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Aquaculture

Jaroslav Andreji et al.

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Authors:

doc. Ing. Jaroslav ANDREJI, PhD. (AQ – 4,0)
Ústav chovu zvierat
Slovenská poľnohospodárska univerzita v Nitre

Ing. Petr DVOŘÁK, Ph.D. (AQ – 2,5)
Fakulta rybářství a ochrany vod
Jihočeská univerzita v Českých Budějovicích

Ing. Ján REGENDA, Ph.D. (AQ – 2,5)
Fakulta rybářství a ochrany vod
Jihočeská univerzita v Českých Budějovicích

doc. Ing. Martin FIK, PhD. (AQ – 1,84)
Ústav chovu zvierat
Slovenská poľnohospodárska univerzita v Nitre

Reviewers:

doc. Ing. Ivan Stráňai, PhD.
Fakulta agrobiológie a potravinových zdrojov SPU v Nitre

dr. hab. Ing. Josef Velíšek, Ph.D.
Jihočeská univerzita v Českých Budějovicích

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Introduction

Fish farming is an important part of aquaculture and has a long-standing tradition. Nowadays, aquaculture is a branch of primary agricultural production which reasonably ensures the production of fish as well as other aquatic organisms such as molluscs, crustaceans, algae etc. Moreover, the fish farming is one of the branches which develop in the fastest way, and it provides almost half of our fish consumption. Aquaculture is a significant part of the national economy of many European countries. Within the whole European Union, the annual production of aquaculture is approximately at the level of 1.3 million tonnes, which equals 2.3% of the world production of aquaculture with a turnover of 2.9 billion euros, and this sector offers approximately 65,000 job vacancies.

According to the farming environment, we distinguish between marine and freshwater aquaculture. While the production of molluscs (mussels, oysters), salmon and gilt-head bream dominates marine aquaculture, rainbow trout (*Oncorhynchus mykiss*) and common carp (*Cyprinus carpio*) dominate freshwater aquaculture.

Gradual increase in global fish pond fishing as well as decreasing quality of the natural environment of seas and oceans caused a considerable reduction of several species of fish. In an effort to prevent such problems from further deepening, the European Commission strives to transfer the ever-increasing demands for fish to marine, or rather to freshwater aquaculture. It is the freshwater aquaculture which has the great potential to assume this duty. The primacy of the trout in the total volume of production, which amounts to almost 200,000 tonnes, or rather 15%, of total European aquaculture production, as well as the common carp, which is the fourth the most produced fish within the European Union with annual production at the level of 70,000 tonnes and 5% share, serve as evidence.

Slovakia as an inland country implements the aquaculture production solely as recreational fishing and fish farming, although conditions for the production of molluscs, crustaceans and even algae exist, too. In our country, fish farming is often implemented in ponds and smaller reservoirs and this form of fish farming is called pond management. For such form, approximately 2,000 ha of water areas are available, in which the common carp and other economically preferred species of lowland fishes (tench – *Tinca tinca*, grass carp – *Ctenopharyngodon idella*, silver carp – *Hypophthalmichthys molitrix*, bighead carp –

Hypophthalmichthys nobilis, wels catfish – *Silurus glanis*, pike-perch – *Sander lucioperca*, northern pike – *Esox lucius*, etc.) are farmed, while the production of the common carp as the main fish, according to The Statistical Office of the Slovak Republic, annually amounts approximately to 450 tonnes and 17% share of the total aquaculture production in Slovakia, which is about 1.2 million euro.

Farming fish in special cultural units of a non-pond type known as trout culture is the second most used form of fish farming. Mainly hatcheries, moats, raceways, channels, pools, cages, silos, fish tanks etc., with a total production volume of more than 40,000 m^3, are used in this form. Rainbow trout is farmed above all, together with other salmonids (brook trout – *salvelinus fontinalis* and huchen – *Hucho hucho*, etc.) and grayling (*Thymallus thymallus*). The brook trout production is more than four times higher than the common carp production – more than 1,100 tonnes annually with the volume of approximately 2.5 million euros and a share value up to 43% of the total aquaculture production.

Concerning fish farming, Slovakia is self-sufficient. The total aquaculture production (fish farming and catches of recreational fishermen) amounts to 4,700 tonnes on the average annually. Apart from this, about 15,000 tonnes of fish and seafood in a volume of approximately 60 – 70 million euros are imported into Slovakia annually. On the contrary, 550 tonnes in a volume of approximately 7 – 8 million euros are exported from Slovakia.

Products gained from fishing, fishery and aquaculture, which are considered to be healthy and rich in proteins play an important part in the European and world nourishment. Consumption of these products (excluding algae) at the world level represents 20.2 kg per person per year, which constitutes 15.7% of the consumption of animal proteins. The average fish consumption in the European Union equals 24.4 kg per person per year. The consumption ranges from 4.6 kg per person per year in Bulgaria to 61.6 kg per person per year in Portugal.

In Slovakia, the consumption of aquaculture products is approximately 8.1 kg per inhabitant per year, while the consumption of fish is around 5,7 kg per person per year, from which the consumption of freshwater fish is approximately 1 kg. However, the recommended fish consumption per inhabitant per year is 6.0 kg.

The aquaculture sector in Slovakia represents just 0.002% of the GDP within the national economy. Although the value is rather low, aquaculture has undeniable significance concerning the protection and creation of the natural environment, preservation of the indigenous gene pool and socially beneficial non-producing functions – landscaping, flood protection, water retention in the landscape, sediment deposition after erosion, interference in microclimate, and development of the countryside and tourism. Within the total number of employees in the Slovak Republic, the employment rate in this sector amounts to 0.00075%. This equals to around 1,000 job vacancies, while for almost two third of the employees it is the main employment, the rest are seasonal labourers.

Introduction

The aim of this textbook is to give students an idea of the fish farming technology concerning the species farmed in Slovakia in ponds or special cultural units, including the fundamental hydrobiological principles taking place in the aquatic environment. Within the pond management, students will acquaint mainly with the reproduction and farming of the carp, which is a species with a dominant status in the aquaculture sector both in production and recreational fishing in Slovakia. Within the trout farming, the focus will be laid on the rainbow trout, which has the leading position in the total production of the Slovak aquaculture. Moreover, students will acquaint with the reproduction systems and technologies of farming this dominant species within the Slovak aquaculture. Apart from this, they will gain further knowledge of other fish species, farmed within the trout farming – brook trout, grayling, and huchen, too.

This textbook will be beneficial not only to students but also to the wide fishing public due to its fundamental overview of reproduction and farming of the chosen fish species, either within pond management or trout culture.

1 Pond management

Pond management is a branch of aquaculture, which focuses on the technology of farming lowland (warm-water) economically preferred species in the pond conditions. This technology is used for farming both consumable fish (either directly or indirectly) and fish fry, which is used to restock the fishing pit. The whole fish production under the pond management is based on the natural form of nourishment and supplement feeding and it takes place within the **complete economy** (closed cycle) – i.e. from farming brood fish, through their regulated reproduction of eggs (eggs), rearing fry, up to farming stock (two-year old) and consumable fish; or within the **incomplete economy** (open cycle) – i.e. only some phases of the production are implemented (most often the reproduction of brood fish, incubation of eggs, and rearing fry and its sale, i.e. from rearing the fry to farming the consumable fish).

1.1 Ponds – history and characteristics

The first references to building ponds come from China and date back approximately to the year 2300 BC. However, pond descriptions with many technological details are included in the written records from around 1100 BC. Ponds in Egypt and Palestine, which were watered by long canals, are known from around 700 BC. Greeks and Romans built water reservoirs as a part of water piping systems and used them for farming fish, too. In the 1st century AD, the Romans built ponds which were watered by sea water.

Due to the Romans, the knowledge of constructing ponds was spread to the area of today's Central Europe. After the fall of the Roman Empire, constructing pond and fish farming became the duties of monasteries. The Slavs participated a bit, too, since they provided their own experience with draining swamps and building ponds. The ponds constructed by them were called **artificial lakes** and they served for retaining water in the landscape and preserving fish until consumed.

The first written records of ponds from the area of today's Slovakia come from the 11th century (1075 – the corporate charter of the Hronskobeňadické abbey). Later, there are records known from the 12th century (1113 – Zoborská charter), and the 13th century in the eastern part of the country (1214 – the donation charter for the Leles monastery). Firstly, the ponds were built by feudal lords, monasteries, the church itself and towns, and later also by townsmen. The greatest expansion of pond management was recorded in the 15th and 16th century, mainly under the reign of king Matthias Corvinus. In this period, ponds were valued more than arable land and their yield was higher, too. Building ponds was felicitous investment in those times for the rich townsmen and owning a pond provided prestige. However, the Ottoman invasion in the 16th century caused a powerful decline of pisciculture and massive extinction of ponds mainly in the fertile southern areas of Slovakia. Later, the decline was accelerated by Bethlen and Rákóczi wars in the 17th century. As a consequence of ever increasing thirst for land, massive pond draining occurred in the 18th and 19th century mainly in the areas of Záhorie region and in the eastern parts of Slovakia nearby Košice and Humenné towns. This lasted until 1948. A certain turning point happened in the 2nd half of the 20th century, when intensification of agriculture and further development of pisciculture took place. New ponds have been built in the area of today's Slovakia and nowadays, their area is approximately 2,200 ha.

A pond is a water reservoir built artificially with possible complete and regular water draining. Its primary purpose is to farm fish but it provides also other secondary functions (landscaping, collecting torrential water, anti-fire function, etc.). For proper functioning, there must be all the necessary technical facilities built in the pond (supplying and draining device, fishing pit, a tub place, etc.) (Fig. 1.1). Other bodies of water with a similar character which do not meet the requirements could not be classified as ponds (lakes, tarns, material pits etc.).

1.1.1 Technical pond facilities

Pond is a significant water management construction which enables to fulfil its fundamental function due to technical facilities. The facilities used in ponds must be simple, effective, manoeuvrable, and last for a long period. Dam, supplying and draining devices, devices for safe overflowing and devices for reduction fishing pond belong among the fundamental technical facilities, which could be found in every pond.

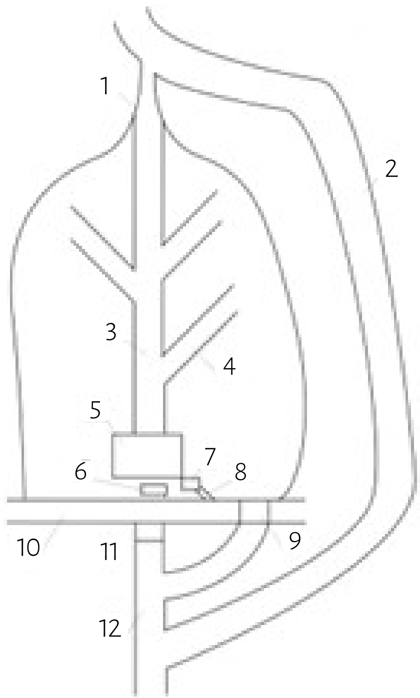


Figure 1.1: Technical pond facilities (Andreji, 1996 – edited): 1 – supplying ditch (canal), 2 – diversion ditch, 3 – main drainage ditch, 4 – side drainage ditch, 5 – fishing pit, 6 – outlet facility, 7 – tub place, 8 – stairs or slope, 9 – safety overflow (weir), 10 – dam, 11 – under-dam pit, 12 – tail-run canal

Dam – this is the fundamental and the biggest construction element of a pond. Almost solely ground materials, which could be found nearby its future location, are used for its construction. Both location and construction depend on the area – size and depth of the reservoir, and quality of the material used for construction. Depending on the type of the used materials, we distinguish between **homogeneous** (built just from one type of soil) and **heterogeneous** (built from two or more types of soil, which are laid in the dam body separately) dams (Fig. 1.2). The homogenous dams could be built up to 6 m of height. According to the dam placement, we divide dams into **front, lateral** and **division** ones.

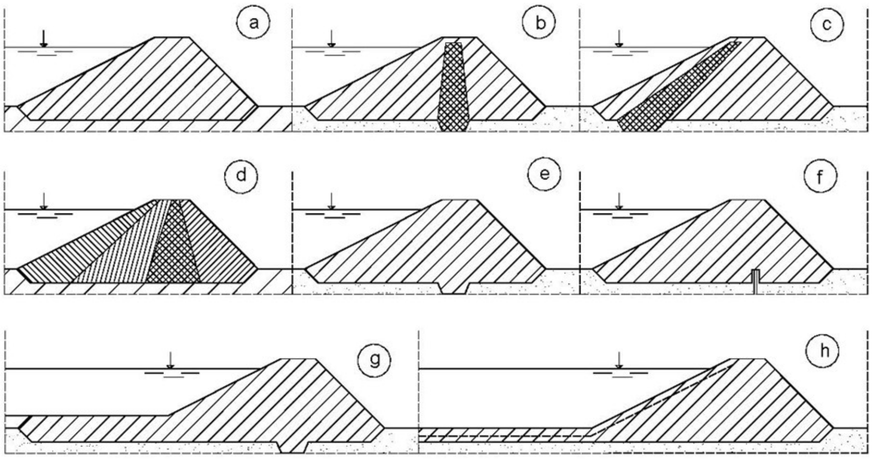


Figure 1.2: Types of ground dams (Čistý, 2005): a) simple homogenous dam, b) dam with an internal sealing core, c) dam with a sealing stop, d) heterogeneous dam, e) homogeneous dam with a sealing lock, f) homogeneous dam with a sealing stilt wall, g) homogeneous dam with sealing carpeting, h) homogeneous dam with a sealing membrane from PVC

Supplying devices – these supply water into the pond. In most cases, water is supplied into the pond by gravity, and only exceptionally by pumping. For such purpose, usually **the supplying ditch (canal)** is used, which supplies water from an offtake object (sill, terrace, weir) into a non-flowing pond. It is better when the supplying ditch is paved or hardened by vegetation, and equipped with a bar screen, sedimentation reservoir and a device for regulating the amount of inflowing water into the pond sluice (gate). This supplying ditch is sometimes built as a reservoir for collecting surface outflow, which is then supplied to the pond. **The diversion ditch** is the other type of the supplying device, which regulates the water inflowing into the pond by draining the superfluous water out of the pond. Due to this, repairs of the pond as well as some soil improvement measures could be implemented (draining water and repairing the pond bottom, etc.). In some cases, it fulfils the function of a safety overflow, too. This occurs usually in new ponds.

Outlet facilities – on one hand, they ensure gradual draining of water from the pond up to its compete draining, and on the other hand, they maintain the requested normal operating level (so called normal). From the construction viewpoint, the draining devices are divided into **open** (flume) and **closed** (pipeline). The open draining devices are composed of ferroconcrete or stone flume, which is usually partitioned by a sluice (gate). These devices are rarely used. Into the main types of pipeline draining devices belong shovels, stopples, stoplogs, sluice gates, segments and monks. The most common draining device in ponds and smaller water reservoirs is **the outlet** (Fig. 1.3). It consists of open or closed cased construction from concrete, ferroconcrete, steel or wood with rabbets, into which stoplogs (wooden boards) are inserted, usually in two rows, one after another, while the water level is regulated by the second (the rear) row. The draining devices are placed in the deepest point of the pond, usually near the dam or directly into the dam, and they run along the whole body of the dam. The outlet hole of the draining device flows into the under-dam pit and the inflow hole is usually equipped with a bar screen, which prevents fish from ecsaping from the pond.

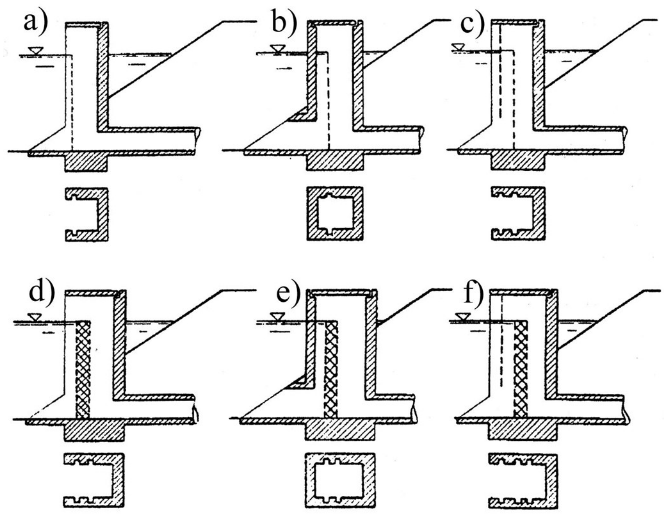


Figure 1.3: Types of outlets (Čistý, 2005): a) open, simple, b) closed, simple, c) open, duple, d) open, simple double, e) closed duple double f) open duple double

Safety overflow – this serves for draining flood flows, and protecting the dam against overflowing, or blowing up. It is the most important and also the most expensive part of the pond. Safety overflow is built on all the flowing ponds and its capacity is calculated by so called **„hundred-year water“**. However, on the non-flowing ponds, it is designed for the lower capacity. Safety overflows on ponds are divided into **dam** and **bank** ones and according to the construction disposition, we distinguish between **front, lateral, shaft-like, trough, siphon, supplementary** and **standby** ones. The most frequent are however the front overflows (Fig. 1.4), which constitute the dam body mainly of the older ponds, and the lateral overflows, too, which are placed in the lateral part of the pond nearby the dam. A bar screen which prevents fish from escaping from the upper water levels is another construction constituent.

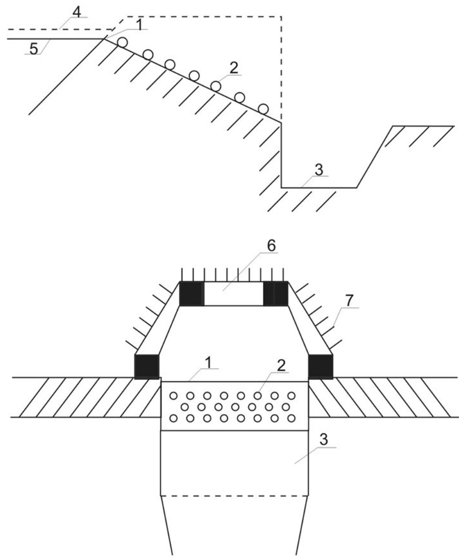


Figure 1.4: Front safety overflow (Andreji, 1996 – edited): 1 – overflowing level, 2 – slide, 3 – under-dam pit, 4 – maximum level, 5 – normal, 6 – service bench, 7 – bar screen

Main draining ditch – this enables thorough drainage and drying of the pond bottom, and during the phase of **drainage**, it leads fish into the fishing pit, and keeps them there. It is built as an open trapezium-shaped canal with a side ratio of at least 1:2, with an outfall into the fishing pit approximately 0.2 m above its bottom (Fig. 1.5). The size of the main ditch depends on the size of the pond, although its minimum depth should be of 0.5 m and width of 1.0 m. Concerning flowing reservoirs, this is composed of the original flow bottom. In case of bigger and indented ponds, there is also one or more **side draining ditches**, apart from the main one. By their shape and size, they correspond with the main ditch, which they flow into under rather an acute angle.

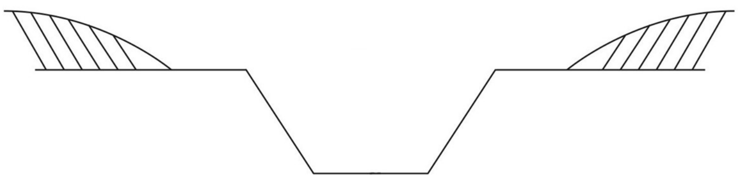


Figure 1.5: Main draining ditch (Andreji, 1996 – edited)

Fishing pit – this is built on the lowest point of the pond directly near the outlet facility (Fig. 1.6). During the phase of drainage, fish are gathered there and fishing is implemented. This facility has a square or rectangular shape and its size and depth depends on the amount of fish. Generally, 100 kg of fish require water volume of 0.6 – 3.0 m^3. More accessible (fishing) side of the fishing pit is usually slanting and paved.

Vat – this is the reinforced space near the fishing pit, which tubs, scales and all the other tools necessary for fishing are placed onto. Moreover, sorting, weighing and loading processes of the fished out fish take place there. It is built along the more accessible side of the fishing pit, and above it. It is usually paved or reinforced by panels with a gentle slope towards the fishing pit. In deeper ponds, there is a so called „**releasing bench**" built on the side heading to water. According to the disposition, we distinguish among these types of vats: **placed perpendicularly to the dam, placed along the dam,** and **transit tub place.** There are stairs leading from the tub place into the crown of the dam built.

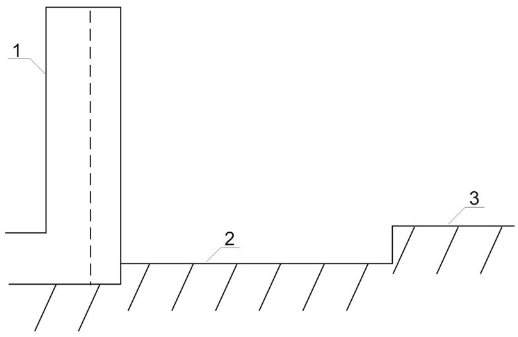


Figure 1.6: Fishing pit (Andreji, 1996 – edited): 1 – outlet facility, 2 – fishing pit, 3 – main drainage ditch

The stairs enable workers to access the pond during the fishing pond phase. Newer and bigger ponds have a **slip** built into the tub place, which enables transporting the fished out fish by motor vehicles.

1.1.2 Classification of ponds

There are several types of ponds within pond management, which are different not only by its character and location in landscape, but also by its utilization. This classification serves as a tool for assessing their natural productivity, and it has an essential impact on choosing the optimum way of utilization, too.

Classification of ponds according to the location:

- **in the highlands** – ponds are located at higher altitude, have lower average annual water temperature, and shorter vegetation period, they are suitable for carp and other warm-water fish species farming,
- **lowland** – ponds are located at lower altitude, they have higher average annual water temperature, and shorter vegetation period, and they are suitable for carp and other warm-water fish species farming.

Classification of ponds according to the environment:

- **field** – they are the most productive due to the washed down nutrients from the surrounding environment,
- **forest** – they are less productive, they are often supplied with acid water,
- **meadow** – concerning the amount of nutrients and natural productivity, they lie between the field and forest ponds.

Classification of ponds according to the main farmed fish species:

- **carp** – they are located at lower altitude, the ponds are warmer, have nutrient-rich water, and soft pond bottom with a layer of mud,
- **trout** – they are located at mean and higher altitude, lack nutrients, have colder water and harder pond bottom, usually without organic sediments.

Classification of ponds according to the function:

- **irrigational** – they irrigate the nearby areas (fields, gardens, vineyards, etc.),
- **anti-fire** – they serve as a water source in case of fire,

- **sewage (biological)** – they help with cleaning and treating wastewater, mainly from food industry,
- **recreational** – the ponds are used for recreation, water sports, etc.,
- **sedimentation** – they retain particles of soil, sand or grit (gravel) washed down by torrential water. The retained sediments must be regularly removed from the pond.

Classification of ponds according to the way of the water supply:

- **sky –** these ponds are without a regular inflow of water. They are usually supplied only by snowfall and rainfall (that is the reason for the name sky), although in the period of drought, the water level is substantially decreased. The amount of inflowing water depends on the size of the basin, its character, and amount and distribution of precipitation throughout the year. Concerning the natural productiveness, these types of ponds are the most productive ones, because all the nutrients from the basin remain in water and could be used in the water cycle. They are used mainly in rearing the fry, because there is no risk of inflow of predatory fishes. However, these ponds are liable to overgrowing and becoming dirty, and are not suitable for wintering the fish,
- **head (spring)** – these are supplied by spring water, which rises either directly in the pond or nearby. Concerning the productivity viewpoint, they are the least productive ponds, because the spring water is usually rather very cold with a low level of oxygen and often high level of various minerals (mainly iron). They are usually deeper and have a harder bottom. The absence of fertilizing alluvium creates an environment which lacks nutrients and significantly limits farming of warm-water species. In certain conditions (under improved oxygen regime), it is possible to farm cold-water species. Moreover, supposing the water source has a steady temperature, these ponds could be used for wintering the fish,
- **flow-through** – they are supplied by a smaller permanent water source (a stream), which flows through the pond with all its capacity. These ponds are also considered to be less suitable concerning the amount of nutrients, because the flow rate causes the nutrients are washed away and the pond is overgrown and turbid. Increasing the natural productivity by soil improvement measures is highly limited because of the flow rate. It is possible that predatory and feeding fishes from the stream swim into such ponds, which is perceived as a disadvantage. Such ponds must be always equipped with a safety overflow and reliable outlet facility. In most cases, these are used as the main ponds,
- **diversion** – these are supplied by a water source (a stream or a river) by a supplying facility (diversion ditch), which enables to completely regulate the water inflow into the pond in accordance with the economic aim. Superfluous but mainly torrential water is drained along the pond by a suitably designed diversion ditch. Such pond is managed through the whole year exclusively by the farmer, and in case of a sufficient amount of water, it is possible to increase the production multiple times by complex soil improvement and intensifying measures. These ponds could be drained and refilled

any time, as well as repaired, and necessary soil improvement measures could be taken to increase their natural productiveness. They could be used for rearing all age categories of the carp as well as for wintering the fish.

Classification of ponds according to the economic utilization:

- **spawning** – these serve for reproduction (natural spawning) of brood fish. We distinguish between 2 types:
  - **spawning ponds used by the so called old Bohemian method** serve for mass spawning of brood fish and simultaneously for rearing the fry until its vegetative period. The ponds are shallow and productive with the size of 2 – 5 ha, usually overgrown with plants with an average depth of 0.4 – 0.5 m,
  - **small spawning ponds (Dubravius pond)** are used just for a short time for spawning of brood fish, incubation of eggs, and gaining carp fry. They are small and ground ponds with the size of 50 – 100 m^2, with bottom and banks covered with continuous grassy growth. The bottom slopes down towards the draining facility, and the depth ranges from 0.2 to 1.0 m. Along the perimeter of the bottom, there is a canal built that serves for fishing the brood fish out after the spawning. Small spawning ponds are used just for 10 days a year, and for the rest of the year, they are left without water and grass cover is maintained in them,
- **fingerling** – they serve for rearing the fry. There are two types:
  - **fingerling pre-pond (fingerling pond of the 1st Order) –** this is a 0.5 – 1.0 ha large and shallow pond with high natural productivity and an average water depth of around 0.5 m. In such ponds, fry is cultured for 4 – 6 weeks (until the stage of the advanced carp) after being fished out from small Dubravius spawning ponds. For the rest of the year, the ponds are drained out,
  - **fingerling pond (fry rearing pond of the 2nd Order)** – this pond is usually a bit larger and highly productive, its size is 2 – 5 ha with an average depth of 0.6 – 0.8 m. It serves for rearing the carp fry until the end of its first vegetation period,
- **rearing** – these serve for producing the two-year old fish (fish stock). These ponds have a medium-large size, not more than 5 – 10 ha, and with an average depth of 0.8 – 1.5 m,
- **main** – they serve for producing the consumable fish. These ponds have an average depth of 1.0 – 2.0 m, and their size is the largest, usually of 30 – 50 ha, but some ponds have the size of more than 100 ha,
- **wintering** – these are used for overwintering the fish. In comparison with the previous types, the wintering ponds are much deeper (at least 2 – 2.5 m) and have a harder bottom, contain lower levels of organic nutrients, and there is a rich water flow. The most common are **traditional** and **special** wintering ponds,

- **brood** – these ponds are used to maintain the brood fish after spawning. They are small with high natural productivity, and they are situated in the most favourable localities. Their duty is to secure a sufficient amount of natural nutrients, which ensure quick regeneration of the exhausted brood fish, and creation of new fine gonadal products for the subsequent period,
- **quarantine** – these ponds provide temporary isolation of sick or suspicious fish as well as of the ones imported from other localities. These are the classical although smaller ponds situated usually at the lower end of the farm with an individual inflow and outflow to eliminate the risk of introduction of water-borne diseases and parasites into other ponds,
- **storage** – these are small reservoirs of a rectangular shape used for maintaining the consumable fish in the period between pond fish fishing and distribution. These reservoirs have hardened banks and bottom, own inflow and outflow and depth of 2 m and more. Their size and number depend on the expected production of the consumable fish.

From the viewpoint of the usage of the individual pond types in a complex pond farm, the surface areas of the individual types should be following:

spawning ponds	0.5%
fingerling pre-ponds	2.5%
fingerling ponds	10.0%
rearing ponds	20 – 25%
main ponds	60 – 65%
wintering ponds	3.0%
storage ponds	1.0%

1.1.3 Pond bottom

Pond bottom is the main factor which influences the natural productivity of a pond. On one hand, it enriches the water by nutrients that are necessary for autotrophic organism (plants). On the other hand, if such released nutrients are not consumed, the bottom binds them again and if needed, it releases them into water again.

Binding and releasing (absorption) of the nutrients takes place in the higher layer of the pond mud, which is called **fine organic mud** in the productive ponds. Basically, the mud is a layer of colloid substances of mainly an organic origin. This is the place where decomposition processes as well as creation of organic compounds in the presence of decomposers (microorganisms) take place. If the nutrients were not absorbed by the mud, they would leak into the lower layers and get washed away. The stated processes occur only in the layer of mud which does not have an acid reaction.

The pond bottom consists of the following layers:

- **a layer of pond mud – the upper mud layer** (5 – 12 cm) has the biggest importance, and it is called "active mud". It contains a great amount of colloid particles which bind and release nutrients in the process of the biogeochemical cycle. The mud has a darker colour, because it contains more humus and there is benthos, too. This layer should cover the whole pond bottom, otherwise the natural productiveness (productivity) of the pond is decreased, and the nutrients added by fertilization leak into the lower layers. This layer is supported by fertilization by the organic fertilizers. Under this layer, there is one more layer – **the bottom mud layer –** of a lighter colour, which is less active in the process of the biogeochemical cycle, and it serves as a source of nutrients. It becomes active after the wintering or summer drying of pond, when the bottom is repaired. The layer of the pond mud should not exceed 30 cm. When the layer is thicker, the pond is considered to be muddy, and the mud must be removed,
- **a layer of a permeable base –** this is the original soil layer which the pond was built on. Usually it has a lighter colour and contains sources of nutrients which could be made accessible for the nutrient cycle, if suitable amelioration measures are taken. The thickness of this layer should not surpass 60 cm,
- **a layer of an impermeable base –** the main duty of this layer is to impound water in the pond. If there is no such layer somewhere in the pond, water starts to leak and thus, demands on the inflow capacity are increased. On the other hand however, the natural productivity of such pond is decreased (nutrients are washed away). If the water source is weaker, the pond may not be supplied to the desired operating level.

1.2 Essence of the pond production

Depending on the intensity of farming, production of fish in ponds is reliant on natural nutrients and provided alternative feed material. The natural food is composed mainly of zooplankton and zoobenthos and to a smaller extent also of phytoplankton, algae and higher aquatic plants (macrovegetation). In semi-intensive farms, mainly feeding cereals or legumes are used as supplementary feed; in intensive farms, there are mainly the feeding mixtures used. Right in these farms, the amount of natural food is very important for effective utilization of feed materials and overall production. Apart from this, the natural food considerably decreases the feed consumption, or rather the Food Conversion Ratio (FCR), which is a significant factor of the fish farming profitability, from the economic viewpoint.

1.2.1 Food chains

There are various mutual relations among populations of two and more species in an ecosystem. Concerning the relations, food ones are the most important, and they are expressed by made food chains, within which a transfer of nutrients (substances) and energy begins. This process consists of several segments, called trophic levels, and their number in the chain is usually limited to 4 – 5. All the organisms that gain food in the same way belong into the same trophic level of the food chain.

Three fundamental types of food chains are distinguished in an ecosystem:

1. **Grazing-predator food chain –** this food chain starts with plants and heads towards herbivores and predators.

algae → cladocerans → planktotrophic fishes → predatory fishes → human

In this food chain, the individual body size of the organisms becomes gradually larger by the trophic levels, although the density of their population is decreased.

2. **Parasitic food chain –** this food chain heads from the host to the parasite, i.e. hyperparasite (a parasite of the other parasite).

fish → leech

Although in this food chain the size of the individual organisms becomes smaller, their amount becomes larger.

3. **Decomposition food chain –** this heads from the necrotic organisms via necrophagi and saprophagi, towards the microorganisms that decompose simpler organic compounds into inorganic ones.

necrotic organism → flatworms → fungus → bacteria

In this food chain, the body size of the individuals becomes smaller, while their amount becomes larger.

1.2.2 Nutrient cycle

The individual food chains are not isolated from one another in an ecosystem, but they are mutually interconnected. Therefore, they create a food network which ensures the nutrient cycle and the energy flow in the given ecosystem.

The nutrient cycle is one of the fundamental features of an ecosystem. It is mainly the cycle of biogenic elements that are getting built into organic compounds from inorganic ones by photosynthesis or chemosynthesis of the producers (green plants, autotrophic bacteria).

The produced plant matter then gets partly into the grazing-predator food chain, in which it becomes the food for consumers (zooplankton, herbivorous fishes), and partly into the detritus food chain, where it is consumed by bacteria. The food which has been taken in must be firstly decomposed into simpler organic compounds in the bodies of animals. Such compounds are used as a source of energy after being absorbed. Only the surplus substances are used by the organism to grow. Thus, the organic matter is used at all trophic levels. At the end, the whole organic matter created at all trophic levels ends in the decomposing food chain.

Speed of the nutrient cycle and the energy flow in an ecosystem depends on the speed of the decomposing processes, because at the end, every organic matter must be decomposed into simple inorganic substances to return back to the nutrient cycle later.

1.2.3 Energy flow

The energy flow is one of the fundamental features of every ecosystem. In contrast to the nutrient cycle, the energy flow is always simplex, because the transfer and transformation of energy are conducted by two fundamental thermodynamic laws:

1. **Law of conservation of energy** states that all ecosystems depend on the energy supply from the outer environment, mainly from the sun. By the transformation of energy, the form changes but the total amount stays the same. The energy is neither created nor destroyed.
2. **Law of energy transformation** states that during every energy transformation from one form into another, there is some energy lost into the environment in a form of heat.

The sun energy is transformed by green plants into organic matter which becomes the energy source for all segments of a food chain. When moving from one segment to another, some energy gets lost into the environment in a form of heat (so called respiratory losses). At the end of the decomposing processes and after mineralization, all energy transformed in the beginning by the plants is released again.

As the amount of the fixed energy is being decreased, production of the individual segments of a food chain becomes lower, too, i.e. when creating new organic matter (biomass), the organism uses 90% of the taken food (energy) for ensuring its basic vital functions (respiration, digestion, excretion etc.) and only the remaining 10% is used for creating new organic matter (growth, reproduction). It is these 10% of energy which are also usable in further segment of a food chain and transformed by the same rules.

When researched deeper, we find out that according to the above mentioned scheme, less than 1% of the original energy fixed by plants reaches the fourth section of a food chain. That is also why the food chains have only four or five sections. In a theoretical way it means that from 1,000 kg of phytoplankton, 100 kg of zooplankton could be produced, and from such, 10 kg of the carp could be produced. From 10 kg of the carp, there could be 1 kg of the pike produced and if a human consumes this kilogram, he could theoretically put on 0.1 kg.

Therefore, it is economically more efficient to use the lower segments of a food chain than the upper ones. Concerning fish farming, e.g. the three-sectional food chain of the carp ponds is suitable: phytoplankton – zooplankton and zoobenthos – carp. Higher usage of energy will be reached by combined farming of the carp and silver carp, which feeds on phytoplankton and together with zooplankton and zoobenthos, it lies at the second trophic level.

Besides the nutrient cycle and energy flow, accumulation of several toxic substances as pesticides, heavy metals, radioactive substances, etc. takes place in food chains, too. These substances are accumulated mainly at the end of a food chain (non-predatory fish, predatory fish, human).

1.2.4 Biological productivity and production

Productivity – this is an ability of organisms to produce organic matter. It provides a total overview of the processes taking place in a water environment, energy flow and nutrient cycle.

Production – this represents the real amount of the produced organic matter in a certain period per unit of surface or volume. This is the real result gained from a water body (e.g. when we farm certain number of fish in a pond, but we fish out just some of them – some fish die, some are killed by water birds, some swim away, etc.). The production value is lower than the productivity value.

We distinguish between two types of production:

1. **Primary production** – it means that the organic matter is created by photosynthesis of green plants or by chemosynthesis of autotrophic bacteria. The primary production could be divided into gross primary production, which is the total organic matter created by producers, and net primary production, which is the value gained when metabolic losses of producers (respiration, excretion) are subtracted from the gross primary production. This net primary production is the biomass which is usable for further sections of a food chain. Although there have been several methods developed to measure the primary production, the ones used the most are chlorophyll, and oxygen methods. The gained data on the gross primary production could be used for considering fertilization, while the data on respiration could serve for predicting oxygen deficiency.
2. **Secondary production** – this represents the growth of organic mass in bodies of all consumers. The growth itself depends on the amount of substances produced at the lower level of a food chain. Unlike the primary production, we could not perceive the secondary production as a whole. The secondary production is set only for a certain population of one species (production of carp, production of trout, etc.) The produced biomass is then the source of production for the next food chain level.

1.3 Methods of pond farming

Methods are determined both by demands on weight per piece of the final product (carp) and the level of farming intensity. These two demands indirectly define the total period of the carp farming – so called **"crop rotation"**. In our conditions, the rotation usually takes three years, less frequent is a two-year or four-year rotation. Concerning farming and economic viewpoint, the shorter the crop rotation, the better. However, the final decision is made by the market demand on size and weight of the marketable carp as the main farmed fish in our area.

