Food and Agriculture
Organization of the
United Nations

SURVEY AND EVALUATION OF WATER QUALITIES

A field guide for managers of inland fisheries and fish farms




SURVEY AND EVALUATION OF WATER QUALITIES

A field guide for managers of inland fisheries and fish farms

By:

András Woynárovich
International Consultant
Budapest, Hungary

Éva Kovács
International Consultant
Budapest, Hungary

and

Sándor Alex Nagy
International Consultant
Debrecen, Hungary

Food and Agriculture Organization of the United Nations

Budapest, 2020

Required citation:

Woynarovich, A., Kovacs, E. & Sandor, A.N. 2020. *Survey and evaluation of water qualities: a field guide for managers of inland fisheries and fish farms*. Budapest, FAO. https://doi.org/10.4060/ca7588en

ISBN 978-92-5-132142-3

PREPARATION OF THIS DOCUMENT

The actual and predicted future status and growth of fish stocks, both in natural[1] and manmade[2] inland fresh waters, are estimated and confirmed indirectly, through for example the quality of the aquatic environment. Therefore the physical, chemical and biological qualities of the water fish live in should routinely be observed, checked and evaluated to help fishery and fish-farm managers in making both routine and special decisions about their waters and fish stocks. In recent decades, the privatization of state and cooperative fish farms where one farm was divided among many new owners, and the extensive leasing of public waters created a very large, new group of stakeholders. This was typical in the inland fishery and aquaculture subsectors throughout Central and Eastern Europe, the Caucasus and Central Asia. In many countries of these regions, new managers and technical decision-makers in the field are neither fully aware of the importance of a healthy physical, chemical and biological environment for their fish stocks, nor do they have a proper knowledge of simple but reliable techniques to sample, measure and evaluate these parameters both routinely and in an emergency. This is also true and valid throughout the world, whether the regions are in temperate, subtropical or tropical climatic zones.

The need for better utilization of freshwater resources calls not only for useful technical solutions, but also for field support in monitoring and following up the properties (i.e. quality) of waters used for fisheries and aquaculture.

Simple and professional regular field monitoring of water properties also helps prepare for dealing with the effects of climate change on fisheries and fish culture.

This field guide aims to fill a gap in the literature focusing on field-oriented information and provide fishery and fish farm managers with the minimum technical knowledge. It provides professional answers as to which water properties should be checked and evaluated both routinely and in an emergency. It explains why, when and how these evaluations should be made. It also describes cases where professional laboratories should be involved.

Consequently, the objective of this field guide is not only to improve knowledge and skills, but also to build capacities and form a better understanding of field situations, so that discrepancies are discovered before real problems appear.

Woynarovich, A., Kovacs, E. & Sandor, A. N. 2020.

Survey and evaluation of water qualities: a field guide for managers of inland fisheries and fish farms.

Budapest, FAO.

[1] Rivers and lakes.
[2] Reservoirs and ponds.

ABSTRACT

This field guide provides practical information on the field monitoring of the physical, chemical and biological properties of inland waters exploited by fisheries and aquaculture.

After introducing the concept and topics, it discusses the qualities of inland waters in detail. Water properties are grouped by chapter, based on abiotic or biotic factor, or indeed both. Chapters and sections are supported by illustrations and practical explanations of how to discover, understand and solve water-quality-related problems. The practical guides presented at the end of each chapter discuss the different water properties important for fisheries and pond fish culture.

As climate change is a problem of increasing importance, an additional chapter on climate and climate change implications, together with the application of meteorology to inland fisheries and aquaculture, is also included.

The annexes provide a guide to identifying water types and the main organisms which live in them. Annex 4 systematically presents equipment, kits and instruments which could be used to check the physical, chemical and biological properties of inland waters used for fisheries and aquaculture.

This richly illustrated guide also includes a glossary where simple and clear definitions and explanations, together with substantial science-based background information, can be found. Terms included in the glossary are asterisked and italicized.

CONTENTS

Preparation of this document iii

Abstract iv

Acknowledgements ix

1. Introduction 1

1.1 Fresh waters, inland waters and their fisheries 1

1.2 Properties, quality and suitability of inland waters for fisheries and fish culture 2

1.3 Scope and use of this field guide 3

2. Basic physical and chemical characteristics of water 5

2.1 Physical characteristics of water 5

2.1.1 Physical states of water 5

2.1.2 Density of water and thermal stratification 8

2.1.3 Specific heat 10

2.1.4 Viscosity of water 10

2.1.5 Surface tension of water 11

2.2 Chemical properties of water 11

2.2.1 Chemical composition and structure of water 11

2.2.2 Chemistry of inland waters in nature 11

3. Water qualities determined by abiotic factors 13

3.1 Motions of water 13

3.2 Temperature of waters 14

3.3 Quantitative and qualitative salt content of waters 17

3.3.1 Halobity 17

3.3.2 Hardness 19

3.4 pH conditions of waters 20

3.5 Alkalinity 22

4. Water qualities determined by abiotic and biotic factors 24

4.1 Light conditions and transparency 24

4.2 Oxygen content and conditions in waters 25

4.3 Inorganic and organic nutrient content of waters – trophity and saprobity 30

4.4 Toxicant content of waters – toxicity 32

5. Water quality determined by biotic factors 35

5.1 Composition and decomposition processes in waters and biological production 35

5.2 Life in the main biotopes of standing waters 37

5.2.1 Life on and below the water surface 37

5.2.2 Life in the water column 38

5.2.3 Biotekton and benthos 44

5.2.4 Macrovegetation in waters 45

6. Application of meteorology in inland fisheries and fish culture 46

7. Summary and conclusions 49

7.1 Surveys, samplings and tests to be completed by managers 50

7.2 When expert assistance is required 50

Glossary 51

References 57

Annexes

Annex 1	Some practical classifications of waters	61
Annex 2	Aquatic organisms important for inland fisheries and pond fish culture	64
Annex 3	Tables of environmental requirements of selected commercially important fish species	76
Annex 4	Inventory of equipment, test kits and instruments used for sampling and measuring the properties of waters in the field	85

Tables

TABLE 1-1	Properties of sea and inland waters and their effects on inland fishing	1
TABLE 2-1	Overview of forms in which different materials are found in waters	12
TABLE 3-1	Classification of water bodies by total dissolved salt (TDS) content	18
TABLE 3-2	Combination of macro-ions in water bodies and the suitability for fish production	18
TABLE 3-3	Scales and values of hardness	20
TABLE 5-1	Fish-catching methods and their suitability for sampling	43
TABLE 7-1	Inventory of water properties and meteorological data to be followed up by field staff	49
TABLE 7-2	Essential information on water bodies used for fisheries and aquaculture	50

TABLE A1-1	Estimation of global water distribution	61
TABLE A1-2	Classification of lakes by their thermal characteristics	62
TABLE A1-3	Summary of classification attribute and threshold definitions	63
TABLE A1-4	Trophity of inland waters under temperate climate and their potential fish production capacities	63
TABLE A2-1	Consumption preferences of grass carp	67
TABLE A3-1	Inventory of water parameters required for fisheries and fish culture – Trout species	77
TABLE A3-2	Inventory of water parameters required for fisheries and fish culture – Warmwater species	78
TABLE A3-3	Optimum temperature ranges of specific life history stages of salmonids and other coldwater species for guideline application	79
TABLE A3-4	Typical feeding habits and food spectrum of selected commercially important fish species	80
TABLE A3-5	Favourable spawning environment and water temperature of selected commercially important fish species	81
TABLE A3-6	Key data of egg incubation of selected commercially important fish species	82
TABLE A3-7	Key data of rearing non-feeding larvae of selected commercially important fish species	83
TABLE A3-8	Key data of feeding larvae of selected commercially important fish species	84

Figures

FIGURE 1-1	Fresh waters by origin and location	1
FIGURE 1-2	Connection between properties, quality and suitability of inland waters	2
FIGURE 1-3	Water properties determined by natural abiotic and biotic factors	3
FIGURE 2-1	Schematic correlation between the speed of ice formation and air temperature	6
FIGURE 2-2	Schematic correlation between the intensity of evaporation and selected environmental conditions	7
FIGURE 2-3	Correlation between water temperature and water density	8

FIGURE 2-4	Warming and cooling patterns of standing waters under temperate climate	9
FIGURE 2-5	Effect of specific heat on the water temperature of a shallow lake under temperate climate (Depth: 1-1.2 m, Period: March – December 2015)	10
FIGURE 2-6	Correlation between the temperature and viscosity of water	10
FIGURE 2-7	Structure of a water molecule with its bounds at three different physical states	11
FIGURE 3-1	Vertical daily circulation of water in summer due to thermal stratification	13
FIGURE 3-2	Ranges of water temperature: optimal, acceptable and lethal for coldwater, warmwater and tropical fish species	14
FIGURE 3-3	Classification of surface fresh waters based on fish species	14
FIGURE 3-4	Typical thermal stratification patterns in bodies of shallow water in a temperate climate	16
FIGURE 3-5	Typical thermal stratification patterns in bodies of shallow water in a tropical climate	16
FIGURE 3-6	Water sampling equipment used to measure temperature and oxygen	17
FIGURE 3-7	pH scale and suitability of waters for fish production	21
FIGURE 3-8	Schematic daily pH fluctuation of waters at different alkalinity and phytoplankton production	21
FIGURE 4-1	Reflection of incident light	24
FIGURE 4-2	Secchi disk	24
FIGURE 4-3	Oxygen content of a fully saturated water at different temperatures	26
FIGURE 4-4	Daily fluctuation of oxygen in eutrophic lakes and fish ponds	26
FIGURE 4-5	Oxygen content in different depths of waters in different seasons	27
FIGURE 4-6	Ranges of optimal oxygen content for different groups of fish species	27
FIGURE 4-7	Correlation between trophity, phosphorus content, biodiversity and the structure of the fish fauna	30
FIGURE 4-8	Symptoms in different phases of fish toxicity	32
FIGURE 5-1	Food pyramid in waters – sources of natural fish food and their consumers	35
FIGURE 5-2	Water strider on and mosquito larvae under the water surface	37
FIGURE 5-3	Naked-eye view of filamentous algae	40
FIGURE 5-4	Judgement of zooplankton by the naked eye	41
FIGURE 6-1	Meteorological data on the web – examples of national services	47
FIGURE 6-2	Meteorological data on the web – examples of international services	48
FIGURE A1-1	Main groups of inland waters	61
FIGURE A1-2	Schematic arrangement of thermal lake types with latitude and altitude	62
FIGURE A2-1	Biotopes of inland standing waters and their typical natural fish food organisms	64
FIGURE A2-2	Phytoplankton	65
FIGURE A2-3	Waterweeds	66
FIGURE A2-4	Zooplankton – Protozoans	67
FIGURE A2-5	Zooplankton – Rotifers	68
FIGURE A2-6	Zooplankton – Cladocerans	68
FIGURE A2-7	Zooplankton – Copepods	69

FIGURE A2-8 Larger water crustaceans 69
FIGURE A2-9 Water insects – mosquitos and chironomids 70
FIGURE A2-10 Water insects – Fly larvae and pupae 71
FIGURE A2-11 Water insects – Mayflies 71
FIGURE A2-12 Water insects – Damselflies and dragonflies 72
FIGURE A2-13 Water insects – Bugs 73
FIGURE A2-14 Water insects – Beetles 73
FIGURE A2-15 Water insects – Beetles and their larvae 74
FIGURE A2-16 Ringed worms 74
FIGURE A2-17 Molluscs 75
FIGURE A2-18 Frogs and toads 75
FIGURE A3-1 Development stages uniformly applicable for all freshwater fish species 76
FIGURE A4-1 Tools of field survey of water properties 85
FIGURE A4-2 Different types of water thermometers and sampling equipment for deeper water 86
FIGURE A4-3 Materials and steps for making a plankton net 87
FIGURE A4-4 Hand nets for checking aquatic insects, young fish and benthos 88
FIGURE A4-5 Selected gear for sampling fish 88
FIGURE A4-6 Widely available magnifiers and loupes to be used in fisheries and fish culture 89
FIGURE A4-7 Stereo microscope 90
FIGURE A4-8 Test kits developed for aquarists 90

Boxes

Box 3-1: Calculation of hour and day degrees 15
Box 3-2: Reading and expressing pH values 20
Box 4-1: Correlation between transparency and fertilization 25
Box 4-2: Estimating the extent of fish mortality 33
Box 5-1: Natural food and the price of different fish species 36
Box 5-2: Organisms in the plankton 38
Box 5-3: Biological control of macrovegetation 45
Box 6-1: Effects of climate change on inland fisheries and aquaculture 46
Box 7-1: Data and information on water samples 50

Box A4-1: The predictable fate of many water analytical instruments 92

ACKNOWLEDGEMENTS

The authors would like to express their gratitude for the consultations and valuable professional support received from Dr Károlyné Papp, retired hydrobiologist from the Hungarian Angling Federation (MOHOSZ). Special thanks also go to Mr László Gáal, chemical engineer, for his professional comments on some specific areas of water chemistry and hydrobiology during the preparation of this publication.

Language review of the field guide was prepared by Ms Mary Murphy (Írj Jól Szolgáltató Kft), while the typography by Copy General. Authors hereby would like to acknowledge their valuable contribution to the finalization of the guide.

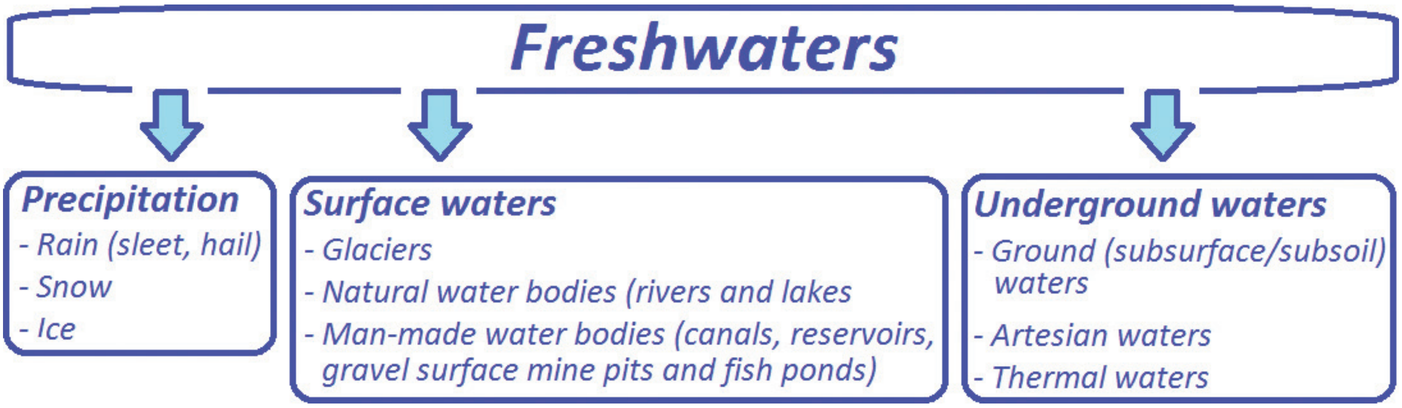
1. INTRODUCTION

While *fisheries** or different *fish culture systems** such as *pond fish culture** and *culture-based fishery* (CBF),* are practiced, it is important to know the physical, chemical and biological characteristics of water bodies in addition to the cultured species. A basic knowledge of hydrobiology could help both fisheries and pond fish farm managers to correctly observe, sample and evaluate the most important qualities of waters in which fish production takes place.

1.1 Fresh waters, inland waters and their fisheries

*Fresh waters** can be found in the atmosphere, on the ground and under the ground. Precipitation, surface and underground waters are distinguished accordingly, all of which are equally essential for different inland fisheries and fish culture systems. While natural and manmade *surface waters** ensure space for fish, precipitation, glaciers and underground waters supply these spaces.

FIGURE 1-1
Fresh waters by origin and location



Most definitions of inland waters are in line with that of the European Commission (2006). They not only include freshwater rivers, natural lakes, water reservoirs, canals and ponds (i.e. fresh waters in general perception), but also saline and brine lakes, as well as coastal lagoons. In this field guide, however, the term inland waters and their fisheries and fish culture mainly refers to freshwater lakes and fish ponds, as summarized in Table 1-1.

TABLE 1-1
Properties of sea and inland waters and their effects on inland fishing

Water body	Sea	Boundary: Coastline	Estuaries and lagoons	Boundary: Upper limit of salt water	Lakes and rivers
Salinity	Salt water		*Brackish** water		Fresh water
Fish species	Sea and *diadromous**		Sea, diadromous and fresh water		Diadromous and fresh water
Fisheries' status	Maritime		Varies by country, as it can be either maritime or inland		Inland
Fishermen	Sea fishermen		Sea or inland fishermen; depends on the country		Sea or inland fisherman; depends on the country

Source: European Commission (2006).

Other practical ways to group inland waters used for fisheries or fish culture are presented in Annex 1. Accordingly, natural and manmade water bodies are often categorized by their physical size (area, width, length and depth), water-carrying or water-holding capacities, seasonality (seasonal or perennial) or utilization.

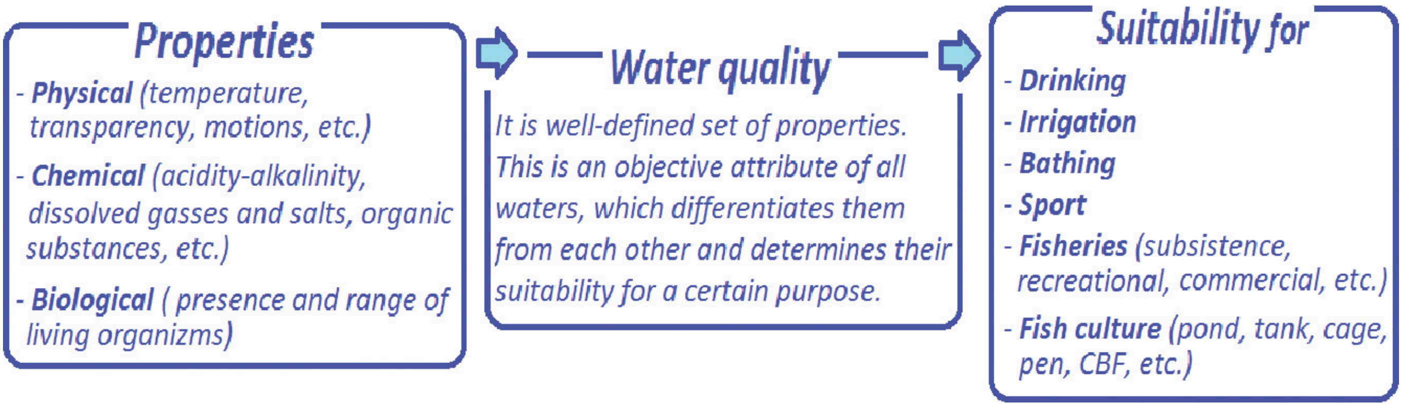
In addition to the listed aspects, water bodies are also categorized by their water qualities, which basically determine the results of fisheries and fish culture.

