate, and thus the need has arisen to define new angling methods (if at all necessary). Already it is no longer possible to classify some popular methods correctly, anglers often combine them and it causes problems in the interpretation of individual methods, especially in relation to the time of year when various methods can be used. This may lead to conflicts, for example, with the fishing guards.

Description of individual angling methods

Angling is a pastime activity that is developing the quickest and which is constantly enriched with new elements (the latest angling methods and their combinations), materials (aluminum, titanium, kevral, graphite, synthetic bait or their ingredients) and equipment (electric motors, GPS, Echo sounder). It is very difficult to characterize individual methods in one paragraph and the reader must be referred to specialized publications which describe the individual methods and their offshoots separately. The basic methods currently being used in angling can be described as follows:

Ledgering is one of the traditional angling methods where an angler sits on the bank or on an anchored boat and his rod leans on forks (or on a boat), the taking of the fish is detected by a bait indicator placed on the line in front of the rod tip or between the eyes. The bait is located at the bottom where it is fixed by the weight, which also allows casting of the bait into the water. This is mainly used for angling of carp species. So-called baiting is used very often when an angler using bait attracts and retains fish at the spot of angling. The angler either drops the bait directly into the water or places it at the so-called feeder, which is part of the rod and also serves as a weight. A variety of mixtures consisting of a natural base (such as grain meal) and taste ingredients are mainly used as bait. For angling, various bait are used, mostly of vegetable (corn, potatoes, pasta, puffed rice) or animal (earthworms, bone or mealworms) origin.

For catching piscivorous fish, small dead or live fish are used as bait. Leaving aside the debate about the ethics of this kind of angling, a clear disadvantage of this method of angling of piscivorous fish consists in

Fig. 7.2. ***Classical bottom angling with strike indicators placed in front of the rod*** *(Lipno Reservoir; photo: M. Hladík).*

the fact that often when an angler strikes the hook cuts internal organs and kills even an undersized fish. For this reason, for example, the South Bohemian Regional Board of the CAU at Lipno Reservoir set the minimum size of bait fish at 20 cm, to protect undersized piscivorous fish, especially pikeperch.

A modern alternative to bottom angling is the **"feeder",** which is characterized by a special design of the "feeder" and the assembly of the whole angle hook and also by the fact that the cast is strained, the rods are being set up almost perpendicularly to the cast's direction and the shot is detected by its fine, reflective-coloured rod tip. For different water types, variants of angling and target fish, diversely strong and sensitive tips can be used.

Another offshoot of bottom fishing is catching carp with the **"boilies",** when balls of various sizes placed on a string off the hook are used as bait. This principle makes use of the habits of carp, which before ingesting bait, tentatively suck and spit out its pieces. In this way they suck the bait and at the moment when they want to spit out the hook, it sticks inside their mouths and the carp during the subsequent escape strikes itself. The composition of bait mixtures and the production of boilies, i.e., bait balls, is a real science; there are dozens of ingredients and flavors, as well as different types of installation. It should be noted that when using this method, it is possible to catch a really big carp, of which anglers have not even dreamed before, and using the appropriate size of a boilie limits catches of smaller fish and thus their injuries are reduced.

"Sipping fishing" is less of a sports method: a special assembly, consisting of a common cast line (0.30 mm), feeder and two hooks on short rigs of braided cord is used. The angler places either corn or some buoyant bait (such as a polystyrene ball) on hooks, or there is even no bait on it and the hooks are pushed into the feeder mixture. The fish sucks the hook together with the feeder mixtures and strikes itself. The method is very effective, but as already mentioned above, its sportiness is doubtful and if it breaks, the mounting is very dangerous for the fish and in some fishing grounds it is even banned.

For float fishing it is also possible to use two rods; the so-called float maintains the bait at the correct height above the bottom, which also indicates the strike. With this kind of angling it is possible to move bait and thus fish a larger area and animate the bait. Again a wide variety of bait is used; specialized float anglers, who have perfected this method, are able to catch dozens of fish per hour. When angling for piscivorous fish, small fish are used as bait. Catfish angling for buoy is an offshoot of this angling; the design of the buoy maintains the baitfish (which can even be a four-pound carp) at a selected spot and helps strike the catfish with its drag resistance.