1.3.1 Labelling the farmed fish

Formerly, the labelling was based on weight per piece, while nowadays, the age, i.e. the number of vegetation (growth) periods of the farmed fish is taken into consideration. For labelling the farmed fish, the capital initial of the Slovak name of the fish species with a small number (index on the bottom of the letter), which expresses the number of the vegetation periods, are used, e.g. K_1, K_2 (one-year-old carp, two-years-old carp), $Š_1$ (one-year-old pike), L_2 (two-years-old tench), etc. If there are more species with the same name, e.g. the brown trout and the rainbow trout, the capital initial of the name of the family is used, followed by small initial of the name of the species with an index number (Pp_1 – one-year-old brown trout, Pd_2 – two-years-old rainbow trout). If the family names start with the same letter, e.g. trout and grayling, in Slovak lieň a lipeň, L and L, or if the graphical representation of the labels look similar – e.g. pike and catfish, in Slovak šťuka and sumec, Š and S – first two letters from the name of the family and species will be used, while the first one will be capital and the second one will be small, with added number in a lower index (e.g. Li_1 one-year-old grayling, Su_2 – two-years-old catfish, etc.). If there are fish which have not lived longer than one vegetation period yet, we use the following labelling – Zu_i – eggs (eggs) of pikeperch, $Š_0$ – pike fry, Pd_k – fed fry of rainbow trout, K_r – forced carp fry, etc.

For the carp, the main farmed fish within pond management, we use the following labelling:

- K_0 – carp sac fry,
- K_r – forced carp fry,
- K_1 – fingerling (after the first vegetation period),
- K_2 – two-years-old carp (after two vegetation periods),
- K_3 (K_t) – three-years-old carp, i.e. marketable carp,
- K_4 (K_v) – four-years-old carp, i.e. selection carp,
- K_{gen} – brood carp.

Similar labelling and names of the categories are used also for other farmed fish species within both pond management and trout culture. The only exceptions are the one-year categories of the Salmonidae, Thymallidae, Coregonidae and predatory fishes. These categories are not called fry but one-year-olds.

1.3.2 Intensity of fish farming

Achieved production within a certain pond is not constant and it could range rather widely. The final value is influenced by the amount and structure of the farmed fish during a certain year and to a lesser extent also by the climate, and the health condition of the fish. Therefore, it is necessary to consider not only the economic criteria but also the water management and recreational conditions for the right choice of the intensity of farming, because these criteria considerably determine the maximum permissible level of the farming intensification.

According to the pond farming intensity, we distinguish the following levels:

- **extensive –** multipurpose ponds are used, in which the fish farming is subordinate to water management or recreational usage. Fish production is based solely on the natural food, and using polycultural fish stock without supplemental feeding and fertilization, or of just little doses. The value of the achieved production ranges between 0.1 and 0.5 $t.ha^{-1}$,
- **semi-intensive –** this is the most used level of farming in our area. The fish production is based on supplemental feeding mainly by cereals, and on raising the natural food by fertilizers. The fish stock is polycultural, serve for a certain purpose, and is determined by the natural production raised by the production gained by fertilization, as well as by supplemental feeding. The value of the achieved production ranges between 0.5 and 1.5 $t.ha^{-1}$,
- **intensive –** this method is used less in Slovakia, because it is based on using pelletized feeding mixtures. The level of fertilization could be higher than at the semi-intensive level. Using cereals is limited to the spring and autumn period of great zooplankton. Development of natural food is influenced mainly by the economic interventions. The value of the achieved production ranges between 1.5 and 3.0 $t.ha^{-1}$,
- **industrial fish farming** – special cultural units with greater fish stock (density of fish) are used in this method. The production is secured by great monocultural fish stock and intensive supplemental feeding by adequate feeding mixtures. Since this kind of production is at rather high level, using mechanization and automation, and regulating the water regime become necessary. Reached production is very high and achieves up to 20 $t.ha^{-1}$. However, at present, this method is not used concerning economic reasons.

2 Carp culture

The common carp is the oldest farmed fish in the world. The first records of its farming come from China and date back to the year 2,300 BC. In Japan, the records are more than 1,900 years old. Concerning the Central European area, the first record of the carp farming comes from the 11^{th} or the 12^{th} century from the area of the today's Czech Republic. In Slovakia, the carp farming has been known since the 11^{th} century.

Nowadays, the common carp is the main farmed fish in Slovakia, which is produced within pond management, while its share is more than 95%. According to the data of The Statistical Office of the Slovak Republic, around 600 tonnes of carp are produced annually, which equals approximately 30% of the total Slovak aquaculture production. Moreover, the carp is also the species fished out the most by recreational fishermen. The catches equal annually around 1,200 tonnes, which represent almost 70% of all the catches of recreational fishermen. Despite this fact, Slovakia is not self-sufficient in the common carp production and Therefore, more than two thirds of the consumed carp are imported from abroad, mainly from the Czech Republic and Hungary.

2.1 Origin and distribution of the carp

The ancestor of today's carp lived in a continuous area of the Caspian region at the end of the Pleistocene. This area was most likely broken into western and eastern part during ice age and thus the carp started to move to the west, to the waters of the Black Sea, and also to the east, to the waters of the Aral Sea and eastern Asia. Therefore, it is possible to distinguish among 4 – 5 geographical areas, in which the carp is endemic and creates subspecies – *Cyprinus carpio carpio* (Linnaeus, 1758), and *Cyprinus carpio haematopterus* (Martens, 1876). The carp appeared in the Danube before 8,000 – 10,000 years. Concerning Central and Western Europe, the carp is the indigenous fish only in the Danube and some of its tributaries, while the river Morava was the western border of its habitat. Only after beginning of pond farming, the carp moved into other rivers of this area, too.

The name "carp" is common for Romance, Germanic and North Slavic nations, and it points to the habitat of the carp ancestor. Aristotle mentioned the carp for the first time in the 4^{th} century BC, later Pliny in the 1^{st} century AD. Nowadays, the common carp lives almost in whole Europe, except for several Nordic countries. Roman legionaries contributed to such phenomenon, since they fished the carp during their presence in the Danubian region, and they transported it from one place to another while conquering. After the fall of the Roman Empire and the expansion of Christianity, the carp was distributed further to Western Europe. The first written records of the carp from England come from the 15th century. Further carp expansion occurred after the development of seafaring and overseas trade, when the carp got beyond the borders of Europe. That is why the carp lives on all the continents nowadays except for Antarctica.

Our common carp comes from the Caspian region, and it has been domesticated from the indigenous wild carp known as "**sazan**". This could be found also nowadays in the Danube, and river Tisa, and in the lower parts of the greater tributaries (the rivers Bodrog, Ipeľ, Hron, Váh, and Morava), however, quite rarely. It is an endangered species. Usually it has a sturdy torpedo-shaped body of almost circular cross-section, which is just very slightly flattened on the sides. Massive head smoothly continues to the back, the mouth is large and strong, and so are fins. During the process of domestication, several morphological and physiological changes occurred and resulted in a distinctive form of the common carp with a relatively small head, shorter but higher body, and smaller fins. In the further domestication or rather rearing, various news forms, breeds, and lineages of the carp have been created.

2.2 Characteristics of the carp

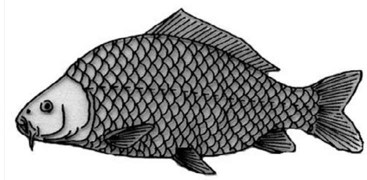
The body of the carp is perfectly adjusted by its shape to the environment which it lives in. In ponds, there live carps with a high back, which creates a so called "hump" just behind the head, while in the flowing water bodies or in the environment with less nutrients, carps have a rather elongated shape.

The body is covered with and protected by big round scales. However, some carps lack such scales completely or at some spots. This deviation from the standard scale cover with larger or smaller reduction of the number of scales is perceived as mutation, stabilized by subsequent selection.

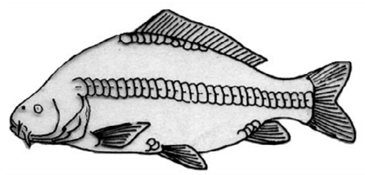
The scale cover of the carp is determined by two genes – **the S gene,** which is in its dominant form responsible for the full scale cover of the body, and **the N gene,** which causes reduction of scales, while in its dominant form. By the mutual combination of the genes, various genotypes come to existence, which are displayed in the phenotype (in an external form) by the above mentioned types of scale cover – **the scaly carp** has the genotype SSnn or Ssnn, **the leather carp** has the genotype NNss or Nnss, **the line carp** has the genotype SSNN, SsNN, SSNn, SsNn, and **the mirror carp** has the genotype ssnn.

Based on the scale cover, we distinguish between **four basic types of the carp:**

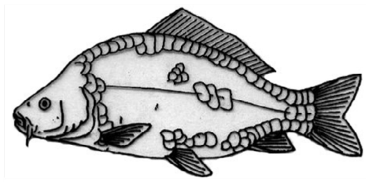
- **scaly carp** has the whole body, except for the head and fins, covered with regular and arranged rows of scales. This species is very hardy and viable,



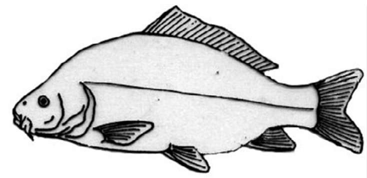
- **line carp** has one continuous row of rather regular scales which skirt the lateral line from head to caudal fin. There is often another row of scale present at the sides of the dorsal fin, and at the base of other fins,



- **mirror carp** has the body, where there are almost no scales, the continual row is seen only in the dorsal area from head to caudal fin. Other clumps of scales are present at the base of even fins, and mainly on the tail. Some other could be scattered along other parts of the body, too,



- **leather carp** has almost no scales on the body, or there are just some scales at the base of fins.



Extreme scale reduction is considered to be a degenerative phenomenon, which:

- **affects the viability of the offspring in a negative way –** both line and leather carp have a lethal factor in their hereditary characteristics, which causes weaker viability. In crossrearing, up to 25% of the offspring dies already in the embryonic stage because of this factor,
- **worsens growth** and weakens the regenerative ability of an organism – because of this factor, the mirror, line, and leather carp lag behind the scaly carp by 12 – 20%,
- the presence of the N gene **decreases the amount of haemoglobin in blood** – this is the reason why the carp with reduced scale cover is less resistant to to lower oxygen content and temperature changes of the water,
- reduction of scale cover is related also to development of **morphological anomalies** of fins, branchial apparatus, and pharyngeal teeth.

By its low demands on the environment, the carp belongs to highly tolerant and adaptable fishes. It lives mainly in fresh water but can also survive in brackish water with content of salts up to 10%. Still water is the most suitable, together with gently flowing shallow reservoirs of an eutrophic character with water plants and soft muddy bottom. The carp is a warm-water fish and Therefore, the normal course of all the vital functions depends mainly on the water temperature and amount of oxygen in the water. The temperature of 20 – 30 °C suits it the best. It can also endure extreme water temperature of tropical climate (around 35 °C), as well as continental winter (around 1 °C). Therefore, the carp is one of the most common fresh water fishes living on all continents. However, sudden changes of temperature harm the carp, and especially the carp fry is highly sensitive to temperature at the beginning of its development.

The water temperature decrease or increase by 1.5 – 3 °C may cause serious health issues. A thermal shock may cause paralysis, spasms of respiratory system, and heart problems. Moreover, all of these can lead to its death.

The carp is not highly demanding on the oxygen amount in the water, and 4 – 5 mg.l^{-1} of O_2 is enough for it. However, the carp fingerling demands higher content (6 – 7 mg.l^{-1} of O_2) concerning its specific needs. It is necessary to have in mind that oxygen consumption level rises with the water temperature, activeness of the fish, food intake and food processing. Lack of oxygen worsens metabolism, growth and can endanger also the process of reproduction. Great decrease in the oxygen content may cause various issues and end in massive mortality. Gradual appearance of the carp near the water surface (blowing), and gathering of the fish near an inflow are the accompanying phenomena of suffocating of the carp. During such, breathing of fish speeds up, fish are turning pale, and their gills are turning blue and red. If the oxygen deficiency continues, the carp loses physiological position and starts to swim sideways and later upside down, too. Fish may be suffocating and dying even for several hours or days sometimes.

The carp is capable of growing very fast. However, the growth intensity depends on hereditary characteristics, water temperature and amount of food. Closer the water temperature to the demanded optimum and higher the nutritional value of the food, faster the growth. The increment of the carp in a pond depends both on the average water temperature and the number of days with the temperature over 20 °C. The carp is a warm-water fish and Therefore, its growth potential could not be fully displayed in less favourable conditions (under 20 °C). In countries with favourable climate, the carp grows all year long. If there is enough food, it can grow by 1 kg or more per year. In our climatic conditions, when the water temperature is 14 – 12 °C, the carp consumes less food, although the fingerling (K_1) consume food also when the temperature is 4 – 5 °C. The water temperature influences not only the intensity of the food intake but also the synthesis in the body of an organism, since when the temperature is below 14 °C, mainly fats are being created from the food. This occurs mainly in the autumn season, when an organism creates necessary fat reserves for having energy during winter. In the pond conditions, this fact is purposefully used in setting the feeding doses with elements of mainly a saccharide character (fat-producing, better preparation of fish for wintering, important especially for the fingerling).

When the temperature falls in autumn, the carp moves to deeper places in a pond, where it spends the winter. In this period, metabolism is lowered to minimum, growth is stopped and the carp loses weight (5 – 15%). Energy for the necessary functions of an organism is used from the reserve substances gathered in the body during the whole vegetation period. With regard to the shorter vegetation period, the carp in our conditions reaches during the growing period up to 15 – 50 g (60 – 120 mm) in the first year, 300 – 600 g (200 – 300 mm) in the second year, and 1,500 – 2,000 g (350 – 500 mm) in the third year.

Concerning the character of the sought and consumed food, we may consider the carp to be a non-predatory omnivorous species. It feeds only on invertebrates – mainly on plankton and benthos.

Moreover, it is able to consume and digest vegetable feed (seeds), too. Appearance of soil elements (mud, sand) as well as of plants (parts of leaves, stems and stalks) in digestive system of the fish should be perceived as food ballast which could not be efficiently digested. It usually consists of components consumed by accident during consuming benthos.

The carp is a freshwater phytophilous fish that does not protect its offspring. In conditions of the temperate climate zone, the carp reproduces once a year. Its sexual maturity depends on temperature and food conditions. Males mature usually between the 2nd and the 3rd year, females between the 3rd and the 4th. The right food and thus faster growth have a positive impact on their sexual maturity, and they mature earlier. In our conditions, the carp is fertile approximately for 16 – 18 years, but in practice, fish in the age of 5 – 8 years are used and are subsequently removed from farming. Senile sterility appears around the 20th year of its life.

The reproduction of the carp takes place in the period when the day water temperature is stabilized at 17 – 20 °C and at night it does not fall below 14 – 15 °C. Typical changes in the behavior of the brood fish are the sign of the upcoming spawning of the carp. Disinterest in the offered feed is seen in ponds, together with constant swimming around the banks, and stable reproduction groups of 3 – 5 members are gradually created. The carp is a typical phytophilous species that spawns on the overgrown littoral banks on water or freshly swamped terrestrial plants. Demand on the spawning substrate is especially distinctive concerning this species. When the brood fish are set for spawning into the environment that lacks oxygen dissolved in the water (below 5 $mg.l^{-1}$ of O_2) or there is rather an acid reaction of water (pH below 6.5), the reproduction does not take place. Concerning the carp species, there is no significant sexual dimorphism developed and thus, it is difficult to distinguish the sexes beyond the period of spawning. In the pre-spawning period, gravid females have an enlarged belly parts and their urogenital papilla is swollen, pinkish and round. On the other hand, sexually active males are slimmer as the sperm starts to be released by pressing on the carp's abdominal cavity since April. Furthermore, during the period of spawning, the male carps usually have slight spawning tubercles on their heads.

The carp is a typical sociable fish living in a shoal. This biological particularity is seen also during the spawning period as this phenomenon always takes place within numerous groups. The absolute fertility is high and the sexually active female could weigh up to 5 – 10 kg, and have 1 – 2 million of eggs. Therefore, it is practical to state rather the relative fertility, which is 100,000 – 200,000 eggs per 1 kg of the female carp weight. Transparent eggs of a yellowish-brow colour are 1.0 – 1.5 mm big and when they come into contact with water, they become sticky, and get filled with water. Unfertilized eggs die, turn white, and become mouldy. The sperm volume gained during the artificial stripping ranges between 5 and 70 ml, the amount of sperms in 1 mm^3 ranges between 8 and 28.10^6, and their motility lasts for just 1.5 – 2 minutes. Fertility of males influences not only their age, but also their health condition, and hormonal stimulation. Concerning the specific characteristics of the gonadal products of fish, the possibility of fertilization is limited in time, and concerning the carp, it lasts 1 – 1.5 minute. Fertilized eggs stick to plant surface, which the incubation takes place on, too. Development of eggs happens when the temperature is from 14 to 25 °C. When the temperature falls below this range, embryos in eggs die, and when the temperature is higher, disorders in the development occur.

Embryonic development (period) begins with the fertilization of eggs and ends when the embryo (the fry) begins to swim. This is the primary development which depends mainly on the water temperature. With the rising temperature, the length of incubation shortens. Fry with a size of 5 – 6 mm is hatched from the eggs, which feeds in an endogenic way – on nutrients from the yolk sac. During the first two days after being hatched, the fry is hanging from solid surface (grass stems, small branches etc.) by adhesive papillae grown for a temporary period on its head.

When the gas bladder is filled with gas, and the fry starts to feed on mixed food, **a larval period** starts, during which the larva gradually switches to solely exogenous food, and organs of its body develop, too. After 14 days, when the fry is 15 – 18 mm long, scales become developed gradually from the head, and after 21 days, the fry resembles the adult fish. At the end of this period, the digestive, respiratory, and excretory system is fully functional, as well as the locomotor system.

In **juvenile period**, the qualitative growth is accomplished and intensive growth of a whole body begins (the forced carp fry). This period ends with completing the sexual maturity.

Adult period is the productive stage of life, during which the growth slows down because a great part of energy taken from food is used for creating gonadal products. It is characterised by intensive reproduction and ends with signs of aging.

Senior period is basically the old age of fish, which is characterised by gradual termination of sexual activity (reproduction), weakening of the organism and death.

The food composition is influenced by the size of the carp. Already, when only a part of the yolk sac is consumed, the fry starts to feed on *Rotatoria* species. Later on, it feeds on zooplankton (*Cladocera*, *Copepoda*), and when it is just 15 – 20 mm big, it feeds on smaller benthos (larvae of *Chironomidae*), too. If there is not sufficient amount of suitable animal food (zooplankton), the fry may alternatively feed also on phytoplankton (algae). In this case, it grows slower.

Concerning the adult fish, the food structure depends greatly on seasonal occurrence of the individual species of invertebrates. Moreover, the fish always prefer easily available and abundant food. The water temperature influences the food activity, and when the temperature is decreased, the fish loses its digestive ability. However, when the temperature rises from 10 °C to 25 °C, the digestion period shortens by half. The time in which the food is processed by the digestive system does not depend only on the water temperature, but also on the type of the consumed food, and the extent to which the digestive system is full. Greater amount of the consumed food is processed worse than smaller doses. The carp could starve for rather a long period while still maintaining the ability to grow further.

Since the carp has quite low demands on the environment, grows fast, is highly fertile, has the ability to use the natural food as well as the artificial feed very well, and its meal as a high consumable value, this species achieved a dominant position in the pond management.

Besides classical pond carp forms, there are also colourful forms existing which are reared in small decorative ponds and reservoirs. In Japan, which is the country of their origin, they are called "**nishikigoi**". From this term, the name "**koi**", which is commonly used nowadays, was created. Breeders distinguish several colour variants, from only one colour to five-colour ones.

2.3 Reproduction

The carp can reproduce either naturally (by natural spawning) or by artificial stripping. Natural spawning is a form of fish reproduction in its natural environment without direct human intervention. However, the artificial stripping is the reproduction form in controlled conditions, and it often takes place in a hatchery with complete human assistance. Mass spawning (the old Bohemian method) and group spawning (the method of Jan Dubravius) belong among the natural forms of reproduction. These methods are the oldest ones, and they were still highly implemented in the 2nd half of the 20th century. When the artificial stripping was introduced as a new method for the carp reproduction in the seventies, gradual decline in the natural ways of reproduction began, and Therefore, we can see them only sporadically nowadays.

2.3.1 Mass spawning (the old Bohemian method)

The mass spawning is the oldest method of the carp reproduction, which dates back to the 12th – 13th century. The natural spawning of the chosen group (6 – 12 pcs.ha^{-1}, ratio of sexes being 1:2 in favour of the sexually active males) of the brood fish in a suitable spawning pond (rather shallow, productive, with the size to 5 ha, and sufficient amount of soft water plants) is the main principle, together with the subsequent rearing of the brood fish and fingerling for the whole vegetation period. Nowadays, this reproduction method is the least implemented one.

Advantages:

- technological simplicity,
- low initial costs
- reliability of the spawning

Disadvantages:

- low rate of fertilization of eggs (60 – 70%),
- unknown amount of the hatched fry,
- uneven maturing of the carp females and unevenness of the offspring concerning size at the end of the vegetation period,

- lower increments – necessity of supplemental feeding or regulative fishing of some fish and their transfer into a different pond,
- imprecise genetic origin,
- more frequent replacement of brood fish due to a reduction in their rearing value in a food-deprived environment.

2.3.2 Group spawning (the method of Jan Dubravius)

This method is also rather old and its foundations were laid by Jan Dubravius in the 16th century. It is used almost in its original and unchanged version still nowadays. In the group spawning, the natural spawning is implemented, although of only the chosen pair (1♀ and 2♂), or of a small group (2♀ and 4♂) in a small, so called „**Dubravius**“ pond (50 – 150 m^2). After this, the brood fish are taken away, and only incubation of eggs and the initial development of the fry take place in the small pond.

Spawning in small grassy ponds, which are filled with water and the brood fish are set into them just before their reproduction, is the principle of this method. The grass cover is maintained all year long by regular mowing. Shorter and medium-tall grasses are the most suitable, since they produce offsets very easily, create thick vegetation, and are able to bear also the short-term flooding. The spawning ponds have a rectangular shape, and there are usually more of them placed below a bigger pond, from which they are supplied by water. This pond is called "**preheating**" – it is shallow and serves for heating the water, and it could not be filled with fish to eliminate the risk of transmission of parasites onto the fry. Besides the spawning ponds, the small ponds are supplied also by the "**handling pond**", in which the brood fish are placed in their pre-spawning period. All these ponds create a so called "**Dubravius spawning system**".

The technological process within the group spawning begins with fishing in wintering ponds in spring and sorting out the brood fish according to their sex. Moreover, sick and hurt individuals are taken away, together with those in bad condition. We handle the brood carps with great caution to prevent injuries.

Then we transport the sorted out brood carps into the spawning system and set them to the handling ponds separately by their sex and various level of readiness to spawn. These ponds could be drained very easily and their area is 1,000 – 2,000 m^2, there is little water vegetation growing in them, and they are supplied with water from the preheating pond. This eliminates the undesirable temperature fluctuation. We stock the fish separately by their sex, although still in one pond. There are two parts created by dividing the pond by a net (bars, mesh). Mutual contact of the sexes thus positively influences the earlier gonad maturation stage.

When the first signs of the incoming spawning in the behaviour of the brood fish are spotted (disinterest in the offered feed, swimming around the banks, gathering near the net dividing the sexes, etc.), such fish are fished out and put into Dubravius spawning ponds under stable weather conditions. The ponds are filled in the morning and only in the afternoon, the brood fish are put into. If the temperature changes unexpectedly, we do not stock in the carps for spawning, since sudden fall in temperature extends the incubation period and massive losses occur.

The spawning takes place early in the morning on the second day after the fish were put into the ponds, and we cannot disturb the fish during reproduction. After the spawning, we raise the water level approximately by 10 cm to cover also the eggs stuck to plants above the water level. Carps usually gather near the bottom of the peripheral canals in this period, from which they are fished out in the evening when the water level is lower. Eggs are not threatened if left above the water level only for a short period. However, they cannot be exposed to sunlight.

The carp fry hatches rather imperfect. Neither fin system, nor digestive system including oral cavity is developed yet. Thus, consuming food from the outer environment is impossible. Moreover, the fry does not have the gas bladder yet. Right after hatching, the fry sticks to plants or other surface by secretion produced by glutinous glands on its head, and it stays in this position immovable for 2 – 3 days. When there is no suitable surface for the fry to stick to, it falls to the bottom and dies. This period when the fry is hanging down is necessary, because both anatomical and physiological development is being completed. In this time, the fry feeds on the nutrients gained from the yolk sac (the period of endogenic diet). When around two thirds of the yolk sac are consumed, the fry starts to swim and look for food (the period of mixed, and later of exogenous diet). It is this moment, when it is being fished out from Dubravius ponds by soft shallow hand-nets (so called Třeboň´s spoon net) from the water surface.

However, sometimes the set brood fish do not reproduce in 48 hour period after being set into the pond. Such fish must be then taken away and placed again into handling ponds. The pond is drained to the water level of the peripheral canals and when the fish are fished out, the grass cover is cleaned from sediments. Only after this cleaning process, whole water volume is drained from the pond and the pond is left to dry. After two or three days, it is possible to use the pond for spawning again.

Advantages:

- higher rate of fertilization of eggs (70 – 90%),
- possibility of selection and precise genetic origin,
- optimization of conditions for spawning and incubation of eggs,
- possibility of regulated rearing.

Disadvantages:

- costs of constructing the spawning system.

2.3.3 Artificial stripping

The artificial stripping is the latest method, and it has a dominant position within the carp reproduction nowadays in our area. It has been used since the seventies. Gaining the gonadal products, artificial fertilization, and creating optimum conditions for subsequent incubation and initial development, are the principles of the method.

The technological process starts already in spring when wintering ponds are fished out. The sorted out fish (healthy, unhurt, in good condition) are put into the handling ponds separately according to their sexes in number of around 25 pcs per 0.1 ha, in which they remain until the phase of planned reproduction. Before the stripping itself, the brood fish are hormonally stimulated by carp pituitary gland, products based on the carp pituitary (Repro-Genol), or by synthetic preparations (Ovopel, Dagin). The hormonal stimulation is implemented by injections, females get two doses, males one.

The stripping is implemented in hatchery under water temperature of 20 – 22 °C, after the anesthesia – usually clove oil or 2-phenoxyethanol. Firstly, the females start to strip. After drying the belly parts with a towel, we gently massage the sides of the fish from the head to the urogenital papillae, and gain eggs, which must be placed into dry plastic containers (bowls). If the female does not release eggs while being massaged, it means she does not reach the peak of her gonadal maturity yet, she is not ovulating. In such case, we place the female back into the the manipulation tank and repeat the stripping later. Sperm is gained in the same way. It is taken, sucked from the male, or could be directly extracted onto the eggs. From a single male, 5 – 70 ml of the sperm could be gained, according to his age, size, and gonadal maturity. The sperm could be stored in a fridge under the temperature of 2 – 8 °C for up to 200 hours. The gonadal products (eggs, sperm) are inactive. They become active when placed into water or fertilization solution.

After the artificial stripping, both sexes are placed into the manipulation tanks with clean water, where they recover from anesthesia. Later they are set into brood ponds, which must provide them with conditions for supplementary natural spawning – so called "**postspawning**". The fish are kept in these ponds until autumn´s pond fishing.

Fertilization of eggs is performed by adding the sperm into the containers filled with eggs (4 – 6 ml of sperm per 200 ml eggs) and their gentle mixing. Then water or the fertilization solution is added and the content is mixed very gently again. Subsequently, the containers are left to rest for 2 – 3 minutes. The fertilization rate of this method reaches 95% (when using fertilization solutions, the rate is increased to 99%). The fertilized eggs **absorb water** – their volume is increased and they reach the size of 1.8 – 2.3 mm on the average. Moreover, they **become sticky** – a sticky layer is created on their surface by which they get stuck onto plants. Therefore, in the artificial stripping method, we must remove the sticky layer from the eggs – "**unsticking**". If this was not implemented, they would stick to one another, which would then limit the optimum washing and oxygen intake, and the embryos would die.

The sticky layer is removed from the eggs by several ways:

- **Woynarovich method –** this is one of the first methods that started to be used in the fifties in Hungary. Chemical effect of the primary solution of urea and sodium chloride (30 g of urea + 45 g of NaCl in 10 l of water) on the eggs per 1 – 2 hours by constant stirring is the main principle of the method. After this, the primary solution is strained and the eggs are placed for 0.5 – 1 hour period into the solution of sodium chloride (60 g of NaCl per 10 l of water). Then, the solution is strained again and the eggs are placed into the last solution of urea (85 of g urea per 10 l of water), in which they are gently stirred for another 1 – 2 hours. Since this process is quite time-consuming (2.5 – 5 hours), it is not used nowadays,

- **modified Woynarovich method –** this method was implemented in the sixties in Romania. Similarly to the previous method, this one is based on the chemical effect of the primary solution of urea and sodium chloride (30 g of urea + 45 g of NaCl in 10 l of water) on the eggs per 1 – 2 hours by constant stirring. After some time, water is poured over the primary solution, and the eggs are flushed by clean water. Subsequently, the eggs are immersed for 8 – 10 seconds into tannin solution (15 g of tannin per 10 l of water). This kind of a short-term bath is repeated two or three times. Observing the stated time is very important in this method – otherwise proteins coagulate in the surface layer of the eggs, and cause complications during the incubation period (worsened exchange of gases, mainly oxygen) and hatching,
- **Hyaluronidase enzyme** – this method was used in the sixties in Russia. The eggs are unstuck by a generically unspecified enzyme of the sperm – hyaluronidase. The primary solution is gained by approximately two-hour infusing of the fresh minced testicles of a bull or a boar in a double volume of physiological saline solution. Before the use, the gained solution is diluted with water in a ratio of 1:5 – 10 and heated up to the temperature of 20 – 22 °C. The phase of unsticking takes 30 – 40 minutes,
- **magnesium silicate (steatite) –** this physical method of unsticking the eggs was developed in the half of the seventies in Russia. Grinding off the sticky layer of the eggs by suspension of steatite and sodium chloride (100 g of steatite + 10–15 g of NaCl per 10 l of water) under constant stirring for 30 – 35 minutes is the main principle of this method. After this time, it is necessary to flush the eggs perfectly,
- **cow's milk –** this method was developed in the half of the seventies in Russia, too. Either fresh diluted milk or powdered milk (100 – 150 g + 10 – 15 g of NaCl per 10 l of water) is used in this method for unsticking the eggs. The milk is diluted according to the fat content – at the fat level below 2% (reduced-fat), the milk is diluted in a ratio of 1 : 2 – 3, at the fat level of 3.5% (whole fat), the ratio is 1:5. The aim is to cover the sticky surface of the eggs with microscopic droplets of fat. Efficiency of this method depends directly on the fat content, and the period of unsticking is usually 30 – 40 minutes,
- **alcalase enzyme –** this is the latest method developed at the turn of the 21st century. In aquaculture, it is used mainly in unsticking the eggs of catfish and tench species (within experiments also in case of pikeperch). The concentration of the enzyme is 5 – 7.5 ml + 1 g of NaCl per 1 l of water for the tench, and 20 ml of the enzyme diluted in v 980 ml of the pond water for the catfish. The time of unsticking is shorter than 2 minutes in both cases.

Concerning the carp species, we use usually steatite or milk nowadays for unsticking the eggs. Low demands on time (short period of unsticking), availability, and the biological nature of the whole process are the advantages of these two methods. The issue of unsticking the eggs of the phytophilous fish species is still topical, while the main importance is laid on simplicity and shorter working process of the new methods.

The unstuck eggs are placed into incubation jars, where the **incubation** takes place under 18 – 22 °C. For the carp, Zugs (Weiss) and Chasse (McDonald) incubation jars with a volume of 5 – 7 litres are the most frequent. The incubation jars are filled up to one third or one half of their volume. The water supply is adjusted in a way to ensure the eggs float slowly, so they are completely washed, and the oxygen intake (at least of 5 $mg.l^{-1}$) is secured. The egg mortality rate during incubation usually does not exceed 20%.

Hatching begins at this temperature approximately after 3 days (60 °D). In the phase when the hatched fry appears among eggs (K_0), the water supply is increased, and the flow is stronger to ensure the little movable hatched fry is raised (washed) to the edge of the jar equipped with a so called collar. By its construction, the collar enables to collect the washed out fry with water into the reservoir (trough), or the fry is gently sucked out by a hose. The hatched fry has a size of 5 – 6 mm, and until it starts swimming (until it consumes around two thirds of the yolk sac), it is placed into hatching tray or special incubators. This is the place, where the development of the fry is accomplished and the yolk sac is consumed for another 2 – 3 days, according to the water temperature. During this phase, the fry is hanging from (it is stuck) either natural (grass stems, small branches, etc.) or synthetic (curtain material, nylon fabric, etc.) substrate. When swimming, the fry is fished out by shallow landing nets or it is sucked by a hose, and stock for further rearing into ponds.

Advantages:

- higher rate of fertilization of eggs (90 – 95%),
- better utilization of the gonadal products,
- implementing selection rearing aims (known genetic origin),
- optimization of the conditions for incubation of the fertilized eggs and the initial rearing of the fry.

Disadvantages:

- high demands on technical facilities and professional staff.

2.3.4 Controlled reproduction

With developing the artificial stripping as a dominant reproduction method of not only farmed and reared brood fish, but also of some other species fished out from nature, the controlled reproduction seems to be a highly necessary tool in contemporary commercial aquaculture. Its aim is to ensure enough fish stock for own needs, for restocking the free water bodies (fishing pit) with fish, and of course for the commercial sale to gain profit.

This method makes it possible to reproduce the majority of our fish species. On the other hand, we must emphasise that the regulated reproduction is not generally used for all the fish species farmed in aquaculture. These are the cases, when the costs of reproduction are higher than the profit from selling the offspring (e.g. when only a small amount of the fry is needed), or when the risk of losing the brood fish is higher than the potential profit from selling the offspring (e.g. of pikeperch). Furthermore, this method is not implemented in cases of some rheophilous species and secondary fish species (bream, roach, rudd, perch, etc.), when the natural reproduction is sufficient. However, controlled reproduction of the protected and endangered fish species (weatherfish, mudminnow, etc.) is seen as an exception.

The aim of the controlled reproduction is to time the artificial stripping biotechnologically, which is then implemented using usually a hormonal stimulant. This raises the level of gonadotropins (GTH–I a GTH–II) in blood, and so called **induction** starts – ovulation or spermiation is induced and its period is shortened. The induction is expressed in hourly degrees (h° – a sum of average water temperatures measured at hourly intervals).

Induction could be induced in two ways:

1. **By affecting pituitary gland –** the pituitary gland of fish (usually of the carp) is used, which is spread in physiological solution either in its fresh or conserved state. This mixture is then applied by injection into the brood fish (so called "**hypophysation**"). Apart from the classical pituitary gland, it is possible to use its calibrated or cleansed extract (CPE), too.
2. **By affecting hypothalamus** – super active gonadotropin-releasing hormone analogues (known also as gonadoliberin) are applied into the brood fish – GnRH (Ovopel, Ovaprim, Ovurelin, Dagin, Lecirelin, Kobarelin, Supergestran, etc.), which are applied with dopamine inhibitors (domperidone, pimozide, metoclopramide, reserpine, isofloxythepin, etc.) concerning the cyprinid species. This is called "**the Linpe method**". When having tench and other salmonids, the dopamine inhibitor is not needed.

In Slovakia, until recently, **the pituitary induction** has been dominating. However, it has caused several problems and risks mainly concerning the fact that pituitary glands contain various concentrations of gonadotropin hormone – GTH (gonadotropins). In general, the maximum amount of these hormones is released in the pituitary in the period before spawning, and the minimum amount in the period after the spawning. Moreover, the active females have higher concentration of these hormones than the males. Apart from this, the pituitary contains also other hormones and their inhibitors. That is why also a "cocktail" of other undesirable hormones were applied besides gonadotropins into the brood fish. This caused that the timing of the artificial stripping failed (it was prolonged by several hours), and when the ovulation did not start, apoptosis occurred (programmed death of eggs and their subsequent absorption). Such fish then did not undergo the pituitary induction for the second time because it was purposeless (after the apoptosis of the eggs, the female could not ovulate), and there was a risk of possible death ("overdosing" on hormones). Concerning the hormones, the highest level of GTH was reached earlier than needed – approximately 3 hours before the level of prostaglandin (the hormone necessary to burst the Graaf´s follicle – to release eggs from ovaries) was raised – approximately 6 hours before the artificial stripping. However, the highest level of prostaglandin is reached around 3 hours before the spawning.

Therefore, nowadays, the **induction of GnRH analogues** is being used more and more. One of the advantages is that they contain only the required hormone, and also the dopamine inhibitor in known concentration. Due to this, not a mixture of various hormones and their inhibitors is applied into the brood fish, and the stripping is planned more accurately concerning time, higher fertility rate is reached, and when the ovulation and the artificial stripping do not take place, it is possible to repeat the hormonal stimulation. Concerning the hormonal level, the highest level of GTH occurs in the period of the artificial stripping, while the highest level of prostaglandin is reached 3 hours before the stripping.