1.2 Properties, quality and suitability of inland waters for fisheries and fish culture

Chemically pure water is a colourless, tasteless and odourless substance with reduced conductivity. However, water in this form is rarely found in nature, as it has a high solvent capacity. For this reason, the composition of waters is influenced by the surrounding environment which determines their physical, chemical and biological properties.

As the grouping options of inland waters listed in Annex 1 indicate, the use and utilization of waters depend on water quality. However, water quality, which is a distinct set of properties, becomes meaningful only if the purpose of using it is already defined (Figure 1-2). For this reason, water quality cannot be good or bad but simply suitable or unsuitable for a certain use. Consequently, the suitability of water is always relative to its utilization. For this reason, it is important to distinguish between the properties, the quality and the suitability of waters and to consider, observe and evaluate these three together (Nagy et al. 2007).

FIGURE 1-2
Connection between properties, quality and suitability of inland waters



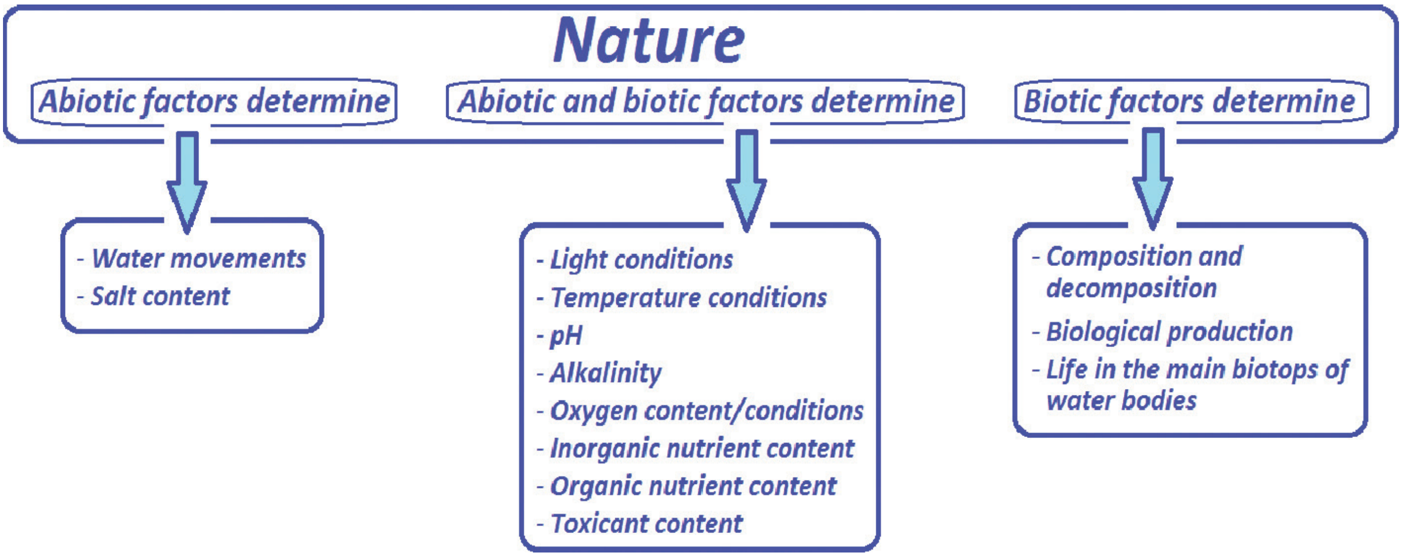
Fish ponds with inundation and drainage function are typically shallow waters in which *eutrophication** is deliberately created and maintained. Large and/or deep-water bodies function differently, according to their actual type (Table A1-2 and Figure A1-2). These waters have their typical hydrobiological processes of which fish are an organic part. Considering that the objective of managers is to produce fish in a sustainable and profitable way, all physical, chemical and biological aspects should be monitored and evaluated with an explicit focus on how these conditions are able to fulfil the requirements of different fish species.

1.3 Scope and use of this field guide

Similarly to the wide range of choices for classifying inland waters, there is an almost endless list of different parameters and combinations thereof which are usually monitored to define whether waters are suitable for certain purposes. Accordingly, the function of a water body determines which properties should be measured and followed up. In this book, the properties and qualities of inland waters are discussed with a focus on how suitable they are for supporting the fish life, and how they influence or ensure the results of fisheries and fish culture.

In different types of fisheries and fish culture, permissible, acceptable and desirable water qualities vary considerably. However, in specific cases there is a set of properties that determines the actual water quality in which fish live, grow and propagate. These properties are determined by natural abiotic and biotic factors (Figure 1-3).

FIGURE 1-3
Water properties determined by natural abiotic and biotic factors



This guide aims to help managers of inland fisheries and pond fish farms in their daily field work. Therefore, the parameters and qualities discussed focus on those which support, slow down or stop the growth of fish, or even endanger them. In other words, this book concentrates on those parameters and water qualities which directly or indirectly influence the results of fish production in still inland waters, such as lakes, reservoirs and fish ponds.

The structure of this field guide is simple. To provide a clear background and facilitate an easy perception of the complex and often complicated aspects of water quality and suitability, after a short introduction to the basic physical and chemical characteristics (Chapter 2), different properties are discussed in three groups:

- water properties determined by abiotic factors (Chapter 3);
- water properties determined by abiotic and biotic factors (Chapter 4);
- water properties determined by biotic factors (Chapter 5).

At the end of each section of the above listed chapters the most important practical information and tips how to react and act are summarized in red framed boxes.

Chapter 6 summarizes the most important aspects of climate change which influence fisheries and fish cultures at field level and provides information on climate, weather, hydrology and water quality, as well as on their interference with each other.

Chapter 7 provides a concise summary of why, when and by whom tests and samplings should be prepared (Section 7.1). It also includes an inventory of cases when professional aid and specialists need to be involved (Section 7.2).

The different chapters are supported by four annexes that introduce a set of systematic background information providing additional detail to interested readers.

Although the authors aimed to use simple language in providing exact terms and explanations, some specific technical terms could not be avoided. These terms (italicized and asterisked on first use) are explained in the glossary, where also supplementary information is provided for some glossary entries.

In the different chapters and annexes recommendations are also made on how to use the different techniques and materials (products) to improve or restore water quality. As the quality and concentration of the mentioned materials/products/chemicals can vary, even under the same brand name, testing them before applying to a larger stock or water area is always recommended.

2. BASIC PHYSICAL AND CHEMICAL CHARACTERISTICS OF WATER

From an *ecological** point of view, water makes up the hydrosphere, one of the Earth's four spheres. Water is in a permanent transition from one state to the other (solid, liquid and vapour/gas), as described by the *hydrological cycle**. These characteristics make water very special, as it is not only essential for all forms of terrestrial life, but also creates a unique environment for aquatic organisms. This environment is both a medium in which fish exist and a habitat in which they hatch, feed, grow and reproduce/propagate (Dévai *et al.,* 1998). For a better and easier understanding of the different abiotic and biotic processes, this chapter offers a short description of the basic physical and chemical characteristics of water.

2.1 Physical characteristics of water

2.1.1 Physical states of water

Water is the only substance which is widely found in nature in three different physical states:

- Ice (and its fine crystal form, snow) is the solid state of water. The melting point and freezing point of ice are the same: 0 °C at a constant atmospheric pressure (*air pressure**). The temperature of ice constantly remains around 0 °C during the entire ice formation and melting process. Ice will become colder than 0 °C only when the air temperature is very cold and the waterbody freezes down to the bottom. Until this point the temperature of ice remains 0 °C, regardless of how much colder the surrounding air is. This difference between the air temperature and ice explains why water birds rest on the ice during cold winter days. While water freezes, heat is released to the environment. When ice melts, heat is extracted from the environment which explains why the microclimate around water bodies remains cooler until the ice is totally melted.
- Water exists between 0 °C and 100 °C in liquid state.
- The gaseous state of water is called vapour or steam (i.e. hot vapour). Vapour is the result of *evaporation** or *sublimation**. Evaporation takes place on the water surface with different intensity, which increases with temperature. It stops when the surrounding air becomes fully saturated.

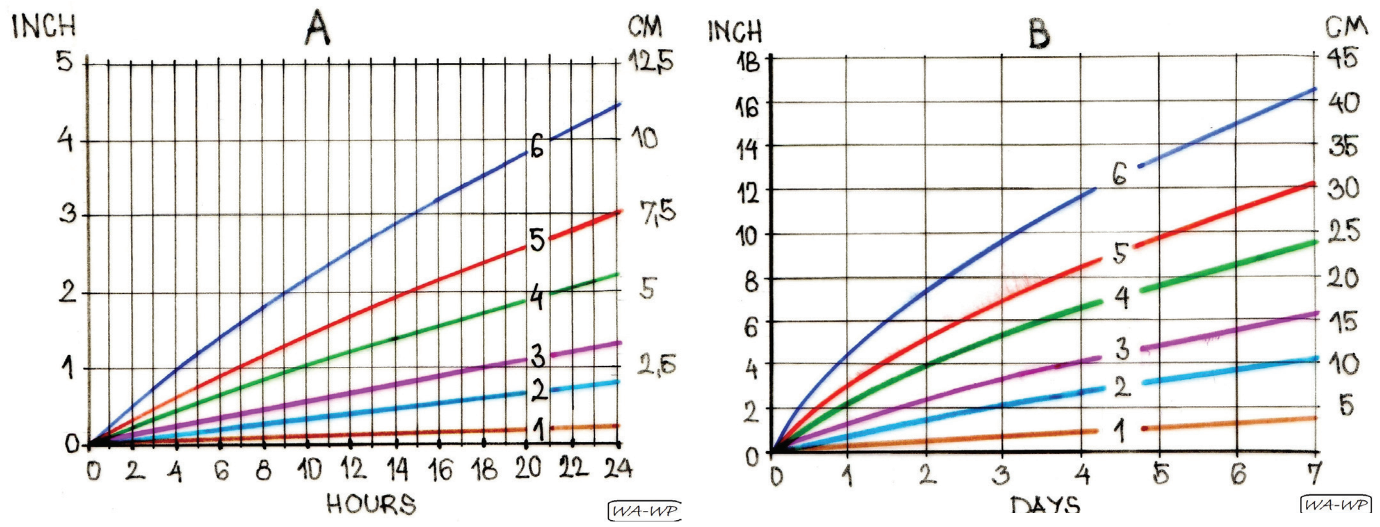
FORMATION AND PRESENCE OF ICE AND WHAT TO DO

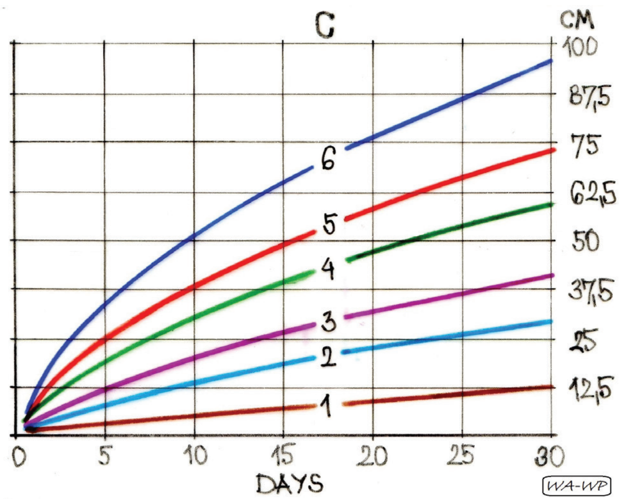
For fisheries and fish culture, the development and presence of ice can cause problems in cold and temperate climates. Ice formation (icing) starts from the surface, where water is in contact with the cold air and develops (thickens) downward by additional layers of water freezing underneath. Significant icing can be expected when the air temperature remains permanently below -1°C and the process accelerates when the temperature lowers, as presented in Figure 2-1.

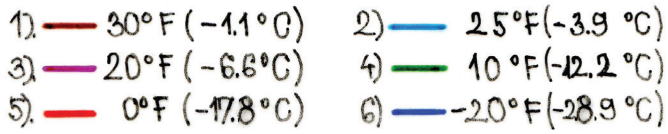
Ice should be monitored because it may cause an oxygen shortage and it can damage concrete and earth structures.

- Ice is usually transparent, but as soon as it is covered by snow, light penetration into the water is blocked. In the dark, the healthy balance of oxygen production and consumption of *phytoplankton** shifts to the direction of consumption (i.e. respiration) (Section 4.2).
  What to do: Cut and maintain ice holes, where light can penetrate, and water can ventilate. At least two or three, 4–6 m^2 holes should be cut into each hectare of water surface. These will prevent the development of unfavourable oxygen conditions under the ice (Fürész and Papp, 1995).
- The volume of ice is about 1.1 times greater than that of water. During ice formation, the volume increases to a point where it will damage or even break dikes and concrete structures (monks, canals, furrows, etc.).
  What to do: Cut ice regularly around and in concrete structures.

FIGURE 2-1
Schematic correlation between the speed of ice formation and air temperature





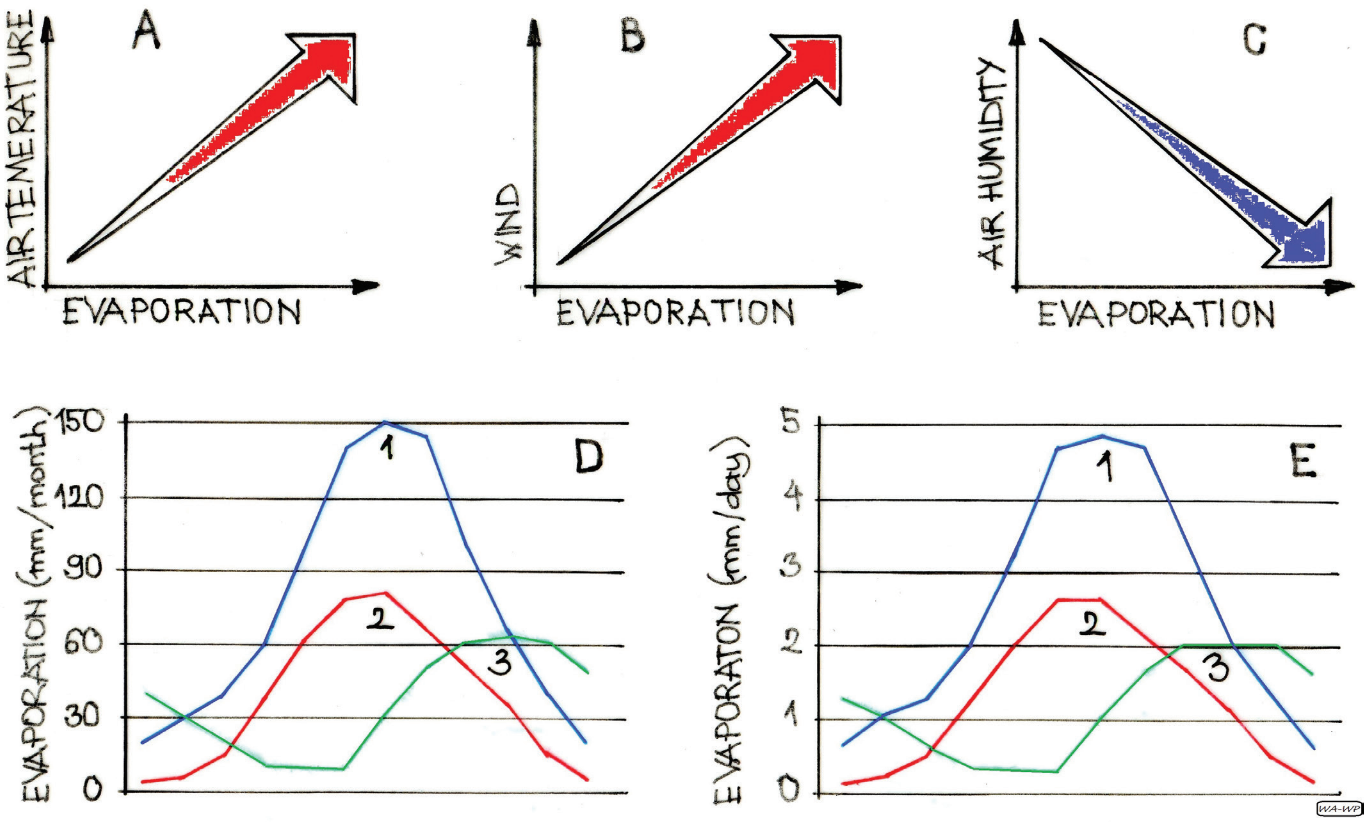


(After: http://lakeice. squarespace.com/ice-growth/.)

A. Growth of ice over a day. **B.** Growth of ice over a week. **C.** Growth of ice over a month.

It is assumed that air temperature remains the same over the given period.

FIGURE 2-2
Schematic correlation between the intensity of evaporation and selected environmental conditions



Sources: Based on Révész (2003), Finch and Calver (2008) and Taghvaeian and Sutherland (2015).

(A) Rate of evaporation and air temperature. (**B)** Rate of evaporation and wind strength. (**C)** Rate of evaporation and air humidity. (**D)** Monthly and (**E)** daily fluctuation of evaporation of standing waters of different depths (**1**: 7 metres, **2**: 20 metres and **3**: 50 metres) in a temperate climate.