With spinning mainly artificial bait are used (although it is possible to use small fish as bait); these can be (for laymen) divided into glitters (which are made of metal or are variously spinning or whirling and flashing during movement), wobblers (plastic or wooden imitations of fish in natural colours fitted with a paddle for ensuring a wobbling motion) and so-called "rubbers" – i.e. bait made of a soft material again mimicking various fish or other animals (banjo, twister, ripper, sandeel, etc.). It is difficult to create a definition since individual types of bait are combined, but this distribution would probably suffice for only a basic orientation. The success in angling depends on finding the right location and selecting the right bait, but also in its directing; when using a rod and reel the bait has to be animated. The accuracy of the cast is often the most decisive factor, because piscivorous fish often seek shelter.

Glitter can be divided into spinners and blinkers (spoons). Spinners are designed so that a curved metal blade (leaf) rotates around a small body of fly, creating sound effects, vibrations and flashes and thus attracting predators to attack. Spoons are made of a piece of metal, often bent or concave, their direction moving from side to side and using flashes to imitate an injured fish. Both types of glitters have a gloss finish complemented with a variety of patterns or printing, either imitating natural colours of fish, or being completely fantastic. The legendary "Potassium cyanide spinner", which is very effective for perch, has a special design – the little body has two parts; the metal sheet revolves around the first one and the second one is used to increase the excitability and to balance the glitter that does not rotate and twist the cast.

***Fig. 7.3.* Float anglers use special seats and rods up to 11 meters long** *(the Vltava River over the Paper mill weir in České Budějovice; photo: M. Hladík).*

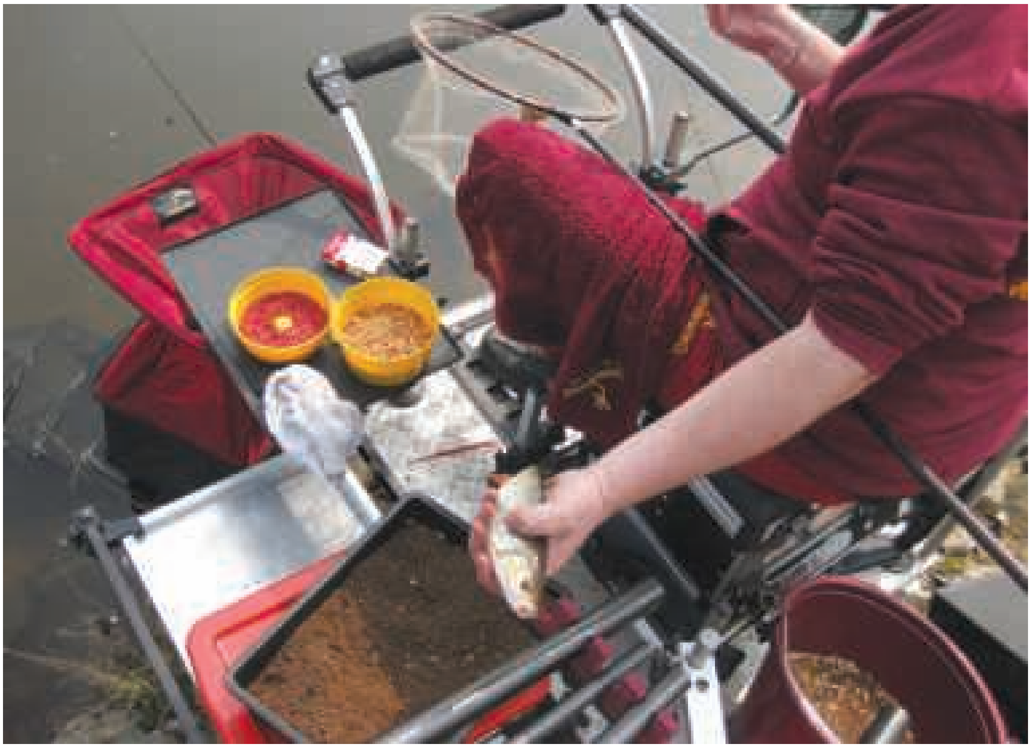

***Fig. 7.4.* The most popular bait for float fishing include mealworms of various colours** *(photo: M. Hladík).*

Fig. 7.5. ***For spinning on large reservoirs it is preferable to use a boat*** *(photo: M. Hladík).*

Wobblers usually swim and we only get them underwater with the movement and resistance of the blade. Depending on the size and angle of the blade variously aggressive movement and different depths of sinking can be achieved. Most often they are of a natural colour mimicking perch, roach, sunbleak, trout or pike and are often accompanied by some attractive element (such as a large eye, orange belly or red tag on a hook); sometimes fluo-colours are surprisingly effective. Some bait have incorporated metallic balls inside of the body that vibrate during the movement and thereby increasing excitability of the bait.