Table 2.1: Examples of hormonal stimulation in the selected fish species

Fish species	♂♂	♀♀
Common carp	**Pituitary gland:** 0.5 – 1.5 mg.kg^{-1} **Ovopel:** 1 ball per 10 kg in a single dose 24 hours before the stripping	**Pituitary gland:** 1. dose of 0.3 – 0.5 mg.kg^{-1} 24 hours before the stripping 2. dose of 2.5 – 2.7 mg.kg^{-1} 10 – 12 hours before the stripping **Ovopel:** 1. dose 1 ball per 5 kg 24 hours before the stripping 2. dose 1 ball per 1 kg 10 – 12 hours before the stripping
Tench	**Pituitary gland:** 1.5 mg.kg^{-1} in a single dose 24 hours before the stripping	**Ovopel:** 1 ball per 1 kg 30 – 35 hours before the stripping
Pikeperch	**Pituitary gland:** 4.0 mg.kg^{-1} in a single dose	**Lecirelin:** 50 µg. kg^{-1} in a single dose, ovulation in 670 – 920 h°
Northern pike	**Pituitary gland:** 2.0 mg.kg^{-1} in a single dose	**Pituitary gland:** 1. dose of 0.5 – 0.7 mg.kg^{-1} 48 hours before the stripping 2. dose of 4.0 – 5.0 mg.kg^{-1} 24 hours before the stripping
Catfish	**Pituitary gland:** 5.0 mg.kg^{-1} in a single dose 24 hours before the stripping	**Pituitary gland:** 5.0 mg. kg^{-1} in a single dose, ovulation in 480 – 520 h° (approximately 24 hours) **Ovopel:** 1 ball per 1 kg in a single dose, ovulation in 480 – 520 h° (approximately 24 hours)

The induction is implemented by inducing the hormonal preparation usually into the dorsal muscles (by an intramuscular injection). Inducing into the abdominal cavity near the ventral fins base between the intestines (by an intraperitoneal injection), or into pericardium near the pectoral fin base (in a pericardial injection) is less frequent. When induced into muscles, the tissues near the puncture must be massaged while pressing the place of the puncture with a finger to prevent the discharge of the hormonal stimulant. When induced into the abdominal cavity or pericardium, neither massage nor pressing is performed.

Kind, amount and count of doses of the induced hormonal preparation depends on the fish species and its weight. In general, the sexually active males are stimulated just by a single dose, the active females by two doses. When using the synthetic GnRH analogues, usually one dose for both sexes is enough (Table 2.1 on the previous page).

2.4 Carp rearing

The carp rearing is technologically demanding and long-term process of producing a food commodity, compared to other sectors of agriculture. In our climatic conditions, this process takes usually 3 – 4 years and includes the rearing technology of the fry (K_0), fingerling (K_1), two-year old fry (K_2), up to marketable carp (K_t), and selection carp (K_v).

2.4.1 Fingerling rearing ($K_0 \Rightarrow K_1$)

As in other sectors of the animal production, rearing the youngest age categories (the fry) is the most difficult and the most complicated phase concerning technology and time. The greatest effort is made to rear them as well as the greatest attention, since the fry undergoes extensive development changes in this phase, which must be taken into consideration by the technology, and taken care of.

This phase of rearing focuses on the period from the early fry stage (K_0) to the final 5-month old autumn fingerling, or 10 – 11-month spring fingerling (K_1). **The rearing itself could be performed in several ways:**

- **mass spawning** (the old Bohemian method – described in the chapter 4.3.1),
- **rearing in fingerling pre-ponds and consequently in fingerling ponds (including depletion of fish)**,
- **rearing in fingerling ponds only**,
- **rearing in special cultural units**.

In Slovakia, the fingerling is rear usually by the method of rearing in fingerling pre-ponds and consequently in fingerling ponds or by the rearing in fingerling ponds only. The least used is the rearing method in special cultural units. Regardless of the chosen method, we must be aware that enough fingerling in good health condition is the base for successful rearing process of the carp in the further years.

The fry rearing is performed usually in the fry ponds (the fry pre-rearing and fry rearing pond). Smaller and highly fertile ponds in good technical state, and secured against inflow of other fishes in the supplied water are used for this purpose. Smaller rearing ponds enable perfect preparation of the rearing environment, but mainly the quicker fishing out of the fish.

Preparation of the fingerling ponds begins right after they are fished out. The aim is to create optimum conditions for mass development of the natural food, which is irreplaceable in this phase. After the fish are fished out, the pond bottom, canals, and fishing pits are disinfected by chlorinated or burnt lime. Before the pond is refilled, we recommend leaving it dry for a longer period, i.e. to perform wintering and partial summer drying. Apart from this, the bottom must be drained carefully to dry out completely and be aerated. In winter period, it is suitable to treat the whole bottom with softly ground limestone. Fertilization is implemented just before refilling the ponds, and usually with organic fertilizers which are applied to the whole-area, or placed onto small heaps at the edges of the pond.

Filling the pond with water depends on the time of stocking the carp fry into the pond. When the pond is refilled earlier, the natural food grows taller by natural development changes, and thus it becomes inaccessible for the fry. On the contrary, when the pond is refilled late, the natural food will not have enough time to grow sufficiently. In both cases, there is a danger that the fry dies because of starvation. It has been proved successful in practice to supply the ponds with water approximately 3 – 5 days before the planned stocking of the fry, in our climatic conditions.

However, before stocking the fry in, it is important to perform the **control of the natural food** (mainly of the plankton). Both quantitative control (the control of the amount) and qualitative control (focused on the structure of species) are necessary. Concerning this, small crustaceans – rotifera – are the most important for the fry. These are the primary components of the natural food the carp fry feeds on. Contrarily, more intense development of cladocerans (water fleas) in the initial phase of the rearing is undesirable because of their size, and because they as the filter feeders eliminate all the smaller crustaceans, including rotifera. Predatory species of plankton, mainly cyclops, which are able to rapidly reduce the stocked fry, are also undesirable.

If we notice the presence of predatory species or excessive size of the natural food, it is effective to implement the authorized insecticide. Such preparations may eliminate cladocerans, cyclops, and water insects with their larvae, when used in low concentration, but are not harmful to rotifera. Since most of these insecticides are toxic to fish, it is necessary to observe the strict operating, hygienic and safety regulations, and stock the fry in only after the safety period.

The carp fry is stocked into the fingerling ponds usually in the morning hours under stable sunny weather, and after previous acclimatization. This is achieved by laying the transport sacs on the shadowed water surface and by pouring the pond water slowly over the fry. The water temperature for stocking the fry in should be at least 17 °C. When the temperature is lower or there is a significant night temperature drop, mortality rate rises. The stocking is performed along the pond banks, usually from a boat, since in this case we do not make the water turbid, which usually happens when walking in the pond, and thus we prevent the fry gills from siltation, as well as the subsequent suffocation and death. The fry is stocked into the pond in smaller shoals near the water plants, where it can hide.

2.4.1.1 Method of rearing in fingerling pre-ponds and consequently in fingerling ponds (including depletion of fish) ($K_0 \Rightarrow K_r \Rightarrow K_1$)

Providing enough natural food for as long as possible in the vegetation period is the main principle of this method. It is achieved by depletion (fishing out) the reared fingerling at least once in the vegetation period, and stocking it again into other fingerling pond, which has been prepared in advance. If we have sufficient number of the fry ponds, we may fish out and stock again the fry 2 – 3 times a vegetation period. Due to this process, we can speed up the development of the organism, which is seen in the higher weight of the fingerling per piece (K_1).

In the first phase ($K_0 \Rightarrow K_r$), the fry (K_0) rearing starts in the fingerling pre-pond, which 200,000 – 1,000,000 pieces of K_0 per one hectare are stocked into. The rearing process itself takes usually 4 – 6 weeks, depending on the amount, quality and accessibility of the natural food, and possibilities of supplemental feeding. We start with the supplemental feeding as soon as possible – usually in one-week period after the fry is stocked in. Firstly, the fry is fed with suspension of meals (corn, wheat) on the surface, later, when the feeding reflexes are created, we provide complete dry feed (e.g. feeding mixture KP 1) twice a day into the feeding frames on the surface. As soon as the fry learns how to take the food from the surface, it is recommended to moisten the feed to form a fairly thick dough and place it on the feeding tables. Considerably better results are achieved when using the feed with the 25% content of animal proteins. The daily dose is around 5% of the fish stock weight.

The fingerling pre-ponds are monitored regularly after the stocking – mainly their functional and technical state (primarily the inflow and outlet facility), and physico-chemical properties of the water (temperature, content of O_2, pH), and the fish stock (amount, growth rate, health condition). When needed, the correction measures are taken. If the the sac fry rearing is performed without any problems and there is sufficient natural food, we may prolong the rearing phase beyond 6 weeks.

The best is to realize the pond fishing into a fishing cage under the dam. If it is not possible, the pond fishing is performed early in the morning in the fishing pit by a surrounding or seine net. All the processes (pond fishing, selection, loading, and transport) must be implemented as quick and carefully as possible. The final product – the forced carp (K_r) grows into length of 30 – 50 mm and weight of 2 – 5 g in this period. Despite the care dedicated to this age category, the losses range from 55 to 65%.

In the second phase ($K_r \Rightarrow K_1$), the forced carp fry is stocked into the fingerling ponds prepared before in an amount of 10,000 – 50,000 pieces per one hectare, where it is reared until the end of the vegetation period. For approximately the first two weeks, the fry feeds on the natural food, but as it is decreased, we start to provide supplemental feed, i.e. we do not wait until the natural food is consumed completely. It is necessary to ensure the daily food dose contains at least ⅓ of the natural food, and thus the provided feed isused reasonably.

The feeding mixture (KP 1) is the most useful one, and a bit weaker results are achieved when using only the cereal feeds (thicker meals, crushed grain, broken grain). The daily food dose is adjusted by the amount of the fish stock, growth rate, water temperature, and intake intensity of the provided feed. It usually does not exceed 6% of the fish stock weight. The feed is placed on the feeding tables unfolded on the pond perimeter in the depth of around 50 cm, while per 5,000 – 10,000 pieces of K_r, we need the table area of 1.5 – 2.0 m^2.

During the rearing, the physico-chemical properties of water must be regularly monitored, and test-fishing is performed to monitor the growth rate and the health condition of fish. If necessary, regulatory measures are taken. At the end of the vegetation period, so called **condition feeding K1** is usually implemented by a suitable energy-rich feeds (usually corn meal). The aim is to supply fish with sufficient fat reserves, which will provide enough energy to survive in the winter period. The fat content in a body of K_1 should compose 4 – 6% of the weight of one piece. At the end of the vegetation period, the fingerling K_1 reaches the weight of 30 – 50 g. Losses during the rearing depend mainly on the amount and food quality, as well as on the health condition of the fish stock, and usually they do not exceed 25%.

The most of the fingerling ponds do not enable safe overwintering of the fingerling K_1. Therefore, at the end of the vegetation period, these ponds are fished out and drained, and the K_1 fry is moved into a suitable wintering pond – so called **fingerling wintering pond**. Since the fingerling actively consumes and digests the feed also under lower temperatures (below 4 – 5 °C), it is necessary to use the supplemental feeding also in the wintering pond. Otherwise the fingerling starts to digest its energy reserves, which may not need to be sufficient for the whole wintering period. This may then worsen its health condition. However, there are also ponds which enable to winter the fingerling – in such cases, the fingerling is kept in the fingerling pond through winter, too, and the pond fishing process is performed in spring.

2.4.1.2 The rearing method without fishing out ($K_0 \Rightarrow K_1$)

This method belongs among the less intensive ones. It is technologically similar to the previous method with the exception of the sac fry (K_0) being stock into the fry fingerling pond in the amount of 50,000 – 200,000 $pcs.ha^{-1}$ for for the whole vegetation period – i.e. the whole rearing process takes place in a single pond. Also bigger ponds (5 – 10 ha) could be used. However, they are filled only partly in the beginning, and they are filled to the normal level during the vegetation period. Due to this measure, longer occurrence of the natural food in the pond is ensured.

The preparation of the pond, supplying it with water, stocking the sac fry, and monitoring and taking care are the same as in the previous method. The pond fishing is usually implemented in autumn, but if the conditions are favourable, we are doing it in next spring. Otherwise, the fished out fingerling needs to be moved into the fingerling wintering pond. By autumn, the fry K_1 reaches the weight of 15 –

30 g. However, losses during the rearing process are rather high (70 – 95%), even despite all the taken improvement measures.

2.4.1.3 Method of rearing in special cultural units (K0 ⇒ Kk)

This method is used the least. We implement it only if we gained K_0 by artificial stripping in thermal/tempered water, and when being transported to other fingerling ponds for further rearing, the weather changed substantially (sudden temperature drop below 17 °C). In other words, if we stock the sac fry into the fingerling ponds in such situation, we would expose it to a temperature shock, which would cause its mass die-off.

In such cases, the rearing is implemented in a hatchery, usually in rearing troughs of diverse construction (plastic, laminate), shape (square, rectangular, hexagonal), and volume (0.5 – 5.0 m^3). Water inflow and outflow must be designed in a way to enable the troughs be quickly supplied with water and drained again (after preventive baths, cleaning, etc.). The water flow rate is calculated for 2.5 $l.s^{-1}$ per 1 m^3 of the trough, while the water should contain at least 4 – 4.5 $mg.l^{-1}$ of O_2, and pH 7 – 8, and it should be stabilized concerning temperature (secured against temperature fluctuations). The troughs must be sufficiently light during the rearing process, i.e. per 12 – 16 hours a day to extend the period of active feeding.

The time of rearing depends on the number of days of the unfavourable weather. If such bad weather is temporary, we use technology of short-term rearing (1 – 3 days). If the bad weather lasts for a longer period, we use technology of long-term rearing (14 – 28 days).

Within **the short-term rearing,** the fry is stock into the trough (in the age of 2 – 3 days) in an amount of 300,000 $pcs.m^{-3}$. The rearing is successful, if there is enough subtle plankton (rotifera). This is gained either by the water offtake from the plankton pond, or by its catching and sorting. Right in this period, we may secure a part of the feed dose by supplemental feeding (dried or cooked egg yolks), which is applied in a form of emulsion in smaller doses but very often (every 1 – 2 hours) per 12 – 16 hours a day. The fed fry (K_k in the age of 5 – 6 days) fed this way is then stock into the fingerling ponds (fingerling pre-pond and fingerling pond) under favourable and stable weather, where its further rearing continues, but now with supplemental feeding, too.

Also within **the long-term rearing,** the sac fry is 2 – 3 days, but the amount of the fish stock changes according to the length of the rearing. If it takes 14 days, the amount is 50,000 – 100,000 $pcs.m^{-3}$. If the rearing continues (for the 3rd week), the fish stock is reduced to 20,000 – 50,000 $pcs.m^{-3}$. Later, if the rearing lasts longer (for the 4th week), the fish stock is reduced again, to the amount of 10,000 – 30,000 $pcs.m^{-3}$. It is however necessary to provide enough natural food (plankton) in this case, too. During the first days of rearing, the plankton may be obtained by the supplying water from the plankton pond, although later it must be gotten by catching, too. Firstly, the food contains mainly the sorted zooplankton, while as the fry grows, we increase also the size of the food organisms. We serve plankton when needed, but we care about its surplus. The daily dose should be 5 – 8 times higher than the weight of the the fish stock. After 10 – 14 days of rearing, we start to feed the fry with supplemental feeding (usually the initial feeding mixture). This is provided at hourly intervals per 16 hours a day, while we gradually increase the doses up to 90% of the total feeding dose (the remaining 10% is composed of zooplankton). Automatic feeders are suitable, too. The daily dose of the feed reaches 15 – 20% of the fish stock weight.

During the rearing, the environment must be hygienically perfect to prevent mass fry die-off. The troughs (walls and bottom) are cleaned daily, and dirt (excrements, rests of the feed, died fish) is removed twice a day. Moreover, the health condition of the fish stock is monitored through the whole rearing period, and if needed, preventive or therapeutic measures are taken. When all the rearing and hygienic regulations are observed, the losses range from 20 to 30%. The fed fry (K_k) is stocked into the fingerling pond for further rearing, when the unfavourable conditions end.

2.4.2 Rearing the larger fry ($K_1 \Rightarrow K_2$)

The process of rearing the two-years-old fish (K_2) begins in spring by fishing out the fingerling wintering ponds, from which the fingerling (K_1) is placed into the rearing ponds. The rearing process lasts for whole vegetation period, and the two-years-old fish is fished out in autumn (or in next spring).

Preparation of the rearing pond is quite similar to the general fingerling ponds. It starts in autumn after the pond fishing, and the disinfection of bottom, fishing pit and canals. Before being refilled again, it is recommended leaving the pond for wintering. It is then suitable to apply liming during winter, together with fertilization to develop natural food. However, the fertilization is applied into the pond at the end of winter or in early spring. Both liming and fertilization could be applied whole-area or only on the margins of the pond. The doses are set exclusively by the needs for the certain nutrients.

Supplying the pond with water is regulated by the capacity of the water source. Ponds with weaker water source are filled with water shortly after the pond fishing process, while the ponds with greater water source capacity are filled only at the end of winter or even in the beginning of spring. The above mentioned improvement (amelioration) conform to this, too.

We stock the fingerling (K_1) into the rearing pond prepared in advance in the amount of 1,000 – 5,000 pcs.ha^{-1}, depending on the intensity of farming. After stocking the fingerling in, we monitor the technical state of the pond – mainly the water inflow and outlet facility, physical and chemical properties of the water, and the fish stock – their health condition and increments. The most difficult period begins in spring, when the greatest losses occur because of the weakened health condition after wintering. The organism is usually highly weakened, stressed out, and more liable to various infectious diseases after winter. Therefore, it is suitable to start with **condition feeding** with saccharide supplemental feeding in spring. The aim of this measure is to get the fish back into good health condition, and prevent any disease to burst out, or subsequent increased die-off. When natural food is created, we continue with feeding by the supplemental cereals, and approximately in the half of the vegetation period, the feeding mixtures or feeding legumes are provided, because the natural food is decreased. At the end of the vegetation period, it is proper to provide an energy-rich feed, which creates sufficient fat reserves in the organism for wintering. When the water temperature falls below 13 – 12 °C, metabolism slows down, feed intake is reduced and further feeding is useless in this phase. Losses during the rearing process usually do not exceed 10 – 30%.

The pond fishing is implemented in autumn in cooler weather conditions and in early morning hours. In this phase, the fingerling (K_1) has grown into a bigger two-years-old fish (K_2) with a weight of 300 – 600 g (800 g). Since most of the rearing ponds do not enable safe wintering, the two-years-old fish is stock again into a wintering pond just after being fished out, and it remains in this wintering pond until spring.

2.4.3 Marketable carp rearing ($K_2 \Rightarrow K_3$)

Rearing the marketable carp is the final phase of the carp production. This phase begins with fishing out the two-years-old fish from the wintering ponds, and its stocking into the main ponds for whole vegetation period, in the amount of 300 – 2,000 $pcs.ha^{-1}$. Preparation of the pond as well as the water supply is performed in the two-years-old fish rearing phases. During the vegetation period, general intensification measures are taken, which are focused on water treatment, restricting water plants, and getting enough food. In the optimum conditions, the carp grows into the final weight of 1,500 – 2,000 g in this period, with losses being 2 – 5%.

The pond fishing processes take place in cooler weather conditions, starting in October. The fished out fish are transported into storage ponds, in which they remain until being distributed into the market. We maintain fish in the fish tanks in clear water to make them get rid of dirt, undesirable tastes, and food from the digestive system. When placed into storage ponds, the fish are no longer fed and thus they lose weight by 2 – 3%, depending on the length of this phase.

In some cases, heavier consumable fish are produced (more than 2.5 kg), the so called **selection carp (K_v)**, which are prepared for the Christmas sale to be sold alive. This is a special food commodity reared for 4 years, which then also prolongs the rearing cycle and increases the costs, too. In this case, lighter fish are reared (K_1 – 20 – 30 g, K_2 – 100 – 200 g, K_3 – 600 – 1,000 g) than during the traditional three-year production cycle, and they are reared usually for two vegetation periods.

Farming in the rearing ponds and the main ponds could be implemented in two ways:

- **one-year farming – stocking in and fishing out processes are implemented annually,**
- **two-years farming – the fish are stocked in for two vegetation periods.**

Each of these ways has both advantages and disadvantages. **The first system of farming** enables to determine the right amount of fish stock per the pond with dependence on the level of intensification, natural productiveness, and planned increments. Annual pond fishing provides information and overview of the reared fish, its health condition, and it also enables to perform negative selection – eliminating non-standard fish from the rearing process. More frequent handling with the fish and higher operating costs connected with the annual pond fishing, transport, and wintering of the fish, which all can cause also various diseases, are the disadvantages of this farming system. Moreover, efficacy of some improvement measures (fertilization and liming) is lower, because it exceeds a single vegetation period (when pond fishing, the "over-fertilized" water is drained out).

When performing **two-year farming**, the fish are fished out only after two years (after two vegetation period), after being stock into the pond. The disadvantages of the first system are eliminated to a certain extent by this measure. On the other hand, determining the amount of fish stock is rather problematic, because if the pond is stocked with the fish in a standard way the first year, it will be over-stocked the second year. It means that we must intermediate fish out a part of the fish stock, feed with higher intensity, or plan lower increments. If the amount of fish is set with regard to the second year, the pond will be under-stocked in the first year and thus it will not be used productively. This system was used quite often in the fifties. However, nowadays it is used just a little.

When deciding which system is more suitable for us, we should have firstly enough information and data gained from the previous years, based on which we may put down advantages and disadvantages of both systems for a certain pond.

2.5 Methods of the pond fishing

The pond fishing is a working method by which the total fish stock is fished out from the pond as quickly and carefully as possible, and subsequently it is transported – either to other pond for further rearing period or to market. The pond fishing represents the highlight of the fishery year, and also it is an attractive event in the presence of the public. It can be compared to the harvest of farmers or vintage of wine growers. In this event, there is a tradition to take on new members to Peter's guild by dubbing them fishermen.

The main season of pond fishing begins in autumn in cooler weather conditions, when the water temperature is around 10 – 5 °C. Firstly, the fingerling ponds are harvested in September – October, then the rearing ponds, and the fishing season ends in October – November with fishing the main ponds. The second pond fishing period continues in spring by fishing out the wintering ponds. These are fished out when the water temperature is 6 – 8 °C, which happens usually in March, in our climatic conditions.

Before the pond fishing, water must be drained out – the process of the so called **pond arranging** – which usually takes several days, depending on the size of the pond. It is necessary to drain water continuously and slowly to ensure the fish manage to react to the decline of the water level, and move from the shallower parts to the deeper ones near the dam – to the fishing pit. Otherwise the fish remain stuck in water plants and terrain holes.

During the arrangement process, it is necessary to stop the water inflow or regulate it to the minimum, at least. Otherwise there is a risk, mainly in warmer weather conditions, that the fish get away up against the flow by the main drainage ditch (canal), which will thus make the whole fishing complicated. The draining must be stopped, when the water level reaches the level of the fishing ground, especially its borders. The outlet facility is closed, at least throttled, and the water level is regulated according to instructions of pond fishing head. Timing of the arrangement must correspond with the date and time of the pond fishing. When not observed, the water level is either higher, delays occur, and the pond fishing period is prolonged, or the water level is too low, which causes possible die-off.

The necessary tools (nets, tubs, sorting facility, weighing machine, etc.) are placed on the tub place early in the morning on the day of the pond fishing, occasionally on the day before.

Just before the pond fishing, **the fish are roused** by long wooden poles. The aim is to gather the fish in the fishing pit. When the ponds are larger and have also larger fishing pit, so called **fencing** is often applied. After the fish are roused into the fishing pit, **a plain net** is spread (a bag and wooden poles) through a part of the fishing pit, usually through the main drainage ditch, and later it is hanged to the taller wooden poles (that is why it is called a fence). The fence prevents fish from getting away from the fishing pit into the main drainage ditch or into the margins of the fishing pit. Only after this, the **pond fishing** takes place, which is implemented by the following ways, depending on the technical conditions:

- in the fishing pit,
- in the under-dam pit,
- summer intermediate fishing.

2.5.1 Pond fishing in the fishing pit

This method is the most common in our area. The pond fishing is being implemented using either **seine net** (a net with a bag – stick net, bag net), or **underlaying net.** The pond fishing with the **seine net** begins with spreading the net at the margin of the fishing pit, stretching out the bag, and binding the haul ropes to wooden poles. These are equipped with two lines – the upper with floats and the lower with weights – and together define the entrance of the net. When the net is ready, the hauling (netting) is performed by two groups of workers who draw the net by the prepared lines usually in a perpendicular way to the tub place situated below the upstream slope of the dam. The net is drawn in the fishing pit by the poles, and when the fishing pit is deeper, the lower line is held from a boats by hooks near the pond bottom to prevent fish from under-swimming the net.

When the net is drawn to the tub place, both groups of workers, who pull the ropes, move closer to the net and grasp the upper and the lower line to keep the fish in the net. Subsequently, the lower line is tied (hanged) to the **fastening stakes** and the net, i.e. its bag is being gradually drawn and pushed off, i.e. **gathered to the center.** The harvested fish are thus gathered at one place. Since there is quite a big amount of fish in rather a small place, it is necessary to spray the fish with water to prevent them from dying. Then the fish are taken out from the net either **by hands** or mechanically by **the short-handled dip net.** Firstly, the predatory species must be taken out, because they are more demanding on oxygen and thus they die earlier. The fish are then directly placed on hand or mechanical **grader (sorter),** where they are sorted by size and species, and then they are moved to **tubs** with clean water. When the tubs are full, the sorted out fish are weighted, and then loaded either by hands or by a mechanical fish loader into transporting tanks onto a car.

After this first hauling – from taking out the fish until loading – the hauling is usually performed one or two more times, depending on the amount of fish in the pond. If there are still some fish in the pond left after the last hauling in the fishing pit, the water level is lowered and they are are fished out by hand. This is typical for greater ponds and older fish – the two-years-old fish and the marketable fish. It usually takes several days to harvest such big ponds.

When pond fishing with the use of **the underlaying net**, this method usually requires one more day, since the underlaying net is placed on the bottom of the fishing pit on the day before the pond fishing itself. It is a square or rectangular-shaped net with smaller meshes, and it is spread from the dam to the pond along the bottom in a way that no fish are left under it. When spread, the edges are bound to the bottom of the fishing pit by bigger wooden stakes. The pond fishing starts in the following morning. Workers stand all around the fishing pit and try to drive, to **rouse** the fish into the underlaying net, while moving slowly to its margins. Suddenly, they quickly lift the net from the bottom. When the net is lifted, it is gathered to its center a bit, and drawn to the tub place, where it is bound to the stakes. Further processes (gathering to the center, taking out the fish, sorting, weighting, loading) are the same as in the previous method. Although this form of the the pond fishing is quicker and gentler to the fish than the pond fishing by the seine net, it requires more workers, and professional and manual skills. Placing the underlaying net into the pond for the second time during one harvest is however impossible. This form is used usually to fishing out younger fish – the fingerling – and smaller ponds.

2.5.2 Pond fishing in the under-dam pit

This method is performed usually in ponds without fishing pit, or in those, where there is a thick layer of mud. Fishing out with nets and the subsequent manipulation with the fish would cause rather high death rate.

The pond fishing is being implemented outside the pond on the down-stream face of the dam. In the place where the water drains out from the pond, **catching facility** is built. Therefore, the fish are flushed from the pond together with water through the outlet facility and pipe in the dam. Then they are gathered in the catching facility below the dam, and fished out either by hands or mechanically by net tools. Subsequently, fish are taken out, sorted out, and loaded, etc. in the same way as when pond fishing in the fishing pit. The outlet facility and the pipe should be designed in a way to provide the fish with smooth crossing without getting hurts. Concerning smaller ponds, when the fry and/or fingerling is being fished out, a fish catching box is usually placed at the end of the outlet. In bigger ponds, fishing pit is built.

2.5.3 Summer intermediate fishing

This method requires neither the usual the pond fishing of all the fish stock in the pond nor the water is drained out from the pond, as in the previous methods. The peculiarity of this method is that the fishing is performed not in autumn, but in spring or summer, when the fish gather in the feeding places. Only some fish are fished out to be subsequently either moved to other pond (only if the pond was prepared for two-year rearing), checked concerning their health condition, or transported to the market (except for Christmas). Such fish are are fished out by a **cast net** or by a **net without the bag** – so called **fence,** usually at feeding places nearby the banks. One of the demands is to have a flat bottom without any barriers in the pond. The fish intermediate fishing itself starts approximately 1 – 2 hours after the feeding at the feeding place.

The way of **using the cast net** is simple and easy concerning time and required staff, and it is performed only in the smaller ponds. The fisherman walks slowly and carefully along the bank with a cast net in his hands towards the feeding place in order not to rouse the fish. Then he throws the net into the water (over the fish), usually from 5 – 10 m distance. When the net falls into the water, it creates a bag, which the fish get stuck in. This method is used mainly for controlling the health condition of the fish stock in the pond, since it is not possibleto fishing out a greater amount of fish with it.

In larger ponds, the **fence** is used the most often. However, this method is quite difficult, and its success depends on the level of professional and manual skills of the staff. After feeding, we sail around the feeding place in a boat as fast as possible while keeping sufficient distance, and throwing the fence into the water. Subsequently, both ends of the fence are drawn towards the bank bank by hauling the ropes, while the lower line is kept near the pond bottom to prevent the fish from under-swimming the fence, and the upper line is lifted above the water level to prevent the fish from jumping over it. All these steps must be performed carefully and in silence in order not to rouse the fed fish. Otherwise all the effort is wasted. When the fence is drawn to the bank, it is centred and the following steps (fishing out, weighting, loading, etc.) are implemented in an identical way as in the usual method of the the pond fishing.

2.6 Wintering of fish

Wintering is used for safe holding the fish through winter. The winter is one of the most difficult and critical period in the life of the warm-water carp. When the temperature falls, its metabolism slows down, it stops eating and starves. The energy required for the basal metabolism is gained by digesting the fat reserves. Therefore, it gradually loses weight, and the organism is being weakened. This lasts usually for 5 – 6 months in our climatic conditions. To eliminate the negative influences, it is necessary to maintain good health condition of the wintered fish during whole this period. Otherwise it may cause serious losses which may end with massive die-off when in combination with other unfavourable factors (lack of oxygen, parasites).

In other words, success of the wintering process depends to a great extent on the energy balance, which the organism gains during the vegetation period, and the energy spent during the wintering period. The ideal wintering process without losses (both, the weight and the count of fish) is the one when the gained energy level equals the used energy level, i.e. when the utilized energy does not exceed the gained one. However, we cannot rely on this situation in our climatic conditions. Therefore, it is necessary to maintain the wintered fish in a good health condition – i.e. to have enough reserve energy in a form of fat which could be used on basic physiological needs without weakening substantially. Moreover, the created fat layer serves as a thermal insulation barrier that prevents the organism from cooling down excessively. The fat content of the wintered fish should be at the level of 4% at least. When it is decreased below 1%, overall exhaustion of the organism is seen. However, the content of proteins should reach 14 – 18% in autumn, and should not fall below 10% during the wintering period.

The greatest attention during the wintering period is paid to the youngest fish – the fingerling, since it responds to the changes of the environment the most sensitively and the losses reach the highest values, usually at the level of 10 – 20%. When the fingerling is wintered in an inappropriate pond or it is in a bad health condition, the losses may reach more than 50%. The older fish is more tolerant of the wintering conditions, and the losses during the wintering phase usually do not surpass the ones from the vegetation period.

2.6.1 Wintering ponds

The whole wintering process takes place in wintering ponds (fingerling wintering pond, traditional wintering pond, special wintering pond, and suitable production pond). These are the special ponds and they are considerably different from the common production ponds (the ponds used during the vegetation period). These ponds are used mostly outside the vegetation period. They are deeper, there is no mud on the bottom, and they provide a water source of great quality.

The base for the successful wintering process of the fish in the pond is **the water.** Its source should be of great quality, should be reliable and sufficient for the whole wintering period, and it should not freeze up even if it is freezing heavily. The water in a traditional wintering pond should be exchanged once in 10 – 20 days. The water inflow at the level of 5 – 10 $l.s^{-1}.ha^{-1}$, which should not exceed the level of 25 $l.s^{-1}.ha^{-1}$, should be in accordance with the water exchange, since the excessive inflow cools down the water too much and often causes the **raising of fish.** Concerning the oxygen content in the inflow water, the values should reach at least 6 – 7 $mg.l^{-1}$ of O_2, while the oxygen saturation of the water should not drop below 60%. It is usually the lack of oxygen in water which causes that the fish are raised. The water temperature of the wintering pond measured near the bottom should range from 2 to 3 °C. When the temperature is higher, the fish think that spring is coming, and they become more active and start to look for food, which is then seen in the loss of their fat reserves. On the contrary, the lower water temperature (0 – 1.5 °C) excessively cools down the organism of the wintered fish when in a weaker condition and thus causes higher loss. The inflow water must not contain higher amount of the organic compounds which could cause the oxygen deficiency in the wintering pond when decomposed.

The bottom of the wintering pond should be harder, usually sandy-loam **or** loamy-sand with a thin layer of mud, in which the carp can hollow out a lying place. A thicker layer of mud is undesirable, because it provides space for decomposition of the organic compounds and uses a great amount of oxygen. Moreover, a gravel bottom is also unsuitable for wintering the carp, although it is appropriate to wintering predatory fishes (pike, pikeperch). The pond bottom should have an even slope without any depressions, and the ditches (the main, the side ones) should be kept in a good condition, too.

When choosing the right pond, we must take its **productivity** into consideration, and we rather choose lless productive ponds, since in the productive ones, a great amount of plankton is created also during winter. However, the carp does not consume it because of the low temperature. The plankton is thus accumulated and becomes a dangerous competitor concerning oxygen consumption. On the contrary, this does not apply to the wintered fingerling (K_1), which consumes the plankton also when the temperature is around 4 – 5 °C.

In the more productive ponds, there are also more water plants living. The so called **soft water plants** are often rather problematic because they have an impact on the physico-chemical properties of water. In winter, there is no assimilation (photosynthesis and production of oxygen) taking place below the ice covered with snow, but only decomposition (breathing – oxygen consumption) occurs, and when the oxygen level is decreased below the critical point, dissociation takes place and the water quality is lowered in a dangerous way.

Having sufficient **depth** is other important factor when choosing the wintering pond. Regarding the traditional wintering ponds, the depth should be at least 2.5 m near the dam. However, such depth should not be present only in the fishing pit, but in a greater area of the whole pond (at least 30 – 50%), too.

The size of the wintering ponds is however the least important. Generally, it is better to have a higher number of smaller wintering ponds. The size is usually 1 – 2 ha and no bigger than 5 ha. This prevents the fishes from mixing with one another, and introducing diseases and parasites from various ponds.

Concerning **the exploitation**, we try to choose the wintering pond in rather a lower altitude. In the higher altitudes, the ponds freeze up earlier in autumn and thaw later in spring. This means that the period is extended and the wintering conditions get worse. It is also beneficial when the wintering pond lies in an open landscape. Autumn winds cool the water down and thus slow down the zooplankton development, which consumes oxygen from the water. Such ponds then freeze up later in autumn and thaw earlier in spring. However, this does not apply to the fingerling wintering ponds, where a protected location is demanded.

Besides **the traditional wintering ponds** which were described earlier, also fingerling wintering ponds, special wintering ponds and suitable production ponds are used for wintering the fish.

- **fingerling wintering pond –** this is a deeper pond with an average depth of at least 1.5 m and the area of 1 – 5 ha, and no muddy bottom. Abundant water source of great quality is needed to ensure water exchange once in 20 – 30 days. It serves solely for wintering the fingerling, while the fish stock of 100 000 – 250 000 pcs.ha^{-1} could be in the pond,
- **special wintering pond –** this is a smaller pond with the size of 0.2 – 0.5 ha and thus resembles storage ponds. It has a rectangular shape with ratio of the sides being 1:2, and a harder non muddy bottom with an average depth of 1 – 1.5 m. There is no fishing pit in the pond, but this facility is situated under the dam of pond, and provided with an inflow of clean water of great quality. The water should have the temperature of at least 2 – 3 °C, oxygen content of at least 10 mg.l^{-1}, and pH at the level of 7 – 8. Both upper (above the water surface) and lower (below thewater surface) inflow of the water are quite peculiar. The lower one is used only at the beginning of the wintering phase, usually right after the fingerling is stock into the pond; on the contrary, the upper inflow is used during the whole wintering period. Such ponds enable to implement anti-parasite baths as well as to provide the fingerling with supplemental feeding until the water level gets frozen,
- **suitable production pond –** this pond is a bit deeper than the general production (fingerling) pond – its depth is 1.5 m on the area of at least 10 – 15% of the total pond area. The pond has an abundant water source of great quality, which enables to exchange the water at least once in 30 days. Concerning the technical parameters, the pond should be easily drainable and its bottom thoroughly dryable.

Advantages of wintering the fish in a suitable production pond:

- the fish remains in its environment – natural, fertile and with a soft bottom,

- the conditions in the production pond enable the fish to consume food in a period longer by 1 month – since the pond is not fished out (not drained) in autumn, the natural food remains in the pond and can develop further until the water level gets frozen completely, and on the other hand, such pond thaws earlier in spring and thus also the natural food could be created earlier,
- stress and mechanical injuries of fish during the pond fishing and transport into wintering ponds are eliminated,
- the fish stock does not exceed the limit – this eliminates the risk of introducing various diseases and parasites from other ponds into the pond,
- lower operating costs.

2.6.2 Maintenance of wintering ponds

The maintenance **begins already in spring** after the pond fishing. Firstly, the bottom and fishing pit are disinfected by chlorinated or burnt lime. Subsequently, the oversummering phase is implemented depending on the pond kind – complete (traditional wintering ponds) or partial (special wintering ponds). Before the pond is refilled with water in autumn, the plants must be eliminated – collected and composted outside the pond. If necessary, ground limestone could be spread on the pond. The filling process starts earlier to ensure the organic matter is decomposed before the water level freezes up. Water inflow must be secured against the entering of predatory or undesirable fish into the pond. Thus the risk of losses and of introducing parasites is eliminated.

After the fish stocking, we monitor the wintering pond daily. Besides the water level (inflow, outflow) and physical and chemical properties, we monitor mainly the fish stock – its behaviour. Regarding the fingerling, we implement the saccharide supplemental feeding until the water level freezes up. In the areas with more severe winter conditions, we need to install defrosting devices before the water level freezes up completely.