EVAPORATION OF WATER AND WHAT TO DO

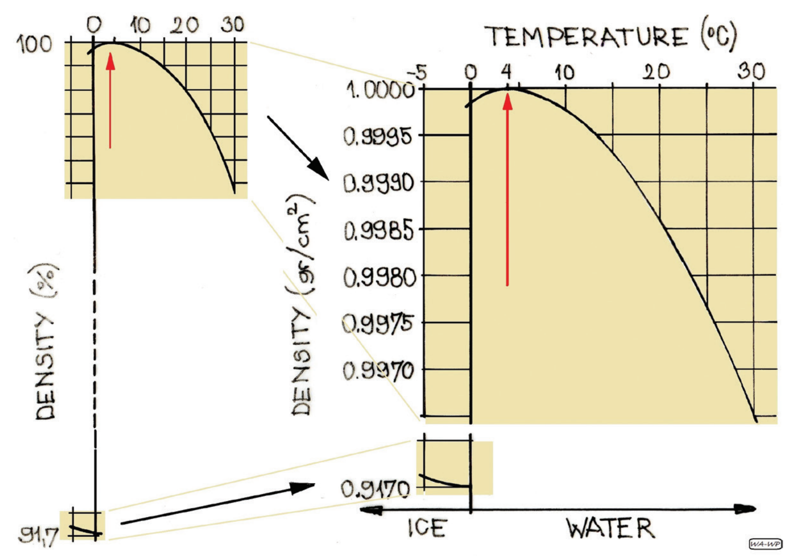
Evaporation is an increasingly important factor for fisheries and pond fish farms. Water management must consider the rate of evaporation which can be substantial, as demonstrated in Figure 2-2. An evaporation pan should be used (http://www.hydrokit.co.uk/46/evaporation-pan-manual.htm) to measure evaporation. The evaporation rate determines two things:

- How fast a water body shrinks without water supply.
  What to do: Calculate the rate of drying and stock and keep fish accordingly.
- How often and to what extent ponds should be supplemented with water.
  What to do: Calculate water losses and replace the water on a regular basis, before the water level shrinks by more than 20–30 percent.

2.1.2 Density of water and thermal stratification

Water density changes with temperature (Figure 2-3). As water temperature decreases, its density and specific weight increases. This inverse (reverse) correlation holds until water reaches 4 °C, where its density is highest. Below 4 °C, water density gradually decreases again until it freezes, when a sharp drop in density occurs. Water density is lowest in this physical state, which is why ice floats on the surface while 4 °C water sinks to the bottom. Because of different densities at different temperatures, stratification appears in standing water bodies.

FIGURE 2-3
Correlation between water temperature and water density



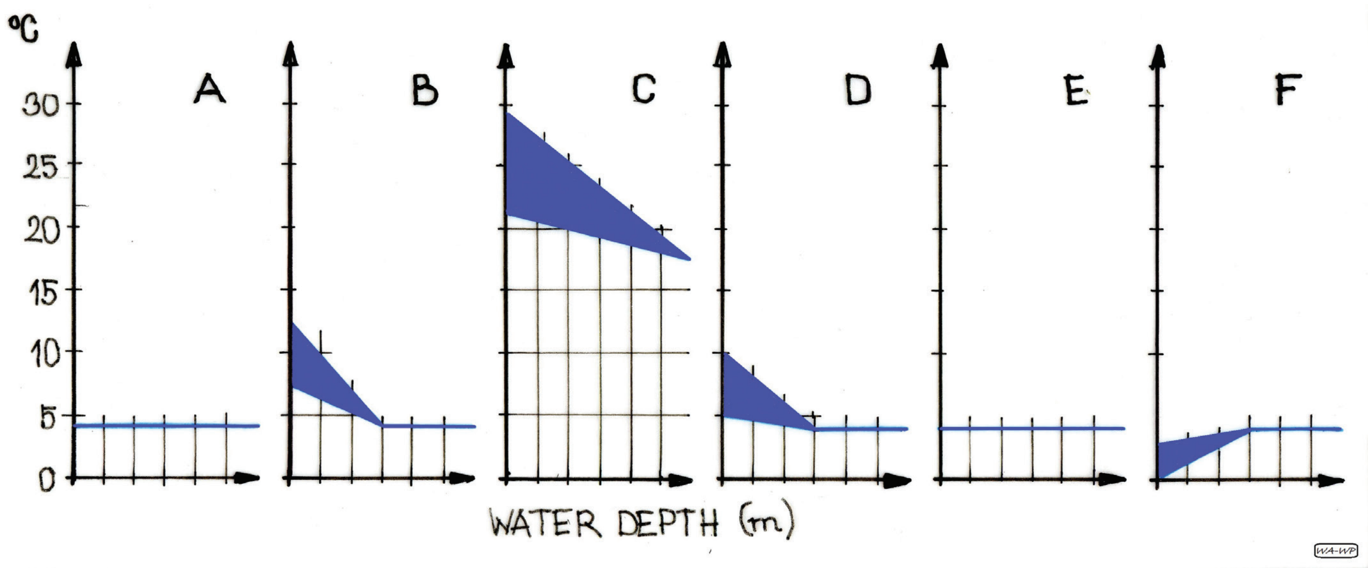
Source: Based on Felföldy (1981).

In summer, warmer layers appear near the water surface, while colder layers stay further down, near the bottom. In winter, when air temperature is below 4 °C, colder layers are near the surface while the 4 °C water remains at the bottom. The actual pattern of stratification depends on the season (Figure 2-4), as well as on the intensity and length of sun radiation and the transparency and depth of the water, as presented in Figures 3-4 and 3-5 in Section 3.2.

IMPORTANCE OF WATER DENSITY IN FISHERIES AND FISH CULTURE

Due to the higher density of water than of the air, hitting the water surface is like hitting a solid material. Therefore, it is important not to throw fish but instead gently release them into the water. Otherwise impact could damage their fragile organs and cause death later.

FIGURE 2-4
Warming and cooling patterns of standing waters under temperate climate



There is a period in spring when water temperature is uniformly 4 °C in standing waters **(A)**. In late spring (**B**), in summer (**C**) and in early autumn (**D**), warmer layers of water are above each other. There is a period in autumn when water temperature is uniformly 4 °C in standing waters **(E)**. In winter colder layers of water are above each other, which is the inverse/opposite of the summer situation **(F)**.

IMPORTANCE OF WATER STRATIFICATION IN FISHERIES AND FISH CULTURE

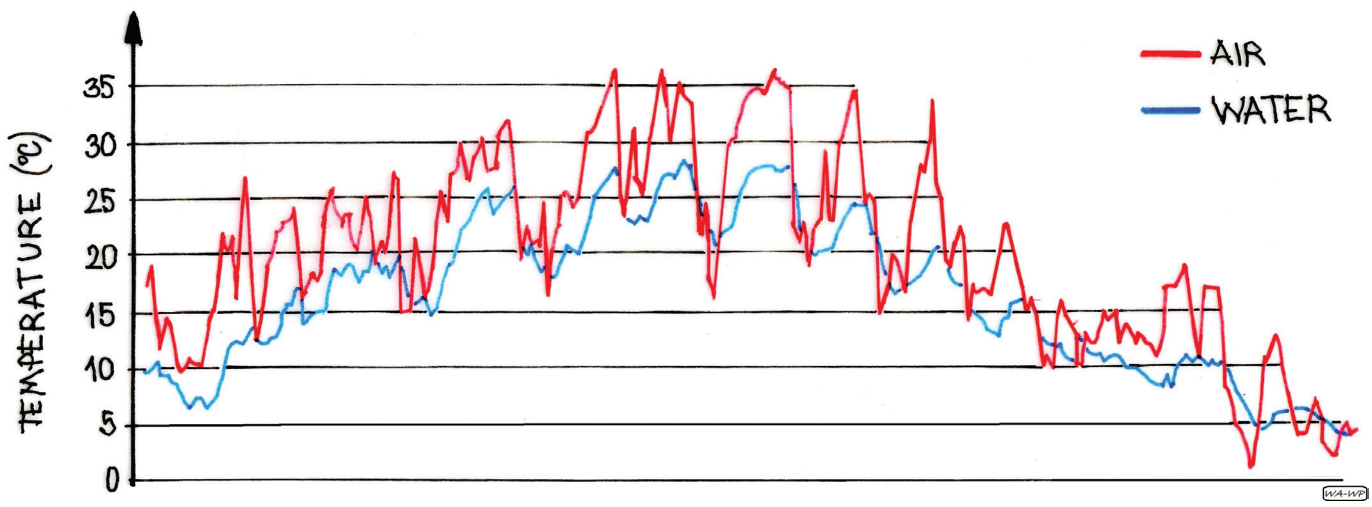
The result of a decreasing density of water at temperatures lower than 4 C° is that a water body freezes from the surface. In deep and undisturbed water, temperature remains at 4 C° at the bottom. This physical characteristic prevents most waters from freezing to the bottom under cold and temperate climates. This layer provides shelter for fish where they can *hibernate** and survive the winter months.

The opposite is valid in the tropical zone. Though the surface temperature of water is often overheated, cooler layers can still be found at the bottom where fish find refuge (Figure 3-5).

Consider the following:

- It is essential to keep fish in deep water bodies (ponds) in winter which do not freeze down to the bottom, even in very cold winters. Following the same logic, fish ponds should be at least 1-1.5 metres deep on average with some deeper parts, where fish can stay both in extremely cold winters and in warm summers.
- When a multispecies hatchery is supplied from a reservoir or pond, it is important to obtain water both from shallower and deeper layers.
- Because of climate change, deeper ponds can better serve fish culture.

FIGURE 2-5
Effect of specific heat on the water temperature of a shallow lake under temperate climate (Depth: 1-1.2 m, Period: March – December 2015)



Source: Based on http://www.eumet.hu/vizhomerseklet.

2.1.3 Specific heat

Specific heat is the amount of *heat** per unit mass required to raise the temperature by 1 °C. Compared to other matters, the specific heat of water is high: 4.2 J/g (1 cal/g) is needed to warm 1 ml (1 cm^3 or 1 gram) water.

Because of its high specific heat, water stores heat well. This ensures that water bodies warm up and cool down slowly, much slower than the surrounding air temperature (Figure 2-5). This characteristic protects *poikilotherm** aquatic organisms from quick and radical changes of temperature, even in smaller water bodies where less heat is stored.

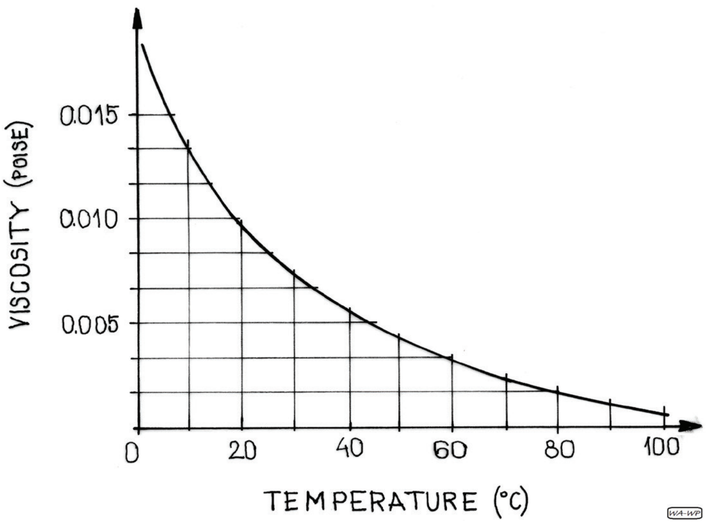
2.1.4 Viscosity of water

The density of most aquatic organisms, both plants and animals, is around 1 g/ml. This, together with a specific air regulating system, makes them capable of changing their average density, thus their specific weight. It allows them to float, sink and rise, which is in close relationship with the viscosity of water shown in Figure 2-6. The sinking and rising speed of an organism is:

- in linear correlation with the difference between the specific weight of water and the organism;
- in negative correlation with the size and shape of the organism and the viscosity of water.

As sinking is slower in cold waters than in warm waters, viscosity is one of the reasons why the shape of the *zooplankton** changes by season (Dévai and Dévai, 1979).

FIGURE 2-6
Correlation between the temperature and viscosity of water



Source: Based on Dévai and Dévai (1979).

2.1.5 Surface tension of water

Tension of a water surface film, which tends to minimize the surface area, is called surface tension. This is caused by the cohesion of water molecules. It makes it possible for certain insects (e.g. water cricket, pond scatter, water strider) to walk and other organisms (e.g. mosquito larvae) to hang on the water surface (Figure 5-2 in Section 5.2.1).

IMPORTANCE OF SURFACE TENSION IN FISHERIES AND FISH CULTURE

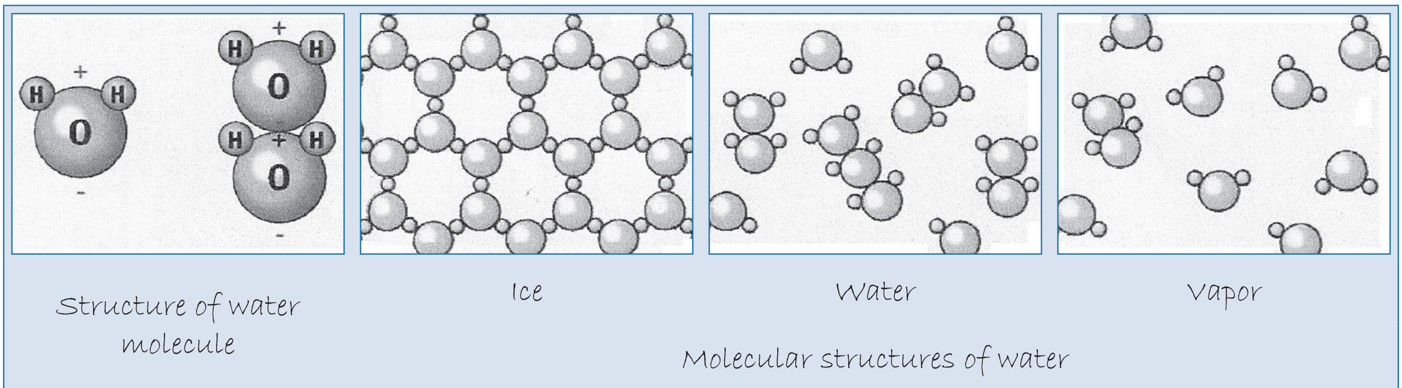
When very fine, dry, powdery feeds are used in nursery ponds, the particles remain floating on the water surface. These floating particles cannot be accessed by the few-days-old developing larvae due to surface tension. Therefore, this type of feed should be diluted before giving them to fish larvae.

2.2 Chemical properties of water

2.2.1 Chemical composition and structure of water

Water is a compound of oxygen and hydrogen. Hydrogen has the lightest *atomic mass** and is the simplest element. Oxygen is an essential element and an ingredient in numerous chemical and all biological processes on Earth. A water molecule is built from one oxygen and two hydrogen atoms and has a relatively small size. Water is a polar molecule with a positive charge on the hydrogen side and a negative charge on the oxygen side (Figure 2-7).

FIGURE 2-7
Structure of a water molecule with its bounds at three different physical states



Sources: (Based on Pidwiny and Jones (2014) and USGS, (2015).

2.2.2 Chemistry of inland waters in nature

The range and properties of different materials found in water determine its chemistry in nature. Chemical composition and physical qualities together make water an excellent solvent. Due to polarity, the positive side of a water molecule links to anions, while the negative side links to cations. These characteristics enable water not only to form real solutions but also to compose *colloids**, *suspensions** and *emulsions** (Table 2-1). Polarity allows water molecules to be attracted to a wide range of different elements, molecules and compounds including gasses, salts, and inorganic and organic compounds.

TABLE 2-1
Overview of forms in which different materials are found in waters

Aspects	Emulsions and suspensions		Colloids	Solution
Size of particles	1000 μ[3] – 500 mμ		500 – 1 mμ	1 – 0.1 mμ
Settling of particles	Quick	Slow	There is no settling	
Settling of particles	Particles can be filtered		Particles cannot be filtered	
Brown motion*	Cannot be observed		Intense	Very intense
Examples	Oil	Different soils	Organic molecules	Dissolved gasses and salts

Source: Dévai and Dévai (1979).

[3] *Micron**.

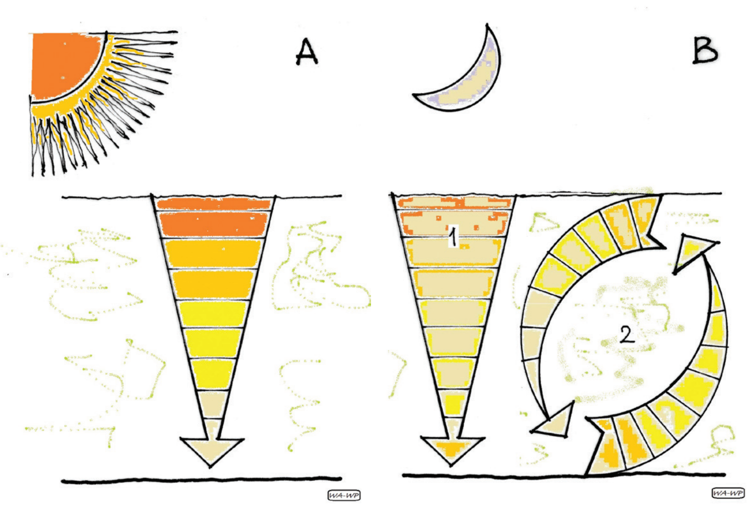
3. WATER QUALITIES DETERMINED BY ABIOTIC FACTORS

3.1 Motions of water

Motions of water in a water body, unless they are unusually harsh and strong, ensure a healthy aquatic life by supporting the exchange of gases and dissolved nutrients between different *biotopes** (surface, water column and bottom). Motions of water have different effects on riverine and lacustrine *ecosystems**. In riverine ecosystems (streams, rivers and canals), gravitation usually determines the motion of the water. In lacustrine ecosystems (standing waters such as lakes, reservoirs and ponds), horizontal and vertical motions are caused by the wind, thermal circulations, and inflowing and outflowing water currents:

- Winds generate waves. The usual direction, length and strength of waves mainly depends on dominant winds.
- Thermal circulation (*convectional** currents) is based on the thermal stratification of water layers. Convectional currents cause a daily vertical circulation in shallow standing waters and in the *epilimnion** of deep ponds. The process demonstrated in Figure 3-1 shows how the upper layer of water, which is in contact with relatively cold air during the night, cools down quicker than the water at the bottom. As the specific weight of cooling water increases, it sinks to the bottom, replacing warmer and lighter water which, as a result, rises. The greater the difference between day and night air temperatures, the more intense the process. This circulation transfers oxygen to the bottom and ensures a nutrient exchange between the water and the sediment. As a negative effect, it may carry nutrients to darker layers where they cannot be properly utilized.
- Currents developed by inflowing and outflowing waters play a role in the proper distribution of nutrients and in the spread of toxicants produced externally or internally.