Fig. 7.6. ***Even in the Czech Republic we sometimes come across special boats adapted for spinning (Lipno Valley Reservoir), where fishing seats make otherwise quite strenuous angling more comfortable*** *(photo: M. Hladík).*

For angling on the surface, so-called "popper-fishing" is used as bait that floats and during pulling they swim doing zigzags across the water surface and create a stir. In this way they imitate an injured fish or fish escaping to the surface. This method is especially irresistible for asp.

The "rubbers", i.e., bait made of soft plastic, are a really important topic. Again, they can be bought in dozens of types, sizes, colours and designs, imitating fish, leeches, frogs and crayfish and other invertebrates, and they are often impregnated with a scent that makes them attractive. The basic version is without any weight when the bait is fixed directly onto the hook with a built-in weight, but there are also bait that already have weight built in their bodies. A common feature of this bait is the position in the water when the hook is turned upwards, which reduces the risk of snagging and also improves the effectiveness of a strike.

The so-called "drop shot" is an interesting method, i.e., a system in which an elongated weight is located at the end of the fishing line whereas the bait, most often a kind of "rubber", is placed about 60 cm away from the end. This enables very slow angling just above the bottom and also sensitive livening up of the bait without the risk of getting stuck; target fish mostly include perch and pikeperch but also pike or catfish can be caught using this method.

The equipment used is appropriate for the intended catch. When angling in rivers anglers generally use finer equipment; they often move across the water and the accuracy of the cast is more important than its length. When angling in lentic waters, more solid angling rods, stronger lines and larger bait are usually used, as larger catches can be expected. When angling from a boat, shorter rods are used because of easier handling; on the other hand when angling from the bank, longer rods are used because it is often necessary to cast the line further away.

While trolling, bait dragged behind a moving boat is used. This method is very popular, for example, at sea or in large lakes abroad; with this method you are able to cover a large area but for its success it is necessary

***Fig. 7.7.* Catch of pikeperch using wobbler** *(Lipno Reservoir; photo: M. Hladík).*

to find the right bait, right depth and speed of movement, including the distance of the bait behind the boat. When an engine and ancillary equipment, such as a GPS and echo sounder are used, it is very effective and also its "sportiness" is discussed. Therefore, for example, at the Orlík and Lipno Valley Reservoirs this practice is only permitted with boats propelled by oars; the engine must be off. An offshoot of this kind of angling called "vertical angling" is popular in Holland and Germany; with this method the motor maintains the boat in one place near the shelters of piscivorous fish, and anglers try to make these repetitive movements to provoke the fish to attack. The strike often comes after a long time, but tends to be very aggressive.

Fly-fishing is considered a royal kind of angling sport, as it exclusively uses artificial bait – flies, mainly one's own production – and because it often requires lots of physical efforts, the art of accurate casts and also knowledge about the biology and behavior of fish in addition to the angling experience. The fly fishing rods are characterized by astonishing lightness, high performance and durability. Flies are cast using a fly fishing line, which has a length of approximately 30 m and which is manufactured either floating or in various types according to the speed of sinking which allows fishing at different depths. A few meters long leader and one to three flies are attached to the line. Although fly fishing is mainly associated with angling of salmonids, it can be used to catch all kinds of fish and there are special designs of flies for carp, chub, roach, perch, pikeperch, pike, etc.

To put it simply, we can discuss the differences in the equipment for angling in rivers and lakes. In rivers we use finer equipment and usually get by with a floating line. We use dry flies (imitating insects floating on the surface or just emerging), wet flies (directing actively or passively in a column or just below the surface to create the illusion of dead insects, emerging development stages of insects or even small fish fry) or nymphs which are weighed and allow for angling near the bottom.