When the water level gets frozen, we need to monitor the inflow mainly. When the winter is more severe, we need to prevent the inflow water from flooding over the ice and ensure that it flows into the pond below the ice. Moreover, we need to pay attention to the draining device, mainly to its tightness, and we also monitor the physical and chemical properties of water, mainly the content of oxygen, pH and alkalinity, on a daily basis. When the ice is 5 cm thick, we start to **break holes in the ice.** This helps with the better exchange of gases – on one hand, the water is enriched with oxygen from the atmosphere, and on the other hand, undesirable gasses leak from water. Besides this, sun rays get through the water in an easier way and contribute to better photosynthesis of the water plants, which then leads to consumption of carbon dioxide and the water is enriched with oxygen. The holes are 1.5 × 20 m large, and they are broken in the deeper places of the wintering pond (above the lying places) in a number of 1 – 2 $pcs.ha^{-1}$. The holes should be placed in a direction the winds usually blow to keep the holes unfrozen for as long possible by water clarification. Smaller holes are broken on the inflow, too – to prevent water from flooding over the ice, and near the outlet facility – so the ice pressure does not damage its tightness.

Various types of **defrosting devices**, which use the so called **thermal anomaly of water**, i.e. the densest and warmest water (4 °C) is near the bottom, and prevents the holes from getting frozen. The defrosting device ensures the warm water flows towards the surface, which is Therefore, kept unfrozen. Ones of the most used defrosting devices are Paulat's wind defroster, turbine defroster, and electric defroster. Most of the electric defrosters which are produced today enable also aeration of water (e.g. jet aerator, ejector, and injector). All these devices are placed on the float construction which must be anchored very well. When using electric defrosters, it is necessary to build an electric connection near the wintering pond.

2.6.3 The fish stocks of the wintering ponds

The fish stocks are influenced by the local conditions and experience, and depend solely on the characteristics of the wintering pond, and quality and capacity of the supplying water source. In general, the fish stock in the wintering pond reaches 3 – 5 times higher values than the amount in the production pond, but in practice, we know also the fish stocks which are multiple times higher (Table 2.2).

Table 2.2: Recommended amounts of the wintered fish (in pcs.ha-1) in the individual types of the wintering ponds

Wintering pond	K_1	K_2
Fingerling wintering pond	100,000 – 250,000	–
Traditional wintering pond	30,000 – 100,000	10,000 – 30,000
Special wintering pond	300,000 – 600,000	30,000 – 50,000

Firstly, the youngest age category of fish is stocked into the wintering ponds – the fingerling K_1, which takes place by the beginning of autumn (usually in September). However, this does not apply to the fingerling wintering ponds, which the fingerling is stocked into by the end of October or by the beginning of November. The carp fry K_2 is set in later, usually in October.

To eliminate the losses during the wintering period to minimum, it is necessary to follow these principles:

- various age categories of the carp must be wintered separately – to prevent the younger and older fish from being wintered together,
- when there are dense stocks (multi-fold fish stocks), prevent fishes from various river basins from mixing together – there is a risk of introducing diseases and parasites,
- secondary fish species should be wintered with the carp or individually,

- when wintering predatory species, we must not forget on the forage fish in the amount of 25 – 33% of the overall weight of the predatory fish stock,
- before stocking the fish in the wintering pond, it is necessary to check the health condition of the fish – remove weak, hurt, and sick fish or those with symptoms,
- handle, transport and stocking in the fish carefully.

2.6.4 When fish are raised

This is an undesirable phenomenon which may occur when the rules for right wintering are not observed. It happens when the living conditions get worse in a critical way and fall below the bearable level. The overwintered fish leave their lying places, swim under the ice, and gather in broken holes and near the inflow. This situation is usually accompanied with great losses per pieces, as well as weight losses, because the fish use most of their fat reserves, which they created during the vegetation period, for swimming.

There could be several **reasons for raising of wintered fish**, although **the deficiency of oxygen in water** is the most frequent one. This, together with accumulated gasses (CO_2, H_2S, CH_4, NH_3, etc.), forces the fish to leave their lying places and move to other safer place. Another reason which happens also quite often is that the fish **are invaded by parasites or get sick.** When the warming lasts longer, a strong inflow of cold and acid water from the **melting snow and ice**, and without oxygen, forces fish to raise. Furthermore, also **great noise** can make the wintered fish raise.

These signs point to the impending danger of the raising:

- lasting decrease in oxygen,
- worsened quality of water – bad smell, turbidity, thick foam in the outflow,
- presence of water insects in the cut holes, and later also of the species more demanding on the oxygen content,
- presence of the diving beetle in the broken hole points to the already raised fish.

If the signs of the impending raising of the fish occur during the wintering period, we must take the **following preventive measures** as soon as possible:

- we increase the water inflow (if there are conditions for such measure), and strive to exchange the water in the pond as quickly as possible; if there are no conditions for such measure, we place various aeration devices into the inflow (jet aerator, splash aerator, paddle wheel aerator, etc.),
- we increase the number of holes, which we place the defroster with an aeration function in.

If these preventive measures do not work and **comes to the raising of fish**, we take the following measures:

- we increase the number of oxygenation devices (compressors, blowers, injectors, ejectors, etc.),
- we strive to exchange the water using large water pumps, or at least stir it to release the harmful gasses.

If the living conditions in the wintering pond were improved by the measures mentioned above, the fish would draw back from the holes and lie back into their lying places. On the other hand, if the situation was not improved despite all the taken measures and the fish remained in the holes, we would have to implement **emergency pond fishing.** It is performed by hands using short-handled and long-handled dip nets, or also by small seine nets (e.g. stick net), in the non-freezing weather conditions. The fished out fish are then placed into storage ponds for the rest of the winter.

2.6.5 Fishing of the wintering ponds

During winter, the fish lie in their lying places, they do not move, and their metabolic activity is at minimum level. As soon as the water starts to get warmer in spring, their metabolism becomes more and more active, the fish leave their lying places, start to swim and look for food. Their demands on the basal metabolism are increased. Since the fish are in the wintering pond without any natural food, and there is quite a high amount of fish, it is necessary to fish out these fish in time to prevent them from suffering from the lack of food.

Great attention should be paid to the the pond fishing in the wintering ponds, because the fish are exhausted after winter, and if they were left in the environment without food, it could hurt them even more. **Fishing of the wintering pond** should not be performed too early in the morning, as there is an impending risk of hurting the fish by the morning frosts, or, on the other hand, there might be no sufficient natural food created in the production pond, which we plan to stock the wintered fish in. On the contrary, if we fish the wintering ponds and the fingerling wintering ponds later, we need to feed the fish with easily digestible saccharide feed (e.g. wheat).

Before the pond fishing, we must perform **test fishing** to check the health condition of the fish. Based on the results, we plan the further procedure – whether we fish the pond in a standard way, or we need to take zoo-veterinary measures to improve the health condition of the wintered fish.

The pond fishing itself must be thoroughly prepared and organized, and performed quickly. We need to handle the fished out fish carefully in order not to hurt it, and during the pond fishing, it should not suffer from the deficiency of oxygen. The pond fishing is usually implemented in the fishing pit using the underlaying net; when we harvest the fingerling, it takes place under the dam, and we also use the underlaying net. Subsequently, we stock the fish into the prepared production ponds with enough natural food. If for any reason we need to place the wintered fish into the torage ponds, we should use this option for as short period as possible, because storage process exhausts the fish excessively.

Losses during wintering occur either concerning the amount of the fish or their weight, and they depend on the health condition of the wintered fish as well as on the conditions and the process of wintering itself. Generally, the **losses per pieces** are around the level of the losses from the vegetation period, although regarding the fingerling, the losses may exceed even the level of 50%. **Losses of weight** usually reach the level of 6 – 7%, but in adverse conditions, they may exceed also the level of 10%.

2.7 Fish stocks

This fish stock shows the total number of fish which were stock into a pond for a certain period (several weeks, half of the vegetation period, whole vegetation period, two vegetation periods, etc.). Usually it is counted as a number of fish per a unit of an area (ha, m^2, etc.) or a volume (l, m^3, etc.). Calculations which express the amount of fish per the whole pond (i.e. regardless of the area or the volume) are rather rare.

The fish stock planned in a right way is the fundamental precondition for reaching the demanded results in fish farming. It is necessary to know the biology of the farmed fish, character and production qualities of the pond, as well as the planned farming intensity while calculating the proper amount. It is then the duty of the farmer to bring such knowledge and information into accord. Such knowledge enables to set the species, amount, age category, initial weight per piece, and the planned increment in a way to use the natural food as well as the provided supplemental feeding in the best way possible.

In practice, there are several types known:

- **monocultural –** there is just one species of fish and one age category (e.g. K_0 or K_r, etc.). It is typical of rearing younger fish.
- **combined –** this is a monocultural type – with just one species – but there are various age categories present (e.g. $K_r + K_2$ or $K_0 + K_1$, etc.). This is the type used the least, and for stocking the fish into the pond for two vegetation periods.
- **polycultural –** this means there are various fish species of different age category (e.g. $K_2 + L_1 + Tp_1 +$ $+ Ab_2$ or $K_2 + Š_1 + Ab_2 + Tb_2$) in the pond. It is typical of the main ponds, and it is the most often used method in practice.
- **base –** this type strives to use the maximum of the natural food in the pond without supplemental feeding. It is usually used when farming extensively.
- **dense –** this type is used in semi-intensive or intensive farming. Its value depends on the amount and quality of the used supplemental feeds during the rearing. In comparison with the base one, this amount is usually several times higher.

To use the pond economically and effectively, it is necessary to set or calculate the fish stock. However, it requires we bring two fundamental requirements into accord:

- to use all the elements from the nutrient cycle in the water environment, i.e. the reserves of natural food (plankton, benthos, water plants, feeding fish, etc.) as effectively as possible,
- to reach the planned increments of the reared fish at the end of the vegetation period.

If the above mentioned demands are not observed, two situations with negative effect may happen:

- firstly, **the pond over-stocking.** It means that a higher amount of fish was stocked into the pond, calculated per unit of the area, than is the production capacity of the pond. Although the natural food is used better, which is then seen in certain increase in the yield per hectare, the higher amount of fish causes high food competition. This then decreases the growth intensity and brings about a **non-standard** final weight per piece of the reared fish. Sometimes it may also cause weakening of the organism and increased incidence of diseases and parasites. Moreover, when the planned increments are not achieved, it has a negative effect on the economic results, since the crop rotation is prolonged and the selling price is decreased, or also unintended costs of treating the fish are created,
- secondly, **the pond under-stocking.** It means that there are much less fish in the pond, calculated per unit of the area, than is the production capacity of the pond. In this case, there is no food competition, although the planned growth is much higher, which also causes that the reared fish have a **non-standard** final weight per piece, as well as a "non-standard" selling price. Since there are less fish in the pond, not all natural food is consumed, which is then left unused. This is another negative effect of this phenomenon. In other words, the investments in the amelioration measures (mainly liming and fertilization) flow away from the pond together with water. This is of course then seen in the considerable decrease in the hectare yields.

2.7.1 Calculation of the base monocultural fish stock

The basic type represents the calculated amount of fish (the carp) of a certain age category, which will be reared in a pond usually for a whole vegetation period and fed only by the natural food, i.e. without any supplemental feeding.

The calculation depends mainly on the natural production of the pond, planned increment per pieces (the difference between weight per piece of the stocked fish and the fished out ones), and expected losses, which generally occur during the vegetation period. The calculation is implemented in two ways – according to **Walter** (1) or **Judin** (2).

1) $$O = \frac{H \times P}{V - v} + s$$

2) $$O = \frac{H \times P \times 100}{(V - v) \times r}$$

where:

O – calculated fish stock per whole pond (pcs)
P – natural productivity of the pond ($kg.ha^{-1}$)
H – size of the pond (ha)
V – weight per piece of the fished out fish ($kg.pcs^{-1}$)
v – weight per piece of the fish stocked into the pond ($kg.pcs^{-1}$)
s – expected losses of fish (%)
r – survival rate of the fish (%)

When all the variables are substituted into the equation, we calculate the amount of fish in pieces, which are needed for the certain pond. Values of the variables are contingent mainly on the species and age category of the farmed fish, but also on the way and intensity of farming, and type and quality of the pond, etc.

The variable "**H**" – **the size of the pond –** this value shows the size of the water surface (not the cadastral area) in hectares. Value of the whole area of the water surface is used in the calculation, although the pond is filled with water gradually (e.g. when rearing K_0 ⇨ K_1, or K_r ⇨ K_1).

The variable "**P**" – **the natural production of the pond –** this value reflects the quality (productivity) of the pond – i.e. the amount of natural food, which is created in the pond in normal conditions during the vegetation period. In other words, **it shows the weight increments of the reared fish per year**. The value is influenced by many factors (altitude, location, capacity of the water source, character of the surrounding areas, length of the vegetation period, average water temperature, presence of the water plants, depth of the pond, thickness of mud, implemented amelioration measures, etc.), and in practice, it is estimated usually by the increments of fish from the previous period (usually 5 – 10 years). If these data are missing, the estimation is performed based on the increments in the similar ponds located nearby, i.e. in the basin. Bonitation of ponds by their productivity may also serve as a tool for estimating the natural production value (Table 2.3).

Table 2.3: Bonitation of ponds by their productivity

Bonitation class	Natural production ($kg.ha^{-1}$)	Character of the pond
I. highly productive	> 200	shallow, with fertile washed down water, loam bottom, lower altitude
II. with good production	100 – 200	shallow, loamy-sand bottom, medium altitude
III. medium productive	50 – 100	deeper, slightly flowing, shadowed or in higher altitudes
IV. little productive	< 50	highly flowing, loamy-gravel bottom, highly overgrown, higher altitude

The natural production value could be calculated by the following equation:

$$3)\qquad P = \frac{V - v - \frac{K}{k}}{H}$$

where:

P – natural production ($kg.ha^{-1}$)
K – amount of the feed (kg)
V – weight of the fished out fish (kg)
k – absolute feed conversion ratio of the feed
v – weight of the fish stocked into the pond (kg)
H – size of the pond (ha)

The variables "**V**" and "**v**" – **weight per piece of the fished out fish, and of the fish stocked into the pond.** The difference between them (V – v) shows **the real increment per piece.** This can range from the record growth, when there is surplus natural food, to minimum values, when there is lack of natural food in adverse conditions. In normal conditions, the carp reaches the following values at the end of the vegetation period: K_1 0.015 – 0.05 kg, K_2 0.3 – 0.6 kg, and K_3 1.5 – 2.0 kg.

The variables "**s**" and "**r**" – **the expected losses and the survival rate.** There are some expected losses from the rearing period of the certain age category. On the other hand, the survival rate shows the amount of fish which are fished out in autumn, i.e. the amount we gain after subtracting the losses **(r = 100 – s)**. Regarding the carp, the losses reach the highest values (and the lowest survival rate) when rearing the fry (K_0), and using method of rearing in fingerling ponds only. The losses of 70 – 95% are expected (with the survival rate of 5 – 30%). When rearing $K_0 \Rightarrow K_r$, the primary losses are expected to be 55 – 65% (with the survival rate of 35 – 45%), and when rearing $K_r \Rightarrow K_1$, the secondary losses are expected to be up to 25% (with the survival rate of up to 75%). Lower losses are expected when rearing the two-years-old fish ($K_1 \Rightarrow K_2$), when we expect the value of 10 – 30% (with the survival rate of 70 – 90%), and the lowest losses (and the highest survival rate) occur when rearing the marketable fish ($K_2 \Rightarrow K_3$) – 2 – 5% (with the survival rate of 95 – 98%).

Task 1

We have a pond with the size of 50 ha and with the natural production of 300 $kg.ha^{-1}$, which serves for producing the marketable carp. Calculate the base fish stock.

Solution 1

Firstly, we need to choose the equation – either according to Walter, or Judin. Secondly, we substitute the data from the task into the equation and calculate it. If some variable is not directly set in the task, we try to derive it from the achieved knowledge. ☺

Calculation 1

- according to Walter: $O = \frac{H \times P}{V - v} + s = \frac{50 \times 300}{1.5 - 0.5} + 3\% = \frac{15{,}000}{1} + 450 = 15{,}450$ pcs of K_2
- according to Judin: $O = \frac{H \times P \times 100}{(V - v) \times r} = \frac{50 \times 300 \times 100}{(1.5 - 0.5) \times 97} = \frac{15{,}000{,}000}{97} \approx 15{,}464$ pcs of K_2

2.7.2 Calculation of the dense monocultural fish stock

The dense monocultural fish stock of fish is quite similar to the base monocultural one, although it reaches much higher values. It shows the calculated amount of fish (the carp) of a certain age category, which will be reared in the pond for a whole vegetation period and fed by both natural food and the supplemental feed. Amount and quality of the supplemental feed affect the increase the base monocultural fish stock.

When calculating the fish stock, we depend on the natural production of the pond, planned increments per pieces (the difference between weight per piece of the fish stocked into the pond and the fished out ones), expected losses, which occur generally during the vegetation period, the amount of food we are able to provide throughout the whole vegetation period, as well as on the absolute feed conversion ratio of the given feed. The calculation could be performed by two ways – according to **Walter** (4) or **Judin** (5).

$$4)\quad O = \frac{H \times P + \frac{K}{k}}{V - v} + s$$

$$5)\quad O = \frac{(H \times P + \frac{K}{k}) \times 100}{(V - v) \times r}$$

where:

K – total amount of feed (kg)

k – absolute feed conversion ratio of the feed (Table 2.4)

Task 2

We farm a pond with the size of 15 ha, which has the natural production of 300 $kg.ha^{-1}$. During the vegetation period, we feed the fish with 20 tonnes of cereals with the absolute feed conversion ratio being 4. Calculate the stock of the carp.

Solution 2

Firstly, we need to choose the equation – either according to Walter, or Judin. Secondly, we substitute the data from the task into the equation and calculate it. If some variable is not directly set in the task, we try to derive it from the achieved knowledge. ☺

Calculation 2

- according to Walter

$$O = \frac{H \times P + \frac{K}{k}}{V - v} + s = \frac{15 \times 300 + \frac{20{,}000}{4}}{1.5 - 0.5} + 3\% = \frac{4{,}500 + 5{,}000}{1} + 285 = 9{,}785 \text{ pcs of } K_2$$

- according to Judin

$$O = \frac{(H \times P + \frac{K}{k}) \times 100}{(V - v) \times r} = \frac{(15 \times 300 + \frac{20{,}000}{4}) \times 100}{(1.5 - 0.5) \times 97} = \frac{950{,}000}{97} \approx 9{,}794 \text{ pcs of } K_2$$

Table 2.4: Overview of the absolute feed conversion ratio of the chosen types of feed materials

Feed	Absolute feed conversion ratio
Lupine, vetch, peas	3 – 4.5
Bean, soya beans	3 – 5
Corn, feeding wheat and barley meal	4 – 6
Wheat, rye, barley	4 – 5
Rye and wheat bran	4 – 7
Malt flower	10 – 12
Marc	3 – 5
Cooked potatoes	20 – 30
Acorns	8 – 9
Horse-chestnut	7 – 10
Fish meal	1.5 – 3
Meat meal	1.5 – 2.5
Fresh blood	5 – 12

2.7.3 Calculation of the combined maximum amount of fish in the pond

When determining the combined fish stock, the aim is to use as much natural food, mainly plankton and benthos, as possible. This is achieved by choosing the age categories of fish (the carp) which do not compete with one another, or at minimum level, when looking for food. By this measure, we may increase the natural production of the pond by 20 – 50% in comparison with the monocultural fish stock. However, there is a disadvantage of the combined type, too, since the fish must be sorted out during the pond fishing.

The natural food is used in the most effective way when the most distant age categories of fish are chosen to stock into the pond – e.g. K_0 or K_r with K_2. This enables to increase the natural production up to 40 – 50%. On the contrary, a lower effect (at the level of max. 20 – 30%) is reached by a combination of fish which are closer to each other concerning their age – e.g. $K_0 + K_1$ or $K_1 + K_2$.

Before the calculation, we must firstly set **the main and the secondary fish species.** There is a rule that the main fish is older and the secondary one is younger. Subsequently, the calculation is performed separately for the main and the secondary fish. We calculate the value for **the main fish (6)** by the equation we used for the monocultural amount, while **the secondary fish (7)** is calculated by a modified equation. All the variables are identical as in the previous calculation. The variable **n** stands for **the percentage of the increase in the natural production**, which is reached by better utilization of the natural food by the secondary fish. The value is 20 – 50%, depending on the combination of the age categories of the reared fish.

6) $$O = \frac{H \times P \times 100}{(V - v) \times r}$$

7) $$O = \frac{H \times P \times n}{(V - v) \times r}$$

Task 3

We have a pond with the size of 6 ha and the natural production of 400 kg.ha^{-1}. Calculate the combined stock of the carp.

Solution 3

The main and the secondary fish are calculated separately, each of them by a different equation mentioned above. This task requires a bit of analytic thinking, because except for the size of the pond and the value of the natural production, not all the variables are set directly in the task. We start with the size of the pond – **6 ha.** Based on this information, we know that it is a **rearing pond,** which serves for **the production of two-years-old fish**. Therefore, we know the variables "**V**", "**v**", and "**r**", and we may finish the calculation for the main fish. The secondary fish is then derived from the main fish (K_1), and we adjust also the variable "**n**". To calculate the value, we then just substitute the variables "**V**", "**v**", and "**r**" into the equation.

Calculation 3

- main fish $$O = \frac{H \times P \times 100}{(V - v) \times r} = \frac{6 \times 400 \times 100}{(0.6 - 0.04) \times 85} = \frac{240{,}000}{47.6} \approx 5{,}042 \text{ pcs of } K_1$$

- secondary fish $$O = \frac{H \times P \times n}{(V - v) \times r} = \frac{6 \times 400 \times 20}{(0.04 - 0.0) \times 10} = \frac{48{,}000}{0.4} \approx 120{,}000 \text{ pcs of } K_0$$

2.7.4 Calculation of the polycultural fish stock

The aim is to use all the natural food elements as effectively as possible, concerning mainly those not used by the carp as the main reared fish, or used to a small extent. By choosing the right fish species (depending on the character of the natural food, which could be found in the pond), we may increase the natural production by more than 20%.

Also in the polycultural maximum amount, **the carp is the main reared fish** and **the other species are additional.** Firstly, the main fish is calculated by the equation for the base or dense monocultural fish stock. Secondly, the secondary fish is added as a proportion of the main fish production. For example, 10 – 20% of tench, 30 – 50% of herbivorous fishes, 10% of pike, and 10 – 15% of pikeperch and catfish are stocked with the carp (100% – the main fish calculated in the same way as the base or dense monocultural fish stock), depending on the reared age category. The second option, although less used, is to calculate the polycultural amount by the equation. This is used mostly for calculating the **amount of carp and tench (8)** or **carp and herbivorous fish species (9)**.

$$8) \quad O = \frac{P_k \times 100}{V} \times \frac{100}{r} \times k$$

where:

O – stock of the tench stocked in with the carp (pcs.ha^{-1})

r – survival rate of the tench (%)

P_k – planned production of the carp (kg.ha^{-1})

k – coefficient for specifying the fish stock in the following year of rearing (in the 1st year, k = 1)

V – planned increment per piece of the tench (kg.pcs^{-1})

$$9) \quad O = \frac{P_k \times A}{V} \times \frac{100}{r} \times k$$

where:

O – stock of herbivorous fishes stocked in with the carp (pcs.ha^{-1})

V – planned increment per piece of the herbivorous fishes (kg.pcs^{-1})

P_k – planned production of the carp (kg.ha^{-1})

r – survival rate of the herbivorous fishes (%)

A – coefficient (grass carp = 30, silver carp = 250)

k – coefficient for specifying the fish stock in the following year of rearing (in the 1st year, k = 1)

3 Nutrition of fish

3.1 Introduction to the nutrition of fish

Fish nutrition is a crucial and intricate aspect of the aquaculture sector. Unlike traditional livestock, fish pose unique challenges with regard to their nutritional needs due to their status as cold-blooded organisms. Cold-blooded, or ectothermic, animals like fish lack the ability to regulate their body temperature internally; instead, their temperature is contingent on their surrounding environment. This underlying physiological variation has a substantial impact on their metabolic processes and dietary requirements. The previously mentioned information point to the fact that when complete feeding mixtures of high quality are used, it is possible to reach the feeding coefficient also below the value of 0.8 – 1.0, i.e. after eating 0.8 kg of the feed material, the fish grows by 1 kg. This apparently absurd mathematical example could be easily explained by different content of the dry basis in the feed material (80 – 90%) and in the body of the fish (20 – 30 %). The nutrition of fish must be approached always individually, with regard to the species (carp, trout, catfish, tilapia, etc.), age category (sac fry, fingerling, two-years-old fish, marketable fish, brood fish), used technology of rearing (pond, cages, flow-through system, recirculating aquaculture system – RAS), or the extent to which the natural food is available within the chosen rearing technology.

Before delving into the study of fish nutrition, it is essential to establish a clear understanding of some key terms. A primary distinction to grasp is the difference between feeding and supplemental feeding. We use the term **feeding** when the provided food is the only or highly dominant food source – for the growth of fish. It concerns mainly the application of food in intensive aquaculture, e.g. in trout farming, when the provided pellets are the main source of food for fish (with regard to the amount of fish, the flying insects or the food floating in the inflow is of no importance concerning the total growth of fish). On the other hand, using **supplemental feeding** means that besides the main food source, e.g. the natural food within pond management, the fish are provided with other feed material (cereals, pellets, etc.). In other words, an "artificial" food component – cereals (as a source of energy) – is

added to the basic source of natural food – zooplankton and zoobenthos (as a source of proteins). The line between the supplemental feeding and feeding could be easily overcome, mainly in case of the great amount of fish (fish biomass) at the end of the vegetation period. This is the moment, when all the natural food could be eaten out in the pond and the fish remain completely dependent on the provided supplemental feed materials, exclusively. By all means, this state is undesirable, because it disproportionally burdens the pond ecosystem (the completely eaten out zooplankton and zoobenthos reduce the possibility for further development of the natural food in the following year), worsens the quality of water (hungry fish seek food in the bottom, and thus increase the turbidity of water, and release more nutrients), increases the consumption of food (both maintaining and production dose of nutrients must be covered by the provided feed materials), worsens the quality of fish (applied doses of saccharide feed materials – cereals have low content of proteins, and they are transformed mainly into fats in the body of the fish), and altogether it worsens the economy of the feed materials.

Additionally, it's crucial to differentiate between the **Absolute Food Conversion Ratio (A-FCR)** and the **Relative Food Conversion Ratio (R-FCR)**. In essence, the feeding coefficient represents the ratio of consumed feed (in kilograms) to the resulting fish growth (in kilograms). This value indicates the quantity of food required to achieve a 1-kilogram increase in fish growth. The A-FCR is employed in calculations when the exact amount of provided feed material is known. It happens mainly in intensive fish farming, where there is no other source of food. In some cases, it is also possible to use the A-FCR in calculations within pond management, mainly when calculating the natural production of the pond with added supplemental feeding, and when calculating the amount of the needed feeds. The R-FCR is used mainly in pond management, where there is natural food in an unknown amount used besides the known "artificial" feed materials (cereals).

Endogenous diet – during the embryonic and larval stage, the demands on nutrients are met by the yolk sac. Quality of the endogenic diet could be influenced only by the quality of the gonadal products of the brood fish, mainly of the active females.

Exogenous diet – this occurs when the fry starts to swim and the nutrients are consumed from the yolk sac partially, and it switches to the natural food, or the supplemental artificial feeds.

3.2 Food intake, digestion and efficiency of the feed material

The success rate in fish farming is intricately tied to the nutritional aspects of the process. Nutrition, in this context, refers to the intricate interplay between food intake and digestion. To economically feed the fish, whether through regular feeding or supplemental feeding, a comprehensive understanding of feeding principles, nutritional requirements, and the feeding behavior of the fish is imperative.

To achieve cost-effective and efficient feeding practices, each stage must be approached meticulously. These stages include **ingestion** (the process of food intake), **digestion, absorption of nutrients, their transportation** within the fish's body to meet metabolic needs, and the subsequent **excretion** of metabolic byproducts (such as excrement, urine, and ammonia through gills). It is paramount to harmonize each of these steps to ensure proper growth and development in fish.

In essence, the key to successful fish farming lies in aligning the processes of food intake, digestion, nutrient absorption, metabolic transport, and waste excretion. By understanding and optimizing each of these individual steps, one can foster the ideal conditions for the overall growth and well-being of the fish.

3.2.1 Ingestion

The way we provide the fish with food must take their physiological behaviour and anatomy in the certain phase of life into consideration. Some species are unable to take food from the bottom and only prey when food is moving through the water column. This behaviour may change as the fish grows. Sight is an important sense for eating for many fish (e.g. pikeperch and trout), other use smell and sense of hearing effectively (e.g. catfish, sturgeon), and some use lateral line to feel the water movement (e.g. pike). Structure and shape of the mouth could help us discover the way the fish eat the food, e.g. the common nase has the inferior mouth adjusted to scrape the algae off, the pike has big mouth with teeth, etc. However, the fish teeth serve only for holding the food and not for crushing or cutting up.

Physical and chemical properties of water have a large impact on the right food intake and digestion. Generally, as the water temperature rises, the fish are more craving for consuming food, and their digestion accelerates, too, mainly due to the higher activity of the digestive enzymes and higher level of the physiological processes in the body of the fish. The temperature of 20 – 25 °C is considered optimum for food intake and digestion for the carp, while for the trout, the temperature is only 14 – 16 °C (or 19 °C when there is enough oxygen). Two-years-old and marketable carps start to consume the food when the water temperature is from 7 – 8 °C, but the fingerling can consume when the water temperature is only 4 – 5 °C. This means the fingerling could be fed with supplemental feeding until the water surface freezes up. The trout does not reduce the food intake unless the water temperature falls below 5 °C. Having enough oxygen is the second important factor for digestion. When there is lack of oxygen, fish sometimes even refuse to consume the provided food, while the physiological lack of oxygen and rejection of food may be caused also by limited respiration capacity of the gill apparatus by a disease (a parasite, necrosis, etc.), or other physiological disorder of the oxygen transport from the outer environment into cells of the fish body. For the right conversion of the feeds, and the growth, it is necessary to maintain the saturation of water with oxygen in the outlet of the reservoir at the level of 70 – 75% for the carp, and at the level of 85 – 90% for the trout. For example, when the fry of the catfish is reared, the water saturation with oxygen is being decreased by 50% for several hours after the fry is fed because of the digestive processes. Therefore, it is important to know and monitor the content of oxygen before and also after the feeding. Otherwise, the fish may die, if the provided feeds would not be sufficiently digested and thus used ineffectively. If it is not possible to ensure the necessary level of oxygen in the water in the rearing reservoir or in the inflow water, we must implement aeration or even oxygenation of the water (by liquid oxygen). Within intensive – industrial fish farms, the water is often saturated with oxygen up to the level of 150 – 200%.

3.2.2 Digestion, absorption and transport of nutrients

Anatomy of the digestive system has a great impact on the way and efficiency of the digestion. It differs between the fish species. It would be sufficient to know the fundamental differences between the digestive system of the carp and the salmonids (predatory fishes). The main difference is that the carp does not have a stomach.

In the oral cavity, the food is covered with mucus (not saliva, because the fish do not produce it), which improves the transport of food through pharynx and oesophagus into further part of the alimentary canal. There have been so called pharyngeal teeth developed in the carp species, which help the carp to crush the consumed food by pressing it against the cartilage disc on the palate. After the oesophagus, the food goes directly into the intestine in the carp species (and also in the European bullhead species and loaches). The initial segment of the intestine in carp species is wider, resembling a stomach in appearance, but it functions differently. This anatomical distinction leads to notable physiological consequences. Carp lack the acidic environment for digestion (hydrochloric acid – HCl) and the pepsin enzyme typically found in stomachs for protein digestion. Consequently, these fish digest their food in a neutral or alkaline environment. The expanded beginning of the intestine in these fish serves as a food reservoir. While it may visually resemble a stomach, the intestine operates differently as it lacks glands responsible for producing HCl and pepsin.

Despite this, in salmonids and predatory species, the food goes directly from oesophagus into stomach. Its anatomical structure enables the stomach to distend when larger food is consumed (mainly by predatory species). The inner surface of the stomach is enlarged by gastric folds, which improves the function of the stomach and starts the digestion of proteins. There are three basic types of glands in the mucous membrane of the stomach. The first type produces and releases hydrochloric acid (HCl), the second one produces the digestive proenzyme – pepsinogen which is activated by the HCl into the pepsin enzyme, and the third type produces protective mucus, which protects the mucous membrane from the effects of the low pH. There is rather low pH – almost 2 – in the stomach due to the production of HCl. However, the pH value in the stomach changes depending on the metabolic activity of the fish. Some fishes have also a kind of blind sac created by the stomach (e.g. perch, eel).

The stomach than continues into the intestine through the pylorus which regulates the movement of the food by a valve and a sphincter.

The intestine is not anatomically distinctly divided into small and large, as it is in the more developed vertebrates. However, their functions differ. The intestine itself could be divided into two parts: anterior (proximal) – the small intestine, and posterior (distal) – the large intestine. Some species have pyloric caeca (appendages) at the beginning of the intestine. The appendages are short and blindly-ended projections from the anterior part of the intestine. Their number differs between species. However, their structure and function are similar to the one of the anterior intestine. They enlarge the digestive surface, slow down the transport of food through the intestine, and produce some enzymes (e.g. lipase to digest fats). Non-predatory species have visibly widened space at the beginning of the intestine which resembles the stomach, but due to the neutral pH it functions as the intestine. It functions as a reservoir of food. At the beginning of the intestine, food is already mixed with bile from the bile duct, and also liver and pancreatic, i.e. hepatopancreatic juices which contain digestive enzymes, end in the intestine. Moreover, some proteolytic enzymes are produced also by the surface of the intestine. They include e.g. aminopeptidase, which decomposes proteins into dipeptides and dipeptidases, and they continue with decomposing into single amino acids. In the anterior part of the intestine, digestion of proteins takes place, but it also serves for absorbing fats. The middle part of the intestine absorbs proteins to the largest extent. In the distal part of the intestine, bigger molecules of proteins are absorbed, too, and this happens due to pinocytosis. This process is significant mainly after long-term starvation, and it takes place usually in spring months (to strengthen the immunity). The last part of the intestine serves for ion exchange between food and blood, and for absorption of water, i.e. osmoregulation. Moreover, exogenous enzymes called autolytic enzymes which are produced by the bodies of the consumed natural food (zooplankton, zoobenthos, etc.), are highly important in digestion of fish. They are necessary mainly for the earlier development stages, when the enzyme systems of the fish do not work yet. Chondrostean fishes, which are older within evolution, (e.g. sturgeon), have the intestine surface enlarged by a spiral valve. Length of the intestine in relation to the length of the body differs by the species, and indicates the preferred food of the species. Predatory fishes as pike and trout have the ratio of 1 : 1, perch and pikeperch of 3 : 2, while omnivorous fishes, including the carp, have the ratio of 1 : 2.5 – 3, and herbivorous fishes even 1 : 5 – 6 (grass carp), or 1 : 13 – 15 (silver carp). In comparison with the terrestrial animals, the fish have quite a small amount of microorganisms (only $10^3 - 10^8$ bacteria per 1 g of the volume of the intestine) in their intestine. This could be caused by changes of conditions throughout the year (cold and starvation in winter, warmth and food in summer). The fish completely lack cellulolytic bacteria (except for the herbivorous species) to digest fibre, which thus becomes almost indigestible. The alimentary canal ends with anus, just in front of the anal fin, in the part between the trunk and the caudal peduncle.

The structure of digestive system influences also the intervals of the usual food intake. Fish without stomach consume generally ceaselessly (e.g. the carp), while the fish with the stomach and complete digestive system consume just once in several days (e.g. the catfish, pike). On the other hand, the fish with stomach which is not highly developed consume food more often, even several times a day (e.g. the salmonids).

Endocrine glands play a pivotal role in digestion as they are responsible for producing digestive enzymes and facilitating the transport of nutrients. Among these glands, the liver holds particular significance due to its multifaceted functions. The liver serves as the largest gland, generating bile, which is subsequently stored in the gallbladder. Gradually released into the initial segment of the intestine, bile plays a crucial role in emulsifying fats from ingested food, forming small droplets for efficient processing.

Additionally, bile contributes to neutralizing the pH value and activating pancreatic lipase, an enzyme responsible for breaking down fats, or lipids. Notably, bile is a byproduct of the decomposition of old erythrocytes, underlining the interconnected processes that occur within the digestive system. Through the bile, the body is able to get rid of some toxins and metabolic remnants (bile acid, urea, etc.). Fundamental elements from food (proteins, fats, saccharides) are collected in liver, too, and they are transported from the intestine by the portal vein. Subsequent metabolic processes take place in the liver, where various elements transform substances suitable for the body. These transformed substances are then transported throughout the entire organism via the bloodstream. In addition to its metabolic functions, the liver serves a crucial role in detoxification. It produces glycogen and stores fats as an energy source. An improper diet can lead to the excessive accumulation of fats in the liver, eventually resulting in its gradual degeneration. Perch species, especially those raised in intensive aquaculture, prove to be highly susceptible to such issues. It is essential to note that feeding them with mixtures initially designed for trout, which often contain high-fat content, is not suitable and can exacerbate the problem. Careful attention to dietary considerations is paramount to maintaining the liver health of perch in aquaculture settings. In comparison to proteins, fats are much cheaper source of energy and Therefore, their content in complete feeding mixtures is higher (in contrast to the perch and pikeperch, salmonids put up with it). Pancreas is another important gland for digestion. In some species, e.g. the carp ones, the pancreas does not work separately but is connected with the liver into one compact organ, which is then called hepatopancreas. Hormones are produced in one part of the pancreas, while enzymes in the other. Mainly insulin and glucagon which regulate the blood sugar level belong among the hormones. The pancreatic enzymes could be divided into three groups according to the element of food they decompose. The ones which decompose proteins are: trypsin, chymotrypsin, carboxypeptidase, elastase, and collagenase. Fats are decomposed by the produced lipase, and amylolytic enzymes decompose saccharides: amylase, maltase, laminarinase, chitinolytic enzymes and other. The pancreatic enzymes are released into the intestine together with the bile.