FIGURE 3-1
Vertical daily circulation of water in summer due to thermal stratification



A. Heat received during the day. Water warms up from the surface. **B**. (1) During the night, water also starts to cool from the surface, as air is colder than water. (2) Heat is lost during the night through convectional current.

IMPORTANCE OF WINDS, WAVES AND CURRENTS

It is especially important to note and consider the negative effects of winds and waves when:

- placing artificial nests for substrate spawning fishes;
- stocking fish larvae;
- planning a new water reservoir or fish pond; inflow and outflow structures should be as far from each other as possible to ensure longer currents in fish ponds.

3.2 Temperature of waters

One of the important significances of water temperature is that fish and most of the aquatic *natural fish food organisms** are poikilotherm, that is, their metabolisms and motions are temperature dependent. In general, their body temperatures do not differ from the surrounding water temperature by more than about 0.6–0.1 °C.

FIGURE 3-2
Ranges of water temperature: optimal, acceptable and lethal for coldwater, warmwater and tropical fish species

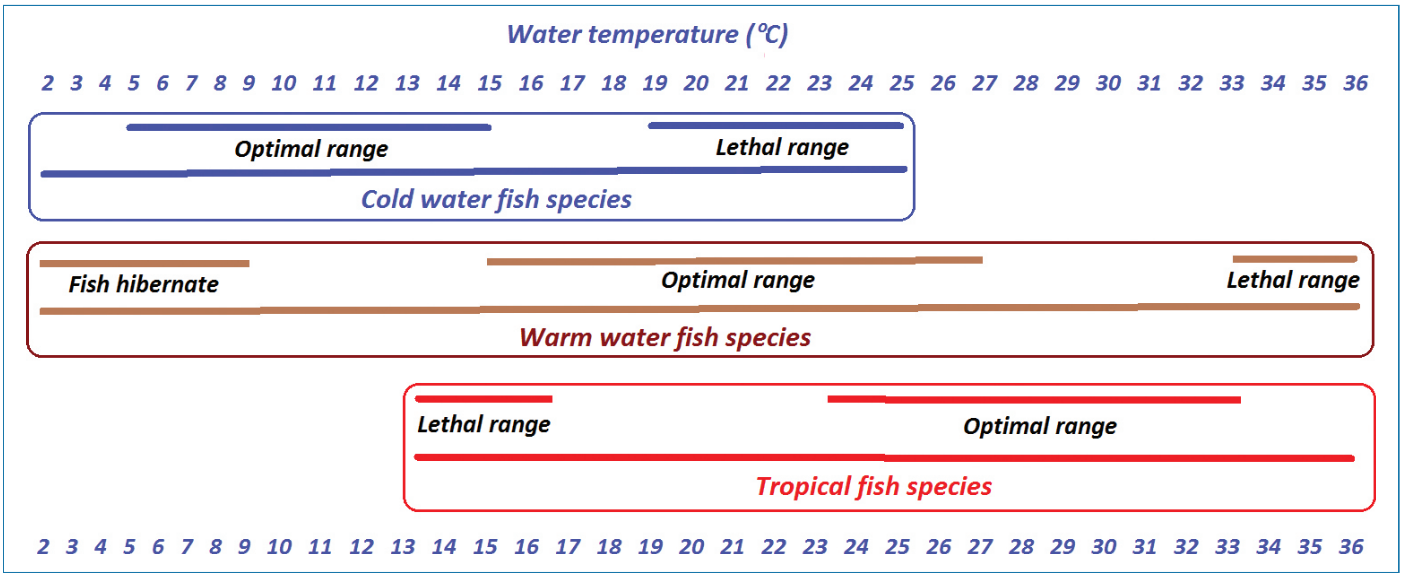
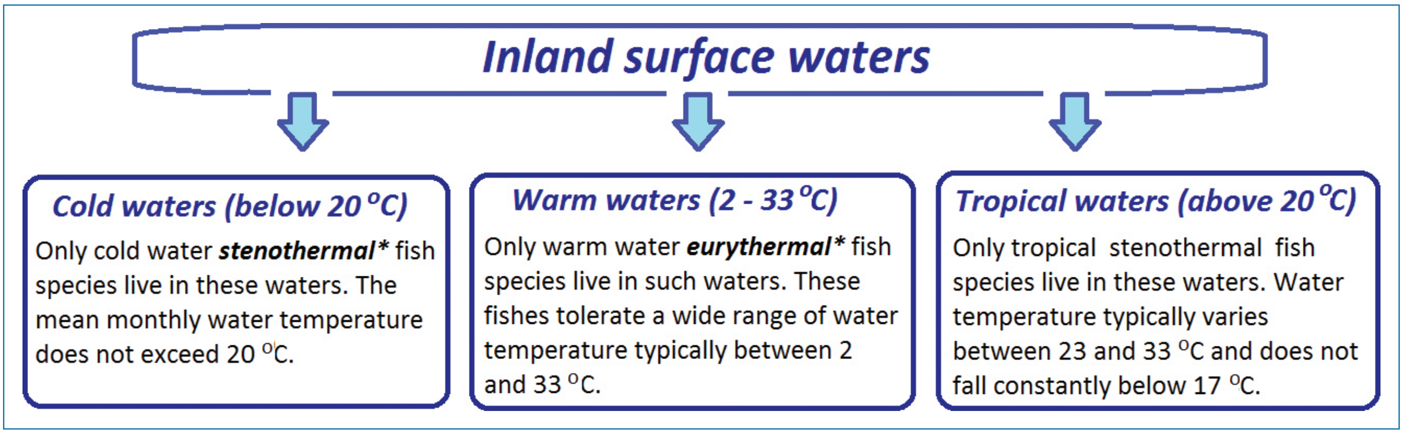


FIGURE 3-3
Classification of surface fresh waters based on fish species



Sources: Based on Flanagan *et al.* (2015) and Robinson *et al.* (2004).

The temperature of water is very important for fish, as can be seen in Figure 3-2 and Annex 3. There are coldwater, warmwater and tropical fish species which survive, grow and propagate in certain ranges of water temperature. Within these ranges, there is an optimal zone of temperature in which fish not only survive, but also feed, grow and propagate. It is true that the appetite of fish grows with increasing temperatures, but only up to a certain point. Above this point, fish lose their appetite and will die if this high temperature remains permanent or even increases.

This reaction is also true in cooling water. As the temperature decreases below the optimal, appetite is gradually lost. After a certain point, tropical fish die, while warmwater fish species hibernate for the winter until spring, when the water temperature rises again.

Inland water bodies can be categorized by their dominant range of temperature and based on fish species that reproduce in them (Figure 3-3 and Table A1-1).

It is important to note that the increased appetite of fish due to higher temperatures does not automatically result in better growth, as the accelerated speed of metabolism will force the digestive tract to pass only a partly digested food.

MEASURING AND EVALUATING WATER TEMPERATURE

Water temperature is the most important physical quality of waters used for fish production and as such should constantly be monitored. Occurrence and speed of all physiological processes during the lifecycle of fish – such as embryonal and larval development, hatching, growing, feeding (appetite) and reproduction – are temperature dependent.

Though experienced managers know how to estimate water temperature characteristics to season, this experience cannot be obtained without a shorter or longer period of systematic measurement/follow-up.

To measure water temperature, a reliable and accurate thermometer (with at least 0.5 °C accuracy) is needed, as detailed in Annex 4.

MONITORING TEMPERATURE DURING FISH PROPAGATION

Why measure – During propagation, fish are especially sensitive to changes/fluctuations in water temperature. A steady deviation from optimal water temperature can slow down or accelerate propagation, egg incubation and fish larvae development. A sudden fall or rise in temperature can stop spawning, corrupt *ovulation** and kill developing embryo and fish larvae. For these reasons, a close and accurate follow-up of water temperature is essential.

How to measure – A water temperature thermometer with an accuracy of at least 0.5 °C is required to be able to calculate the expected time and duration of spawning, ovulation, egg incubation, hatching and larvae development and the start of exogenous feeding.

What and how to calculate – Required information is provided in Box 3-1.

Box 3-1: Calculation of hour and day degrees

Hour degree (H°) is the sum of heat received by fish during a shorter period, usually less than a day. It is calculated by adding up the mean water temperatures of each hour. It is used to calculate the expected time of spawning.

Day degree (D°) is the sum of heat received by fish within a longer period. It is calculated by adding up daily mean water temperatures. It is used to calculate and express the extent of:

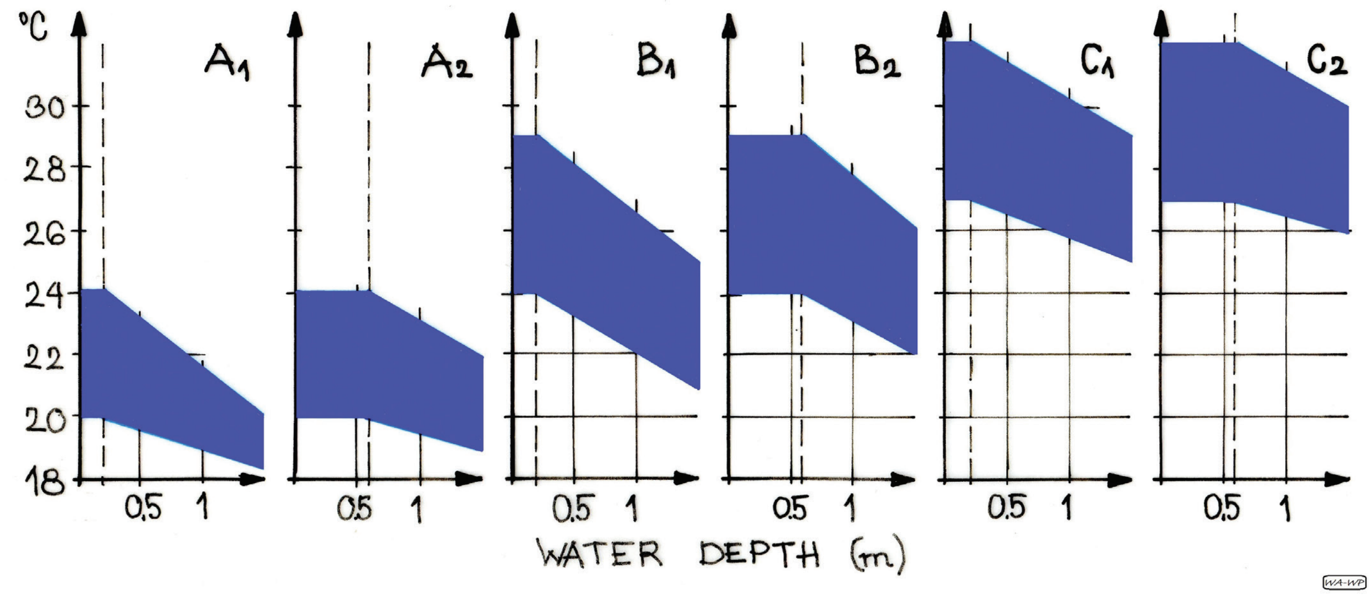
- sexual maturation of different fish species;
- period for propagation after winter;
- length of egg incubation (i.e. development period of fish embryos);
- development period of non-feeding fish larvae.

A similar calculation is used when determining the *minimum withdrawal period** for testing and using new chemicals for treating fish.

The actual temperature and the daily and seasonal fluctuation of water temperature depend on the strength and length of sun radiation and the transparency and depth of the water as demonstrated in Figures 3-4 and 3-5.

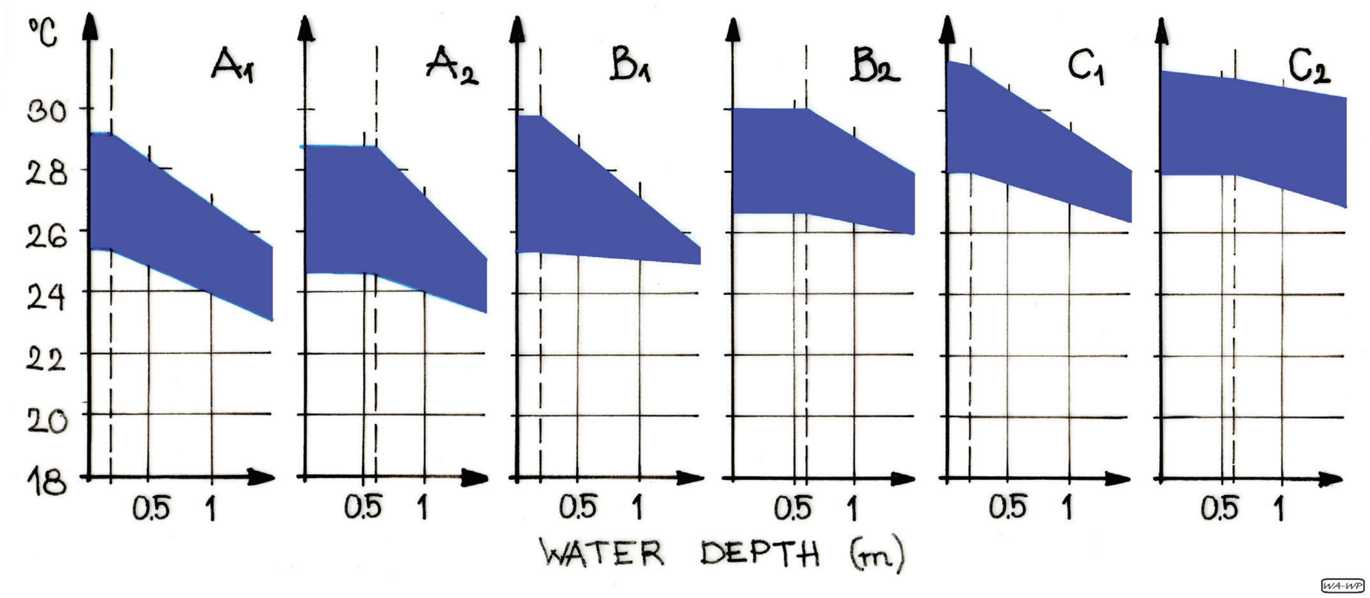
Temperature conditions in rivers are based on the same physical principles characteristic for standing waters. Therefore, they can be attributed to environmental factors such as altitude, water source, speed and volume of the water, shape and depth of the river bed, and the shape and *flora** of the banks.

FIGURE 3-4
Typical thermal stratification patterns in bodies of shallow water in a temperate climate



(A) Spring. (**B)** Summer. (**C)** Very hot summer periods, (1) low and (2) high transparencies.

FIGURE 3-5
Typical thermal stratification patterns in bodies of shallow water in a tropical climate



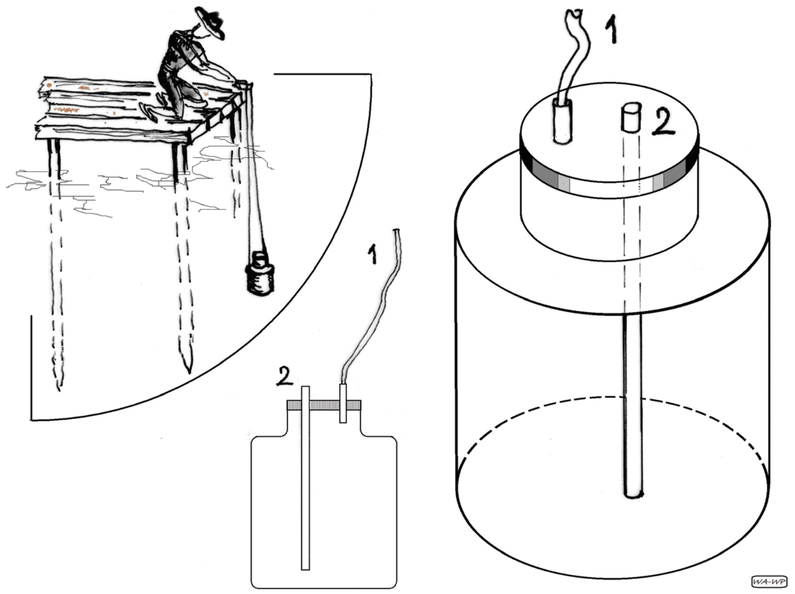
(A) Cold season. (**B)** Transition. (**C)** Warm season, (1) low and (2) high transparencies. Based on Woynarovich (1988).

MONITORING WATER TEMPERATURE IN SURFACE WATERS

Why measure – The temperature of open waters has both daily and seasonal fluctuations. These change by depth. Daily and seasonal differences depend on climatic conditions and on transparency, as demonstrated in Figures 3-4 and 3-5.

When to measure – Measuring water temperature in the mornings (around 08:00 hours) and afternoons (around 16:00 hours) provides satisfactory information. It is important not to measure temperature at the surface, since here water warms up or cools down quickly. Consequently, figures obtained from this layer do not represent the temperature of the water body where fish stay. Ideally, water temperature should be measured both at the point of transparency and near the bottom of the water column with an equipment described in Figure 3-6 and Annex 4.

FIGURE 3-6
Water sampling equipment used to measure temperature and oxygen



A 0.3-0.5 litre bottle equipped with both an outlet (1) and an inlet (2) pipe is used. These are fixed to a measuring stick to take water samples from deeper parts of a body of water.

What to do – Feeding should always be adjusted to current water temperature.

3.3 Quantitative and qualitative salt content of waters

Inorganic chemical compounds and salt content of rocks and soils determine the inorganic chemical qualities of waters. Chemical qualities are characterized by halobity, alkalinity and hardness.

3.3.1 Halobity

Halobity, a biologically important inorganic chemical characteristic of water, is typified by the following:

- The total (quantity of) dissolved salt (TDS) measured and expressed by the total concentration of salt (mg/l or ppt – part per thousand) or by specific conductivity (μS/cm – microsimens per centimetre). Classification of water bodies based on the TDS can be found in Table 3-1.
- he type of dissolved salts measured and expressed by the proportions of the eight macro-ions. The four macro-*cations** are sodium (Na^+), potassium (K^+), calcium (Ca^{++}) and magnesium (Mg^{++}) while the four macro-*anions** are carbonate (CO_3^{--}), hydrogen-carbonate (HCO_3^-), chlorine (Cl^-) and sulphate (SO_4^{--}). Similarly to TDS, classification by the dominant macro-ion content presented in Table 3-2 provides information on the suitability of water for fish production.