The development of technology of fly fishing rod manufacturing allows the design of extra fine and long rods and consequently the development of the "French nymph", where for the casting of nymphs is used only a very long tapered (it means that it is getting gradually thinner) leader and where the line is not necessary. This allows fine fishing with tiny flies and very close contact between the flies and the angler. Therefore the efficiency of angling greatly increases and even very cautious fish can be caught using this method.

Fig. 7.8. ***Dry fly angling in the Vltava 29 fishing ground near Lipno*** *(photo: M. Hladík).*

Fig. 7.9. A lake fly angler's box full of colours *(photo: M. Hladík).*

Fig. 7.10. ***Fly fishing from a belly-boat at the Kvetonov Reservoir, Czech Republic*** *(photo: T. Randák).*

"Streamer fishing" is a special fly fishing method both on rivers and lakes, where various sinking lines are used and mostly fish imitations are used, which are actively directed near the bottom and the method is therefore effective for large trout, but also for large chub, pikeperch, asp and pike.

In lentic waters, the correct depth at which fish are feeding must be discovered in addition to the proper location of angling. The correct depth is often a critical parameter for success, and therefore a wide variety of fly fishing lines is used. Listing them we can start with floating lines, followed by the "Midge tip" with a very short transparent sinking end and which allows for rig plunging below the surface. The "Ghost tip" has a transparent tip about 2 meters long. The "Hover" is very popular which only sinks beneath the surface. There are also various intermediate lines sinking at the speed of 2–10 cm per second, and also sinking lines, which have their core filled with tungsten powder and which are able to sink at a speed of 20 cm per second, and it is possible to achieve a depth of about 10 meters with them. When angling from the bank, the art of faraway casting is necessary, therefore longer and stronger rods are used.

Fly fishing from boats drifting in the wind on lakes (so-called Loch-style) is a basic and traditional method of fly fishing especially popular in the British Isles, where anglers fish from a freely drifting boat, the direction of which is maintained by the so-called drogue. Anglers only fish downwind in front of the boat, and thanks to the boat's movement, they are able to cover a large area. In the Czech Republic there are no suitable waters for this practice, but hopefully some will appear in the future.

Tying of artificial flies from a variety of natural or synthetic materials is another important issue. Although we know some of the basic patterns of popular flies, there are millions of variations and each fly angler has his own box full of his best patterns. Tying competitions are held and such competitions are often a kind of art or expression of aesthetic sensibilities. It gives another dimension to fly fishing- no fly angler would use a fly he would not like himself. More and more fly anglers use barbless hooks which limit fish injuries.

Angling from boats is generally prohibited and can only be performed in fishing grounds where this is expressly permitted. An interesting new feature is angling from "belly-boats". This is an inflatable device in which a angler sits on the surface and moves using flippers. Spinning and fly fishing are the most common methods used in this way.

Ice fishing is very popular in Nordic countries. For this purpose it is necessary to drill a hole in the ice and use a special short rod. Mainly fish active in winter are fished, i.e., whitefish, pike, perch, trout and brook trout, sometimes even sturgeon. Pursuant to Czech legislation, this practice is officially banned but an exception from this ban can be made, which many private owners of ponds use, and consequently ice fishing is becoming very popular in the Czech Republic. Joint events or races can also be organised, where close contact between fishermen is possible. Within the legislation it would be appropriate to cancel the ban on ice fishing and define its rules instead.

Angling in fishponds

It is also possible to organize angling in fishponds; its rules are governed or rather are not governed by § 3 of the Act, paragraph 2, which states that angling is carried out either in bulk using efficient methods (in particular by way of a net) or by angling, whereas angling can be performed by the pond owner himself/herself or by an authorized person. The law does not impose any other restrictions on this kind of angling and anglers do not need a state angling license in these waters; the angling rules are solely specified by the fish farmer, therefore, they are often much more flexible compared to the conditions in fishing grounds (fishing at night, using more rods, ice fishing). This concept of angling is conceived as a commercial form of entertainment. Rates are much higher in comparison with the conditions of the CAU and catches are also more aggressively limited. This is because of the market relationship where an angler can hardly be allowed to take more from the water than he pays for.