The swallowed food is digested in the stomach and intestine and decomposed into smaller elements which due to their size can be then absorbed through the bowel wall into blood. Such blood is transported by the portal venous system into liver, in which its further processing takes place. The absorbed nutrients are then transported by the portal vein into the liver, from which the blood is transported directly into venous heart.

3.2.3 Excretion

The process of excreting metabolic products in fish differs significantly from terrestrial animals. In fish, up to 90% of the byproducts from protein metabolism are expelled as ammonia through the gills, with the remaining 10% eliminated as urea in urine. However, chondrostean fish, such as sturgeon, exhibit a unique pattern where up to 100% of metabolic remnants are excreted in the form of urea.The quantity of solid excrement produced varies among fish species and is influenced by factors such as the amount and quality of the provided feed material. The digestibility of elements is directly affected by the quality and quantity of the food, contributing to the variability in the excretion process among different fish species.

3.2.4 Nutrient metabolism

Two opposing types of metabolic processes take place simultaneously in every organism. Catabolic processes ensure that the more complex compounds are biochemically decomposed into simple ones (saccharides – glycolysis, fats – lipolysis, proteins – proteolysis), due to which energy is released. This is then digested for the functioning of the organism as well as for the anabolic processes. These energy sources are created either from food or the body reserves. The anabolic processes ensure that the nutrients are changed into substances the body can absorb (e.g. synthesis of the body fats, proteins, glycogen, etc.), while the necessary energy is gained from the catabolic processes. Based on the dominant process of these two, the body either gains weight (grows), or loses weight.

In the assessment of fish food, it is crucial to monitor and evaluate fundamental elements, particularly **Crude Proteins (CP)**, which are categorized into **proteins** and **non-protein nitrogens** such as amides, amines, nucleic acids, glycosides, alkaloids, and more. Notably, among the non-protein nitrogens, it is noteworthy that amides play a vital role in fish nutrition, serving as a valuable source of certain amino acids (AMA), alkaloids, and glycosides. However, it's essential to be mindful that an elevated content of these compounds in the food may lead to complications in the digestive processes.

Nitrogen-free Extract (NFE) include **saccharides** (sugars/glycides/carbohydrates) and **fats** (lipids). **Mineral substances** are other significant elements, which could be divided into **biogenic elements**, or macroelements (C, O, H, Ca, P, S, N, K, Na, Cl, Mg), and **trace elements**, or microelements (Fe, Cu, Zn, Mn, Co, I, F, Se). **Vitamins** are important, too. These could be divided into **fat-soluble** vitamins (A, D, E, K + essential fatty acids – known as vitamin F) and **water-soluble** vitamins (complex of vitamins B, C, P). Water is the particular element of food.

Proteins

In the assessment of fish food, it is crucial to monitor and evaluate fundamental elements, particularly nitrogenous substances, which are categorized into proteins and non-protein nitrogenous compounds such as amides, amines, nucleic acids, glycosides, alkaloids, and more. Notably, among the non-protein nitrogenous compounds, it is noteworthy that amides play a vital role in fish nutrition, serving as a valuable source of certain amino acids (AMA), alkaloids, and glycosides. However, it's essential to be mindful that an elevated content of these compounds in the food may lead to complications in the digestive processes. However, digesting proteins for energy is undesirable, and it occurs in nature mainly during the period of long-term starvation, e.g. during wintering phase, or when the fish stay in fish tanks for a long period. Proteins belong among the most expensive elements within feeding mixtures.

Amino acids (AMA) serve as the foundational building blocks of proteins, analogous to the bricks shaping the structure of a fish's body. They can be categorized into essential AMA, which are irreplaceable and cannot be synthesized by the organism due to their complex structure. Fish obtain these essential amino acids exclusively from their diet, and any deficiency may impede fish growth or compromise the overall health of the organism. In the realm of fish nutrition, there are ten essential amino acids: arginine, phenylalanine, histidine, isoleucine, leucine, lysine, methionine, threonine, tryptophan, and valine. The second group encompasses the so-called nonessential amino acids, implying that they can be, to some extent, replaced or synthesized by the organism. When needed, the organism is able to synthesize them by reconstructing one AMA into another. However, they should not be lacking in the food for a longer period, because the growth would be limited. There are around fifteen types of AMA, including e.g.: alanine, glycine, cysteine, asparagusic acid, glutamic acid, etc.

Proteins could be divided also into complete – those which contain all essential AMA – and incomplete – those which contain only some essential AMA. Among the complete proteins belong the ones of animal origin, mainly fish meal, various meat and meat and bone meal, or even yeast (generally the proteins from unicellular organisms). Among the incomplete belong mainly the plant-based proteins, e.g. soya. Digestibility of the complete proteins is at quite high level and may reach 80 – 95%. The final metabolic product of proteins in fish is ammonia (up to 90%) and urea (around 10%), in chondrostean fishes – sturgeons – only the urea. Fish excretes the ammonia through gills. If there is high content of ammonia in the water, the fish cannot excrete its metabolic products from the body against the concentration gradient, and so called autointoxication by ammonia happens. This means the fish is poisoned by its own metabolic products, and it dies.

Fats (lipids)

Fats play a vital role as a significant energy source for fish. Additionally, they serve as a structural and functional component of the body, particularly in the composition of cell membranes. Fats also influence the absorption of fat-soluble vitamins within the body. There are three primary categories of fats: triglycerides (neutral fats), phospholipids, and cholesteryl ester. Certain types of fats, categorized as „functional," are essential for fish but cannot be synthesized by the organism itself. Therefore, they must be obtained from the diet in their entirety. These essential fatty acids include linoleic acid, linolenic acid, and arachidonic acid. The inadequate presence of these acids in the diet may lead to growth-related issues.

The neutral fats are decomposed after they are emulsified by the bile and lipase into monoglycerides and then into glycerine and higher fatty acids. The lipase enzyme is produced mainly by pancreas and partly also by the surface of the intestine. The lipase is the most effective under the pH level of 8.4 – 8.7. Fats are digested in the anterior part of the intestine, and it is rather slow process. On the other hand, the digestibility rate of the fine fats reaches up to 90%. It is affected positively by autolytic enzymes from the consumed food, as in case of proteins. Energy is then released into the body from the absorbed fats due to lipolysis. The energy rate reaches 2.3 times higher value than when proteins or saccharides are decomposed. Fish store energy in fats for the period of starvation. Reserve fat is usually deposited into liver, sometimes into muscles or even below the skin. In many species, excess, or reserve fat is stored in the abdominal cavity – so called **visceral fat.** Fall of temperature and shortening of the day affect the way the fish deposits fat, because it is a natural signal for the organism to prepare itself for winter. Amount of fat is conditioned also by the species. Therefore, it is possible to divide fishes into three groups according to the fat content in their bodies: little fat, with the fat content of around 1% (e.g. the predatory species), medium fat with the fat content of 3 – 10% (e.g. the carp), and fat with the fat content of more than 10% (e.g. the eel, silver carp). Excessive intake of fats or saccharides in food increases the amount of the deposited reserves in the body. We must also mention that the fish fat contains greater amounts of healthy Omega-3 unsaturated fatty acids.

Saccharides

In general, the saccharides are not as important food elements for fish as the proteins and fats. Fish consume saccharides in a form of simpler sugars (monosaccharides and disaccharides), or in a form of polysaccharides (starch, cellulose, etc.). Also saccharides serve as an energy source, when they are decomposed into glucose. When the glucose is decomposed further by glycolysis, energy is released. When more saccharides are consumed than needed, they are transformed by gluconeogensis into glycogen – the polysaccharide deposited into the liver or hepatopancreas. Its amount is increased in autumn, when the fish body prepares itself for winter, or even spring. Metabolism of saccharides is regulated in a neurohormonal manner by insulin, glucagon, adrenaline, and noradrenaline. Blood sugar level reflects the current stress level of the organism, as well as it responds to the amount of oxygen in water. Low amount of oxygen in water affects the intensity of the metabolic processes in the body – glucose is not decomposed and its level in blood remains high. The same phenomenon occurs when the fish is in a stressful situation, since not enough oxygen is consumed by the organism and thus the content of non-metabolised glucose in blood is increased quite quickly.

Digestion of saccharides is performed due to amylolytic enzymes, mainly the amylase. This is produced in pancreas and partly also in the distal part of the intestine and its surface. In the carp and herbivorous fishes, maltase helps with digestion, too. Moreover, the herbivorous fishes have also the enzyme laminarinase produced, which decomposes the polysaccharide laminarin. On the contrary, fish that consume insects have special chitinolytic enzymes produced in stomach or in the intestine surface, if the species do not have the stomach. Moreover, autolytic enzymes from the natural food help to digest saccharides. The digestion happens in the distal part of the intestine and does not begin in the oral cavity as in mammals. Digestibility of saccharides is highly influenced by the complexity of their structure. Concerning monosaccharides, e.g. glucose, the digestibility can be over 90%, while of polysaccharides, it reaches only 40% (e.g. unprocessed starch). Digestion of fibre – the complex and long polysaccharides – is little effective in fish, as they lack suitable gut microbiota and stabile temperature.

Vitamins

Vitamins play a crucial role in the well-being of fish as they are unable to synthesize them, with the exception of vitamin C. Classified as biocatalysts, vitamins are essential components without which certain biochemical reactions in the body cannot take place. Vitamin deficiencies can result in growth disorders. There are two states associated with vitamin deficiency: hypovitaminosis, a partial deficiency in a specific vitamin leading to reduced efficiency, compromised immunity, and diminished reproductive capabilities, and avitaminosis, a genuine deficiency in a specific vitamin causing disease. Younger fish, those in the reproductive phase, and those dealing with illnesses are particularly sensitive to vitamin deficiencies. Under certain circumstances, hypervitaminosis can occur when there is an excessive accumulation of fat-soluble vitamins in the body. Conversely, excess water-soluble vitamins can be excreted from the body, providing a regulatory mechanism.

Since vitamins have a simpler structure, they are not decomposed during digestion in stomach and intestine. They are absorbed through the bowel wall into the blood. Vitamins are gained from the consumed food of both plant and animal origin. Within the intensive farms, the vitamins are usually added to the feed material in a form of premix. These are either "ready-to-digest" vitamins or they are consumed in a form of provitamin which is then converted into the vitamin in the body. More detailed characteristics of the vitamins are provided in the Table 3.1.

Mineral substances

Mineral substances could be found in the body fluids of the fish in a form of molecules and ions, or they are built in bones, teeth, etc. They are consumed within food, or they are absorbed by skin and gills, and excreted by urine, excrement, fish secrete, bile and gills. Deficiency in some mineral substances may cause various health problems.

Table 3.1: Brief overview of the importance and sources of some vitamins for fish (Dubský et al., 2003; Jirásek et al., 2005; Dvořák et al., 2014)

Vitamin	Importance and impact when in deficiency	Source
Fat-soluble vitamins		
Vitamin A (retinol, axerophtol) isomers from A_1 to A_5	This vitamin affects growth and development of the organism and condition of the epithelial cells on the surfaces of the inner organs. It also influences metabolism of proteins, fats, and saccharides. It is also a constituent of visual pigment, rhodopsin. Its deficiency causes development disorders, growth retardation, decreased immunity against diseases, increased level of fat deposited in the liver, and eye inflammation.	Fish oil and fish meal, plant-based feed material with the provitamin of beta carotene.
Vitamin D (calciferol) isomers from D_1 to D_3	This vitamin affects resorption of Ca and P in the digestive system, and contributes to ossification of bones. Its deficiency ends often with rachitis, and bones that become thin (osteomalacia). Moreover, imperfect development of branchial arches could happen, too.	Animal fats, isomers of D_2 and D_3 are the most important, they are produced from the provitamin in skin after UV radiation.
Vitamin E (tocopherol)	This vitamin has antioxidant effects. It prevents toxic peroxides from being produced. It protects unsaturated fatty acids from undesirable oxidation, and affects permeability of cell membranes, and synthesis of fats, mainly the phospholipids. Moreover, it helps with tissue respiration and affects the utilization of vitamin A. Deficiency in the vitamin E reduces fertilization of eggs, causes reproduction problems, liver degeneration, and muscular dystrophy.	Plant-based feed material: seeds of cereals, cereal sprouts. Animal feed material: liver.
Vitamin K	This vitamin affects coagulation. Its deficiency could be caused after treatment by sulphonamides.	Green parts of the plant-based feed material.
Vitamin F (linoleic, linolenic, and arachidonic acid)	This group of three essential fatty acids has an effect mainly on metabolism of fats, and functions of reproductive organs, endocrine glands, and stomach mucous membrane. Deficiency causes growth disorders and fat degeneration of the liver.	Linoleic and linolenic acid could be found in plant fats, while arachidonic acid in animal fats.
Water-soluble vitamins		
Vitamin B complex B_1 (thiamine)	This vitamin is important for the metabolism of saccharides. Its deficiency slows the growth down, reduces food intake, and causes disorders of the nervous system.	Cereals, yeast, bran, animal feed material (fish meal, blood, milk).
B_2 (riboflavin)	It participates in metabolism of proteins and fats. Its deficiency slows the growth down.	
B_5 (pantothenic acid)	This vitamin is important for the metabolism of all the nutrients in the body. Deficiency causes retardation of growth and skin disorders, too (boils, inflammations).	
B_6 (pyridoxine)	This vitamin is important for energy metabolism and proper functioning of the digestive system. Its deficiency slows the growth down.	
B_7 (vitamin H, biotin)	This is important for metabolism of all the nutrients. Deficiency reduces the growth and causes skin diseases.	

continuation of the table 3.1

Vitamin	Importance and impact when in deficiency	Source
B_8 (choline)	This vitamin helps with metabolism of fats, and participates in production and regeneration of cell membranes. It is also important for nervous system, as it helps with transfer of nerve impulses. Its deficiency may cause degenerative changes of the liver as well as slow the growth down.	Cereals, yeast, bran, animal feed material (fish meal, blood, milk).
B_{12} (cobalamin)	This vitamin affects mainly the production of erythrocytes, and participates in the metabolism of proteins. It is important for nervous system and synthesis of DNA and ATP. Its deficiency worsens conversion of feed material, and slows the growth down.	
Vitamin C (ascorbic acid)	It participates in the metabolism of proteins and saccharides. It is also important for immunity of the organism. In intensive farms, this vitamin is added to the feed material to limit effects of stress. Deficiency causes absence of appetite and stops the growth. It may also lead to bleeding into the liver, intestine or kidneys.	Fish can synthesize this vitamin. Plant-based feed material is the source of this vitamin.
Vitamin P (citrin)	This vitamin complements the vitamin C and they usually work together. This vitamin consists of three substances which affect elasticity and permeability of capillaries.	

Water

Total body weight of fish, depending on the species and content of fat, is made up of 60 – 80% of water. The water content is maintained by osmoregulation. Body of freshwater fish contains more "salts" and Therefore, the water constantly flows into the body. On the other hand, ions tend to leave the body and be released into the surrounding environment. Freshwater fish must excrete a huge amount of water through kidneys. However, their urine has low content of salt and thus is hypoosmotic (Therefore, it can activate the sperm earlier than needed during the artificial stripping). Despite this, the body of the freshwater fish tries to collect ions of salts as much as possible and prevents them from leaking into the surrounding environment. Concerning the marine fish, the situation is different. Due to higher salinity, water constantly leaves the body of the fish. Marine fish are Therefore, forced to drink a huge amount of water incessantly, which is absorbed through the intestine into the whole body. Kidneys of such fish thus excrete just a little amount of urine. However, the urine is very rich in salts (hyperosmotic).

3.3 Characteristics of the natural food of fish

In their natural environment, fish feed solely on the natural food provided by the ecosystem. Although in mature age every species may feed on different food, at the beginning of their exogenous diet, fish always feed on zooplankton, or zoobenthos. The size of the consumed food depends on the size of the mouth as well as on the general way of feeding. When feeding the earlier stages of fish, we must remember that due to great content of water, certain space deformation of the food may occur when feeding e.g. by zooplankton, according to the needs of the fry. However, this could not be expected when feeding the fish by dry feed material with low content of water, which could not be compressed.

In general, the natural food of fish could be characterised by having relatively low content of dry basis (10 – 15%), high content of proteins (30 – 70%), low content of fat (5 – 20%), and relatively stable content of saccharides (15 – 38%). Besides the ratio of the nutrients, ratio of crude proteins and nitrogen-free extracts (fats and saccharides) is also important, and it usually reaches the value of 1:1 (1:0.3 – 1.8). More detailed overview of the natural food of fish is provided in the Table 3.2 and 3.3. The natural food is very well digestible, and it contains all the essential elements. The included proteins hold by rather short bonds, and thus they are digestible very easily, which is demanded mainly by the earlier stages. Larvae of *Chironomidae* contain higher amounts of proteins than zooplankton, and it changes throughout the year. One of the important attributes of the natural food is that the digestive enzymes of the consumed organisms help fish with the digestion.

Table 3.2: Nutritional values of the chosen groups of the natural food of fish (Schwarz et al., 1995; Chábera, 1973)

Parameter	Zooplankton	Oligochaeta	*Daphnia*	Chironomidae	*Artemia salina*
Dry matter (%)	10.5 – 13.3				
Crude proteins (%)	54.8 – 69.8	40	30.0	48.40	41.40
Fats (%)	5.7 – 13.2	8.8	5.14	4.30	18.80
Saccharides (%)		38.0	16.80	26.30	3.48
Ash (%)	9.0 – 21.0				
Salts (%)		6.20	33.06	12.40	34.24
Chitin (%)		7.0	15.0	8.60	
Energy (kJ.g^{-1})	18.2 – 23.2				

Table 3.3: Average values of the nutrient composition of the important groups of animals consumed by the carp shown in % of the dry basis and some cereals in a raw state (Füllner et al., 2000; Guziur et al., 2003)

Group of organisms	Crude protein	Fats	NFE[1)]	Ash	Nutrient ratio[2)]
Chironomidae	52.1	7.7	26.7	7.7	1 : 0.6
Daphnia sp.	43.6	9.6	23.4	17.0	1 : 1
Copepoda	42.0	33.0	20.0	6.0	–
Ephemera	60.5	15.9	15.4	8.7	1 : 0.8
wheat, (12% humidity)	12.1 – 15.2	2.1 – 2.3	78.3 – 81.0[1)]	1.9 – 2.2	1 : 4 – 5
corn, (12% humidity)	10.7 – 11.0	2.5 – 4.7	80.2 – 84.4[1)]	0.9 – 1.7	1 : 5 – 6

Note: 1) NFE (nitrogen-free extrats) are partly almost non-digestible by the carp, e.g. chitin (shells of zooplankton), other elements of NFE, e.g. cereals (usually starch) are easily digestible NFE by the carp

2) the nutrient ratio is the ratio of the digestible proteins to the other digestible BNLV, both numbers set in the ratio are converted into a caloric value (Guziur, 2003)

Within pond management and semi-intensive rearing, the optimum ratio of the natural food to the provided artificial feed material (cereals) is 1 : 1, although the minimum is 1 : 3. The natural food could be substituted only for complete feeding mixtures, which observe the nutritional demands of the species and the age category. Light zooplankton is some sort of "mother's milk" for the earliest stages of fish, since it enables the fry to develop in the best way possible. Therefore, it is so hard to replace it, mainly concerning the carp species.

3.4 Nutritional requirements of fish

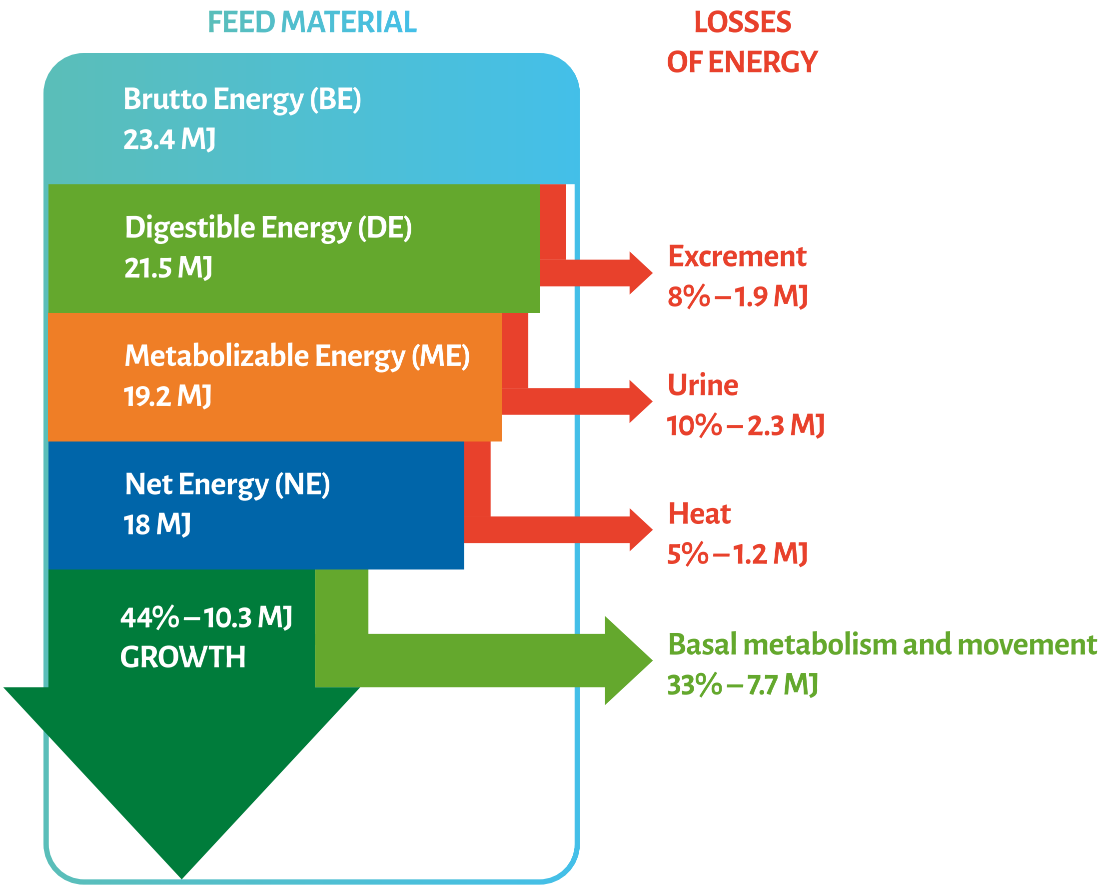
Since the fish are cold-blooded organisms, their need for energy is considerably lower in comparison to the warm-blooded ones. Besides other reasons, they do not need to maintain their body temperature constant. Movement in the water – swimming – is also less energy-consuming than walking or running. Moreover, assimilation of the consumed food and basal metabolism (the basic processes of life) are also less burdening. Finally, excretion of the products from the metabolism of the nitrogenous substances also saves energy. While in the higher warm-blooded animals the remnants of the nitrogenous substances must be metabolized into molecules and excreted through kidneys in a form of urine (this process requires energy), in fish it does not happen. Fish excrete molecules of ammonia (NH_3) directly from their bodies. They are excreted from blood into water. On the other hand, they are susceptible to poisoning when the content of ammonia in the water is high, since they are not able to excrete NH_3 from their bodies against the concentration gradient. In such cases, so called autointoxication by ammonia happens, which causes death. Due to the facts mentioned above, the fish reach lower feeding coefficients compared to poultry, pigs, etc.

As the size and weight of the fish raises, intensity of the metabolism is decreased. That is why we never calculate the necessary energy and nutrients from the current weight of fish, but the feeding dose is derived from the so called metabolic weight. This feeding exponent reaches in case of fish the value of 0.8, and the metabolic weight is calculated as $W^{0.8}$, where W means the weight of fish. In practice, the feeding dose for fish is calculated as a proportion to the current weight (biomass).

3.4.1 Energy requirements

Daily need for the minimum maintaining energy for fish under optimum temperature ranges from 40 to 100 kJ.kg$W^{0.8}$. In comparison to the warm-blooded animals with the same weight, the value is 10 – 20%. The highest losses of the received brutto energy – BE – within the feeds are the excreted undigested remnants of the feeds – the excrement. Regarding the type and quality of the feeds, the losses reach 8 – 40% from the BE (Picture 3.1). Losses of energy caused by respiration and urine reach only 8 – 12% from the digestible energy (DE), which is 9 – 16% from the BE. During the nutrient metabolism, energy is released in a form of warmth. These losses are not high and they reach around 5% from the BE. However, when fish are farmed in recirculating systems, greater biomass of fish (tens of tonnes) could increase the temperature by their metabolism by 1 – 2 °C. The energy requirements within nutrition of fish are usually stated in a form of BE or DE. Metabolizable energy (ME) is not used for fish, since it is difficult to state it (because of a rather problematic way to collect fish urine), and it is similar to the DE. Needed DE and BE for the carp and trout is given in the Table 3.5 and 3.6. Lack of energy in the feeds slows the growth down, and worsens utilization of proteins in the feeds. Since proteins are the most expensive components of the feeding mixtures, it is important to favour mainly fats (for the trout) and saccharides (for the carp) for the energy.

We may estimate the content of DE in the given foods due to the known data of the content of the basic nutrients and content of energy in the individual elements. It is usually derived from the knowledge of the content of energy in the feeds, which is listed in the Table 3.4.



Picture 3.1: Graph of the utilization of the received energy from the feed material by the salmonids, and identification of the losses (source: BioMar Group)

Table 3.4: Overview of the content of energy in the basic nutrients within the feed material of the carp and trout (Jirásek et al., 2005)

Nutrients	Content of BE (kJ)	Carp		Trout	
		DE (kJ)	Coefficient of digestibility (%)	DE (kJ)	Coefficient of digestibility (%)
Crude proteins (1 g)	23.9	16.8	70.29	16.8	70.29
Fats (1 g)	39.8	33.5	84.17	33.5	84.17
Saccharides (1 g)	17.6	14.7	83.52	8.4	47.73

Based on the data stated in the Table 3.4, we can calculate the content of the DE in the feeds for both the carp and trout, using these 2 equations:

$$1)\ DE\ carp = 0.0168 \times NL + 0.0335 \times Fat + 0.0147 \times NFE$$

$$2)\ DE\ trout = 0.0168 \times NL + 0.0335 \times Fat + 0.0084 \times NFE$$

where:

CP – content of the crude proteins in the feeds,
Fat – content of fat in the feeds,
NFE – content of nitrogen-free extracts in the feeds

3.4.2 Protein requirements

The protein requirements for fish are determined in relation to the crude proteins (CP) content in the dry matter of their feed. Depending on the species, age category, and breeding technology employed, fish typically require protein levels ranging from 20% to 65% in their feeds (refer to Tables 3.5 and 3.6 for specifics). Predatory species such as trout, pikeperch, and catfish have a higher demand for proteins compared to omnivorous species like carp and tilapia. Furthermore, younger age categories of fish, particularly fry experiencing rapid growth, necessitate a higher protein content in their diet compared to adult fish. This nuanced understanding of protein requirements tailored to species, age, and breeding methods is essential for optimizing fish nutrition and fostering healthy growth. Finally, the necessary level of proteins in the feed material is affected also by the accessibility of the natural food within the particular farming technology. Fish farmed in ponds with more natural food demand considerably lower content of proteins in the feeds. Concerning salmonids, the need for proteins is decreased if enough energy is provided by other sources, mainly by fats. This then reduces the energy utilization of proteins.

In general, the feeding mixtures for the fry of salmonids contain up to 48 – 50% of CP, while for the one-year old fish, it is only 44 – 46% of CP, and for the marketable fish, even 40 – 42%. On the contrary, for the carp fry (less than 50 g of weight) reared in the pond, the content of CP is at the level of 27 – 30%, and when an insufficient amount of natural food is provided, the level is 32% of CP. For the two-year old carp with the weight less than 300 g, the level is around 25% of CP, and when it gains weight, the level is decreased to 20 – 22% of CP. In summer, when the water temperature is optimum but there is lack of natural food, the carp demands higher content of proteins in the provided feeds: K_1 (less than 50 g) demands 40 – 42%, K_2 (less than 500 g) demands 35 – 40%, and K_3 (more than 500 g) demands 30% of CP. This shows that as the carp grows, the proteins requirement is decreased. Similar interdependence occurs also concerning the water temperature – as the water temperature is decreased, decreased, proteins requirement is decreased, too. It is known that the minimum necessary level of proteins is approximately 1 g.kg^{-1}.day^{-1}, while the optimum conversion and growth is reached when the amount of proteins is 6 – 7 g.kg^{-1}.day^{-1}, i.e. it reaches the maximum growth when the content is 12 g.kg^{-1}.day^{-1}.

Lately, the requirement for digestible crude protein (DCP) in a ratio to the digestible energy (DE) has been expressed and reviewed, both for the trout and carp (g DCP/ MJ DE^{-1}). For the trout, this ratio should reach 22 – 24 g DCP.MJ DE trout^{-1} in the production mixtures, while for the carp, it should be just 18 – 20 g DCP.MJ DE carp^{-1}.

Fish, like other animals, lack the ability to synthesize certain amino acids, rendering them irreplaceable and essential for their well-being. Approximately ten such amino acids include cystine, methionine, tryptophan, valine, threonine, leucine, isoleucine, arginine, histidine, lysine, and phenylalanine. An improper proportion of these essential amino acids in the feeds can diminish the overall efficiency of protein utilization in the diet. Therefore, chosen amino acids, mainly lysine, methionine, and cystine, are added sometimes to the feeding mixtures.

Table 3.5: Recommended content of energy and nutrients in the feeding mixtures for the carp and trout (Jirásek et al., 2005)

Species and category of feeds/fish	Crude proteins (%)	Fats (%)	NFE (%)	Fibre (%)	Ash (%)	Brutto energy (kJ.g^{-1})	Size of particles (mm)
Carp							
Preliminary feeds	45 – 55	12 – 15	15.0		10.0 – 12.5	20.3 – 21.0	0.1 – 1.5
The initial feeds	40 – 42	8 – 12	15 – 20		7.0 – 10.0	18.5 – 20.0	1.5 – 6.0
Supplemental feeds	32 – 35	6 – 7	38 – 42		7.5 – 8.0	17.0 – 17.5	
Growth and health-supporting feeds for K1	20 – 22	10 – 12	50 – 55		7.0 – 9.0	17.5 – 18.5	
Supplemental feeding of K_2 and K_t	25 – 27	4 – 5	60 – 65				
Trout							
Fry	47 – 64	7 – 20		0.2 – 0.8	6.5 – 9.0		0.3 – 1.3
One-year-old fish	42 – 55	12 – 23		0.1 – 1.5	6.5 – 11.0		1.3 – 2.0
Marketable fish	38 – 48	13 – 27		0.7 – 2.4	5.5 – 11.3		2.0 – 6.0

Fish meal could be considered to be the ideal source of proteins. Concerning its global scarcity on the world market and thus rather high price, we try to limit its use to the minimum. Substitutions for the fish meal are provided mainly by the plant-based products – soya, lupin, corn, rapeseed, unicellular organisms (proteins of bacteria and yeast), krill, algae, etc. It is expected that also meat and bone meals from the warm-blooded animals would be used again.

However, they are prohibited to prevent bovine spongiform encephalopathy from spreading. Without satisfactory solution to the rising proteins requirement for the feeding mixtures, it would not be possible to maintain the contemporary increase in the fish production within intensive aquaculture. This is the reason why we should not be worried for the future of of pond management, concerning this problem.

3.4.3 Fat requirements

Fats are an important source of energy, mainly for the predatory species, for which the digestion of saccharides is more difficult. Also some vitamins are bonded with fat, as well as are the essential fatty acids. Mainly the oils with a low point of solidification and high content of unsaturated fatty acids satisfy the fish. Fat gained from big farm animals (fat, suet) is not suitable for feeding fish, because it has a high point of solidification. Poultry fat is a bit more suitable. The fish oil is the ideal source of fat for the feeding mixtures for fish. However, similarly to the fish meal, the fish oil is lacking on the market and its price rises. Therefore, it is usually substituted by alternative oils, mainly the plant-based ones (rapeseed, flax, etc.). Demands on the content of fat for the carp and trout are listed in Tables 3.5 and 3.6.

For the carp, the optimum content of fat in the feeds is 8 – 10 (12)%, while the most intensive growth is reached when the fat level is 17 – 18%. Despite this, the fat content over 10% usually causes extensive depositing of fat in the fish body. Salmonids require much higher content of fats, up to 27%, since the fat is the main source of energy for them, and they are able to use it effectively. Their optimum growth level is achieved when the fat content in the feeds is 18 – 22%. On the contrary, using the feeding mixtures set primarily for the salmonids with the fat content above 12 – 15% to feed the perch or pikeperch in intensive aquaculture may lead to serious health issues – fat degeneration of the liver. It is hence necessary to choose the fat content in the feeds responsibly and with respect to the species. Higher fat content in the feeds raises the growth intensity of fish and conversion of nutrients, which then leads to a higher level of depositing the fats in the internal organs, and reduces yield of fish in the processing. Moreover, higher fat content in the feed material at the exclusion of saccharides reduces growth intensity of the carp. As previously emphasized, the presence of essential fatty acids is paramount in fish nutrition. A deficiency in these acids can lead to growth retardation, impaired conversion of feeds, excessive fat deposition in the liver, and manifestations of shock syndromes, such as apathy. The recommended levels for linoleic acid are 0.8% for trout and 1.0% for carp, while the suggested levels for linolenic acid are 1.0% for trout and 0.5% for carp. Achieving these recommended levels is crucial to ensure optimal health and growth in fish.

Table 3.6: Need for nutrients, energy, mineral substances and vitamins in the feeding mixtures for the carp and in the complete feeding mixtures for the trout – content per 1 kg (Jirásek et al., 2005)

Nutrient	Carp fry	Production feeding mixture for K_{2-t}	Feeding mixture for K–ponds	Trout fry	One-year-old trout	Marketable trout
Dry matter (g)	880	880	880	880	880	880
Digestible energy (MJ)	16.0	15.0	14.0	20.1	20.5	19.7
Fibre (g)				2 – 8	10 – 15	7 – 24
Fat (g)	120	80	60	70 – 200	120– 230	130 – 270
Crude proteins (g)	420	350	250	500	460	420
Lysine (g)	22.0	20.0	17.0	19.9	18.3	16.7
Methionine (g)	15.4	14.0	11.9	14.3	13.2	12.0
Methionine + cysteine (g)	20.7	18.8	16.0	18.7	17.2	15.7
Threonine (g)	16.1	14.6	12.4	14.5	13.4	12.2
Tryptophan (g)	3.3	3.0	2.6	2.4	2.2	2.0
Arginine (g)	22.7	16.0	17.5	20.5	18.8	17.2
Calcium (g)	3.0 – 7.0	3.0 – 7.0	3.0 – 7.0	15.0	15.0	15.0
Phosphorus (g)	4.0 – 6.0	4.0 – 6.0	4.0 – 6.0	13.0	13.0	13.0
Magnesium (g)	0.4 – 0.7	0.4 – 0.7	0.4 – 0.7	0.4 – 0.7	0.4 – 0.7	0.50
Potassium (g)	6.0– 12.0	6.0 – 12.0	6.0 – 12.0	6.0– 12.0	6.0– 12.0	7.0
Sodium (g)	12 – 30	12 – 30	12 – 30	12 – 30	12 – 30	6.0
Chlorine (g)						9.0
Manganese (mg)	13.0	13.0	13.0	13.0	13.0	13.0
Zinc (mg)	80 – 200	80 – 200	80 – 200	80 – 200	80 – 200	30
Iron (mg)	200	200	200	200	200	60
Copper (mg)	3.0	3.0	3.0	3.0	3.0	3.0
Iodine (mg)						1.1
Selenium (mg)	0. 5 – 1.0	0.5 – 1.0	0.5 – 1.0	0.5 – 1.0	0.5 – 1.0	0.3
Vitamin a (tis. Iu)	10.0	9.50	8.0	10.0	6.0	2.5
Vitamin D_3 (tis. IU)	2.40	1.75	1.50	2.4	2.4	2.2
Vitamin E (mg)	250	200	100	400	300	50
Vitamin K_3 (mg)	10	8	7	10	10	
Vitamin B_1 (mg)	20	15	10	20	15	1.0
Vitamin B_2 (mg)	20	17.5	15	30	25	4.0
Vitamin B_6 (mg)	15	10	10	25	20	
Vitamin B_{12} (mg)	0.04	0.035	0.20	0.05	0.04	0.01
Biotin (mg)	1.00	0.75	0.60	1.0	0.9	1.0
Folic acid (mg)	7.0	5.5	5.0	0.01	8.0	1.0
Niacin (mg)	120	100	80	180	175	10.0
Pantothenic acid (mg)	50	45	40	50	50	20
Choline (mg)	1,000	800	750	2,000	750	700
Vitamin C (mg)	250	200	150	250	225	50
Myoinositol (mg)						300

3.4.4 Saccharides requirements

Although saccharides are an important source of energy for the terrestrial animals, they are not irreplaceable nutrients for fish. As we have mentioned earlier, fish are able to gain enough energy from proteins and fats. Moreover, their natural food is quite poor in saccharides. This is the reason why the appropriate enzymatic systems for digestion of saccharides have not been developed in some species (mainly the predatory fishes). Omnivorous species, including the carp, are more able to digest saccharides. The carp can gain up to 75% of the BE from raw starch in the feeds, while the trout can gain only 50% of the BE. Hydrothermal treatment of starch increases its digestibility for the trout by 10 – 15%. In the feeding mixtures for the salmonids, the content of the untreated starch should not be higher than 12%. When the starch is treated in a hydrothermal way, its content could be increased up to 20 – 22% for the trout. Within pond management, suitable proportion of saccharides for the carp fry reaches the level of 40 – 50%, while for the older carp (including the marketable carp), we may increase the content of saccharides up to 70%. Regarding such high content of saccharides in the feeding mixtures, we must be aware of the risk of depositing the surplus energy into a form of body fats (the process of lipogenesis). In general, the optimum level of saccharides in the complete feeding mixture is 26 – 35% for the carp. Digestion of fibre is highly problematic, because fish do not have the suitable gut microbiota developed. Excessive amount of crude fibre thus reduces digestibility of nutrients in the feeds, and also increases production of excrement (water pollution). The amount of thick fibre should not surpass 2% for the trout and 6% for the carp within the feeding mixtures.