TABLE 3-1
Classification of water bodies by total dissolved salt (TDS) content

Categories	Total dissolved salt (TDS) content			Approximate conductivity (µS/cm)
	mg/L or ppm*	‰ or ppt*	%	
Distilled waters	0	0	0	0
Diluted fresh waters	< 150	< 0.150	< 0.015	< 240
Fresh waters	< 500	< 0.50	< 0.050	< 780
Concentrate fresh waters	500-1 000	0.5-1.0	0.05-0.10	780-1 560
Diluted salt waters	1 000-5 000	1.0-5.0	0.10-0.50	1 560-7 800
Moderate salt waters	5 000-18 000	5.0-18.0	0.50-1.80	7 800-28 080
Concentrated salt waters	18 000-30 000	18.0-30.0	1.80-3.00	28 080-46 800
Very concentrated salt waters	30 000-40 000	30.0-40.0	3.00-4.00	48 800-62 400
Hypersaline brine waters	> 40 000	> 40.0	> 4.00	> 62 400

Sources: Felföldy (1974).

TABLE 3-2
Combination of macro-ions in water bodies and the suitability for fish production

Cations	Anions			
	Carbonate (CO_3^{2-})	Hydrogen-carbonate (HCO_3^-)	Sulphate (SO_4^{2-})	Chloride (Cl^-)
Potassium (K^+)	Rare combination	Rare combination	Rare combination	Rare combination
Sodium (Na^+)	Not suitable	Suitable	Less suitable	Sea water – suitable
Calcium (Ca^{2+})	–	Suitable	–	Rare combination
Magnesium (Mg^{2+})	–	Suitable	Less suitable	Rare combination

Source: Ribiánszky and Woynarovich (1962).

Dominant cations basically determine the suitability of water bodies for fish production. Based on productivity, inland waters can be divided into two main groups:

- **α-limno-type waters** where the dominant cations are sodium (Na^+) and potassium (K^+). pH value is above 8.3. These waters do not contain free carbon-dioxide and have no *buffer capacity**, so they are not suitable for fish production. When biological production (i.e. respiration) occurs, the produced CO_2 will transform to CO_3^{2-} and will further increase the basicity of water (Felföldy, 1974).
- **β-limno-type waters** where the dominant cations are calcium (Ca^{++}) and magnesium (Mg^{++}). These waters are suitable for fish production, as they contain free carbon-dioxide and hydro-carbonate anions which buffer their pH. Such waters are stable, and their pH values remain below 8.3 (Felföldy, 1974).

MEASURING AND EVALUATING TDS

When to measure – If the suitability of a water body for fisheries and fish culture is being determined, it is recommended to measure the TDS. As the TDS does not change radically over time. If there is a substantial supply of water, it is enough to measure this parameter only when considerable thickening/changes are suspected due to evaporation or pollution.

How to measure

- When using traditional or digital salinity refractometers, figures can directly be read.
- When using a conductivity meter after measuring the electrical conductivity (EC), the TDS must be calculated by the help of an equation:
  TDS (mg/L) = EC (µS/cm) x 0.6 (at 25 °C).

Suitable equipment is listed in Annex 4.

How to evaluate received figures

- The TDS content is characteristic of the type of waters presented in Table 3.
- The desirable EC value in a fish pond remains between 1 000 and 2 700 µS/cm, while the acceptable minimum and maximum values are 250 and 6 000 µS/cm (Horváth and Pékh, 1984).

MEASURING AND EVALUATING THE QUALITY OF SALT CONTENT

When to measure – If the suitability of a water body for fisheries and fish culture is determined for the first time, it is recommended to measure the salt content as well. As this parameter does not change radically over time, it is enough to measure this parameter only when considerable thickening/changes are suspected due to evaporation or pollution.

How to measure – Measure in laboratories with a chromatograph.

How to evaluate received figures – Evaluation is done by the laboratory based on both quantities and proportions of the eight macro-ions.

In some inland waters, iron (Fe^{++}) can also be found but its presence is insignificant as iron with oxygen forms iron-oxide which is insoluble (Table A3-1).

3.3.2 Hardness

The presence of calcium (Ca^{++}) and magnesium (Mg^{++}) ions is responsible for the hardness of waters. Their concentration gives the total hardness of waters which is expressed on a scale from very soft to very hard (Table 3-3).

Hardness is commonly expressed by the following: (1) Calcium carbonate concentration (mg $CaCO_3$/l). (2) Calcium oxide concentration (mg CaO/l). 1 mg CaO/l equals to 1.78 mg $CaCO_3$/l. (3) Clark (°e) or English degree (°eH). 1 °eH equals to 14.25 mg $CaCO_3$/l. (4) French degree (°fH). 1 °fH equals to 10 mg $CaCO_3$/l. (5) German degree (°dH). 1 °dH equals to 17.85 mg $CaCO_3$/l. (6) Grain per gallon (°gpg). 1 °gpg equals to 17.12 mg $CaCO_3$/l. (7) Millimol per litre (mmol/l). 1 mmol/l equals to 100 mg $CaCO_3$/l. Total hardness of waters expressed in $CaCO_3$ concentration can be converted to any of the above units and vice versa for which there are converters on the Internet.

TABLE 3-3
Scales and values of hardness

Categories	Values expressed by		Example
	mg $CaCO_3$/l	(°dH)	
Very soft	below 40	below 4	Rain water
Soft	40–80	4–8	
Moderately hard	80–180	8–18	
Hard	180–300	18–30	Artesian and karst waters
Very hard	over 300	over 30	Fossil waters

Sources: United Utilities (2015) and Fairfax (2015).

MEASURING AND EVALUATING HARDNESS

When to measure – If the suitability of a water body for fisheries and fish culture is determined for the first time, it is recommended to measure the hardness of waters. As hardness in natural waters does not change radically over time, it is enough to measure only when a problem is suspected. In the case of intensive pond fish culture, measuring of hardness at 2–3-week intervals can help with a better assessment of water quality.

How to measure

- Test strips are the simplest and most accepted way. A colour develops on the strip when it is immersed in the water. This colour is then matched to a chart.
- If accuracy is important, a titration with an EDTA (ethylenediaminetetraacetic acid) solution should be used. Titration implies adding small amounts of a solution to a water sample until the colour of the sample is changed. To define total hardness, a burette or hardwater test kit should be used (HACH, 2015).
- Kits using a digital titrator can measure hardness concentrations very accurately (Annex 4).

How to evaluate received figures – Pond fish culture require a total hardness of 75–200 mg $CaCO_3$/l (Wurts, 2004).

What to do – In fish ponds, hardness reduces by time as calcium builds into the body of different aquatic organisms, including fish. A regular (bi-weekly) supply of lime in small doses is advantageous.

- Quicklime (calcium oxide – CaO): about 250 kg/ha/season. A rather aggressive material.
- Slaked or hydrated lime ($Ca(OH)_2$): about 250-300 kg/ha/season. A rather aggressive material that quickly increases pH.
- Limestone or agricultural lime (calcium carbonate – $CaCO_3$): about 500 kg/ha/season.
- Limestone or agricultural lime: about 1 600 kg/ha/season distributed in smaller doses of 170–220 kg/ha (Hepher and Pruginin, 1981). This is recommended for acidic African ponds.

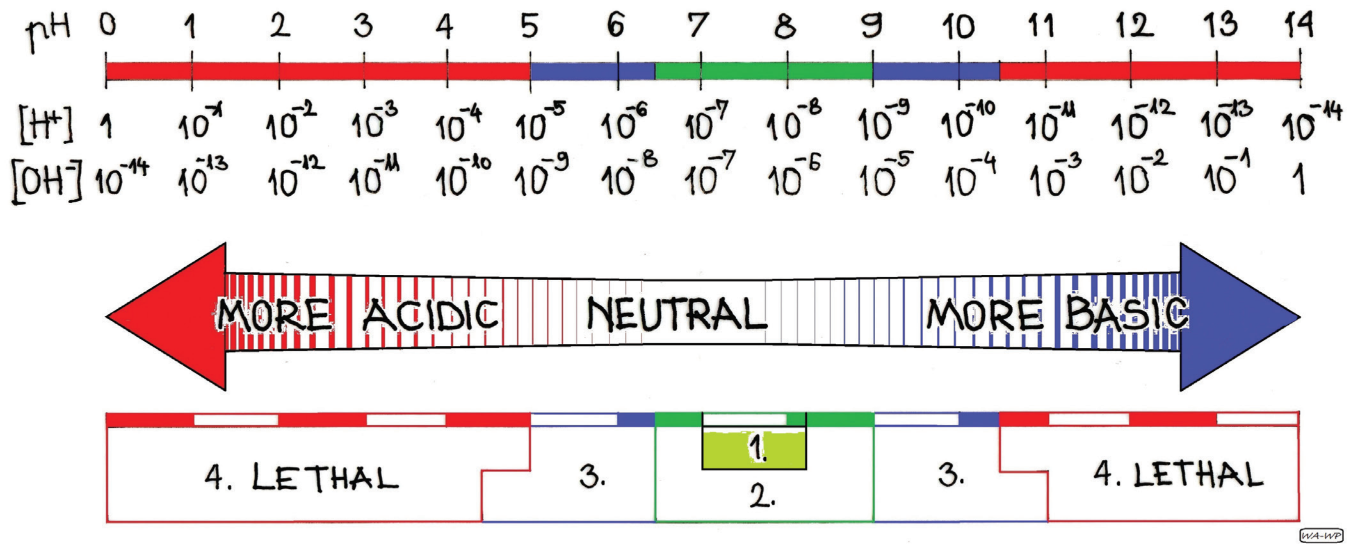
3.4 pH conditions of waters

Water can be naturally (originally) acidic or alkaline (i.e. base) due to permanently contacting (being surrounded or filtrating through) acid or alkaline soils. The extent of acidity and alkalinity is expressed by pH (Box 3-2 and Figure 3-7).

Box 3-2: Reading and expressing pH values

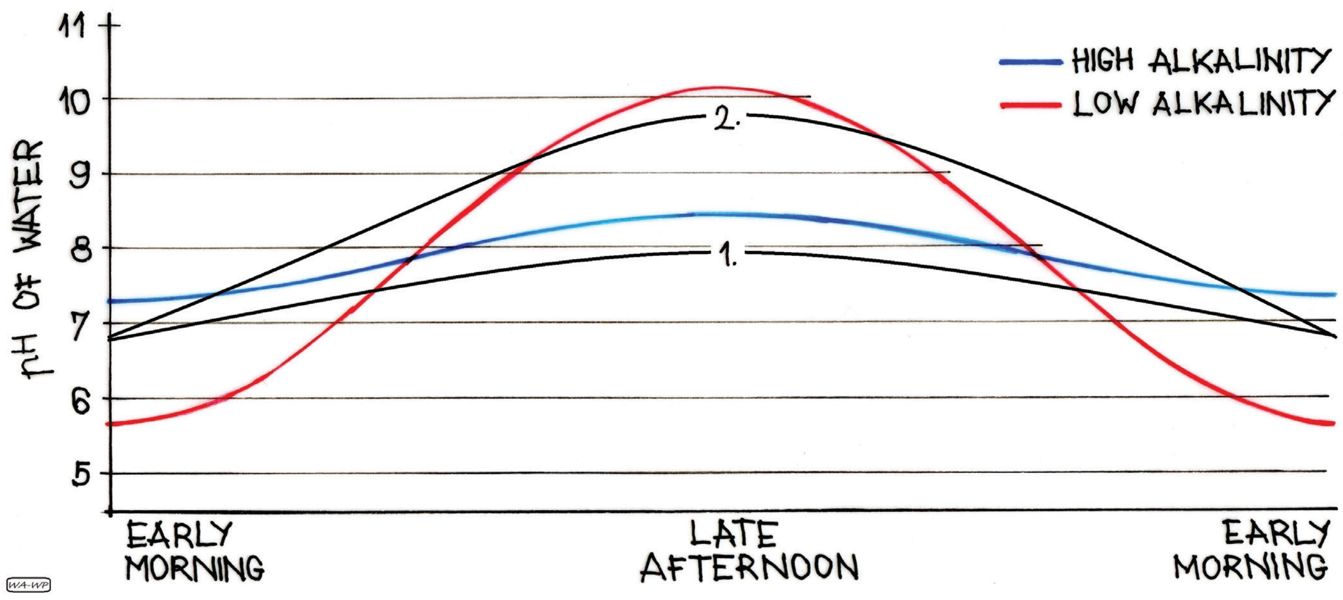
In everyday conversations, actual pH values and their changes are expressed as low, high, increasing or decreasing. For the sake of a wider acceptance, this guide also uses this terminology even if in science it is considered correct only when the words “acidity” or “alkalinity” (“basicity”) are also added.

FIGURE 3-7
pH scale and suitability of waters for fish production



(**1**) Optimal range of pH for fisheries and fish culture: 7.0–8.3. (**2**) Acceptable ranges of pH: 6.5–7.0 and 8.3–9.0. (**3**) Ranges of pH 4.0–4.5 to 6.5 and 9.0 to 10–10.5 are harmful for egg and larvae development of most fish species. (**4**) Water with pH below 4.0–4.5 and above 10.0–10.5 are toxic to most freshwater fish species (Hepher and Pruginin, 1981).

FIGURE 3-8
Schematic daily pH fluctuation of waters at different alkalinity and phytoplankton production



There is less pH fluctuation in waters with higher alkalinity than in water with lower alkalinity (Wurts, 2004).

Changes of pH at (**1**) low and (**2**) high phytoplankton production. Fish and most of their natural food organisms can tolerate rather well such daily fluctuations of pH caused by photosynthesis.

Acidic waters are common in humid regions where water percolates through soils with low calcium and high humic acid content. Alkaline waters contact with calcium-rich soils, which can result in excessive alkalinity (even above pH 9). However, this high pH value is harmful only if it is a permanent pH of water, caused by the surrounding abiotic environment. If high pH is caused by rich phytoplankton life, higher temporary figures during afternoons are normal. Consequently, the daily fluctuation of pH due to an intensive daytime *assimilation** and night-time *dissimilation** of phytoplankton is well tolerated by most fish (Figure 3-8).

MEASURING AND EVALUATING pH

Acidity or alkalinity of water is basically determined by abiotic factors but can also be modified by biotic factors. Knowing the value of pH in waters is important because of the following:

- The stability and productivity of waters depend on the value of pH (Figure 3-7).
- All chemical processes in waters have an optimal pH value or spectrum.
- The toxicity of many natural and/or artificial compounds in waters is pH dependent.
- The existence and development of all aquatic organisms have an optimal range of pH.
- All aquatic organisms, including fish and their natural food organisms, are sensitive to changes of pH, albeit to a different extent. Changing the pH value by only 1 unit represents a 10-fold change in acidity (Figure 3-7).
- Many of the materials and chemicals used in fish ponds to increase the productivity of water or treat fish diseases have a direct effect on pH.

When to measure

- In lakes, reservoirs and extensive fish ponds, it is enough to measure the pH once. pH should be measured when it is unknown or when problems are suspected. Figures obtained at daybreak indicate the true pH of a certain water (Hepher and Pruginin, 1981).
- In *eutrophic** waters and intensive fish ponds, pH should be measured on a regular basis.
- Before applying manure, fertilizer, lime or any other chemicals which effect pH.
- When any other chemical parameters of waters are measured.
- When pollution is suspected, or a mass mortality of fish happens.
- pH should be measured in early morning and late afternoon before sunset.

How to measure – Indicator test strips, pH test kits or different digital test equipment can be used for the measurements (Annex 4).

How to evaluate received figures – Optimal and acceptable ranges of pH are presented in Figure 3-7.

What to do – When selecting materials and chemicals to increase fish production or treat fish diseases, their pH sensitivity together with their effects on pH should also be considered.

3.5 Alkalinity

To determine whether a water is acid, neutral or base, pH is determined. The term alkalinity (that is, basicity) has two meanings:

- It refers to the quantity and kinds of compounds which together shift the pH to the alkaline side of neutrality (Wetzel, 1983) and
- it is used to express/indicate the *pH buffer capacity** of waters. This is the ability of waters to resist large pH changes caused by photosynthesis (Wurts, 2004).

Similarly to pH, waters also have an original (permanent) and a temporal alkalinity. Original alkalinity depends on the surrounding abiotic nature (i.e. soil quality), while temporal alkalinity depends on the presence and quantity of carbon dioxide in the waters.

MEASURING AND EVALUATING TOTAL ALKALINITY

When to measure – If the suitability of a water for fisheries and fish culture is being determined, it is recommended to measure total alkalinity. Original alkalinity does not change radically over time. It is enough to check it seasonally or when pollution is suspected.

How to measure – Swimming-pool test kits or specific alkalinity test kits are used to measure the parameter (Annex 4).

How to evaluate received figures – The desirable total alkalinity of water remains between 50 and 150 mg $CaCO_3$/l but should not be lower than 20 mg $CaCO_3$/l (Wurts, 2004).

What to do – In moderately acid and neutral fish ponds, alkalinity should be increased if calcium hardness concentration is below 20 mg/l. Normally lime is used for this.

- Quicklime (calcium oxide – CaO): about 250 kg/ha/season should be used. A rather aggressive material.
- Slaked or hydrated lime ($Ca(OH)_2$): about 250-300 kg/ha/season should be used. Also rather aggressive and quickly raises pH.
- Limestone or agricultural lime[4] (calcium carbonate – $CaCO_3$): about 500 kg/ha/season
- Limestone (calcium carbonate – $CaCO_3$): = about 1600 kg/ha/season distributed in smaller doses of 170–220 kg/ha (Hepher and Pruginin, 1981). Used in acid African ponds.

[4] A finely crushed limestone.