Methods for making fishing grounds more attractive

Within the CAU, some options to make angling more attractive have been gradually applied. Ponds that are not listed as fishing grounds any more have started to appear; here angling is operated within pond management allowing owners to set their own rules for angling, although still based on the rules to which we are accustomed in fishing grounds, and which have their justification. At these localities or even in some reservoirs night angling, i.e., so-called 24-hour angling is allowed in the summertime on the basis of an exception. This brings both trophy fish catches and creates some adventure for fishermen. At a number of fishing grounds the K70 rule has been established, which consists in the obligation to return all carp longer than 70 cm back to the water. It aims to increase the attractiveness of the grounds and lets more anglers enjoy a trophy fish catch.

There are salmonid fishing grounds with special regime exempt from regional management, where only a local permit applies that is several times more expensive than a regional permit. Anglers can catch larger trout regularly stocked in large numbers; the fishing guards also work more intensely and a better service is provided. Often stricter rules and catch limits apply.

Ethics of sport angling

At the end of this chapter we consider it necessary to emphasize that the current development of angling equipment has been greatly in favor of anglers and it is very difficult for fish to endure this angling pressure for a long time. Without a significant tightening of angling rules and changes to the ethics of this beautiful sport, it ceases to be a sport, but rather a battle of technology with nature. Rods weighing a few grams only made from graphite composites are able to cast their lines a hundred yards and no fish has a chance to escape. Braided leaders with a diameter of a few tenths of a millimeter perhaps cannot even be broken; fluoro-carbon lines are not visible in the water and some artificial bait look and smell better than their natural patterns. GPS leads us exactly to the place of angling and an echo sounder shows us both the bottom relief and fish. If anglers took all the fish they catch away, there would be soon no fish in our fishing grounds. Therefore, a variety of methods of angling restrictions are applied and the number of fish that you can carry with you is limited, but all this does not help unless the thinking of anglers change and they stop considering "sport angling" an inexpensive way to provide dinner for themselves and their friends, or sell fish for money. Catching a fish is an experience, but throwing it back in the water is even a superior experience.

Fig. 7.11. ***Rainbow trout are a suitable enhancement to some grounds due to their aggressiveness,*** *but, for example, in some grounds, such as in national parks or protected areas, this enhancement of rainbow trout is inadequate and there should be an attempt here to restore the original fish stock (photo: M. Hladík)*

Fig. 7.12. ***Brown trout have started to become a rare species in a number of fishing grounds*** *(Vltava 29; photo: M. Hladík).*

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ABSTRACT

The publication concentrates on the characteristics of open water and describes the ways in which it can be managed and used for fishing. Attention is focused mainly on the issue of fishing grounds management including the legislative framework. Modern approaches to fisheries management in salmonid and non-salmonid fishing grounds are described in the book, as well as the possibilities of using reservoirs for fishing. Other chapters discuss the isues of fish predators impacts in open waters, and water pollution and its influence on fish including accidental kills. The main causes of the damage to aquatic ecosystems and potential ways for their restoration are described. Attention is also given to the issue of fish catches for maintenance and monitoring purposes, fish farming and stocking of fishing grounds, fish migrations including the characteristics of fish ladders and barriers to migration, the protection of the biodiversity of fish communities in the Czech Republic and recreational fishery.

Keywords: fish ecology, fish protection, fish populations, fishery management, fishing grounds, recreational fisheries

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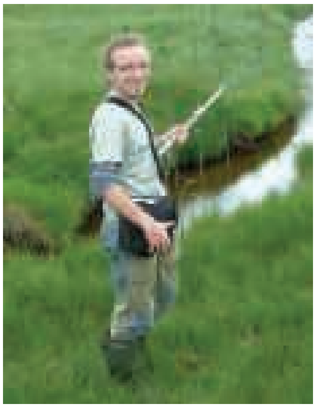

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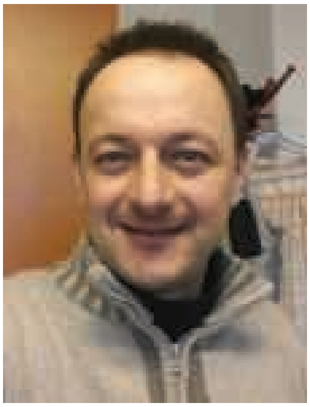

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