3.4.5 Mineral substances and vitamins requirements

Need of fish for mineral substances is similar to the need of terrestrial animals. However, fish may gain some elements from the surrounding environment, too – from water through gills and skin (e.g. Ca), and not only from the food. Requirements for mineral substances and vitamins are listed in the Table 3.6. Greater attention should be paid to the requirement for phosphorus, which is a significant eutrophic element of water ecosystems. On the other hand, its deficiency causes growth problems (ossification of bones), affects metabolism of proteins, saccharides and fats, and influences also the production of erythrocytes and reproductive cells. Retention of the consumed phosphorus in the body of the fish is quite low and reaches the value of 32%. Therefore, the remaining 68% of the consumed P is excreted from the organism by excrement (ichthyo-eutrophication of water). The phosphorus contained in the feeds must be therefore, in a **bioaccessible form**. The phosphorus is mainly inorganic and in a form of monocalcium phosphate. So called **phytate P** that is contained in cereals cannot be digested by fish, since they lack the phytase enzyme. The phosphorus requirement for the trout is at the level of 0.7 – 0.8%, and for the carp, at the level of 0.6 – 0.7%. The proportion of Ca to P should be 1.1 : 1. Yeast and monocalcium phosphate are a great source of phosphorus for fish, because the bioaccessibility rate of P in them exceeds 90%.

Vitamins requirement is relatively low. Within intensive (industrial) farming, it is better to add some vitamins to the feeds in higher content (vitamins C, B – complex) to enable fish to overcome stress easily.

3.5 Choice and characteristics of the feeds for fish

So called **nutrition proportion** is sometimes used to assess the quality of the feeds. It is defined as a ratio of the content of digestible CP proteins to digestible NFE, while both values are expressed as a caloric value (MJ) for better understanding. The range is quite small concerning the natural food, and depending on the food organisms, it is usually 1 : 0.6 – 1. This value is given by a relatively high amount of proteins and low content of NFE (mainly indigestible chitin). For cereals, the value is different, the ratio is 1 : 4 – 6. This is caused by low content of proteins and high amount of saccharides (mainly the starch). Using the feeding mixtures with high content of CP for the carp rearing in the pond conditions is uneconomical. Regarding the accessibility of the natural food with high content of NL, it is possible to use the feeds with low content of CP, with the nutrition proportion of 1 : 6 – 8, for supplemental feeding of the carp. This is impossible when the biomass of fish is large and there is lack of natural food.

In general, we can divide the feeds into **protein** and **saccharide** (glycide), and according to their origin into **plant-based, animal** and **microbial** (bacteria and yeast). Nutritional values of the chosen feeds are listed in the Table 3.7.

3.5.1 Protein plant-based feeds

Lupin belongs among the feeds which were used in pond management mainly in the past for its low price and low nutrition proportion (it contains up to 33% of CP). Today, regarding its insignificant production within the plant production, it is of the peripheral importance. Consumable fish are provided with whole lupin, while the fry and younger fish are provided with crushed or grinded lupin which remains bitter. Yellow lupin: A-FCR 3 – 4, blue lupin: A-FCR 4 – 5, white lupin: A-FCR 5.

Vetch was used in the past mainly as waste after cleaning cereals, in which it dominated. A-FCR 3 – 5.

Pea is willingly consumed by the fish. However, as a feeds it is used rather rarely, only when it is damaged after pond fishing or storing. Before provided to fish, it must be left in water for 24 hours to increase its volume. Otherwise, when provided dry, there is the risk of tearing up the intestine of fish. Pea plants with big grains should be grinded first. A-FCR 3.4 – 5.

Soya is an important and promising component of the feeding mixtures for fish today, and it is rich in CP. Seeds in natural state are used in a limited manner. Various soya coarse meals and feeding flours are used quite often. A-FCR 3 – 5.

Lentil is also quite popular among fish. Usually it is damaged lentil in some way, which is given to the fish. AKK 3 – 5.

Pomaces is produced as waste after oil seeds are pressed. It has quite high content of CP as well as fats. The fats are liable to turn yellow (oxidation). Oxidised fats in the feeds are always very dangerous for fish. Apart from their health condition and digestion, the fats negatively affect also the sensory characteristics of the fish. The marc is used mainly as a component of the feeding mixtures.

Extracted meals are produced after fats are extracted from the ground oil seeds. In comparison with the pomaces, the content of fats is lower, while the content of proteins remains the same. They are used mainly as components of the feeding mixtures. Sunflower extracted meal: A-FCR 3 – 5, flaxseed extracted meal: A-FCR 4, rapeseed extracted meal: A-FCR 4 – 9, hemp extracted meal: A-FCR 5, soya extracted meal: A-FCR 3 – 5, ricin extracted meal: A-FCR 8 (it is not harmful to fish).

3.5.2 Saccharide plant-based feeds

Wheat is one of the most used feed materials in pond management. It is also the most accessible and affordable. Common cereals are given to big fish, of approximately 0.5 kg, as a whole without being treated. However, for the fry and fingerling, it is necessary to grind the cereals (for the fry), or at least squeeze them (for the fingerling). A-FCR 4 – 5.

Triticale is a hybrid cereal created by crossing wheat and rye. It provides good yield as the wheat, and is tolerant of poor soils as the rye, although some farm animals do not like it very much. Fish are different. The triticale is also less expensive than the wheat and Therefore, it is used instead of wheat for feeding the carp. In comparison to other cereals, the triticale provides fish with better sensory qualities, as the rye does. This is achieved also after a longer period. A-FCR 4 – 5.

Rye, just after the corn, has the best values of the feeding coefficients. In some parts of Germany, the rye is considered to affect the sensory qualities of the carp meat positively, and Therefore, it is preferred in feeding. However, this generally happens in small family farms, where they are able to cover the requirement for the feeds from their own sources. A-FCR 4 – 5.

Barley has a bit higher values of the feeding coefficients in comparison to other cereals. On the contrary, it affects the sensory qualities of the fish meat positively, too. A-FCR 4 – 5.

Oat does not belong among the typical cereals used for supplemental feeding of fish. Due to the higher content of chaff and bigger surface of the grains, it is more suitable for the fish that cannot digest cellulose. A-FCR 6 – 8.

Corn has proved the best productive results in many feeding experiments. After consuming the corn, the fish meat reaches its typical smell and consistency, which are different from those reached when feeding the fish with other cereals. Fish gain also more fats. This is typical of the Hungarian carps, since in Hungary, almost solely corn is used for feeding the fish in ponds. In case of the fish transported to

Slovakia from the Czech Republic, the situation is different, since they use almost solely the wheat and triticale, or also some other cereals except for the corn for feeding. On the other hand, it is suitable to use the nutrition benefits of the corn to provide the fry with supplemental feeding in autumn. Due to high content of DE, it is possible to feed K_1 with corn coarse meal from the half of September until the water surface freezes up. Regarding the size of the corn grains, some sorts must be ground before feeding. A-FCR 4 – 6.

Millet is a suitable feed for feeding mainly the fry due to the size of its grains. A-FCR 6 – 7.

Potatoes are not often used as a supplementary food. However, if employed, they should be either cooked, steamed, or ensiled. More commonly, potatoes are integrated into feeding mixtures alongside animal meals. They prove particularly beneficial for autumn feeding to maintain the optimal health condition of fish (K_1) when presented in the form of potato flakes. A-FCR levels that are suggested range from 20 to 30.

Feeding meals and bran are used mainly as components of the feeding mixtures. Despite this, we must emphasise that they usually lack some essential amino acids, e.g. tryptophan and methionine, in case of wheat, lysine, and in case of soya, methione, too. Meals: A-FCR 4 – 6, bran: A-FCR 4 – 7.

Feeding pasta is used mainly in the last period of rearing. We use pasta which was originally set for humans, but became hygienically or technologically unsuitable. It could be bought for good price in pasta-producing factories. Since the pasta was cooked and some other ingredients were added, easily digestible saccharides are contained in it. The pasta is suitable mainly for the fry and fingerling due to its size. Originally dry and hard pasta becomes softer in water, and still keeps its shape for tens of hours. Due to this, it is easily consumed by small fish, too. A-FCR 4 – 5.

Brewer's spent grain is produced as waste after filtering malt in beer production. Malt is produced from crushed malting barley. When in a raw state, we use it for feeding only in a smaller amount. It spoils quickly in summer. When dried, it is used in feeding mixtures. It supports growth, and it is rich in mineral substances. However, it is quite difficult to get it nowadays (since breweries are being closed down).

Molasses is basically the sugar which is left after processing the sugar beet. It is rich in sugars (up to 50%) which are bound with various additives, and Therefore, they could not be gained by crystallization. It has slimy consistency and is highly sticky. Molasses is generally added to the feeding mixtures as a bonding agent. Due to its sweetness, it works as an attractant, too. It is also rich in biologically effective substances.

Also other less valuable grains of the farm crops, or seeds of grass and herbs, including weeds, which could be occasionally gained from the primary producers or drying facilities (storages) of the plant commodities, could be used for feeding the fish in ponds. Furthermore, using also various mixtures of grains of cereals and oil plants, which are gained after cleaning storages of the feed materials, and roads, could be economically and nutritionally very effective. In case of the cereals of lower quality and with higher content of chaff, and seed of weeds, we need to take a higher value of feeding coefficient into account. This deficiency is usually counterbalanced by adequately lower price.

3.5.3 Animal feeds

With respect to their nature, they are used almost exclusively as components of the feeding mixtures.

Fish meal is a significant source of proteins for fish, because it has the ideal nutrition structure. It is gained almost solely from marine species of fish fished out exclusively for this purpose (up to 75%, while 25% of the input materials consist of various waste from fish processing). Almost 200 kg of fish meal and 50 kg of fish oil is gained from one tonne of "raw fishes". Its global production has been reduced in the last years from almost 7 mil tonnes per year to almost 5 mil tonnes, while the need within aquaculture and other fields has been rising constantly. Therefore, the price of the fish meal rises, too. Concerning the fish oil, the situation is similar. Its production has been decreased from original approximately 1.5 mil tonnes to approximately 1.0 mil tonnes per year. This is the reason why farmers make a great effort to replace the fish meal with other components. Fish meals are of different quality concerning the chosen production technology: lighter/darker, while the lighter are of greater quality; or concerning the type of the material used for its production (whole fish/various remnants of the fish). A-FCR 1.5 – 2.

Poultry meal is a source of CP in the feeding mixtures of relatively high quality. However, the content of fats is a bit higher. Its utilization could be restricted by the legislation, which prohibits using the animal meals from the warm-blooded animals to produce feeding mixtures because of the prevention of the BSE (bovine spongiform encephalopathy) disease.

Meat and bone meal is produced in rendering plants from the bodies of dead farm animals. In the past, it was an important and cheap source of CP for the feeding mixtures. However, nowadays its utilization is almost prohibited, based on the above mentioned restrictions (BSE). A-FCR 1.5 – 3.

Blood meal has high content of CP and low content of fat. Its quality depends on the production process. Blood meal of higher quality should have a red-brown colour. If its colour is brown or even black, its nutritional value will be lower. A-FCR 1.5 – 2. In the past, also fresh blood was used for feeding, either without any processing or often after being mixed with feeding flour or potatoes. A-FCR 2 – 4.

Because of the deficiency in the fish meal and mainly fish oil, these irreplaceable sources have been used more economically in intensive farming of the predatory species of fish recently by changing the feeding strategy. Since we know that the quality of fish meat is considerably influenced by the provided food, plant-based sources of proteins and fats used in feeding mixtures for "fattening" are being replaced by the feed materials of high quality on the basis of fish oil and fish meal in the last phase of rearing. This process is called "**finishing feeding**". Due to this three-week procedure, the muscles of fish reach the same quality as when the fish are fed by feeding mixtures of great quality for a long period.

Table 3.7: Nutritional values of the chosen feeds – content per 1 kg (Jirásek et al., 2005)

Feeds	Dry matter (g)	DE–K (MJ)	DE–Pd (MJ)	CP (g)	Fat (g)	NFE (g)	Fibre (g)	P (g)	Ca (g)
Wheat	860	12.54	8.19	111.8	15.5	689.7	25.8	3.0	0.5
Triticale	876	12.62	8.25	113.6	13.1	705.2	25.8	3.4	0.8
Barley	860	10.53	7.08	105.8	21.5	546.1	43.9	3.4	0.9
Rye	891	10.18	7.08	131.4	22.3	491.3	130.0	3.3	0.3
Oat	918	12.24	9.02	155.0	63.3	510.9	97.3	4.8	0.5
Millet	890	12.57	8.33	97.7	31.2	672.0	57.9	2.7	0.4
Corn	890	13.43	8.81	85.4	36.5	732.5	22.3	2.7	0.9
Flax	900	18.40	16.79	207.0	333.0	256.5	63.0	6.3	1.8
Rapeseed	900	19.65	18.47	198.0	405.0	187.2	64.8	7.2	3.6
Pea	860	12.04	8.69	223.6	13.8	532.3	60.2	5.2	0.9
Lupin	860	10.03	7.75	249.4	15.5	362.1	77.4	7.7	1.3
Lentil	880	12.85	9.39	255.2	15.0	548.2	35.2	2.6	
Soya	890	15.76	14.19	356.0	182.5	249.2	53.4	4.5	2.7
Extracted meals, meals and molasses									
Soya	880	12.44	10.59	448.8	17.6	293.0	61.6	5.7	2.6
Rapeseed	880	11.85	9.61	338.8	28.2	354.6	96.8	10.6	7.9
Sunflower	880	10.05	8.28	316.8	17.6	281.6	202.4	10.6	2.6
Flax	880	12.48	10.44	334.4	62.5	324.7	101.2	8.8	4.4
Molasses	750	10.10	6.22	56.3	3.0	615.8		0.8	4.5
Animal meals and yeast									
Fish	910	13.55	13.83	664.3	91.0		4.6	24.6	31.9
Poultry	900	15.85	15.14	522.0	162.0	112.5	13.5	9.0	18.0
Feather	900	14.02	14.43	774.0	58.5		5.4	6.8	5.4
Blood	990	16.16	15.29	821.7	9.9	137.6	1.0	2.0	2.0
Meat and bone	910	12.29	12.26	491.4	118.3	4.6	22.8	42.8	82.8
Whey	968	13.05	8.51	125.2	10.4	720.8		9.0	7.7
Yeast	934	13.78	12.30	491.3	61.6	235.4	16.8	14.0	1.6

Note: DE – digestible energy, K – carp, Pd – rainbow trout, NFE – nitrogen-free substances essential (equivalent of saccharides), CP – nitrogenous substances, P – phosphorus, Ca – calcium

Moreover, costs of plant-based feeding mixtures are lower. This is one of the main strategies nowadays for "saving" the fish meal and fish oil, while the production of fish meat of great quality of the predatory (salmonids) species is rising.

In the Table 3.8, there are reached results of RKK while using various types of cereals listed. The data show that the corn reaches the lowest feeding coefficient, and the triticale is the second, followed by rye, barley and wheat. On the other hand, the discovered differences in RKK are very small, and they change from year to year. Nutritional and production differences between the individual types of cereals disappear when the proportion of the natural food to the total growth of fish in ponds (up to 70%) is high.

Table 3.8: Compared values of the Food Conversion Ratio (FCR) within various types of cereals (Hůda, 2009; Másilko et al. 2009; Másilko et al., 2014)

Crop	Experiment	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average	Total average
Wheat	storage ponds	1.57	2.27							1.94	1.93	1.97
	fish tanks			1.76	1.47				2.39	2.38	2.00	
Triticale	storage ponds	1.61	2.55	1.78	2.10			1.75	1.15		1.82	1.84
	fish tanks		1.40	1.29	1.72	2.08	1.27	2.55	2.63		1.85	
Barley	storage ponds											1.90
	fish tanks		1.54	1.49	1.59	2.50			2.36		1.90	
Rye	storage ponds	1.58	2.11	2.07	1.72						1.87	1.90
	fish tanks		1.36	1.67	2.00	2.17			2.38		1.92	
Corn	storage ponds			1.60							1.60	1.51
	fish tanks		1.47	1.47							1.47	
Average	storage ponds	1.59	2.31	1.82	1.91			1.75	1.15	1.94	1.78	1.87
	fish tanks		1.44	1.54	1.70	2.25	1.27	2.55	2.44	2.38	1.95	
Total average		**1.59**	**1.83**	**1.65**	**1.78**	**2.25**	**1.27**	**2.15**	**2.07**	**2.16**	**1.83**	**1.83**

3.6 Treatment of the feeds

The feeds are treated for three reasons. The most frequent is the treatment of the size of the feeding particles concerning the size of fish (grinding, crushing). Another reason concerns better digestibility of the nutrients (soaking in water, crushing, and heat treatment). Treating the feeds in order to artificially mix various components together into one food feeding mixture (pellets, extrudate, medicated feeds, etc.) is the third reason. It is also possible to combine the reasons.

The method of **soaking the feeds in water** is used mainly in case of feeds which tend to increase their volume in water. These are mainly the legumes: pea, lupin, and bean (Table 3.9). This must be performed otherwise after being consumed, these feeds increase their volume quickly in the digestive systems of fish, and thus may subsequently cause great health problems. Mass die-off of fish occurs quite often when this need is neglected, because the intestines of fish are torn after consuming dry pea. Soaking cereals has proved quite good results, too (it raises the digestibility of nutrients). It is suitable to soak also lighter seeds or feeding flours (coarse meals) right before feeding to ensure they sink quickly to the bottom in the feeding place and do not float pointlessly on the water surface. Due to the soaking method, we can also partially release some harmful substances, or also get rid of chaff or seeds of weeds.

The feeds are usually soaked for 24 hours, and not more than 48 hours to prevent it from fermenting in warm water. In practice, soaking is applied only in the smaller ponds (up to 10 ha). The daily dose in the bigger ponds, the size being several quitals (metric cents) or tens of quintals, could be managed only with difficulties, both organizational and handling.

Table 3.9: Weight increase in the chosen feeds after soaking in water (Čítek et al., 1998)

Crop	Time of increasing in the volume (hours)				
	1	3	6	12	24
Wheat	24	34	41	48	50
Oat	47	54	65	74	79
Lupine	26	58	92	125	130
Vetch	24	60	82	92	92
Pea	25	74	132	182	204

Grinding and crushing are the fundamental methods for treating the size of particles of the feed regarding the size (age) of the fish. Fine grinding and crushing improve digestibility of nutrients, but on the other hand, these methods cause that more nutrients are leached into water (up to 50%), and thus increase the losses of the nutrients carried away in water (up to 30%).

Therefore, we must choose the optimum size of the feed particles very carefully, regarding the size of the mouth of the fish (Table 3.10). To prevent the loose feed from being carried away in the water, we recommend applying the feed into floating frames in the feeding place, or making dough of it when mixed with water. Unconsumed feed could negatively affect the quality of water, apart from the direct economic losses. Fine grinding of the feeding flours is necessary in the production of the feeding mixtures to ensure suitable homogeneity of pellets.

Table 3.10: Compared values of the Food Conversion Ratio (FCR) under various levels of crushing/grinding the triticale (Másilko et al. 2009; Másilko et al., 2014)

Cereal	Storage ponds 2009 (RKK)	Treated feeds saving (%)	Storage ponds 2010 (RKK)	Treated feeds saving (%)
Triticale – without treatment	1.27		2.55	
Triticale – crushed	0.83	**34.65**	2.19	**14.12**
Triticale – meal 1.0 mm	1.15	**9.45**	2.37	**7.06**
Triticale – meal 1.1 mm	1.21	**4.73**	2.84	**-11.37**
Triticale – meal 1.2 mm	103	**18.90**	2.69	**-5.49**
Triticale – meal 1.3 mm	1.18	**7.09**	2.36	**7.45**

The method of **crushing** has become more popular lately, concerning mainly cereals. It means that the grain is crushed between two rollers which move towards each other. The grain breaks and its content is thus more accessible while digesting.

Table 3.11: Compared values of the Relative Food Conversion Ratio (FCR) when treating the chosen cereals by crushing (Másilko et al. 2009; Másilko et al., 2014)

Crop	Experiment	2006	2007	2008	2009	2010	Average	Total average	Treated feed saving
Triticale	storage ponds							**1.91**	
	fish tanks		1.72	2.08	1.27	2.55	1.91		
Crushed triticale	storage ponds							**1.66**	13.12%
	fish tanks		1.47	2.13	0.83	2.19	1.66		
Rye	storage ponds		1.72				1.72	**1.89**	
	fish tanks	1.67	2.00	2.17			1.95		
Crushed rye	storage ponds		1.66				1.91	**1.69**	10.58%
	fish tanks	1.40	1.57	2.13			1.70		
Barley	storage ponds							**2.50**	
	fish tanks			2.50			2.50		
Crushed barley	storage ponds							**2.43**	2.80%
	fish tanks			2.43			2.43		
Average	storage ponds		1.69				1.69	**1.76**	
	fish tanks	1.54	1.69	2.24	1.05	2.37	1.78		
Total average		**1.54**	**1.69**	**2.24**	**1.05**	**2.37**	**1.78**	**1.78**	

Moreover, such broken grain absorbs water more quickly (it gets softer), which affects the efficiency of digestion positively. This treatment is suitable predominantly for lighter fish. In total, R-FCR is lowered due to crushing by 2 – 20% in comparison to the untreated cereals (Table 3.11). Cereals that were treated this way can be stored only for a limited period, usually for weeks (max. a month). Therefore, they are not suitable for storing in silos for the whole vegetation period. Moreover, moistness of the grains and right setting of the rollers affect the optimum quality of the crushing process.

Heat treatment (hygienization) is one of the new methods which have been used lately to improve digestibility of the feeds. It is used mainly in pond management to treat cereals. Due to a shorter period of treatment (60 – 90 seconds) and high temperature (75 – 85 °C) provided in a form of steam (95 – 100 °C), the starch becomes slimy up to the level of 60 – 90%. This raises digestibility of nutrients, and eliminates anti-nutritional substances and pathogens, which then decreases the R-FCR (Table 3.12). On the other hand, in comparison to squeezing, water resistance of the grain membrane is maintained (nutrients are not leached).

Table 3.12: Compared values of the Relative Feed Conversion Ratio (R-FCR) of the chosen cereals under various temperatures (Másilko et al. 2009; Másilko et al., 2014)

Cereal	fish tanks 2010 (RKK)	treated feed material saving (%)	fish tanks 2011 (RKK)	treated feed material saving (%)	fish tanks 2012 (RKK)	treated feed material saving (%)
Triticale – untreated	2.55		2.63			
Triticale – squeezed	2.19	**14.12**				
Triticale – treated with heat of 100 °C	2.05	**19.61**	2.35	**10.65**		
Triticale – treated with heat of 120 °C	2.75	**-7.84**				
Triticale – squeezed and treated with heat of 120 °C	2.31	**9.41**				
Barley – untreated			2.36			
Barley – treated with heat of 100 °C			2.04	**13.56**		
Rye – untreated			2.38			
Rye – treated with heat of 100 °C			2.23	**6.30**		
Wheat – untreated			2.39		2.38	
Wheat – treated with heat of 100 °C			2.58	**-7.95**	2.44	**-2.52**
Wheat – squeezed and treated with heat of 100 °C					2.21	**7.14**
Cereals together – untreated			2.44			
Cereals together – treated with heat of 100 °C			2.30	5.74		

In practice, it is quite difficult to verify whether the heat treatment was performed technologically correctly. It is impossible to distinguish the treated grains from the untreated at first sight. Implementing the test of germinability is the only way to prove the right way of the heat treatment.

Pelletization is essentially the process of homogenizing and compacting finely ground, moistened feeding components into pellets. Typically, a pressure of 30 – 60 MPa.cm-2 is applied, and the temperature of the pelletized material ranges from 70 to 120 °C, often limited to 80 °C for a few minutes. The application of heat causes starch to become gelatinous (15 – 30%), enhancing the digestion of saccharides. There are two distinct pelletization processes – dry and moist. In the moist process, a loose mixture of components is steamed, undergoing hydrothermal treatment. The resulting mushy material is then pressed through a matrix with the required mesh diameter (for carp, typically 2.5 – 4 mm). Rotating knife then cuts off the mixture in the necessary length and thus creates pellets. The Pellets must be then immediately cooled down and dried to maintain their quality. There are several risks connected with this methods – pellets being steamed up, multiplying of germs (e.g. salmonella, moulds, etc.), or debasing some components by high temperature (e.g. fats, vitamins). By the pelletizing process, it is possible to reach the proportion of fats in the mixture only up to 8 – 12%. If the content of fat is higher, stability of pellets is disrupted (compactness). Within aquaculture, stability of pellets in water is quite problematic when using the pelletized feeding mixtures. Pellets of lower quality tend to fall apart after being soaked in water and thus become problematic for consumption, not mentioning the release and infusion of the nutrients or medicaments. These are the reasons, why the pellets set for fish should remain stable, mainly concerning their shape, for at least six hours. Before buying any pellets, it is necessary to test their compactness, e.g. in a glass of water. With respect to the difficulty of production, concerning mainly energy, which subsequently affects also the price, the pelletizing method is used only partially in pond management. Pellets are used usually to feed the fingerling as well as two-years-old fish in autumn and to support the health condition of fish. These mixtures are relatively poor in NL, but rich in saccharides. When there is not enough natural food in the ponds, feeds with higher content of NL could be used. The pelletized mixtures are used quite often also as a vehicle of medicaments (see the medicated feeds).

Extrusion is a newer way to produce shaped feeding mixtures. In comparison to pelletizing, higher temperature (over 100 °C) is used for a shorter period, usually only for seconds. Due to this, the level of the starch sliminess is high and reaches 80 – 100%. This has a positive effect on digestibility and stability of pellets. Heated matter is pressed through a matrix with the necessary size of mesh (0.3 – 8 mm). It expands after the contact of air and cools down, and the moistness is decreased below 8%. Due to this technology, we may reach the content of fats in the mixture up to 27% and produce pellets with different weight, in the range from those floating on the water surface to those sinking quickly to the bottom. All the feeding mixtures for salmonids and some other species of fish farmed in intensive aquaculture are produced by extrusion nowadays.

Surface finish is used in some specific cases, e.g. **obduction – spraying a layer** of e.g. fats on the **surface** of the produced pellets. Due to this process, we may increase the content of fats in the feed, since the demanded final value could cause technological problems in the production of the pellets with high content of fats. Secondly, some specific substances could be added (e.g. vitamins, antioxidants, and medicaments) on the pellets, since such substances would not "endure" the forming process. Additional surface finish may be performed also to strengthen the stability of the pellets in water and reduce the amount of crumbs.

Medicated feeds are basically the general pelletized or extruded feeding mixtures enriched by medicaments and attractant (the substance for taste). They are used to treat the fish directly in the ponds or rearing units, without fishing them out. The medicaments are applied by veterinary prescription only. However, consumption of food in a certain stage of some diseases might be quite problematic, or the fish might stop to consume the feed completely. Thus, treatment with the medicated feed is basically impossible in such case. It is also important to teach the fish to consume the feed in the feeding places before providing the medicated feed. To raise the appetite for food, it is recommended leaving out one feeding dose of the standard feed before serving the medicaments. Starved fish would consume more willingly and in shorter time, so the level of diffusing the medicament into the water would be decreased. It is ideal to provide the medicaments in the morning. Fish should be drawn to the feeding place in order to ensure that every fish consumes at least several pellets with medicaments. According to the instructions of the producer and veterinary prescription, pellets are served repeatedly for several times. In pisciculture, two types of feeding mixtures with medicaments are served more often. This feed is named **Rupin Special** – it contains broad-spectrum antibiotics called oxytetracycline with added vitamin A and some other additional substances. It is used for treating bacterial diseases, mainly erythrodermatitis. Wheat flour serves as the vehicle. Pellets which were produced the right way remain stable for 12 hours in the water. One-time feeding dose equals 15 $g.kg^{-1}$ of the weight of the amount of fish in the pond. The Rupin Special is provided repeatedly four times in a period of 2 – 3 days. The fish should consume the mixture ideally in 6 hours. The water temperature during the treating process as well as in the two-week period after the treatment should be over 12 °C. The safety period is 378 °D, which means that the fish should not be transported and provided on the market for human consumption until the end of this period (since the antibiotics must be sufficiently released from the fish). The feed could be used approximately for 6 months (the expiration period). The second used feed is named **Taenifugin carp.** It is used for treating the intestinal helminthiasis (trematode, cestode). Piperazine salt of niclosamide (as the sodium salt), Prazicest, is the effective substance which destroys parasites in the digestive system right in several hours after consuming the feed. The pellets remain stable for 12 hours in the water. The one-time feeding dose equals 1 – 2% of the weight of the total amount of fish in the pond. It is provided repeatedly every 48 hours. After 2 – 4 days, we may perform a control medical examination of the fish. If the result is still positive, we repeat the treatment. When the treatment is over, it is suitable to make the repeated veterinary examination of fish every 3 – 4 weeks, since in this period, another generation of parasites matures. The safety period for the Taenifugin carp is 36 hours, and the expiration period is 6 months. We must point out the fact that there is no sense in sparing expense on the medicated feed. The feed bought from the local producer of the feeding mixtures for farm animals must also have sufficient stability in water. When this condition is not met, the money is utilized ineffectively and without the demanded treating effect. When rearing the salmonids, feeding mixtures, produced in a special way, are enriched by approved medicaments and offered by all the reputable producers. They are ordered and applied only by the veterinary prescription.

Semi-moistened feeding mixtures are used when switching from the natural food to pelletized mixtures, mainly for the predatory species (catfish, pikeperch, eel, and perch). They are produced from finely ground fish meat (ideally from fillets without head and bones). Species as silver carp, crucian carp and other white or less valuable fish (up to 50% from the mixture) are used. The rest is composed from various animal meals (e.g. fish meal), plant components (e.g. wheat and soya flour, rapeseed oil), bonding agent (e.g. dried whey), and premix of vitamins and minerals. The individual components are mutually homogenised and the created paste is then pressed through a matrix for meat mincing. The gained noodles are frozen and subsequently provided when needed. Medicaments may be added to the semi-moistened feeding mixtures, too.

Fish silage was used in the past for feeding the salmonids. It is produced from undesirable species of fish (e.g. non indigenous invasive fish species and/or less valuable fish). The dead fish set for ensiling are firstly ground and pressed through the matrix of the mincer with the size of the mesh being 10 – 15 mm. The gained mixture is homogenised in the mixer (for 3 – 4 minutes) together with the formic acid (85%) in the amount of 30 g per 1 kg of the ground fish, and added antioxidant (e.g. Curasan 200 $mg.kg^{-1}$). The silage is stored in closed plastic barrels or plastic sacks. Depending on the temperature, the silage is liquefied and ready for application in 2 or 3 weeks. During the time the silage ripens, it is recommended stirring the mixture from time to time. The silage of good quality has the pH value in the interval of 3.9 – 4.5. Spoiled silage has putrid smell with the scent of ammonia. The standard nutritional values of the fish silage are approximately 13% of NL, 15% of fats and up to 4% of ashes, when the content of the dry matter is 26%. Various moistened feeds – feeding pastes – are produced from the silage. They are produced after mixing the dry plant-based flours (wheat, soya) or the animal meals (fish, meat and bone) with the silage in a ratio of 1 : 1.

3.7 Supplementary feeding technique

Supplemental feeding stands out as one of the most effective intensification measures to boost fish production per unit area. As mentioned earlier, the core concept involves combining natural food as a protein source with „artificially“ introduced saccharide feeds, typically derived from cereals, serving as an energy source. This strategy efficiently conserves valuable proteins for growth by utilizing them primarily as an energy source. It is imperative to initiate supplemental feeding at the earliest opportunity to preserve natural food sources, such as zooplankton and zoobenthos, to the maximum extent. This proactive approach extends the presence of natural food in the pond. For a visual representation, refer to the basic classification of zooplankton illustrated in Picture 3.1.

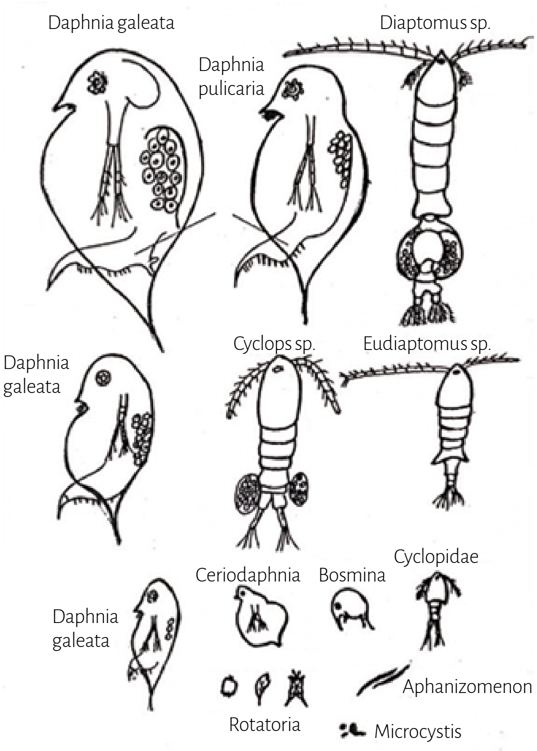
The annual consumption of the feed could be derived approximately from the fact that usually 2 – 3 tonnes (semi-intensive ponds) of cereals are consumed per 1 ha of the pond per 1 year, or up to 6 tonnes (intensive ponds). Multiplying the planned fish production by the acceptable R-FCR at the level of 2 (the planned production of fish multiplied by 2) is the second way to count the annual requirement for feeds quickly. The right way to count the required amount of the feed for a certain pond should take the total desired growth of fish and natural pond production – added growth reached by supplemental feeding – into consideration (see the chapter on the fish stock). The total annual planned consumption of the feeds is determined for the individual months in accordance with the Table 3.13. The table shows roughly the required monthly growths per piece, too.

Table 3.13: Consumption of the feed by the individual months (Pokorný et al., 2004)

Month	Amount of the feed material (%)		
	Fry K_1	Younger fish K_2	Consumable fish K_3
April	–	5*	5*
May	–	5–10	5–10
June	5	10–15	15–20
July	30–35	20–25	25–30
August	35–40	30–35	30–35
September	10–15	10–15	5–10
October	5	5	–

Note: * Condition feeding

Daily feeding dose is derived from the monthly ration of the feed and is counted out of the fish biomass (the weight of the maximum amount of fish) and with regard to the development of the natural food of fish, current water temperature, oxygen content, health condition of fish, and kind of feed. The value usually ranges from 1 to 4% of the weight the maximum of fish stock. In summer, when the content of oxygen in water is below 4.0 mg.l^{-1}, supplemental feeding is no longer provided. Daily doses of feed for the carp are listed in the Table 3.14 in detail.



Picture 3.1: Basic classification of zooplankton by size (Faina, 1984)

Whether the doses were determined in a right way is verified in monthly intervals by test fishing, when the health condition and the reached growth are checked. Concerning the younger fish like the fry, we do it more often (twice a month). If the planned growth is surpassed, we may reduce the daily feeding dose and vice versa. Time and speed in which the fish consume the provided dose could guide us, too. If it is consumed in two hours, it is small, and if it remains in the water also after six hours, it is probably too big. It is also necessary to check whether all the feed from the previous dose is consumed, before the next feeding.

Table 3.14: Daily doses of the feed for the carp in (K2-3) % of the weight of the maximum fish stock (Pokorný et al., 2004)

Intensity of feeding	Minimum content of oxygen ($mg.l^{-1}$)	Daily dose under the water temperature (°C) in %						
		10 – 11	12 – 13	14 – 15	16 – 17	18 – 19	20 – 21	22 – 26
I.	7	0.6	0.9	1.4	2.0	3.0	4.0	5.0
II.	6	0.4	0.6	0.9	1.4	2.0	3.0	4.0
III.	5	0.2	0.4	0.6	0.9	1.4	2.0	3.0
IV.	4	0.1	0.2	0.4	0.6	0.9	1.4	2.0

Note: I. – no usable zooplankton, II. – sporadic zooplankton, III. – sparse zooplankton, IV. – abundant zooplankton

3.8 Assessment of the feeds efficiency

When we assess the quality of the feeding mixtures and their efficiency, we could use the basic parameters, which are described below. In practice, we use the Feed Conversion Ratio (FCR), either absolute within intensive aquaculture, or relative within pond management.

Feed Convertion Ratio (FCR) – this is a quantity which determines how much feed is required to reach growth of fish by 1 kg. The lower the value, the better the production result.

$$FCR = \frac{F}{wt - w0}$$

where:

F – amount of the consumed feed (kg)

W0 – weight of the fish at the beginning of the monitoring (kg)

Wt – weight of the fish at the end of the monitoring (kg)

Feed Conversion Efficiency (FCE) – this is an inverted value of the FCR, which defines what the achieved growth of fish from 1 kg of the given feed is. The higher the value, the better the production result.

$$FCE = \frac{wt - w0}{F}$$

where:

F – amount of the consumed feed (kg)

W0 – weight of the fish at the beginning of the monitoring (kg)

Wt – weight of fish at the end of the monitoring (kg)

Specific Weight Growth Rate (SWGR) – this shows by how many percents the average weight of the fish rises daily. The higher the value, the better the production result. Besides weight, we may monitor also the growth in length, when the weight is replaced with the length of the fish body.

$$SWGR\ (\%.day^{-1}) = [(\ln wt - \ln wo) \times t^{-1}] \times 100$$

where:

In W0 – natural logarithm of the average weight of the fish at the beginning of the monitoring
In Wt – natural logarithm of the average weight of the fish at the end of the monitoring
t – time of the monitoring, in days

3.9 Application and storage of feeds

3.9.1 Fish feeders

The ways we provide fish with feed are other important aspects of the fish feeding. In smaller farms, feed is usually provided by hand. However, when the farming capacity is high and concentrated at one place, mainly within intensive aquaculture, we could not imagine feeding the fish without **"technical support"**. Although the machinery replaces human hands, it still cannot replace human eyes and mind. Therefore, the farmer still has to perform a real contact with the fish. According to the reaction of the fish to the feed, the farmer can consider the health condition of the fish. In case there is not enough oxygen in the water, or the fish do not consume the feed from any other reason (disease, stress, fullness, etc.), there is no purpose to continue in feeding the fish. Therefore, when using any kinds of feeders, regular control and supervision of the farmer is inevitable.