4. WATER QUALITIES DETERMINED BY ABIOTIC AND BIOTIC FACTORS

4.1 Light conditions and transparency

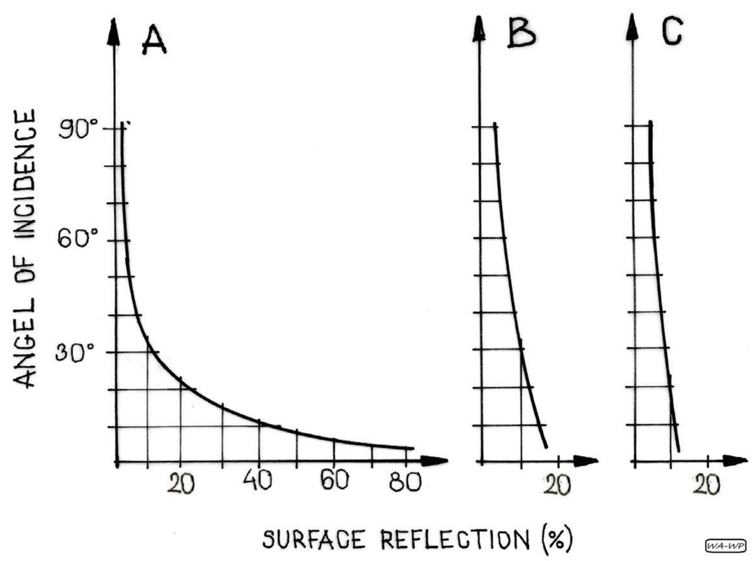
Light, more precisely sunlight, is the most important source of energy on Earth. Light and light conditions in surface waters determine, among others, the temperature and the intensity of *photosynthesis**.

Light conditions in waters depend on the direction, length and intensity of sunlight and the transparency of the water, which is influenced by *turbidity** and the *colour of the water**. From these parameters, the angle in which incident light falls through the water surface determines the proportion of light reflected and absorbed, as demonstrated in Figure 4-1.

It is a widely held opinion that transparency, measured with a Secchi disk, may indicate the density of phytoplankton in waters.

However, the importance of this tool should not be overestimated, as phytoplankton stratifies according to the strength of sunlight. If it is too strong, phytoplankton sinks deeper. If the light is weak, it rises nearer to the surface where light conditions are optimal.

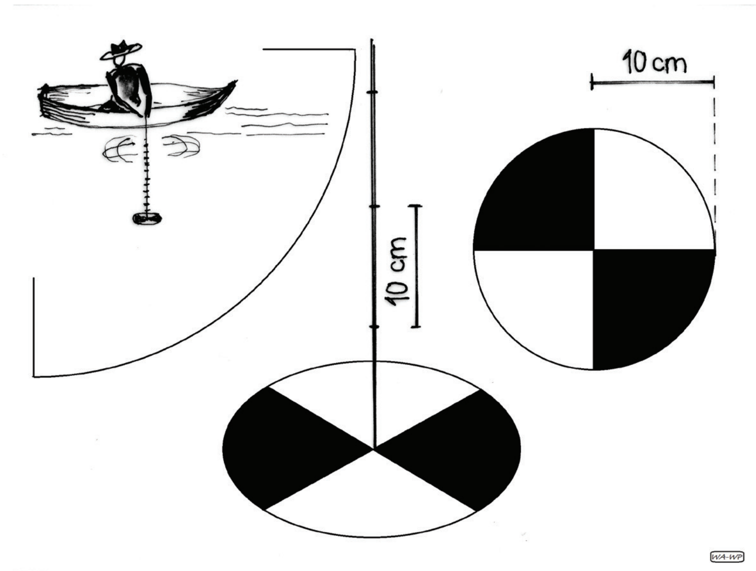
FIGURE 4-1
Reflection of incident light



Surface reflection, as a percentage of total solar radiation at angles of incidence different from the horizontal. (**A)** Clear, cloudless conditions. (**B)** Reflection of diffuse light at moderate cloud cover. (**C)** Heavily overcast conditions.

Sources: Based on Dévai and Dévai (1979) and Wetzel (1983).

FIGURE 4-2
Secchi disk



MEASURING AND EVALUATING TRANSPARENCY WITH A SECCHI DISC

The more transparent the water is, the more intensively the sunlight can penetrate it. As a result, water can overheat. Too much light is also unfavourable for phytoplankton. Similarly, in very turbid waters, insufficient light conditions slow down photosynthesis. For these reasons transparency should regularly be checked and followed up.

When and how to measure – Transparency can be simply measured by a Secchi disc (Figure 13). First, the disk should sink into the water until it disappears. Then it should be pulled slowly upwards until it appears again. This point will be the depth of transparency. When correctly done, this procedure provides reliable results. To receive correct information, transparency should always be measured at midday, not very close to the shore. Following this practice, the manager's skills will develop over time and eventually they will not always need a Secchi disk to estimate the transparency of a regularly monitored body of water.

Box 4-1: Correlation between transparency and fertilization

It is useful to know and consider two different opinions on how to estimate the need for manure/fertilizer determined based on transparency.

1. In most cases, turbidity measurements by Secchi disk may indicate the need for fertilization. Based on experience, it is possible to use turbidity as an indicator. Determining the need for fertilization solely on the basis of transparency (i.e. transparent water) should be done carefully, as misleading or even incorrect conclusions may cause harm (Rahman, 1992).
2. In fish ponds, Secchi transparency shows a correlation between floating organic materials and the concentration of chlorophyll indicated by the phytoplankton. However, there is no generally applicable pattern as transparency, in addition to phytoplankton, is also influenced by the turbidity and the colour of water (Ördög, 2000).

As zooplankton may filter the water clear, measuring pond water transparency should always be done together with zooplankton investigation.

How to evaluate received readings – It is important to know whether the rate of transparency is the result of biotic (plankton) or abiotic (turbidity) factors. Optimal transparency in nursery ponds is 20–25 cm. In intensive fish ponds, it is about 30 cm, while in extensive ponds and reservoirs 30–50 cm transparency may still indicate good fish production potential. At 30–50 cm Secchi disc transparency, a gradually decreasing amount of light is still effective. Thus, photosynthesis can still occur about 2-2.5-fold deeper than the actual reading. This means that at a 30–50 cm Secchi reading, effective photosynthesis can still be expected at 75–100 cm (Woynarovich, 1975).

What to do – The water should be fertilized based on these considerations and those presented in Box 4-1.

4.2 Oxygen content and conditions in waters

The existence of all aquatic *aerobic organisms** depends on the presence of oxygen dissolved in the water. Therefore, oxygen content and conditions in waters have a primary importance for both fish and their natural food organisms. The main sources of oxygen in waters are as follows:

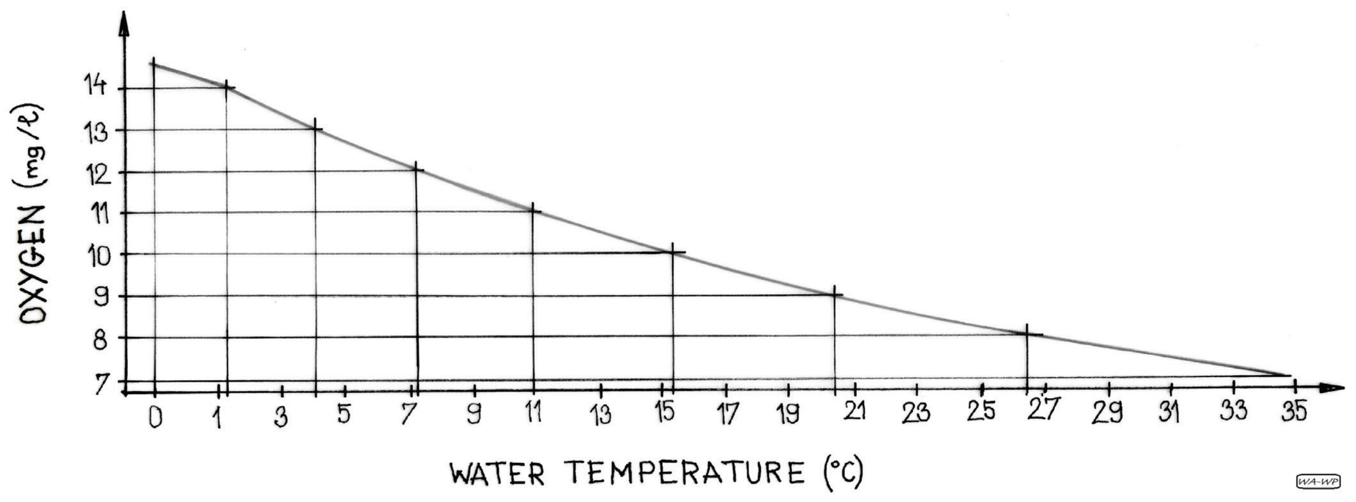
- **Abiotic.** Oxygen penetrates the water from the atmosphere through *diffusion**. It happens in the upper torrents and rapids of rivers, but strong winds and rains can also increase the oxygen content.
- **Biotic.** Photosynthesis of *autotrophic organisms**.

Due to intensive diffusion or photosynthesis, water can temporarily be oversaturated but the excess oxygen will diffuse to the atmosphere as soon as the source ceases. The main reasons for oxygen reduction in waters are as follows:

- **Abiotic.** Temperature and chemical processes such as *mineralization** and *oxygen consuming gasses**.
- **Biotic.** *Biosynthesis** and respiration of aquatic plants and animals. Fish populations are usually not the largest oxygen consumers, which is especially true in eutrophic waters and fish ponds.

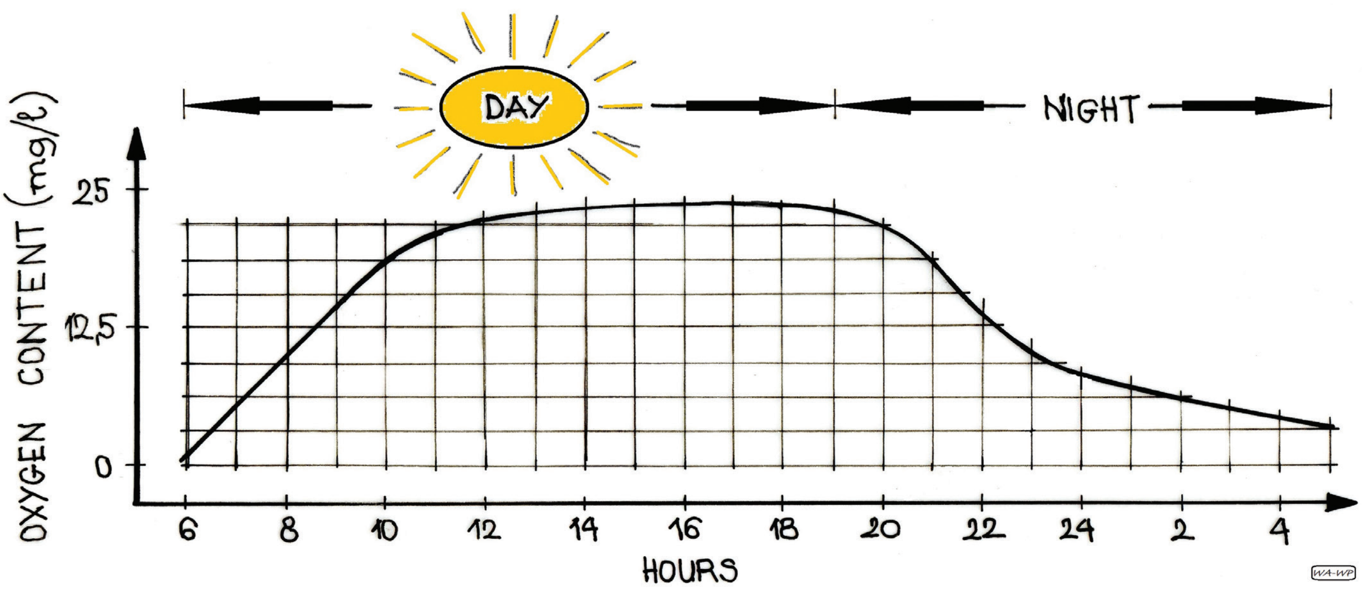
Oxygen content of water changes during the day and with depth of the water body as demonstrated in Figures 4-4 and 4-5.

FIGURE 4-3
Oxygen content of a fully saturated water at different temperatures



Dissolved oxygen (DO) content slightly changes by the quality and quantity of dissolved materials, as well as by altitude (air pressure).

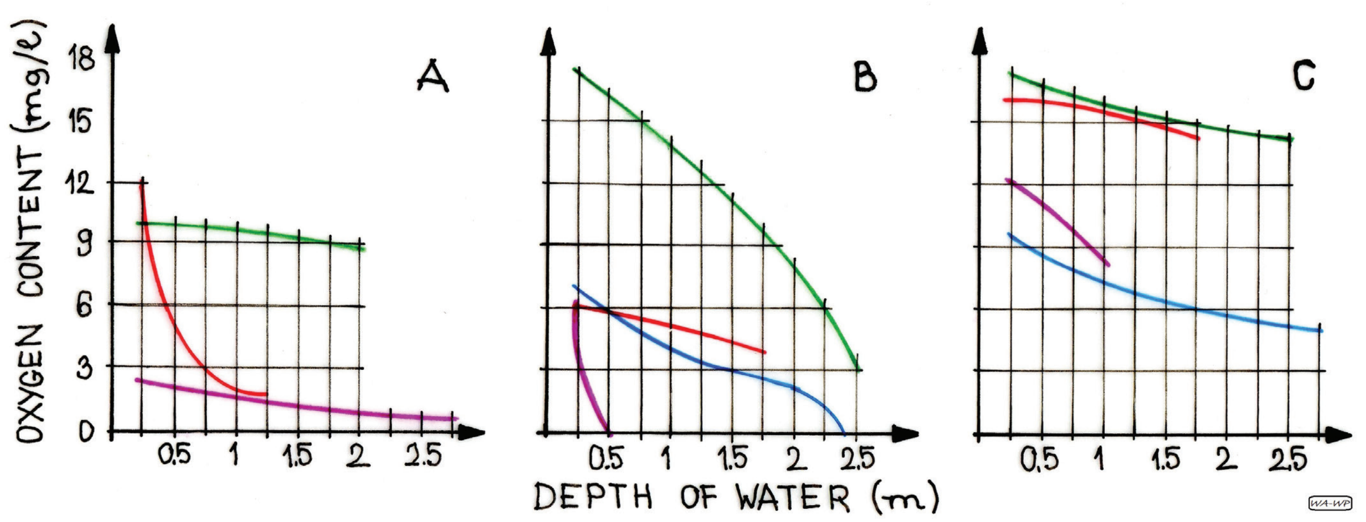
FIGURE 4-4
Daily fluctuation of oxygen in eutrophic lakes and fish ponds



In the light period, when photosynthesis happens, algae (i.e. phytoplankton) produce the majority of DO. However, no oxygen is produced in the dark period. All organisms, including plants, consume oxygen continuously, day and night. The result of these two processes is a daily fluctuation of the oxygen level in waters. Oxygen content drops sharply after its production stops and the excess DO above full saturation diffuses into the air. From this point, the remaining limited quantity of oxygen will be consumed in the dark by the huge biomass. If the biomass is large enough, it can cause a partial or even a total oxygen shortage by the next dawn (Woynarovich *et al.,* 2010).

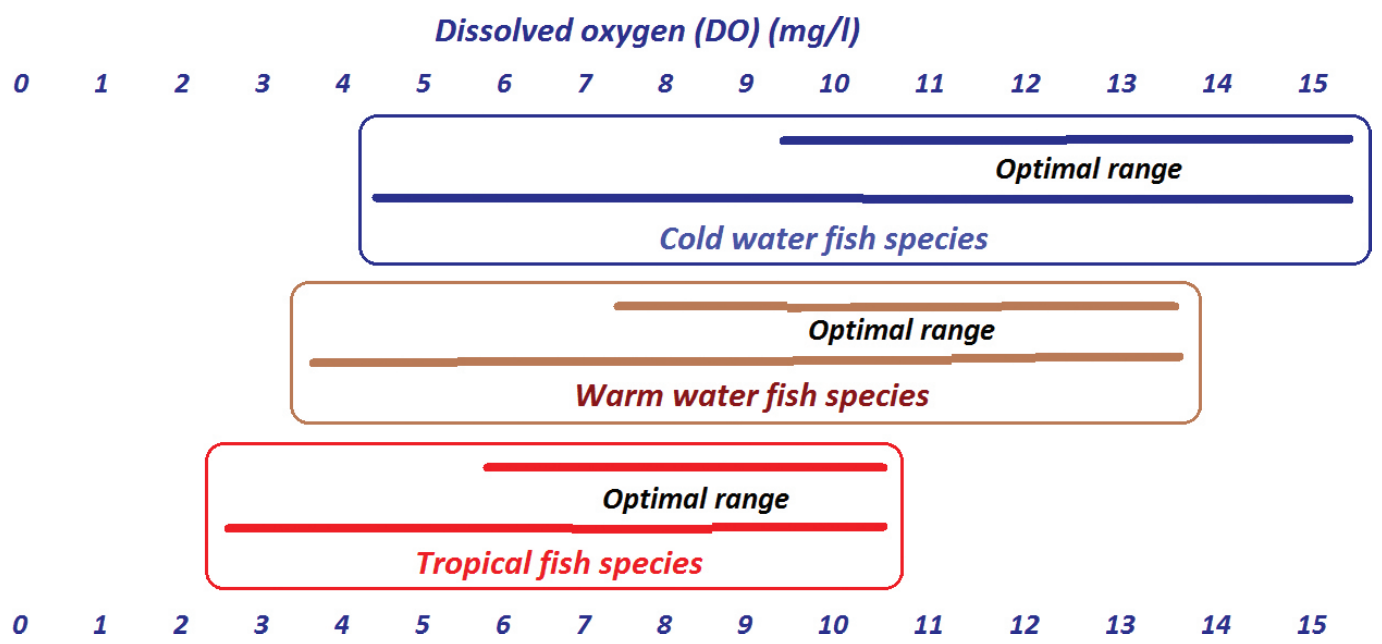
Though water is a good solvent, oxygen does not dissolve well. The maximum oxygen content of waters is also limited by temperature. Accordingly, there is a specific maximum quantity of oxygen, expressed in mg/l, which in equilibrium remains solved at a certain temperature (Table 4-3). At these maximum values waters are fully (i.e. 100 percent) saturated. Saturation level can be below 100 percent when oxygen consumption is dominant, while it will be above full saturation if oxygen producing processes dominate. In lakes and reservoirs, the fluctuation of *oxygen saturation** between 70 and 150 percent is a usual, natural process.

FIGURE 4-5
Oxygen content in different depths of waters in different seasons



Some typical curves of dissolved oxygen (DO) in different water bodies: (**A**) summer, (**B**) early autumn and (**C**) late autumn. *Trophity** levels: (1) low, (2) medium and (3-4) high.

FIGURE 4-6
Ranges of optimal oxygen content for different groups of fish species



MEASURING AND EVALUATING OXYGEN CONTENT – GENERAL ASPECTS

Why to measure – Except for *labyrinth fishes**, oxygen content is a limiting factor for most fish species. Coldwater, warmwater and tropical fish species can tolerate reduced oxygen content of waters in different ways (Figure 4-6). Even a minimum reduction of oxygen has an effect on spawning and appetite. Therefore, monitoring oxygen conditions during fish propagation and production is one of the basic tasks of inland fisheries and fish farm managers.

How to measure – In the case of oxygen, it is important to take the water sample properly, without altering the original oxygen content. The sample should be taken without bubbles. When water is taken from the surface, the bottle should be filled carefully without bubbling. When samples are taken from depth, equipment presented in Figure 3-6 should be used. In hatcheries, a simple glass carefully filled with water serves the purpose.

Equipment to use – A dissolved oxygen test kit or a digital dissolved oxygen meter can be used (Annex 4).

MEASURING AND EVALUATING OXYGEN CONTENT – FISH PROPAGATION

Why to measure

- During propagation, broodfish, especially females, which are about to spawn and/or *ovulate** need the maximum possible concentration of oxygen in the water, otherwise the progressing physiological process may stop and spawning/ovulation will fail.
- Chronic insufficient oxygen concentration often causes deformed embryos or larvae, whereas an acute oxygen shortage will kill them.
- Broodfish concentrating at inlets and gulping for air or dying embryos and larvae are already a drastic sign of oxygen shortage in the hatchery. This should be avoided by a regular checking of oxygen content in the inflow water.

When to measure – Fish hatcheries must be supplied with water fully saturated with oxygen. Oxygen content should be routinely checked, especially when the hatchery is supplied from a water reservoir or a fish pond with a high trophity level. When an oxygen shortage is suspected, immediate action is recommended.

What to do – If a reduced oxygen content of hatchery water is experienced, do the following:

- Aerate and/or reduce trophity in the reservoir or pond where water is received from.
- Aerate or oxygenate the water in a central tank in the hatchery.
- Aerate the broodfish tanks at inlets with compressed air or pure oxygen.

MEASURING AND EVALUATING OXYGEN CONTENT – FISH PRODUCTION IN PONDS

Why measure – An occasional oxygen shortage in eutrophic waters including fish ponds is very frequent at dawn, especially in the second half of the production season. It happens due to a daily fluctuation and in-depth changes of oxygen content (Figures 4-4 and 4-5). A typical sign of an oxygen shortage is that fish concentrate at the water surface and gulp for air.

When to measure – The oxygen content of water should be checked not only when the problem is already evident. Measuring oxygen content in advance at late afternoon is the most appropriate way to predict an oxygen shortage at daybreak.

How to evaluate received figures

- In warmwater and tropical fish ponds, 5–12 mg/l oxygen content at or above 70 percent saturation is desirable (Horvath and Pékh, 1984).
- When 5 mg/l oxygen content at 50 percent saturation is measured, an oxygen shortage can be expected the following dawn because of the biological and chemical oxygen consumption during the night.
- In hot summers, when more than 12 mg/l oxygen content is measured in ponds, attention should be paid as increased respiration of phytoplankton can be expected during the night. However, 18-20 mg/l or even higher (24 mg/l) DO in late afternoon is also a warning sign of a likely oxygen shortage the following dawn (Figure 22).
- Waters supplied by water from below hydropower stations may become hyper-saturated. A saturation percent of 400–450 is dangerous. Above 450 percent saturation of DO, embolism occurs under any weather conditions as oxygen dissolved in blood will separate in molecular form (i.e. O_2). (Nagy *et al.,* 2007)

What to do – In the case of an oxygen shortage:

- Stop feeding immediately and reduce or even stop manuring/fertilization.
- Reduce the biomass of phytoplankton by using either (1) quicklime (200 kg/ha in about three portions distributed in strips over the water surface (do not use it at high pH) or (2) calcium hypochlorite or bleaching powder ($Ca(OCl)_2$) (7-10 kg/ha distributed in strips over the water surface, repeated maximum three times every fourth or fifth day) or (3) copper sulphate ($CuSO_4$) (used against filamentous algae in a total quantity of 8-10 kg/ha/year which should be divided and distributed evenly over the pond water surface in three equal portions when needed with an interval of 3-4 weeks) (Molnár *et al.,* 2015).
- Prepare for oxygen shortage at dawn and aerate water from late night till early morning.

MEASURING AND EVALUATING OXYGEN CONTENT – WINTERING FISH

Why measure – Under cold and temperate climate during winter, ice develops on the water surface. Though ice is transparent, this is not true when it is covered with snow. Even a 2 cm thick layer of snow can almost totally block the penetration of light into the water. Phytoplankton cannot produce oxygen without light but will only consume oxygen in the dark.

When and where to measure – Measuring oxygen in waters and ponds where fish stocks are wintered should be a daily routine. Sampling should happen at the depth where fish hibernate. If fish stocks are wintered in smaller ponds with a correctly set continuous water exchange, measuring the oxygen content of outflowing water should be a proper solution, provided the water is from the depth where fish are found.

How to evaluate received figures – It is advantageous to have the oxygen content near to saturation level, which at 4 °C is around 13 mg/l.

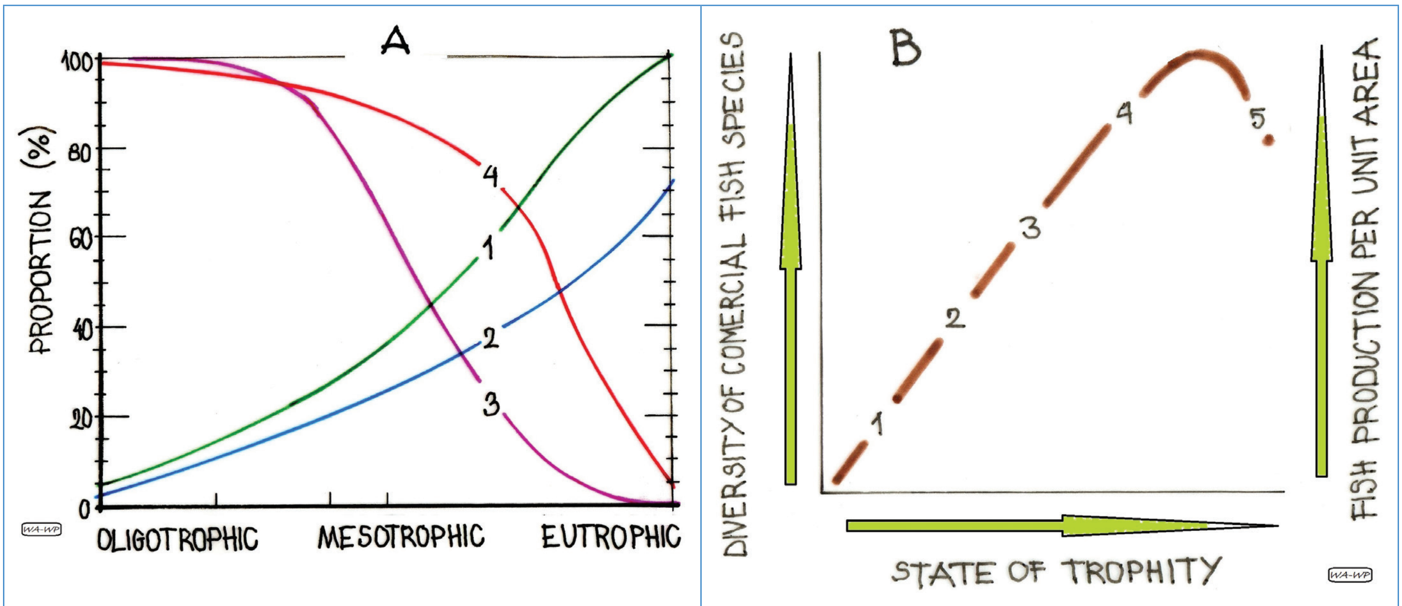
What to do

- Cut two or three ice holes of about 4 – 6 m^2 in size on each hectare of water surface (Fürész and Papp, 1995).
- Aerate waters at the inlet and/or within the pond. Aeration will also stop icing.

4.3 Inorganic and organic nutrient content of waters – trophity and saprobity

Qualitative and quantitative inorganic plant nutrient content of waters determines the extent of their trophity. Two groups, the nitrogen and *phosphorus** forms, define **trophity** i.e. whether a water is oligotrophic, mesotrophic, eutrophic or hypertrophic (Figure 4-7 and Table A1-3).

FIGURE 4-7
Correlation between trophity, phosphorus content, biodiversity and the structure of the fish fauna



A: (**1**) Primary production. (**2**) Phosphorus input. (**3**) Dissolved oxygen. (**4**) Biodiversity also including commercially less valuable fish species. Source: Correl (1998).

B: Correlation between trophity, fish *fauna** and fish production per unit area of standing waters. (**1**) Certain Salmonids. (**2**) Coregonids, Salmonids. (**3**) Coregonids, Perch, Cyprinids. (**4**) Perch, Cyprinids. (**5**) Cyprinids, Pike. Source: Bíró (2011).

The different forms of nitrogen in waters are responsible for the *vegetative growth** of plants. Nitrogen is present in waters as molecular nitrogen (N_2), nitrite (NO_3^-), and nitrate (NO_2^-), ammonium ion (NH_4^+) or as organic compounds. These forms develop from each other mainly by the help of different bacteria. From the listed forms of nitrogen, measurement and evaluation of nitrite and nitrate are described based on Papp and Fűrész (2003), while *ammonia** is discussed in Chapter 4.4.

MEASURING AND EVALUATING NITRITE AND NITRATE IN WATERS

Nitrite (NO_2^-)

Nitrite is an intermediate oxide between ammonium and nitrate, which in higher concentrations can also be toxic. It is measured seasonally unless there is an emergency case.

Equipment to use – Test kits (Annex 4).

Evaluation of results – Around maximum 0.1 mg/l is usually normal, while below 0.3 mg/l is acceptable. Higher concentrations may indicate organic water pollution, mainly blue algae (Papp and Fürész 2003).

Nitrate (NO_3^-)

Nitrate is important for phytoplankton growth. Knowing its value helps to determine the need for manure/ fertilizer.

Equipment to use – There are test kits which ensure the required accuracy (Annex 4).

Evaluation of results – About 1-10 mg/l is required, 20 mg/l is normal, while below 40 mg/l is acceptable (Horváth and Pékh, 1984; Papp and Fürész, 2003).

Phosphorus is essential for the *generative growth** of plants, which is a main cause of eutrophication in natural waters and is often a limiting factor of natural food production in fish ponds. Sources of phosphorus in natural waters can be domestic (detergents) and agricultural (fertilizers) pollutants. Measuring and evaluating phosphorus concentration in waters are summarized based on Papp and Fürész (2003).

MEASURING AND EVALUATING PHOSPHORUS IN WATERS

Why measure – From a general point of view, total phosphorus load should be measured. In fisheries and fish culture where increased productivity of water is advantageous, the concentration of a soluble phosphorus, the *orthophosphate**, should also be measured. As plants can take up this nutrient, it is responsible for increased phytoplankton (plant) production.

Equipment to be used – There are test kits available that will ensure the required accuracy (Annex 4).

Evaluation of results – Evaluation of results depends on the type of water checked:

- In natural waters, the acceptable limit expressed in orthophosphate is 0.3 mg/l (Papp and Fűrész, 2003).
- In intensive fish ponds, the desirable value is between 0.6 and 1.8 mg/l, while the acceptable higher limit is 2 mg/l (Horváth and Pékh, 1984).

Saprobity indicates how waters are supplied with organic nutrients. These particles have an important role because they can serve as micro-nutrients for many different aquatic organisms, especially for zooplankton. Saprobity is measured with the *chemical oxygen demand (CDO)**.

MEASURING, ASSESSING AND EVALUATING TROPHITY AND SAPROBITY OF WATERS

The role of phosphorus in eutrophication is evident. Similarly to increased trophity, increased saprobity of waters is also considered a negative quality when drinking water, bathing water or drip irrigation are examined. When looking at fish and fish production, increased trophity and saprobity within certain limits are advantageous, so much so that waters are manured whenever possible/feasible.

Trophity is measured in laboratories by skilled specialists. This is normally a routine process for scientists when environmentally and economically important water bodies and systems are examined.

- Trophity is measured to provide precise qualitative and quantitative analyses of dissolved inorganic plant nutrients.
- It is used to measure primary production, that is to determine Chlorophyll a and quantitative and qualitative characteristics of phytoplankton (Section 5.2.2).

Saprobity of waters is determined by COD. It is an important parameter and, according to Horváth and Pékh (1984) should be around 18–22 mg/l, and a maximum of 30 mg/l in productive waters. Other authors set these limits to 8 mg/l and 12 mg/l, respectively (Papp and Fürész, 2003).

Feasible field assessments – In fisheries and pond fish cultures, it is desirable to maintain a possibly optimal water productivity. Therefore, techniques for measuring trophity and saprobity in the field should be simple and reliable. Two common methods are used:

- Judging productivity based on transparency is less reliable, unless done by a very skilled person. Related details are discussed in Sections 4.1 and 5.2.
- Evaluating quantitative and qualitative status of zooplankton and *zoobenthos** to determine water productivity in the field is a simple and reliable method (Horváth, 2000). Detailed information on sampling zooplankton and zoobenthos is presented in Section 5.2.

What to do

- In fish ponds, if the productivity of pond water is declining or already low, the application of manure and fertilizers can restore natural fish food production.
- In large open waters (lakes and reservoirs), there is no scope (or need) to increase water productivity by using manure or fertilizer. Still, it is important to know the trophity and saprobity of the water to help to estimate the expected fish yield and to compile realistic plans for stocking, if culture-based fishery is practised.

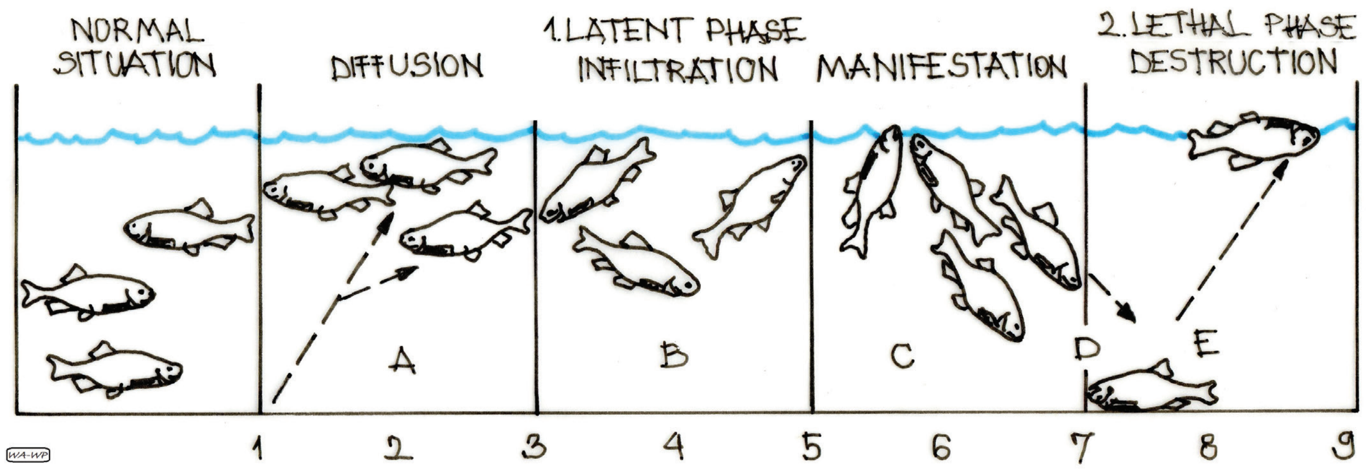
4.4 Toxicant content of waters – toxicity

Assessment of water toxicity is done based on toxicants present in them. The source of toxicants can be external (agricultural, industrial and communal) or internal. There is a wide range of external toxicants. When problems appear, they should be investigated case by case. Therefore, the role of the manager in such cases is to take a set of measurements described in Section 7.2, take samples, and call professional assistance to determine and solve the problem. General symptoms and the phases of fish toxicity are presented in Figure 4-8.

Most frequent toxicants internally produced/developed in waters are as follows:

- Ammonia is produced by different groups of living organisms as an end-product of their metabolism. One-third of consumed nitrogen is excreted by fish through the gills in the form of ammonia during respiration. Free ammonia (NH_3) and ammonium ion (NH_4^+) together represent the total ammonia ($NH_3 + NH_4^+$) content of pond water. Toxicity of ammonia is pH dependent. The amount of toxicant ammonia increases with the alkalinity of water as described in the Glossary under 'ammonia'.
- *Hydrogen sulphide** (H_2S) is produced by an anaerobic bacterial decomposition of proteins, degraded organic materials and sulphates present in the mud of pond bottom. Sulphur hydrogen dissolves very well in water. It is strongly poisonous, especially when the pH of water is acidic.
- Algal toxicants, in a strict sense, do not belong to dangerous organisms. Still, they may cause massive fish mortality as under certain conditions some species are able to produce toxic materials or dangerously reduce the oxygen content of water when blooming (Molnár *et al.,* 2015).

FIGURE 4-8
Symptoms in different phases of fish toxicity



Source: Based on Bíró (1979).

Normal situation: (**A**) First latent phase – diffusion. (**B**) – infiltration. (**C**) – manifestation. (**D**-**E**) Second lethal phase – destruction.

(**1**) A toxic substance is discharged in the water. (**2**) The toxic pollution reaches 1-50 percent of the fish population. (**3**) There is an obvious reaction in some of the fish to the poison. It is manifested in unusual (forced, unsteady, vague, etc.) motions. (**4**) Fifty percent of the fish population reacts to the toxicant. (**5**) One hundred percent of the fish population reacts to the toxicant. (**6**) Irreversible damage is caused, such as dazing or death. (**7**) Fifty percent of the fish die. (**8**) All the fish die.

In case of mass-mortality the extent of losses should be estimated as described in Box 4-2.