The most common kinds of feeders are depicted in the Picture 3.2. Concerning the younger age categories of fish, a feeder with clock mechanism (Picture 3.2a) is used. This can ensure that the feed is provided for a long-term period and in smaller amounts. Fry and consumable fish are sometimes fed by a feeder with a bait rod or so called touch feeder (Picture 3.2b). In trout farming, pneumatic feeders which apply daily feeding dose from the container by pressed air are used quite often (Picture 3.2c). New and modern farms with industrial fish farming use automatic feeding systems more and more often, which transport the feeding dose from the central storeroom (silo) directly to the individual reservoirs by pipes for even tens of metres (Picture 3.2d). The movement of the feed through the pipes is either pneumatic or ensured by a spiral conveyor.

3.9.2 Storage of feeds

All types of the feed must be properly stored. In every farm (pond), there must be enough feed for fish ensured to prevent fish from starving. According to the used feed material, its amount and fish farming technology, we establish proper storing facilities. The storehouses must be always dry and uncontaminated by rodents and birds. In intensive fish farming, the feeds are supplied usually on pallets in sacks of 20 – 25 kg each, or in high-volume sacks (big-bag), which happens exceptionally when the purchase is big. However, the situation is different in pond management – pelletized feeding mixtures are used to a minimum extent (feeds for good health condition of fish and with medicaments), and rather great volumes of cereals of different quality dominate in such productions. Since the ponds are usually placed far from one another, proper planning and building the storing facilities is demanded to optimise the production costs (Picture 3.3).

A silo emerges as one of the most practical choices for storing feeds in pond operations. While it may not be a budget-friendly solution upfront, its long-term benefits make it a worthwhile investment, especially for ponds exceeding 5 hectares in size. Although a silo doesn't directly enhance fish production, it significantly improves working hygiene for employees, diminishes strenuous physical labor, and results in savings in both time and money associated with packaging and transporting feeds in sacks. When acquiring and installing new silos for pond use, it's crucial to account for associated secondary expenses. It is necessary to build an adequate concrete base below the silo. This is very important, because fish will always look for some remaining feed in the water below the silo. By such activity, the fish may reach further below the bottom and thus disrupt the stability of the shallow foundations. The base below the silo is usually built in a way to enable a small boat to sail directly under the hopper between the props of the silo. Buying the boat to transport the feed into the feeding places is another type of expenses. Apart from all of this, it is necessary to choose the right capacity of silo, too.

Therefore, a compromise is needed. One of the main criteria in choosing the size of the silo is the general amount of the feed for the particular pond per year, or whether the silo will store feed also for some other ponds lying nearby. For small ponds (the size of 5 – 10 ha), the bottom capacity of the silo is set for year-round consumption of the feed in a way to fill the silo only once a year. The upper limit is usually given by the capacity of the transportation vehicle used for storing (approximately 10 tonnes). If there are two or three ponds with lower consumption of the feed next to each other or placed on one route, it is efficient to plan the capacity of their silos in order to divide the feed proportionately. Concerning big ponds with high consumption of the feeds, silos with multiplied capacity (multiplied by the transporting capacity of the supplying vehicles) are installed, or several silos are placed next to each other or on the other side of the pond. There are several feeding places on the bigger ponds and Therefore, it is suitable to ensure shorter transportation distances (from the silo to the feeding place). Moreover, there are some old tin silos built on many ponds (Picture 3.4a and 3.4f). However, one of their greatest disadvantages is the need for their regular maintenance – painting and repairing rusty spots. They are also liable to leaking which then causes that the stored grains start to go mouldy or sprout. Furthermore, since the metal is thermally conductive, the feed is quite often „sintered“, and water is condensed on the inner walls. Nowadays, mainly fibreglass silos produced in Italy are used (Picture 3.4b). For supplementary charge (approximately 5 – 10%), the producer can supply the silos not in standard white but in any other demanded colour, e.g. in dark green.

Picture. 3.2: Kinds of fish feeders (photo J. Regenda); a – a feeder with clock mechanism, b – a feeder with a bait rod (a touch feeder), c – a pneumatic feeder that can apply feeding doses in intervals and amounts set in advance from the container by pressed air – by a typical „blow", d – an automatic feeder that scatters the feed over the reservoir in set intervals by a rotating disc, this feeder is supplied directly from the silo by a spiral conveyor

Picture 3.3: Storage of feeds (photo J. Regenda); a – a large capacity silo placed directly at the bank of a big pond with transport routes and a facility for treating the grain mechanically (crushing, grinding), b – a central storehouse of the feeds in the area of the storage ponds with routes and facility for treating the grain mechanically (grinding)

The higher the capacity, the lower the price for storing 1 tonne of a feed. This means that the smaller silos are more expensive in comparison to the bigger ones. On the other hand, big silos are quite high and they do not fit into the landscape very much.

Picture 3.4: Ways of storing the feeds (photo J. Regenda); a – an old large-capacity tin silo hidden among the trees on the dam, b – a new fibreglass silo painted green during production to fit into the landscape better, c – a brick feeding hut for storing the feed in sacks, d – a storehouse with the sacks of the feed in the centre, wooden ramp enables to load the sacks from the higher places to the lower ones (lorry – ramp – pick-up), e – during the pond fishing period, it is possible to feed the fish with cheap cereals directly from the lorry, f – we may store cereals placed on the bank of the pond for a shorter period, too; silver (white) colour of the silo decreases its inner temperature, although it does not fit into the landscape

In smaller ponds, where investing in a silo may not be cost-effective for fish production, feeds are stored in wooden or brick feeding huts (see Picture 3.4c and 3.4d). The feed is typically packed into 50 kg sacks. However, the routine packaging and transportation of feeds to the pond can incur significant expenses. Additionally, stored feeds in these huts are often vulnerable to damage by rodents, with sacks being gnawed through and contaminated by urine and excrement. Managing such a burden with its associated hygiene challenges becomes particularly uncomfortable during hot summer days. In the summer, especially during the harvesting period, a short-term solution involves storing the feed directly at the pond's bank. Alternatively, feeding fish directly from a lorry is another viable option (see Picture 3.4e and 3.4f). However, when storing feeds near ponds in the field, whether in silos or feeding huts, the risk of theft must be considered, especially in economically disadvantaged regions. Consequently, it is advisable to construct centralized storage facilities for feeds within closed and guarded compounds, particularly for small and more compact farms (see Picture 3.3).

4 Trout culture

Trout culture is a branch of aquaculture that focuses on farming technology and rearing salmonids and grayling species (so called cold-water organisms) in special facilities of almost non-pond type (flumes, raceways, concrete pools, cages, circular ponds, etc.). Not only marketable fish but also the fry for restocking the fishing grounds is farmed this way. In Slovakia, the rainbow trout, brook trout, and brown trout are reared into the stage of a marketable fish. The huchen (Danube salmon) and grayling are reared only for the the one-year-olds or two-years-old fish, since their rearing process is more complicated.

Mechanization, automation, filtration, recirculation and using monitoring systems in management and operation of the farm are the typical features. **Intensive fish farming** is being implemented in such rearing systems, both in complete and incomplete management, solely on the basis of the Complete Feeding Mixtures (CFM), i.e. without or only with minimum utilization of the natural food.

4.1 Rearing systems

The water source is the main factor for choosing a rearing system, mainly its quality and capacity. This affects also the structure of the species and age categories of the reared fishes, as well as their produced amount. Nowadays, we distinguish four rearing systems – cage, emi-flow-through, flow-through and recirculating.

4.1.1 Cage systems

This fish rearing system is known mainly in Asia, where it has been used for more than 2,000 years for producing various fish species. In Europe, this system has been known since the fifties, mainly for marine aquaculture. In Slovakia, this system has been used since the half of the seventies, mainly to produce the marketable rainbow trout.

For this method, rearing net cages of different construction are used, which are installed in arrays into suitable water bodies (water reservoirs, deep ponds, material pits, etc.). Such water body should be sufficiently big (to produce 1 tonne of the consumable rainbow trout, we need the area of 10 ha) and deep (at least 5 m). The bottom of the cage should be placed 2 – 3 m above the bottom of the reservoir, or at least 1 m, to prevent the fish from coming into contact with sediments. The water temperature in summer should not be higher than 20 °C and the chemical water properties should follow the physiological needs of the rainbow trout. This is mainly the reason why such rearing system is used only in two water reservoirs in Slovakia nowadays – in Liptovská Mara and Palcmanská Maša (the water reservoir Dedinky).

Cages are operated by staff from a boat or a service bench. Monocultural amount of the rainbow trout is placed into the cages early in spring, right after the ice melts down. The fishing out is implemented when the size of a marketable fish is reached. The fish are fished out by hand or by pumps after gathering the net to the centre, directly at the place the cages are installed in, or the cages are drawn to the pier. Nowadays, approximately up to 10 – 15% of the total production of the consumable rainbow trout are produced in Slovakia by this rearing system. Low investment (founding) expenses and high economic effect are the advantages, while difficult prevention and hard physical work are the disadvantages.

4.1.2 Semi-flow-through systems

Within this system of rearing, suitable carp ponds are used – with the depth of 1.5 – 2 m, partially flow-through, situated at higher altitude (above 500 m above sea level), with natural production not surpassing 100 $kg.ha^{-1}$, and constant water source with temperature of not more than 24 °C in summer, and content of oxygen of not less than 5 $mg.l^{-1}$. In this case, the rainbow trout is being reared in a polycultural fish stock way together with the carp, or also with the tench as the main or secondary species. In Slovakia, this system is not used for producing the marketable rainbow trout, except for the production for personal consumption.

4.1.3 Flow-through systems

The flow-through systems represent the traditional way of trout farming in Slovakia, and such facilities were built in the half of the 20th century. These are the systems by which various salmonids and grayling species of fish are grayling species are reared in a monocultural fish stock. Water is flowing through the individual technological units (e.g. hatchery, troughery, rearing tanks, etc.) and subsequently flows away from the farm into the recipient. Depending on the capacity of the water source, these technological objects could be **supplied in a parallel way**, i.e. every object has its own inflow and outflow, or these objects are **linked into a series**, i.e. the individual objects are ordered one after another and the water flows from one object to another. However, the second option is less common and also the less suitable from the veterinary viewpoint.

This rearing system is the most frequent in Slovakia, and up to 85 – 90% of the production of the consumable trout, or up to 100% of the fry/one-year-olds production determined for restocking the fishing grounds, is produced this way.

Water source of good quality and capacity, together with the sufficient area for the optimum deployment of the technological objects are the basic requirements of this rearing system. Lower founding and operating costs are the main advantages, while higher water consumption and higher content of organic sediments in the wastewater are the disadvantages. The wastewater contains also an increased amount of organic substances and residues of medicaments, or disinfectant.

4.1.4 Recirculating systems

Recirculating systems are the modern facilities used for intensive production of various fish species, usually in monoculture. The main idea of this system is to use the water that flows away repeatedly for several times. This water is cleaned and treated (mechanical and biological filtration, aeration/oxygenation, disinfection/sterilization, adjustment of temperature, pH, etc.) to meet the qualitative parameters for the repeated utilization. Circulation of water is achieved in the whole system, and only a small part of it with collected dirt is drained outside the system. Water losses caused by treatment of the recirculating water, draining the dirt, or evaporation are continuously replaced from the water source, which maintains the constant water volume in the system.

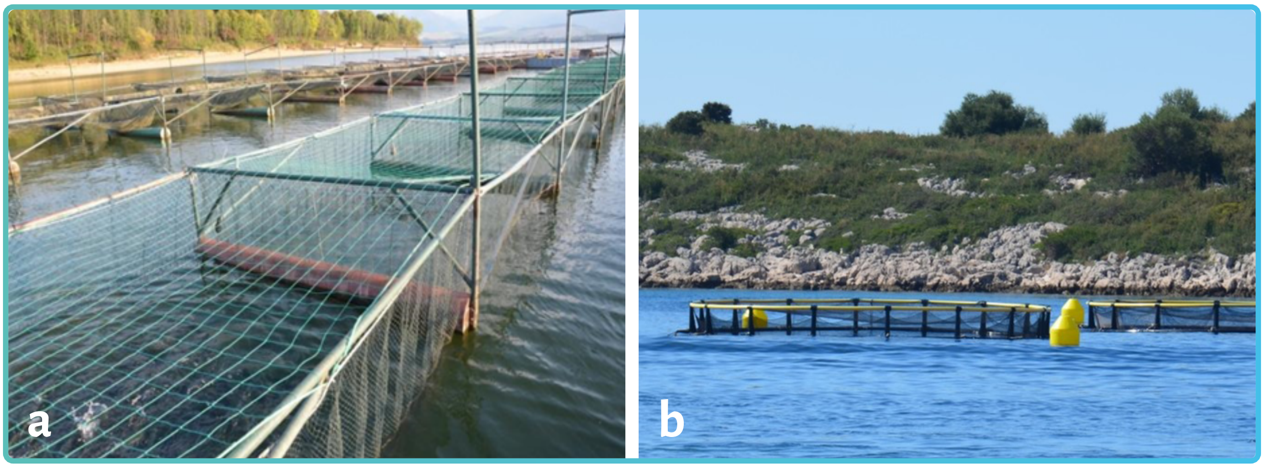
Lower water consumption, decreased demands on space (built-up area), low incidence of health problems, reduced requirement for human work, and minimum or no production of wastewater are the advantages of this system. On the other hand, higher investment and operating costs, higher demands on technology, equipments and security of the area, as well as on expertness and reliability of the staff, and uninterruptible power supply are the disadvantages of the system. For salmonids and grayling species, the rearing system must be situated in higher altitude, above 500 m above sea level, because of rather high average summer temperatures.

Nowadays, there is only one rearing system of this type in Slovakia (Turčianske Teplice). Originally it served for the production of the marketable eel, but now aquarium fishes are produced there. Concerning pollution of the environment, the recirculating systems seem to be a promising alternative in intensive fish production, in comparison with the traditional flow-through systems, mainly when speaking of the tightening the legislative norms for protecting water up, either within the European Union or in Slovakia.

4.2 Rearing facilities

4.2.1 Net Cages

Cages are floating rearing facilities with metal or plastic construction, of various sizes, usually of circular, square, rectangular, hexagonal, or octagonal shape, and they are anchored to the bottom by anchor blocks or to the banks by anchoring ropes. Netting made from artificial fibres (polyamide, polyethylene, polyester, or by their combination) with diameter of mesh of 2 – 20 mm is placed on such construction, and it provides rearing space, while approximately 1 m is projecting above the water level. For protecting the fish against piscivorous birds, the upper part of the cages is covered with protecting nets. Individual species and age categories need different kind of netting, especially different diameter of the mesh. The net must prevent fish from cage escaping, and also ensure good exchange of water and stability of the whole cage. Depending on the age and weight of the reared fish, we recommend the following size of the mesh: 4 mm for the fish of 1 – 5 g, 6 mm for the fish of 5 – 20 g, 10 up to 12 mm for the fish of 20 – 50 g, and 15 up to 20 mm for the fish of more than 50 g. Cages of square and rectangular shape are mutually connected into more compact units – so called **battery**, placed next to each other usually in two rows, between which a service bench for staff is situated, or there is space left for the handling boat to sail through.



Picture 4.1: Cages (photo: J. Andreji); a – of a rectangular shape, b – of a circular shape

There are two construction types used in Slovakia – cages of metal construction and rectangular shape (Picture 4.1a) with the size of 4 x 3 m, and the depth of netting of 4 m, and cages of plastic construction and circular shape (Picture 4.1b) with the diameter of 12 m and the depth of netting of 7 m. Both types are used for the production of the marketable rainbow trout, while the cages of rectangular construction serve for the production of the the one-year-olds, too.

4.2.2 Ground ponds

These are the first and thus the oldest rearing facilities built for rearing salmonids and grayling species. They are the flow-through ponds of a rectangular shape with a hard bottom and banks, and they are situated in higher altitudes. Their size ranges usually from 100 to 500 m^2, with the ratio of the sides of 1:4 – 8, depth of 1 – 2 m, and volume of water of 70 – 1 000 m^3. Water should be exchanged once in 1 – 2 hours in the pond, water temperature should reach 14 – 16 °C, and the level of oxygen should be at the level of 9 – 12 mg.l^{-1} in the inflow, and at the level of at least 6 mg.l^{-1} in the outflow. These ponds have their own inflow and outflow of water, secured against fish escapes. Both size and number of such ponds depend on the quality and capacity of the water source, terrain conditions and planned production. These ponds are used for the production of all species and age categories of the salmonids and grayling in Slovakia.

Picture 4.2: Earthen ponds (photo: J. Andreji)

The earthen ponds (Picture 4.2) are built very rarely nowadays, although they belong among the cheapest rearing facilities concerning construction investments. The main reasons for this are the more difficult implementation of hygienic measures and increased risk of incidence of parasites.

4.2.3 Concrete pools (canals)

These facilities were built on a mass scale in the sixties and seventies, and Therefore, they are the most common rearing facilities used for rearing salmonids in Slovakia nowadays. They are made from concrete and have a long rectangular shape – of so called Italian type with individual inflow and outflow of water. Their number and size depend on the planned production, which reaches the highest level from all the rearing facilities.

The pools are 60 – 100 m long, sometimes they are divided by bars into 2 – 3 sections, with the width of 2 – 4 m, depth of 1 – 2 m, and the total volume of 120 – 800 m^3. Water should be exchanged every 15 – 30 minutes, while the water temperature should be around 16 °C and the content of oxygen at the level of 9 – 12 $mg.l^{-1}$ in the inflow, and at the level of at least 6 $mg.l^{-1}$ in the outflow.

Since the pools are divided by bars into several sections, the amount of the fish in the second section should be decreased by 25 – 30%, and in the third section, the amount should be lowered again by further 20 – 30% (in total up to 50 – 60%). The last section does not serve for rearing but for sedimentation.

This type of rearing facility is used mainly for rearing the one-year-olds and marketable rainbow trout in Slovakia.

Picture 4.3: Concrete pools (photo: J. Andreji)

4.2.4 Plastic troughs and tanks

These facilities are used mostly for rearing the fry, or one-year-olds. Troughs are flow-through facilities of a rectangular shape and length of 3 – 6 m, width of 0.3 – 0.7 m, height of 0.2 – 0.7 m, and total volume of 3 – 8 m^3 (Picture 4.4a). When using troughs, we must maintain the optimum ratio of the length to the width of 4 – 10 : 1, because if the troughs are too long, risk of oxygen deficiency occurs on the outflow, and sediments and excrement are washed away worse. In the past, such troughs were produced from laminate, while nowadays, they are made from plastic usually (polypropylene).

Plastic tanks of the square shape with rounded corners and the size of 2 x 2 m and depth of 0.5 – 0.75 m are also used for rearing the fry (Picture 4.4b). Water is supplied by directional spray nozzles, which ensure that the water is exchanged evenly and sediments are easily washed to the central waste pipe.

Apart from the plastic troughs and tanks, hanging rubber-textile tanks of square and rectangular shape (Picture 4.4c), or hexagonal shape (Picture 4.4d) fastened to metal construction are used, too. One of the advantages is their constructional character, due to which they save space and are operative and flexible. Moreover, they are cleaned and maintained very easily.

Picture 4.4: Troughs and tanks (photo: J. Andreji); a – plastic troughs, b – plastic square tanks with rounded corners, c – portable rubber-canvas tank (rectangular), d – portable rubber-canvas tank (hexagonal)

4.2.5 Circular tanks

After troughs, circular tanks are the second most used facilities to rear fry and one-year-olds. They have diameter of 2 – 8.6 m, depth of 0.5 – 1.0 m, and total volume of 1.5 – 58 m^3, with a bottom declining to the center. In the past, they were produced from concrete (Picture 4.5a), metal (steel plate) with enamel or stainless surface finish (Picture 4.5b), or laminate. Today, plastic (polypropylene) is the most frequent construction material (Picture 4.5c). These tanks are usually embedded in the ground, but we may find the above-ground tanks, too. The water is supplied by a perforated pipe from the edge to the center of the tank (Picture 4.5d), or by directional spray nozzles along the edge of the tank. The aim is to ensure circular movement of water in the whole volume of the tank, which secures equal distribution of fish in the tank as well as the concentration of excrement and dirt in the center of the tank near the outflow, from which they are easily removed and drained out – by pulling out the central pipe.

Picture 4.5: Circular tanks (photo: J. Andreji); a – a concrete circular tank, b – a metal circular tank, c – a plastic circular tank, d – a plastic circular tank with water supply by a perforated pipe

5 Rearing salmonids and grayling species

The oldest reared salmonid species in Slovakia is the brown trout. The first written record of its rearing comes from the 17th century from the municipality of Kláštor pod Znievom, although there are also records from the 15th and the 16th century, in which fish farming in ponds in northern Slovakia is mentioned. However, these records do not state the fish species. It is highly probable that besides the carp, also the brown trout was reared there.

Fish farming of other salmonids and grayling species dates back to the second half of the 19th century. This is related mainly to the development of trout culture as well as to the import of new fish species from North America. Records of farming the grayling, rainbow trout, brook trout and huchen are known from this period.

Nowadays, the rainbow trout is the main farmed fish in Slovakia within trout culture, with the proportion of around 99%. According to The Statistical Office of SR, more than 1,100 tonnes of the rainbow trout are produced annually on the average, which equals 43% of the aquaculture production in Slovakia. Most of the production is however exported abroad.

Besides this, the rainbow trout is the most fished out fish by recreational fishermen among the salmonids and grayling species. The catches reach annually 40 tonnes on the average, which equals almost 70% of the fished out salmonids and grayling species, or rather 2.5% of all the fished out fishes.

5.1 Characteristics of the individual reared fish species

5.1.1 Brown trout (*Salmo trutta* morpha *fario* LINNAEUS, 1758)

This is our indigenous fish, which lives mainly in mountain and partially submontane brooks and rivers. It can be found in clear flowing rivers with hard gravel or rocky bottom and enough hiding places, in altitudes from 120 m above sea level (Danube) to 1,600 m above sea level (Ľadový brook in High Tatras). It requires cold water, and it is demanding on the level of oxygen dissolved in water. The optimum water temperature is 10 – 15 °C, and during summer, the temperature should not exceed 18 °C, and the oxygen content should be at the level of 9 – 11 $mg.l^{-1}$.

The brown trout is one of the three ecological forms (termed in Latin as „*morpha*"), created by the Atlantic trout (*Salmo trutta* Linnaeus, 1758), and the Black Sea trout (*Salmo labrax* Pallas, 1811). These species are quite similar concerning morphology, and all live in the running water bodies of Continental Europe. Originally, the Atlantic trout was found in the river basins in the Baltic Sea catchment area (approximately 4% of the area of the SR), and the Black Sea trout was found in the river basins in the Black Sea catchment area (approximately 96% of the area of the SR). As time passed by, and mainly inappropriate fishing management took place, massive hybridization of these two species occurred and the interpopulation divergence got lost. Therefore, we could not definitely say based on the morphological features, whether a fish is the Atlantic trout or the the Black Sea trout, and thus the term brown trout is used for this species.

Regarding bionomy, the brown trout is a rheophilous and lithophilous species, which hides its eggs. Distinct sexual dimorphism is seen. Sexually active males have longer head, corners of the mouth extend beyond the posterior edge of the eye, older males have hooked lower jaws, and during the spawning period, the males wear a **wedding dress** – more distinctive colour and darker pigment spots occur on belly and sides. Sexually immature fish have darker transverse marks (stripes) along the sides. Sexually mature fish have red spots scattered around the lateral line, usually with whitish edges.

Spawning of the brown trout occurs from September till December, depending on the altitude. In this time, the fish migrate upstream for a short period, usually to the nearby tributaries and often overcome various obstacles and barriers. Sexually active female of the brown trout trout hides the fertilized eggs after the spawning into a hole prepared in advance – so called **nest** in the bottom. One female has 200 – 5,000 eggs on the average, with dependence on the size, while the relative fertility rate reaches the level of 1,500 – 2,500 eggs per 1 kg of the weight of the female. The eggs have yellow-orange or orange colour and their size is 4 – 5 mm on the average. The period of incubation takes usually 500 – 530 °D (daily degrees). Fish become sexually mature from the 2nd to the 4th year of their lives, while females attain maturity a year after males.

After hatching, the fry is 20 – 25 mm long and hides in rocks. When the fry consumes the yolk sac, which takes usually 20 days, it starts to consume the natural food. Firstly, it consumes small benthos, later becomes predatory. Its growth and size depend on the environment, since the environment is as important as the amount, quality and accessibility of the food. Trout living in alpine brooks with a low food base usually grow to 150 or 200 mm maximum. In normal conditions, this fish grows to 60 – 120 mm in the first year, 100 – 180 mm in the second year, and 150 – 250 mm and 150 – 200 g in the third year. In very good conditions, the trout grows quickly and in 2 – 3 years, it reaches the weight of 0.5 kg.

When reared in farm conditions, the optimum temperature is 12 – 14 °C, while the maximum temperature is around 21 °C. If the water is cooler (below 8 °C), the growth and digestion slow down; if the temperature is high, the level of oxygen dissolved in water is decreased, and there is a risk of die-off.

5.1.2 Brook trout (*Salvelinus fontinalis* MITCHILL, 1815)

This is an allochthonous species, imported from North America in 1884 to Germany, from where it was transported to Slovakia, too. In our area, it lives in running brooks of mountain and submontane zones. It has almost identical demands on the environment as the brown trout, although it could be found rather sporadically (Štrbské tarn, river basins of Torysa, Turiec, Nitra and Čierny Váh). It needs clean, cold and highly oxygenated water, while it tolerates more acid water, too (pH < 5). Due to this, it could live both in forest and peaty biotopes. Unlike the brown trout, it does not demand that many hiding places, so it could be stocked into regulated sections of rivers, too. However, the brook trout could not be stocked into the same rivers as the brown trout because they are mutual competitors, concerning both space and food.

The brook trout is also rheophilous and lithophilous species, which hides its eggs, although it is much more colourful. Its back is olive-green up to bluish green with typical light meander stripes – so called **marbling**. There are also dense red, yellowish and whitish spots on its body. The first ray of pectoral, pelvic and anal fins is cream-coloured, followed by black-coloured, while the rest of the fin is reddish. The sexually active males differ from the females by more intensive colours and hooked lower jaws.

The spawning period takes place from September to December, sometimes to January, too, and at the same place as the spawning of the brown trout. Due to this (the same time and place of reproduction), interspecies crossbreeding sometimes happens, and so called **tiger fish** is produced – infertile hybrid fish with typical marbling all over its body without colourful spots. In autumn, in the spawning period, the sexually active females dig up a nest in the gravel bottom of clean and cold brooks, into which they spawn the eggs, and when the eggs are fertilized, females hide them there. Up to 100 – 7,000 eggs could be achieved from one sexually active female, depending on its size, while the relative fertility rate is 1,000 – 2,000 eggs. The eggs are 4 mm big and have light yellow or yellow colour. The incubation period takes 510 – 520 °D. The brook trout is sexually mature in the 2nd – 3rd year, while males mature year earlier than females.

The food of the brook trout is identical to the food of the brown trout; therefore, they are mutual food competitors. The hatched fry consumes zooplankton at first, then small benthos, and when it is around 60 – 80 mm long, it consumes also winged insects. Bigger fish become a predator. Growth of the brook trout is quicker in the optimum condition, in comparison to the brown trout. It is quite rapacious (throaty) and in the first year, it grows to 100 – 150 mm, and to 200 – 250 mm in the second year. Therefore, the brook trout seems to be the prospective species for the cold-water aquaculture. In farm conditions, its growth is even more intensive. Besides indigenous forms of the brook trout, also special forms have been reared for farming, and lately, triploid fish have been produced. Within farming conditions, 10 – 14 °C is the optimum temperature. When the temperature is above 16 °C, food is consumed with decreased intensity, while the temperature maximum is around 20 °C. On the other hand, the brook trout can consume food under temperatures below 5 °C.

5.1.3 Rainbow trout (*Oncorhynchus mykiss* WALBAUM, 1792).

This allochthonous species was imported from the western part of North America firstly to Germany and then, in 1880 to Slovakia by Viliam Migazzi. Later, in the 2nd half of the 20th century, various forms and lines of the rainbow trout determined mainly for farming were imported to our area (within former Czechoslovakia) from Denmark, France, USA and Bulgaria. The rainbow trout is being imported also nowadays, mainly from France and Denmark.

In our area, the rainbow trout lives both in running and standing water bodies, rich in oxygen. This trout species is less demanding on the water quality, in comparison to other salmonids, and it tolerates also mild turbidity of water. The optimum temperature for the rainbow trout is 10 – 18 °C, and in certain conditions (enough oxygen, gradual temperature rise), it also endures the temperature of 24 – 25 °C. For farming the rainbow trout, it is recommended having the temperature between 14 and 17 °C, with the dissolved oxygen at the level of 9 – 11 mg.l^{-1}, which should not fall below 6 mg.l^{-1}.

The rainbow trout is eurytopic and lithophilous, in comparison to the previous species, and it hides its eggs, too. Its body is rather dumpy of silver colour with dark blue or dark green back, covered with dense black spots without edges, including dorsal, adipose, caudal, and the pectoral, pelvic and anal fins, depending on the form. Reddish or purple strip along the whole lateral line from the gill cover to the anal fin is a typical feature of the rainbow trout. Fins have dark pigments. During the spawning period, distinctive **sexual dimorphism** is seen – the sexually active males are coloured more intensively (the wedding dress), and the front edge of the pectoral, pelvic and anal fins is grey-white. Besides this, the males have the front part of their head pointed and the lower jaws hooked slightly. The younger fish have dark transverse spots (stripes) along the sides, similarly to the brown trout.

The spawning period takes place from February to May, or in case of the Kamloops line (the autumn form of the rainbow trout), the spawning takes place from September to November, on the sandy gravel bottom, when the water temperature is 8 – 10 °C. This species makes rather short migrations into suitable spawning grounds, too, which the sexually active females clean properly at first (make the hole) and then prepare a nest there. There the females lay eggs and the sexually active males fertilize them. After the spawning, the eggs are covered with the bottom substrate by a swirling movement of the fish. The relative fertility rate reaches the value of 1,500 – 2,500 eggs per 1 kg of the weight of the rainbow trout, while 500 – 5,000 eggs could be gained from one sexually active female. The eggs have orange or red-orange colour and have 4 – 4.5 mm of size. The incubation period takes 300 – 410 °D. The fish reach sexual maturity in their 2nd or 3rd year of life, while again, males mature earlier than females. For reproduction in farming conditions, brood fish reared directly on the farm in the age of 3 – 6 years are used.

The rainbow trout appreciates the food almost during a whole year. The food intake is limited only when the temperature falls below 5 °C, or the oxygen content falls below 7.0 mg.l^{-1}. The rainbow trout feeds on similar food as the brown trout – firstly plankton, then benthos and winged insects, while the bigger fish become a predator. It also willingly consumes feeding mixtures, which rates it on the first place in farming salmonids and grayling species in Slovakia. In normal conditions in nature, the rainbow trout reaches 100 – 150 mm in the first year, and 200 – 300 mm and weight up to 300 g in the second year. In farming conditions, the growth is even quicker, and the marketable weight of 250 – 350 g is reached in 10 – 14 months (in 12 – 13 months on the average), depending on the farming conditions and water temperature. Besides the reared forms and lines, triploid fish have been produced more intensively lately.

5.1.4 Danube salmon, the huchen (*Hucho hucho* LINNAEUS, 1758)

This is our autochthonous species and also the biggest salmonid fish not only in our area but in whole Europe, too. In Slovakia, it lives in clear, bigger, deeper and faster running submountain rivers with cold and highly oxygenated water (Danube, and rivers Váh, Orava, Kysuca, Turiec, Hron, Hornád, Poprad, and Dunajec). The optimum water temperature is 8 – 14 °C and the oxygen content at the level of 8 – 11 $mg.l^{-1}$. This fish demands space and hiding places, and it is very sensitive to pollution, which is also the main reason for its decreased occurrence in nature during the 20th century. Its distribution was reached by long-term management (stocking, protection, angling) by the Slovak Angling Association.

The huchen is a rheophilous and lithophilous species, which hides its eggs. Its body is rather slim and fusiform (torpedo-shaped). Its colour changes depending on the age and season. Adult huchen have dark brown back with mild greenish tones, the sides are lighter, while the belly is whitish or grey-white. Younger fish have typical big dark spots on their sides and white or silver belly. There are dark spots on the head, back and sides, as well as on the dorsal and caudal fin, which could create a shape of the letter X on the sides. Fins are yellowish with brownish or reddish tones on the edges. The adipose fin is red or brown-red and its base extends beyond the half-base of the anal fin. The sexual dimorphism is less distinctive, even during the spawning period. The sexually active males have more intensive colours, and their skin is thicker and rougher on the sides and back.

Spawning takes place in spring in our area, from March till May, usually in April, when the water temperature is 6 – 10 °C. The huchen leaves its territory and makes short migrating journeys against the flow to the spawning grounds. It spawns in pairs into a nest in the clean gravel-rocky bottom, which was prepared in advance by both sexes. The size of the nest is usually 1 – 2 m. After the spawning, the huchen returns back to its territory. We may gain up to 2,000 – 36,000 eggs from one sexually active female, while the relative fertility rate ranges between 1,000 and 1,500 eggs per 1 kg of the huchen weight. Eggs are of yellow-orange or orange colour and reach 5 – 6 mm on the average. The incubation period takes 220 – 300 °D. The huchen matures in its 5th – 6th year of life, when it weights around 1.5 kg, or is 550 – 600 mm long. As in the previous species, males mature earlier.

The hatched fry consumes plankton, then, when it is 40 – 50 mm long, it starts to consume invertebrates, mainly larvae and pupae or water insects, crustaceans, molluscs (benthos), and flying insects, and later, when it is 60 – 80 mm long, it starts to consume also the fry of other fishes. The older huchen feeds almost solely on fish (e.g. the common nase). From all our predatory species, the huchen is the predator with the most intensive growth. When it has enough food, the huchen grows very quickly – in the first year, it reaches 150 – 250 mm, 300 – 350 mm in the second year, and 0.5 – 1.5 kg in further years, while the older fish grow faster than the younger ones.

The brood fish are reared almost solely on farms, where they reproduce and their offspring is reared for 1 or maximum 2 years, rarely for longer time. Rearing of the older fish is connected with worsened intake of the supplemental feed, when adequately size and amount of natural food (fish) is less accessible. In Slovakia, the huchen is reared only in two farms nowadays (Martin and Svit). Despite the regular stocking of the huchen into nature, this species belongs among those with decreasing population. Therefore, the Danube salmon is protected under home (e.g. the law no. 139/2002 Z. z. on fishing) and European (e.g. Bern Convention, regulation of the Council no. 92/43/EHS on the protection of biotopes, wild animals and plants) laws.

5.1.5 European grayling, the grayling (*Thymallus thymallus* LINNAEUS, 1758)

This species is one of our autochthonous grayling species, which lives in running rivers of the submountain zone. It prefers wider rivers with harder sandy bottom or gravel bottom, in which still water changes with flows, or shallow parts with deeper ones. No hiding places are necessary, but on the other hand, the grayling needs more space. It is less demanding on the quality of water than the salmonids and it tolerates mild turbidity of water, too. The water temperature of 14 – 18 °C is considered optimum, together with the oxygen content at the level of 8 – 10 $mg.l^{-1}$. For a shorter period, it can bear also temperatures around 20 – 25 °C, provided the oxygen level is not below 5 – 7 $mg.l^{-1}$.

The grayling is a rheophilous and lithophilous species, which hides its eggs, similarly to the salmonids. It has a slim elongated torpedo-shaped body, which is slightly slimmer on the sides, and covered with big scales placed in lengthwise rows. The head is distinctively small with big eyes. The mouth is terminal with slightly protruding upper jaw, while there are many small bristle teeth on the jaws. The dorsal fin is big, long and colourful. The sexually active males have a higher dorsal fin with a pointed end, while the sexually active females have a shorter and smaller fin, and its ending is not pointed. The adipose fin is small, and the caudal fin is v-shaped.

The colour of the grayling depends on its age and environment it lives in. In general, small fish are silver almost all over their bodies, while on the sides, there are bigger oval or transverse and elongated darker spots. The belly is white or silver-white. Fully grown fish have a dark greyish-green back, sometimes with bluish shades (metal shine), the sides are lighter, greyish-green or greyish-blue with silver shine, and the belly is white or creamy. On the back and sides, there are darker spots placed unevenly.

The grayling lives short, usually for 5 – 6 years, rarely more. Therefore, it matures earlier – the males in the 2nd – 3rd year of their life, females in the 3rd – 4th year of their life. The spawning takes place in spring, from the end of March till the beginning of May, usually when the water temperature is 8 – 11 °C. The grayling makes shorter upstream migrations to the spawning grounds with more suitable bottom substrate (sand, gravel). It differs from the salmonids by spawning – the males come first and prepare the spawning nest, and actively protect their territory against other males. The process of spawning takes place in pairs, while the bottom substrate is swirled up and covers the eggs. After the spawning, the male expels the female from the nest. The relative fertility rate is between 3,000 and 5,000 eggs per 1 kg of the weight of the grayling, while 1,500 – 6,000 eggs could be gained from one sexually active female. The eggs are 3 – 3.5 mm big and have a yellow colour. The incubation period is around 200 °D.

The grayling feeds on plankton at first, then on various invertebrates, mainly on larvae of water insects, crustaceans, worms, mollusc (benthos), winged insects and occasionally on eggs and fry of other fishes, too. The growth depends on the amount and accessibility of the food. In the environment with the sufficient amount of food, the grayling reaches the size of 100 – 130 mm in the first year, 150 – 200 mm in the second year, and 250 – 300 mm in the third year.

The brood fish are nowadays reared mainly in farms, and only occasionally, they are gained from wildlife during the natural spawning period, directly in the spawning grounds. Rearing the offspring is quite problematic, and it is connected with the worsened intake of the supplemental feed. Therefore, the grayling is reared usually for one year, or for two years, and only in several farms. Despite being regularly stock in the fishing grounds, the grayling is the species, whose population is decreasing annually.

5.2 Demands on the quality of water

When farming salmonids and grayling species, it is necessary to point out that this is the intensive fish farming which takes place in the facilities of a non-pond type and it is based on the dense amount of fish fed by complete feeding mixtures. This rearing environment differs from the conditions the fish have in nature and Therefore, the farmer strives to provide the fish with such conditions not only to live but to enable necessary production, too. This is achieved mainly by optimization of the physical and chemical properties of water, because they affect fish both individually and in combination of several qualities.

Water temperature is one of the fundamental factors of the outer environment, which affects not only metabolism and biological activities of fish, but also further physico-chemical properties of water. It directly influences food intake and utilization of the feed, growth intensity, sexual maturity, reproduction, and incubation of eggs, etc. Within the chemical properties, it affects oxygen saturation of water indirectly proportionally, i.e. the higher the temperature, the lower the oxygen level.

For farming the salmonids and grayling, **temperature stabilization** is very important, since no sudden **changes of temperature, so called shocks**, should occur during the rearing process. The shocks often cause various injuries to the organism, or even death. This means that the maximum water temperature should not exceed the optimum temperature by more than 25% (mainly when rearing the fry). In other words, if the optimum temperature for the grayling is 16 °C, the maximum temperature should not thus be higher than 20 °C.

Level of oxygen is another very important factor which has an impact on the success of the rearing process, since both salmonids and grayling species are quite demanding on the oxygen level dissolved in the water. As the content is indirectly proportional to the water temperature, the situation when the water saturation is 90 – 100% on the inflow of the rearing facility, and it does not fall below 60% on the outflow, is considered favourable. Shown in absolute values, these concentrations should be at the level of 9 – 12 $mg.l^{-1}$, or do not fall below 7 – 6 $mg.l^{-1}$, because these are the limits which cause stress to fish from not having enough oxygen. Younger and smaller fish require higher concentration of oxygen than the older and bigger ones.

Other gasses dissolved in water significantly influence the quality of the rearing environment and thus also the physiological state of fish. Nitrogen (N_2) can cause air embolism related to death, mainly in the facilities using warmed water. Therefore, the nitrogen saturation should not exceed 103% for the fry, 105% for the one-year-olds, and 115% for the older fish. Moreover, we must pay attention to the nitrogen compounds, which get into water either by being washed down from the surrounding fields or as products of fish metabolism. The most dangerous is the toxic ammonia (NH_3), which could be released from the nontoxic cation of NH_4^+ in an alkaline environment. The values of 0.006 $mg.l^{-1}$ for the trout fry, and 0.0125 $mg.l^{-1}$ for the adult fish are given as the limit concentrations. Nitrites (NO_2^-) dissolved in water are also highly toxic for the fish. Their toxicity is indirectly proportional to the content of chlorides in water. For the salmonids, the safe ratio of Cl^-:NO_2^- is 17 : 1. When the concentration of Cl^- is high, the lethal values of nitrites are around10 $mg.l^{-1}$, and when the chlorides are lacking, the nitrites are toxic already at the level of 0.1 $mg.l^{-1}$. Water contains also certain amount of carbon dioxide (CO_2), usually at the level of 2 – 4 $mg.l^{-1}$. When the level is higher, there may be a risk of organic pollution of water. Concentration of free CO_2 in water should not be higher than 10 $mg.l^{-1}$ for the fry, and 20 $mg.l^{-1}$ for the older fish. Shorter effect of the higher concentration of free CO_2 is used for anaesthesia of some fish species.

Reaction of water (pH) should remain neutral or slightly alkaline in the rearing facilities. The optimum range of pH is 6.5 – 8.0 for the trout. Decrease below 6.0 or increase over 8.5 are considered critical, mainly because the pH value is tightly related to the toxicity of some substances.

Soluble substances are the compounds created by anions as carbonates, chlorides, sulphates, nitrites, nitrates, etc. High concentration of these substances could become a stress factor for the fish and decrease the growth rate, worsen food intake, cause reproduction disorders and increase mortality rate. Hardness of water is the most significant sign of the presence of the soluble substances in water. For rearing, the hardness of water should reach the value of at least 0.2 $mmol.l^{-1}$ and more, while the optimum value is around 1.2 $mmol.l^{-1}$. More intensive growth of the fry of the rainbow trout was monitored in the water with higher content of salts. The quality and suitability of water for rearing could be also negatively affected by the presence of some metals in a form of soluble salts. Problems may be caused mainly by Zn, Cd, Cu, Pb, Al and Fe, which become toxic for fish by accumulation in the organism or by a change of state. Foreign substances as pesticides, tensides, oil substances, PCBs, etc. may also affect utilization of water for rearing fish.

Organic pollution should remain at the lowest level and when rearing salmonids, it is considered the most important factor. As the organic substances are decomposed in water, O_2 is consumed from the water and toxic substances are created (NH_3, H_2S, CH_4 and etc.). Therefore, the risk of bacterial diseases, mycoses and disease of gills is increased. Organic pollution is expressed as chemical (COD) or biological oxygen demand (BOD). The values of organic pollution should not exceed the level of 10 $mg.l^{-1}$ (COD), or 4 $mg.l^{-1}$ (BOD) of O_2.

Insoluble (suspended) solids are the substances of both organic and inorganic origin, which get into water after more abundant precipitation or from human activities. Any turbidity is unacceptable for the fish. These substances limit food intake, cause respiratory problems, and considerably decrease the efficiency of filters and UV sterilization facilities. Sedimentation of such substances in incubation devices is the most common reason for death of the eggs and the fry.

Exchange of water is the fundamental precondition for supply of O_2 and elimination of sediments and metabolic products. In rearing facilities, the water volume should be exchanged once in 1 – 2 hours. Water velocity flowing is related to the water exchange, and should be at the level of 0.005 – 0.05 $m.s^{-1}$. Higher values may considerably worsen the productive conditions, since the fish need more energy to overcome the water flow. With regard to the physiological needs, velocity at the level of 0.005 – 0.01 $m.s^{-1}$ is recommended for fish with weight below 1 g per piece, and at the level of 0.01 – 0.03 $m.s^{-1}$ for fish with weight over 1 g per piece.

Lighting is another important factor when rearing fish, as it affects several physiological functions in the organism. Sufficient lighting ensures good food intake, while good health condition is strengthened. By regulating the light regime (photoperiods and the light intensity), it is possible to affect sexual maturity and thus also the stripping period. On the other hand, it must be emphasised that the direct sunlight harms both eggs and sac fry, since it is highly sensitive to light.

5.3 Reproduction

The brood fish are reared almost exclusively in farms and their reproduction is performed in hatchery by the artificial stripping. Only exceptionally, the brood fish are fished out from nature during their natural spawning period. Therefore, the stripping could be implemented artificially directly in nature, while the stripped fish are returned back to the water while the gonadal products (eggs and sperms), or the fertilized eggs are transported to the hatchery. Another possibility is to transport the fished out brood fish and implement the artificial stripping in the hatchery.

The process of artificial stripping starts with transportation of the brood fish from the rearing facilities to the tanks for handling placed directly in the hatchery or nearby, where the fish are no longer fed. When needed, the water temperature is adjusted and readiness of the brood fish for stripping is monitored. However, the monitoring phase must be limited to minimum in order not to stress and injure the fish. Gonadal mature fish release the gonadal products when slightly pressed on the belly. On the contrary, gonadal immature fish need to be left to mature in the tanks for handling.

Table 5.1: Examples of hormonal stimulation in the chosen salmonids and grayling species (Švinger – Kouřil, 2012 – edited)

Fish species	Water temperature (°C)	Product	Dose		Date of stripping (number of days after giving the 1st dose)	
			One-time with gradual release	Double acute	One-time with gradual release	Double acute
Rainbow trout	7 – 10	**OvaRH, Ovaplant**	25 μg.kg^{-1}	not recommended	16 – 20	–
Brown trout	6 – 8	**OvaRH**	15 – 30 μg.kg^{-1}	2 × 25μg.kg^{-1} with a two-day interval	10 – 14	13 – 14
Brook trout	6 – 7	**OvaRH**	20 – 25 μg.kg^{-1}	2 × 25μg.kg^{-1} with a two – three-day interval	14 – 15	13 – 14
European grayling	6 – 8	**OvaRH**	15 – 20 μg.kg^{-1}	–	11 – 12	–
		Supergestran	–	2 × 10 μg.kg^{-1} with a two-day interval	–	11 – 12

Hormonal stimulation of the salmonids and grayling species is not necessary, and it is not generally performed in practice, because the fish mature on their own. However, when needed, for example to shorten the reproduction period or raise flexibility of the used reproduction processes, it is possible to use the carp pituitary gland or synthetic GnRH analogues (Supergestran, Gonazon, OvaRH, Ovaplant etc.) at once or in two doses, with gradual (FIA – Freud´s Incomplete Adjuvants) or instant (acute) release of the hormone, which is given only to the females.

The artificial stripping should be performed after providing the brood fish with anaesthesia. The most common types of anaesthesia for the salmonids and grayling species are clove oil, 2-phenoxyethanol, and MS-222 solution.

Table 5.2: Optimum water temperatures for stripping of the chosen species

Fish species	Optimum temperature (°C)	Time of spawning (month)
Brown trout	5 – 7	IX – XII
Rainbow trout	8 – 10	IX – XI* and II – V
Brook trout	4 – 6	IX – I
European grayling	8 – 11	III – V
Danube salmon	6 – 10	III – V

Note: * concerns rainbow trout – Kamloops

The stripping of the brood fish is performed by Russian or German method in the hatchery, under optimum temperatures for the chosen species (Table 5.2). When implementing the **Russian method**, eggs are stripped on the sieve, but the ovarian liquid must be left for draining (dripping off) first. Sperm is subsequently added either directly on the sieve or into the bowl, into which the eggs were placed, too. In both cases, water is added into the bowl to activate the eggs and sperm. However, quite big amount of sperm is needed, which is also the main disadvantage of this method. Therefore, the **German method** is used much more in practice. Eggs are spawned directly into a dry bowl together with the ovarian liquid. Subsequently, sperm is added and when the products are mixed together a bit, water for activation of the fertilization is added, too. The ovarian plasma affects the sperm favourably and prolongs the time of its motility, which is perceived as the advantage of this method.

The working **procedure of the stripping** is the same in both methods – i.e. anaesthesia is provided, belly, urinary and genital aperture are softly dried, in case of males, also the anal fin, to prevent the gametes from coming into contact with water. This is rather problematic in males, because the pressed out sperm often flows down the anal fin. Subsequently, the gonadal products are gained – after massaging the belly parts slightly, and short pulls by two fingers while pressing the belly, firstly in the urogenital aperture, then of the whole belly, both times in the direction from head to tail. During the stripping, we hold the fish in moist towel with a slightly bended back.

Females are stripped first. During the stripping, we must hold them right over the edge of the bowl to prevent the eggs from falling from height and harming. It is suitable to place the eggs from one female into one bowl (clean and dry). In this way, we prevent contamination of eggs by excrement or blood, in comparison to the stripping of several females into the same bowl. On the other hand, we must emphasise that when smaller fish are spawned, or when they have little eggs, it is quite common to use one bowl for several females. It is necessary to strip the females thoroughly, to squeeze out as many eggs as possible to prevent further reproduction disorders in the following years. The same procedure is applied when stripping males. Sperm is squeezed out usually directly on the eggs in the bowl, or it is collected into small tubs, or removed by a pump or a suction unit and poured over the eggs. After the stripping, the fish are placed back into the tanks for handling, which they recover from anaesthesia in, and usually on the second day, they are transported back to the rearing facilities.

Gained eggs are then fertilized by the sperm from various males (heterospermia). The fertilization rate of the eggs is thus increased, while the genetic diversity is decreased, since due to different motility of sperms, only the males with the "quickest" sperms participate in fertilization. Furthermore, the number of fathers participating in the production of the offspring of the next generation is thus considerably lowered. Therefore, it is recommended increasing the genetic diversity back, mainly in the fish genetic reserves breeding, by fertilizing the eggs from more females by sperm of only one male, even though the fertilization rate would be low.

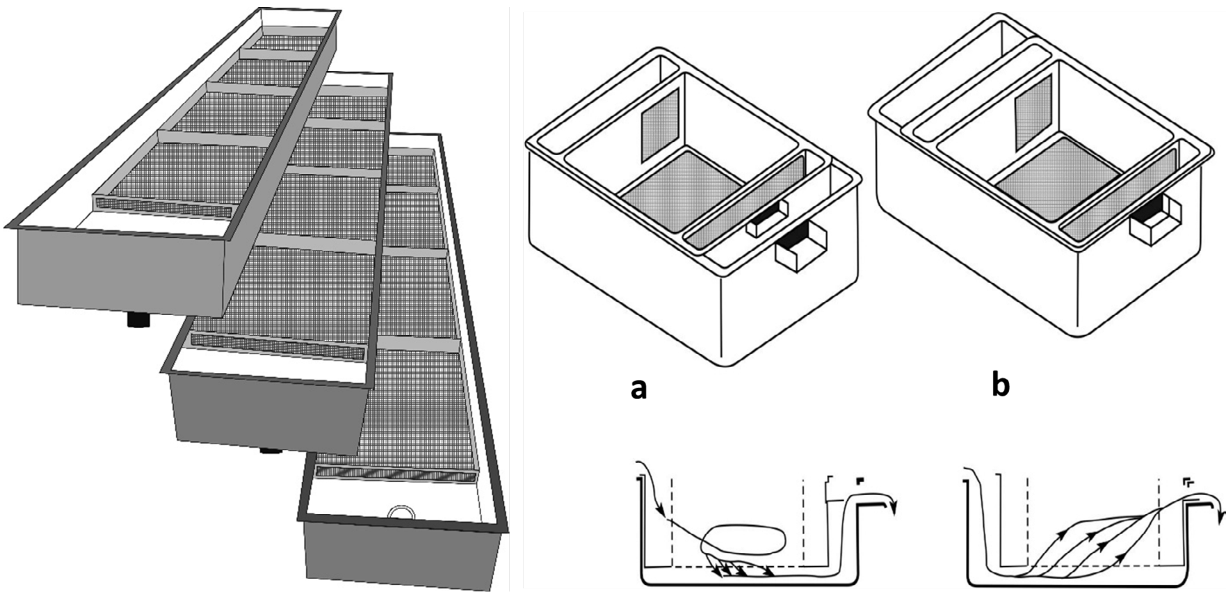
Eggs are mixed with sperm and then water or fertilizing solution is added before the fertilization. This mixture must be left to stand for 2 minutes, so the fertilization takes place without any interference. The rate of successful fertilization of eggs depends on several factors, while the quality of sperm is the most important one – its concentration and motility. When the solution is diluted too much (too much water was added to the bowl), the fertilization rate is decreased. Therefore, we recommend adding only the amount of water to raise the water level to 10 mm above the eggs. Using fertilizing (activating) solutions for fertilizing the eggs is an alternative process. The fertilizing solutions are the solutions of salts or organic compounds in water, which create a suitable environment for sperms to move by its pH value, specified proportion of ions, and osmotic pressure. Moreover, such substances prolong the motility of the sperms twice or three times, which also increases the fertilization rate by 10 – 25%. In the past, Ringer's, Hamor's, and modified Ringer's solution was used for such purpose; today, they are replaced by the solutions like Dilleur 532, tris-glycine-NaCl, and physiological saline solution (0.2% NaCl).

After fertilization, the eggs are flushed with water several times, by which the rest of the sperm is washed out of the bowl, and the eggs are no longer that sticky. Stickiness of these eggs is rather low, in comparison to phytophilous species, and it is eliminated completely only after being flushed by clean water for several times. The flushed eggs are subsequently placed for incubation into incubation facilities.

5.4 Incubation of eggs and hatching of the fry

Incubation devices (apparatus) are generally used for incubation of eggs. These devices have usually two parts and consist of a container (outer case) and a hatching tray made from harmless materials with easy manipulation, maintenance (cleaning), and perfect water exchange. Many of such devices enable also the initial rearing of the fry. Eggs are placed into these devices in one or two layers maximum, depending on the water quality and construction of the device, and the way the eggs are washed by water.

The Clark-Williamson flowing troughs are one of the most used incubation devices in Slovakia, made from laminate or polypropylene, and with length of 2 – 4 m, width of 0.3 – 0.5 m, and depth of 0.2 – 0.3 m. Plastic or aluminium trays with eggs are placed into containers (Picture 5.1). When turned by 180°, we reach the change of the water flow – from the upper (through the front of the tray) to the lower (through the bottom). Up to 40,000 – 50,000 eggs of the rainbow trout are incubated in one trough generally, but when whole capacity is used, 80,000 – 100,000 eggs could be incubated there, while the water flow is about 10 l.min^{-1}. When the small fry is hatched, the trays are eliminated and the rearing process of the fry continues in the troughs.



Picture 5.1: Clark-Williamson flumes with the incubation liners (1), Rückel-Vack incubation device (2) (Kostomarov, 1958 – edited). a – circular flow, b – bottom flow

Rückel-Vacek incubation apparatus is another used incubation device in Slovakia. It also consists of two parts – a container and a tray, due to which, the water flow could be adjusted either to **upper circular flow** or **bottom flow** (Picture 5.1). The circular flow is used almost during the whole incubation period. During the hatching phase, the tray is moved and the flow changes from circular to bottom flow, which is maintained until the end of hatching, or initial rearing. This ensures the yolk sac does not „fall through“ the holes at the bottom of the tray. The older devices used to have metal construction, while the current ones are made from plastic (polypropylene). In hatchery, they are placed next to each other (in parallel), and for each apparatus, there is separate inflow, or they are placed one below the other (as in a cascade), when the water flows from one apparatus to the next one. Depending on the size of the incubation apparatus, up to 5,000 – 8,000 eggs of the trout are placed generally into the device. Besides incubation, this apparatus enables also the initial rearing phase of the fry.

Glass incubation jars (Zugs, Chasse, Kannengieter), as we know them, are not used for incubation of the salmonids or grayling species in Slovakia. However, these glass jars are commonly used on big farms abroad with the capacity of several tens up to hundreds of millions eggs. Furthermore, **vertical incubation devices** are used, too. These are composed of a stand with telescopic trays, which the eggs are placed in. Depending on the principle the water is supplied to the eggs, these incubation devices could be divided into **flow-through** and **shower**. In case of the flow-through incubation devices, the water flows through the individual liners from the top to the bottom; while in case of the shower ones, the eggs are not constantly submerged in the water but moistened by permanent showering. Low water consumption is the main advantage of these vertical incubation devices, together with low demands on space, protection of eggs against light, good monitoring and easy prevention. On the other hand, limited possibility of hatching or initial rearing of the fry is the main disadvantage, since the eggs right before hatching and the hatched fry must be moved into the troughs, which their further rearing will continue in.

It is necessary to ensure a sufficient amount of water as well as adequate content of O_2 for the successful incubation period, because as the incubation proceeds, the oxygen consumption by the eggs rises, and the hatched fry needs approximately 10 times higher level of O_2 than the eggs at the beginning of the incubation period. Deficiency in oxygen causes development disorders and higher losses. Moreover, water temperature affects the process and length of the incubation considerably, too. This process (from fertilization to hatching) is called **incubation period (ID)**, and it is expressed in **daily degrees (°D)**. These daily degrees express the value which is gained as a sum of daily average water temperatures. In other words, when the incubation period of the rainbow trout is 410 °D, and its eggs are incubated under average water temperature of 10 °C per 24 hours, hatching could be expected approximately in 41 days. However, the number of days needed for incubation differs. Within a species, it may fluctuate between several tens and hundreds of °D. The incubation period Therefore, depends mainly on the water temperature, and the higher the temperature is, the shorter the IP is and the less °D are needed.

Length of the IP could be generally derived also from the average size of the eggs. Fish with big eggs reproduce usually in autumn or before winter or early in spring, when the temperature is low. Under this temperature, the development is slower (longer IP), and the hatched fry has a big yolk sac, which it gains nutrition from for a longer period, until it switches to exogenous food. On the contrary, fish with smaller eggs reproduce in spring when the water temperature is rising and thus the incubation is quicker, and the hatched fry has a smaller yolk sac, and switches to exogenous food earlier.

During incubation, development changes and processes of both qualitative and quantitative character take place in the eggs, while at the beginning of the incubation period (the embryonic stage), qualitative changes predominate. Development is quite quick in this stage and many development stages last only for several hours or days. From this viewpoint, we divide the incubation of eggs into several development periods:

- **fertilization** – when gametes (eggs and sperm) come into contact with water, they are activated and fertilization takes place. Moreover, they increase their volume – the eggs absorb water (swell) and their surface becomes hard and smooth gradually. However, water does not get into the inner parts of the eggs, it remains just under the roe membrane. In this period, the eggs are highly sensitive. When the volume is increased, the eggs become solid (hard) and since this moment, we may work with them – count, transport, put into incubation devices, etc. Approximately after two hours after the fertilization, cleaving process begins. Therefore, all the working processes with eggs must be terminated in 10 hours after fertilization, or 24 hours maximum,
- **resting period** – after 48 hours after fertilization, the eggs are very sensitive to outer impulses, mainly shakes, because in this period, further cleaving process takes place, together with the initial embryonic division. Period between 70 – 100 °D is highly critical for the rainbow trout, and no manipulation with eggs is recommended (shakes, transport, elimination of dead eggs, removing sediments, changing flow, etc.). This phase is quite long and lasts approximately for 100 – 120 °D, until the base of the eyes in the embryo are seen (the **so called eyed egg period**),
- **eyed egg period** – this is characterised by the possibility to see two dark spots – the pigment base of the eyes of the embryo, and to see how the originally bright colour of the eggs becomes darker. In this period, the eggs become resistant to outer impulses and we may clean and wash them, eliminate the dead eggs, transport them, etc. This period lasts until the beginning of hatching. Several days before hatching, the sensitivity of eggs raises again, and the demands on the O_2 content are increased, too,
- **hatching period** – this is the last and the shortest period of incubation. The roe membrane is torn due to intensive moves and effects of the proteolytic enzymes, which the embryo produces, and thus the fry hatches. The length of this period depends on the water temperature and could last for several days. The hatched fry lies at the bottom and has a big yolk sac, which it consumes nutrition from until the end of the embryonic stage, or the beginning of the larval stage. The fry starts to move after consuming ⅔ of the yolk sac, i.e. approximately after two weeks after the hatching. During the hatching period, we increase the water inflow and remove the egg shells as well as the dead fry.

Losses during the hatching period are at the level of 10 – 15%. After 2 – 3 weeks after the hatching, the fry starts to swim and consume exogenous (natural) food. Until then, the fry must be protected against direct sunlight, because it is highly sensitive to light. Right after the fry consumes ½ up to ⅔ of the yolk sac and starts to look for food, it is stocked into the rearing brooks, or for further rearing in the farm.

5.5 Rearing the fry

First (passive) phase of the fry rearing starts immediately after the hatching and takes place usually in the incubation devices. The fry almost does not move, it lies on the side and gains nutrition from the yolk sac. After several days, it starts to gain pigment (becomes darker) and move. In this period, the fry is sensitive to light and Therefore, we must overshadow the incubation devices sufficiently. After consuming approximately ½ up to ⅔ of the yolk sac (2 – 3 weeks after being hatched), it starts to swim and look for food.

Second (active) phase of the rearing begins when the fry starts swimming and its food reflex starts, too. The fry switches from endogenous to exogenous diet gradually, becomes less sensitive to light, and no later than in this period, it is transported from the incubation devices into the rearing tanks, which its further rearing continues in.

Picture 5.2: Rearing the fry in troughs (a), and in circular tanks (b) (photo: J. Andreji)

The rearing takes place usually in troughs or in circular tanks (Ø 2 – 2.5 m), or in square-shaped tanks with rounded corners (the length of the side up to 2 m), and the size up to 35 – 50 mm and weight of 0.8 – 1.5 g per piece (Picture 5.2). This is technologically the most difficult phase of rearing, which affects the whole production of the marketable rainbow trout considerably.

5.5.1 Initial feeding of the fry (first phase)

Former farmers used to feed the fry already in the incubation devices. Nowadays however, there is a trend to feed the fry after stocking it in the rearing tanks, since its demands on the total space and water inflow are increased. Moreover, higher light intensity, in comparison to the incubation devices, helps with looking for the food and consuming. This phase of rearing lasts for 10 – 15 days, depending on the water temperature, and its aim is to induce a food reflex in the fry to a maximum extent – i.e. to teach the fry to consume the given feed, and create preconditions for its intensive growth in the further period. On the other hand, this phase requires the personal attitude and care of the staff excessively.

Suitable and nutritionally balanced feed with right size structure determined for the particular species and its age category should be used for the initial feeding. These feeds should be provided regularly, in short time intervals (every 1 – 2 hours) and for as long as possible through the day (at least for 10 – 12 hours, the light regime should be prolonged, if necessary) to prevent even short-term starvation. The feed is applied in small doses above the whole water surface, while the non-consumed feed is removed (by suction). Cleaning the rearing tanks regularly contributes to maintaining the good rearing hygiene of the environment and reducing the losses from the rearing period.

The feed should be provided by hand in this period to control the fry better, and more feed should be given in order to provide enough food constantly. Therefore, the water level is decreased to approximately 0.2 m. Fundamental physico-chemical parameters of the water quality, mainly the temperature, level of O_2 and pH, are monitored, as well. The optimum temperature should range between 12 and 16 °C, and the level of O_2 should be at least of 8 $mg.l^{-1}$ in the inflow, and it should not be decreased below 6 $mg.l^{-1}$ in the outflow. It could be increased by additional aeration or oxygenation of the rearing tanks, if needed. The initial stock of the fry per 1 m^3 is 80,000 – 100,000. Losses during the initial feeding phase should not exceed 10%. At the end of this phase, the fry weighs up to 0.15 – 0.18 g, and the eating habits for the regular food (feed) intake have been created successfully, which is seen in the excrement present at the bottom of the rearing tanks.

In the past, so called „**wet feeds**“ were used for feeding the fry. These were the moistened feeds of animal origin (liver and spleen of the farm animals, fish meat, etc.), which were provided firstly in a form of suspension, and later as a feeding paste given in the feeding places. However, such feeds are no longer used nowadays. The reasons for that are mainly the hygienic standards (it was difficult for cleaning, water exchange, etc.), and the limited possibility to get enough such feeds (reduction in slaughterhouses). To a smaller extent, also zooplankton (live and frozen) was used for initial feeding, which was later also abandoned mainly for introduction of diseases and parasites. All of this is provided exclusively by the complete feeding mixtures (CFM) nowadays.

5.5.2 Feeding the fry (second phase)

The fry starts to be fed regularly after approximately 2 weeks after the initial feeding, when the fry already has the eating habits created for the regular food intake. After the initial feeding, the fish stock is lowered to 40,000 – 50,000 $pcs.m^{-3}$, or even to 20,000 – 30,000 $pcs.m^{-3}$, depending on the quality of water, and the water level is increased to approximately 0.4 m in the rearing tanks. In this phase, the frequency of feeding is reduced to 5 – 6 times a day, while the daily feeding dose (FD) equals approximately 10% of the weight of the fish stock. This remains as stated until the fry is fully reared. The feed is provided either by hand or by mechanical or automatic feeders of different construction, usually electromagnetic or with clock mechanism. These enable to dose the feeding mixture (FM) continually or in certain time intervals.

Feeding is performed with the same feed the fry was initially fed on. Most of the producers of the FM have their own feeding programme adjusted to the physiological needs not only of the fish species, but of the age categories, too, so the switch is performed usually without any problems. If a change of the feed occurs, it is necessary to perform the switch gradually for several days to give the fry the time to get used to the new feed well. At the end of the rearing phase, approximately after 1 – 2 months, we achieve the forced fry with the size of 35 – 50 mm and the weight of 0.8 – 1.5 g. The losses of the rearing should be around 15%.

During the rearing process, we must **monitor the water quality** at least once a day, unless it is monitored automatically. By **removing (by suction) the excrement and dead fish regularly**, as well as by **cleaning and disinfecting the rearing tanks**, we suppress the development of bacteria and moulds, which could cause health problems to the fry. It is suitable to **monitor the growth** at least once in 14 days. By weighting, measuring and counting the randomly chosen samples, we may calculate the average weight or length, and based on this data, we may adjust the FD, or the feeding system.

Table 5.3: Overview of the chemical substances used in preventive-treating baths of the fry of the salmonids and grayling species

Bath	Dosage	Time period	Effect
Table salt	20 g.$^{-1}$	15 min	against ectoparasites of the genus of *Cryptobia*, *Ichthyobodo*, *Chilodonella*, *Trichodina*, *Trichodinella*; lower efficiency against *Dactylogyrus*, *Gyrodactylus*, *Piscicola*, *Argulus* and surface moulding
Formaldehyde	0.25 ml.l^{-1} (to 10°C) 0.20 ml.l^{-1} (10 – 15 °C) 0.17 ml.l^{-1} (over 15 °C)	30 – 60 min	against parasites of the genus of *Cryptobia*, *Ichthyobodo*, *Chilodonella*, *Trichodina*, *Trichodinella*, *Dactylogyrus*, *Gyrodactylus*, *Silurodiscoides* and surface moulding
Blue vitriol	0.5 g.l^{-1}	1 min	treating against flavobacteria on the gills
Chloramine T	20 mg.l^{-1}	P – 20 min, 2 – 3× a week L – 1 hour, 7 days	treating against flavobacteria on the gills
BioCareSPC, (ú. l. hydrogen peroxide)	60 mg.l^{-1}	25 min	antimycoticum, antiparasiticum, for bacterial infections
Excis (ú. l. Cypermethrin)	5 µl.l^{-1}	1 hour	against ectoparasites of the class of *Copepoda*
Salmosan (ú. l. Azamethiphos)	0.20 mg.l^{-1}	30 – 60 min	against ectoparasites of the class of *Copepoda*
Pyceze (ú. l. Bronopol)	0.4 ml.l^{-1}	30 min	antimycoticum (*Saprolegnia* spp.)

Note: ú. l. – effective substance, P – preventive, L – treatment

Preventive-treating baths of the fry are highly important to maintain good health condition of the fish stock. Frequency and type of the used bath depend on the rearing conditions, water quality and hygiene of the environment. The baths are performed gradually, firstly in the rearing tanks, which were cleaned and all the sediments were removed (it is not performed in all the tanks at once). Before the baths, the fish are not fed for 8 – 12 hours, and the water volume is partially lowered in the tank (lower consumption of chemicals). The applied preventive-treating substance must be sufficiently stirred up and mixed in the water to ensure the same concentration in the whole volume. The same temperature of the bathing water and the water in the reservoir must be ensured, too. Before the bath is applied, it is better to perform a test of tolerance. An overview of the chosen baths is listed in the Table 5.3.

5.6 Rearing the one-year-olds

After the forced trout fry is reared, we place it into bigger rearing tanks usually outside the hatchery area, where the rearing process continues until it is one year old, for next 5 – 6 months, depending on the rearing conditions. At the end of the rearing process, one-year-olds weights 50 – 100 g on the average, or even 150 g in some bred lines.

In Slovakia, the year-olds are reared in the earthen ponds, concrete pools, cages and circular tanks, and in dense fish stocks. However, the fry which was reared in lower fish stocks is scattered through the whole rearing tank, has weaker eating habits, is shy, grows slowly and the mortality rate is higher.

5.6.1 Rearing in small earthen ponds

Rearing the one-year-olds in the earthen ponds is one of the most common methods of rearing in Slovakia. Smaller flow-through ponds with hard non-muddy bottom are used for such purpose, described in the chapter 4.2.2. If there are good conditions, the rearing ponds should be covered with protective netting, usually of a darker colour. The reared fry is thus protected against piscivorous birds, it is calmer, and consumes food better. Feeding is performed usually by hand, or automatic feeders of different construction are used (electric, pneumatic, touch feeders, etc.). The stock of the forced fry ranges from 40 to 80 pcs.m^{-2}, and by aeration and oxygenation of the water, it could be increased up to 100 – 120 pcs.m^{-2}, but still the value depends on the water quality. Losses during the rearing process are generally at the level of 10 – 20%.

5.6.2 Rearing in concrete pools (canals)

This rearing process is implemented in a way similar to the rearing in the earthen ponds, in exterior, outside the hatchery area. In comparison to the ponds, the pools are not constructed individually, but there are more of them, and they are divided by a thin wall. Together they create one cultural unit (described in the chapter 4.2.3). Also in this case it is recommended covering the object with protective netting against the piscivorous birds. The feeding is performed usually by mechanical or self-moving feeders, or exceptionally by hand, too, because of the technical construction of the rearing objects (long and narrow canals). The stock of the forced fry up to 10,000 pcs.m^{-3} is used for rearing, and after additional oxygenation, it could be increased to 15,000 – 30,000 pcs.m^{-3}. However, quality and capacity of the water source are the determinative factors. Losses during the rearing process do not surpass 20%.

5.6.3 Rearing in net cages

Rearing the one-year-olds in net cages is one of the least used methods for rearing this age category in Slovakia. The rearing is implemented in the floating rectangular-shaped cages with denser mesh (described in the chapter 4.2.1), with the initial fish stock 200 – 300 pcs.m^{-3} of forced fry, depending on the water quality. At the beginning, the production volume is gathered (folded) to approximately ½, later as the fish grow, the netting is filled with whole volume of cage. This reduced production volume enables fish to consume the feed better and thus it strengthens their feeding reflex. As the fish grow, the amount is proportionally reduced, and at the end of the rearing, the fish stock is only 100 – 120 pcs.m^{-3}. Feeding is performed by hand from a boat or a service bench. High losses, generally reaching up to 50%, and the limited possibility for taking preventive and treating measures are the reasons why this method is used the least.

5.6.4 Rearing in circular tanks

The year-olds is usually reared abroad in bigger circular tanks (Ø 5 – 10 m) placed outside the hatchery. These objects are placed under a roof or at least covered with protective netting against the piscivorous birds, and there is often a service bench over a water surface heading from the edge of the reservoir to its centre. Due to the circular movement of water, the reared fish is evenly distributed in the whole volume of the tank. Dirt, including excrement and the unconsumed leftovers of the feeds are gathered at the bottom and in the centre of the tank, which they are drained out from automatically. The feeding process is implemented by hand or by automatic feeders. The nitial stock of forced fry depends on the quality and capacity of water, and usually ranges between 1,500 and 2,500 pcs.m^{-3}, while the losses usually do not exceed the value of 20%. Despite the several advantages (saved space, low water consumption) this method offers, it has not been used very much in Slovakia.

5.7 Production of the marketable fish

Production of the marketable fish is the final phase of rearing, which ensures the supply of the marketable fish of the demanded size throughout the year. In our area, mainly the rainbow trout, to a smaller extent also the brook trout, and after 2009 (viral hemorrhagic septicemia disease), also the brown trout are reared to a consumable size. The one-year-olds (rarely half-year-olds – the fish between forced fry and one-year-olds in the age of 91 – 150 days, with the size of 70 – 100 mm, or 3 – 10 g) with the average weight of 60 – 90 g is placed into the earthen ponds, concrete pools or net cages for 4 – 6 months for rearing. At the end of the rearing process, we gain the marketable fish with the weight of 300 – 350 g. The bigger the fish placed for rearing, the shorter the rearing period, and *vice versa*.

5.7.1 Rearing in concrete pools (canals)

This method is the dominating one within the production of the marketable fish in Slovakia. Annually up to 50 – 55 % of marketable trout is produced in the concrete pools. Placement, equipment and the way of the rearing are the same as when rearing the one-year-olds. Sorting out based on the size of the reared fish is the only exception in this method, by which the small or too big fish, or sick or hurt fish are removed from the rearing. The aim of such sorting process is to maintain the fish stock with the same size, which then evenly affects the feeding intensity in the feeders. The fry of Pd_1 in the amount of 120 – 150 pcs.m^{-3} is set in for the rearing, depending on the water quality; if we use additional oxygenation, the amount could be doubled. Losses during the rearing process reach the level of 2 – 4%.

5.7.2 Rearing in earthen ponds

Rearing fish in the earthen ponds is the second most used method of the production of the marketable fish in Slovakia, with proportion of almost 30 – 35 %. This method has the same characteristics as described in the chapter 5.6.1., when rearing the the one-year-olds in the earthen ponds. Moreover, the reared fish are regularly sorted out only by size. The fish stock is rather low, at the level of 20 – 35 pcs.m^{-2}, while the losses are rarely higher than 3 – 4 %.

5.7.3 Rearing in net cages

This is the latest way of producing the marketable fish. It has been used since the seventies in Slovakia, and its proportion of the production of the marketable fish reaches 10 – 15%. The rearing process takes place in net cages of a rectangular or circular shape with rather sparse netting (described in the chapter 4.2.1), while the one-year-olds is stocked into the full production volume of the cage (not gathered to the centre as when stocking the forced fry) in the amount of 30 – 50 pcs.m^{-3}, depending on the quality of water. During the rearing process, the one-year-olds is regularly sorted out by its size and simultaneously the weak, hurt or sick fish are removed. Feeding is performed usually by hand from a boat or a service bench. Losses during the rearing phase generally reach the level of 2 – 4 %.

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