Box 4-2: Estimating the extent of fish mortality

Before removing and properly eliminating dead fish (hygiene must also be considered), it is important to estimate the extent of fish mortality as outlined by Papp and Fürész (2003). In rivers, the number and age (size) groups of different fish species floating downstream within a certain period should be recorded. Wire fences placed on and under the water surface will help to guide the bodies to the shore. In standing waters, dead fish can be collected with scoop nets from the shore or from boats. The real number of dead fish is usually more than that counted. To estimate the real number of dead fish, constant factors are used based on weight groups:

- Fish size between 10-20 grams: real number of dead fish is 20-50 times higher.
- Fish size between 20-50 grams: real number of dead fish is 10-30 times higher.
- Fish size between 50-100 grams: real number of dead fish is 5-20 times higher.
- Fish size between 100-300 grams: real number of dead fish is 5-10 times higher.
- fish size above 300 grams: real number of dead fish is 2-5 times higher.

CAUSES AND POSSIBLE ACTIONS WITH REGARD TO TOXICITY

Poisonous gasses

Ammonia is always present in waters and is one of the most frequent toxicants. It can be an end-product of metabolism or a result of degradation of protein-rich organic matter or urine. Ammonia can also get into the water via sewage water or run-off water from fertilized agricultural fields. Fish can survive 5-10 mg/l concentrations of total ammonia in neutral waters (pH 7), but in alkaline waters, it becomes more and more toxic and can cause poisoning in very low concentrations (0.2-0.5 mg/l). The desirable and acceptable concentrations of ammonium are 1.0 mg/l and 2.5 mg/l, as free ammonia is poisonous from 0.02 mg/l concentration (Papp and Fürész, 2003).

Hydrogen sulphide gas accumulates in the mud. When temperature quickly decreases or air pressure drops, hydrogen sulphide is released from the mud. As the gas dissolves well in water, it kills fish. Hydrogen sulphide is dangerous at 0.002 mg/l. Its lethal effect is higher at low oxygen concentration and higher acidity (i.e. pH below 7). Hydrogen sulphide also reduces DO in the water, causing an oxygen shortage.

Symptoms of poisoning – Both ammonia and hydrogen sulphide are neural poisons. Tainted fish become restless and show spasmodic symptoms at the surface. The mouth of a dead fish is open and blood exudates from the gills. The only protection is prevention. Both gasses are naturally produced in waters, especially in intensively manured fish ponds. Therefore, it is important to do the following:

- Keep pH as stable as possible.
- Ensure there is enough DO in the water.
- Do not dump manure in heaps but rather distribute evenly over the entire water surface of the pond.

Toxic algae

Some species of algae, especially cyanobacteria (blue algae), produce toxins and can cause mortality, even in low concentrations. This toxicosis occurs both in wild waters and in fish ponds where organic and chemical fertilizers are excessively used.

Algal bloom – Increased algal blooms, both in natural and artificial waters, including fish ponds, are frequent. In ponds rich in plant nutrition, excess algae proliferation can take place on hot summer days. Algae covering the water surface prevents light entering the water which causes an oxygen shortage during the day. In addition, increased algae biomass will intensively consume oxygen during the night.

Symptoms – Enervated fish at the water surface gulping air at dawns indicate a problem. In a severe situation, fish may start to suffocate during the day and early evening.

In fry-rearing ponds, young fish can be damaged by algae covering gill filaments.

Protection – Protection against toxic algae and algal bloom includes the eradication or reduction of algae (Molnár *et al.*, 2015) by:

- Using either (1) quicklime (200 kg/ha in three portions distributed in strips over the water surface (do not use at high pH) or (2) calcium hypochlorite or bleaching powder ($Ca(OCl)_2$) (used in basic waters (pH>7), when 7-10 kg/ha is distributed in strips over the water surface, repeated maximum three times on every fourth or fifth day) or (3) copper sulphate ($CuSO_4$) (used against filamentous algae in a total quantity of 8-10 kg/ha/year, which is divided and distributed evenly over the pond water surface in three equal portions when needed, with an interval of 3-4 weeks) (Molnár *et al.*, 2015).
- Using straw (maximum 5 000 kg/ha/season in 90–500 kg/ha doses) is a recently discovered and tested environmentally friendly technique to eradicate phytoplankton blooms (Tamás *et al.*, 2008, Stiller, 2012; Horváth, 2015).

5. WATER QUALITY DETERMINED BY BIOTIC FACTORS

5.1 Composition and decomposition processes in waters and biological production

A principle of all biological activities within aquatic ecosystems is biological productivity or aquatic production:

- Primary production, in which living organisms, mainly plants, form energy-rich organic materials from energy-poor inorganic materials through photosynthesis.
- Secondary production, in which organic materials are transformed through consumption.

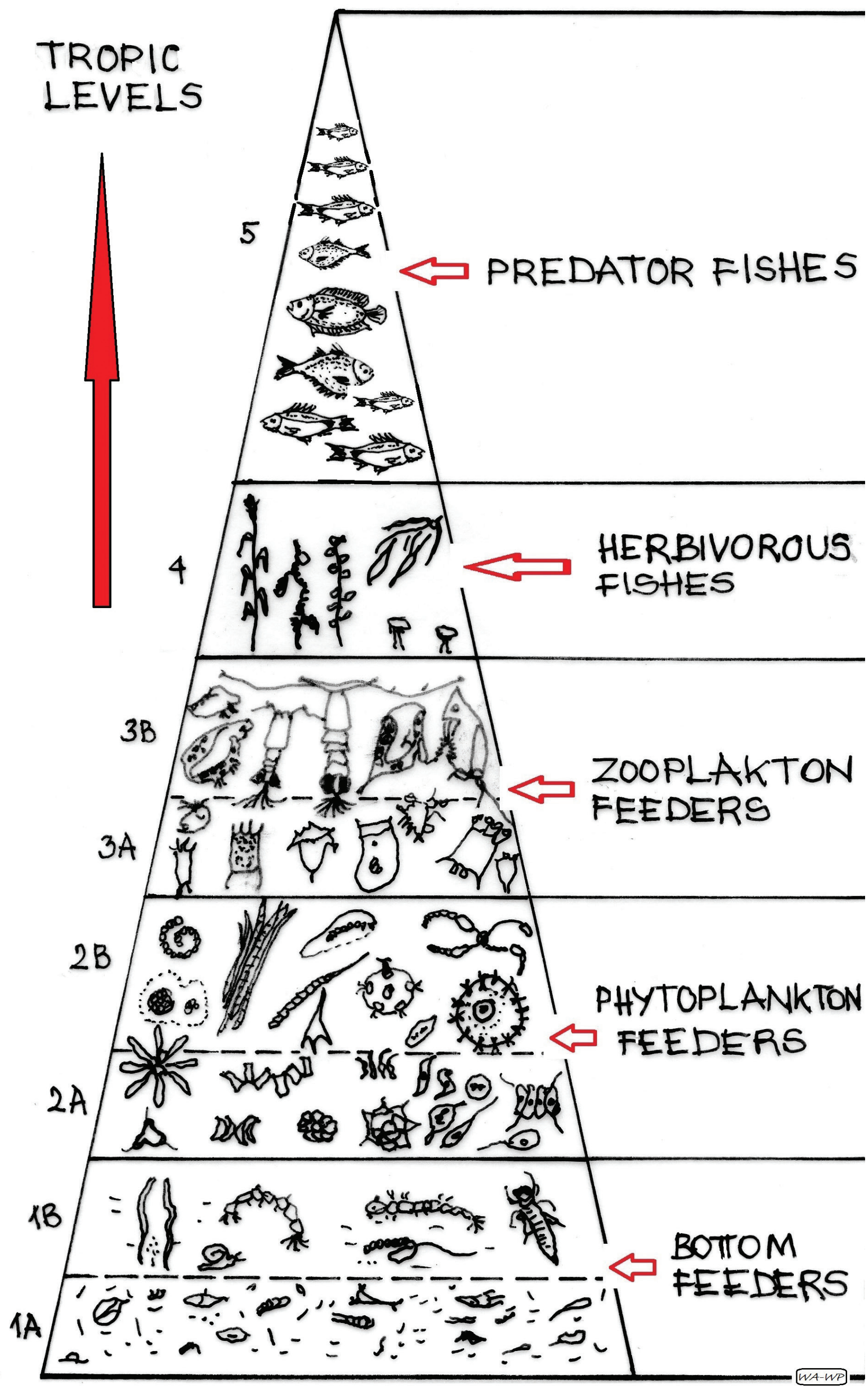
In case of fisheries and pond culture, fish are the result of a complex biological cycle which takes place in waters (Huet, 1972). This cycle, which includes primary and secondary production and the decomposition of living organic substances is discussed in this chapter.

Water is a basis of life. There are no surface waters where life cannot be found. The wide range of organisms detailed in Annex 2 live in different *biotopes** of standing waters, linked to each other in a complex food web.

For practical reasons and simplicity, "food web" is often discussed as a food chain or a food pyramid. These expressions illustrate how the life of different organisms in waters are built on and depend on the existence of the others (Figure 5-1).

The food pyramid is based on the primary production of autotrophic organisms. These, mainly green plants, can produce organic substances from inorganic ones such as carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus and other substances in smaller quantities.

FIGURE 5-1
Food pyramid in waters – sources of natural fish food and their consumers



Source: Based on Ribiánszky and Woynarovich (1962).

Different *trophic levels** of fish feed. (**1A**) Detritus. (**1B**) Zoobenthos. (**2A and 2B**) Phytoplankton. (**3A and 3B**) Zooplankton. (**4**) Waterweeds. (**5**) Fish (Annexes 2 and 3).

During photosynthesis, nutrients are fixed in high-energy organic forms in living organisms. Energy required by the process is gained from sun radiation. Though the efficiency of photosynthesis is only 1 percent, because of the huge amount of radiation received the process is still the base of life on Earth.

For these reasons, photosynthesizing organisms (i.e. plants) are the primary producers and their metabolism is autotroph type. In waters, these organisms can easily be identified by their green colour. They float in the water column (as floating algae or phytoplankton), float on or under the water surface (rooted or unrooted plants) or emerge above the water surface (different waterweeds, reed grasses, etc.) (Figure A2-3).

The second largest group of aquatic organisms includes *heterotrophic organisms**. Their metabolism is a decomposing type. They are called secondary producers. Their common characteristic is that they cannot produce organic substances from inorganic ones. They can use only organic substances by converting and building them into their own bodies. These organisms, including fish, are found at different trophic levels as shown in Figure 5-1.

In the living world, and in waters, materials fixed in organic substances are moved from one level to another as illustrated by the food pyramid. From an energy point of view, the utilization of consumed food among heterotrophic organisms is about 10 percent between different levels of the food pyramid, while the efficiency of photosynthesis is 1 percent. This means that about 1 percent of the energy of sun radiation is transformed into organic molecular energy and remains stored this way. The correlation between the utilization of trophic levels and fish culture is explained in Box 5-1.

Box 5-1: Natural food and the price of different fish species

From a biological point of view, the cheapest fish to produce are those that feed on organisms from lower trophic levels. Consequently, it is cheapest to rear fish species that feed on plants in general and phytoplankton or waterweeds in particular. This gives phytoplankton feeders and herbivorous fish species an important role in the affordable supply of animal protein for the human diet.

It is important to distinguish between the circulation of materials and the flow of energy. Though these are considered the same in physics, in water ecosystems the circulation of materials and the flow of energy can and should be viewed and interpreted differently. Materials and energy are not lost, only transformed into the maintenance and growth of aquatic plants and animals. In this process, energy fixed and accumulated during photosynthesis gradually decreases within the aquatic ecosystem. By the time organic materials are fully mineralized, the energy fixed during photosynthesis is also entirely used up.

Part of food consumed is used to maintain life and develop the body. The part which cannot be utilized is removed to the environment. Faeces are further consumed mainly by bacteria until all organic substances are broken down into inorganic substances and elements. The same decomposition happens with dead organisms at all levels.

Simple organic and inorganic substances produced as explained will serves as plant nutrients in the next step of the cycle, unless taken out of the ecosystem. Energy and material are lost when some animals leave (e.g. insects flying out) or are taken (e.g. harvested reeds or fish) from the system (i.e. the water body). In the case of eutrophication or intensive fish ponds, the continuous supply of nutrients makes and keeps the water fertile (i.e. eutrophic).

5.2 Life in the main biotopes of standing waters

Water for aquatic organisms is not only a medium where they exist (i.e. take oxygen from), it also serves as a habitat where they live, feed, grow, propagate, die and decay (Dévai and Dévai, 1989). Conditions within a water body can be diverse, depending on its exact position. This makes it possible to distinguish between different biotopes with well- definable flora and fauna. These biotopes offer a wide range of living conditions. Though there is a limited variety of bacteria, plants and animals living in these environments, they are well adapted to their specific conditions. These organisms share the space and resources of the biotopes either by sharing or exploiting them in different ways. In lakes, reservoirs and ponds, four biotopes are important for fish production:

- water surface
- water column
- bottom
- spaces covered by microvegetation.

Being familiar with these biotopes and the organisms living in them is especially important, as they not only afford natural food but also breed competitors and enemies of fish. When farmers cannot afford fish feed, some of the fish produced feed exclusively on natural food (Box 5-1). This explains why natural fish food has and will have a special role, even in decades to come.

In the following sections, life in biotopes is discussed, together with field survey and evaluation practices. Knowing the range and quantity of organisms in different biotopes allows inland fisheries and pond fish farm managers to estimate the productivity of their waters and intervene as required.

5.2.1 Life on and below the water surface

The water surface –facial – is a space for plants and animals which utilize surface tension. They can live here permanently or for a certain period within their lifecycle. Different species of flora and the fauna live on and under the water surface:

- On the air side, some mosses (Figures 5-3 and A2-2), waterweeds with floating leaves and roots hanging free in the water column (Figure A2-3), oil-patch-like iridescent films of bacteria and different insects (Figures 5-2 and A2-13) can be found.
- On the water side, in addition to bacteria, protozoans, hydroids and some rotifers, larvae of most mosquito species, flatworms and some snails live (Figures 5-2, A2-3 and A2-9).

FIGURE 5-2
Water strider on and mosquito larvae under the water surface

Sources:
http://www.microcosmos.nl/bugs1/velia06.htm and https://www.beckerwindmills.com/.

IMPORTANCE OF WATER SURFACE IN FISHERIES AND FISH CULTURE

Flora and fauna of the water surface are less important for fisheries and fish culture, unless they can be found extensively and are consumed by one or more fish species. Duck weed and to some extent water hyacinth, as well as some surface insects and mosquito larvae are a suitable food source for a wide range of fish species.

If waterweeds are overpopulated, they will not only consume most of the plant nutrients, but will also block the penetration of sunlight, causing darkness and oxygen shortage already during the day.

What to do – See Chapter 5.2.4.

5.2.2 Life in the water column

The water column is a most important biotope of standing waters, especially in fish ponds. It is inhabited by two main types of organisms: *plankton** and *nekton**. Practically all cultured fish species are nekton, while plankton provides important natural food for fish. Zooplankton is the first food of practically all fish species. Therefore, plankton in general, and zooplankton in particular, have a distinguished role in the large-scale pond rearing of advanced fry (0.5–1 g), which usually lasts for 4–6 weeks. The first food for predator fish fry is zooplankton, which helps them to learn how to feed. After about 2–4 weeks, they already prey on other fish. The feeding habits and food spectrum of omnivorous and herbivorous fish fry is very similar in the first 4–6 weeks. They start to feed on smaller members of the zooplankton (e.g. protozoans, rotifers, nauplii and young and small specimens of Cladocerans) and later adjust to larger ones (e.g. planktonic crustaceans).

This made it possible to elaborate an effective, uniformly applicable large-scale advanced fry production technology in nursery ponds (Tamás and Horváth, 1972, 1976; Horváth and Tamás, 1981; Nagy, 1998).

In addition to most fish fry, there are some species which continue filtering phytoplankton and zooplankton throughout their entire life (Annex 3).

Plankton

Plankton is the collective name of the microscopic and tiny organisms floating or drifting in the water column (Box 5-2). While these creatures can move independently, and compared to their real size, some of them move rather fast, their own capacities are not sufficient for them to move independently of currents and turbulence.

Plankton unevenly occupy waters and are scattered in clouds, both horizontally and vertically. These floating clouds of plankton move by currents and try to find optimal light (e.g. phytoplankton) or feeding (e.g. zooplankton) conditions.

Groups of organisms within plankton include bacteria, algae, ciliates, rotifers and planktonic crustaceans, as well as different developmental stages of certain insects (e.g. larvae of chironomids) and fish parasites. Organisms in plankton can be classified according to many different aspects, from which two are used regularly. The first is based on sampling and the second is distinguished between bacterioplankton, phytoplankton and zooplankton which are separately observed/investigated.

Plankton sampling is done either with a calibrated vessel or with a plankton net. Both techniques will be discussed later.

Box 5-2: Organisms in the plankton

Plankton consists of

1. Bacterioplankton
2. **Phytoplankton**
    - **2.1. Cyanobacteria** (or blue algae)
    - **2.2. Unicellular green algae**
    - **2.3. Filamentous algae**
    - 2.4. Diatoms
    - 2.5. Euglenas
3. **Zooplankton**
    - 3.1. **Protozoans**
    - **3.2. Rotifers**
    - **3.3. Cladocerans**
    - **3.4. Copepods**

From listed groups those highlighted in bold are discussed in detail in this chapter.

Phytoplankton

Phytoplankton is mostly comprised of microscopic, single-celled photosynthetic organisms that live suspended in the water. Like terrestrial plants, they take up carbon dioxide, make carbohydrates using the energy of light and release oxygen. They are known as primary producers of waters, organisms that create the base of the food chain. As they need light, phytoplankton live near the surface where enough sunlight can penetrate to enable photosynthesis (Woods Hole Oceanographic Institution, 2015).

Phytoplankton comprise two very different kinds of organisms: cyanobacteria and unicellular green algae. Considering the role of different phytoplankton organisms (e.g. cyanobacteria, unicellular green and filamentous algae), unicellular green algae is the most required for fisheries and fish culture.

Cyanobacteria

Cyanobacteria are believed to be among the oldest organisms on Earth. Photosynthetic *organelles** in plant cells, known as chloroplasts, are also originated from them (Woods Hole Oceanographic Institution, 2015).

From the main groups of phytoplankton, cyanobacteria, earlier called blue algae, are related to bacteria but are capable of photosynthesis, too (Figure A2-2). This group, which under certain conditions can overpopulate waters with super production, is not desirable in natural waters and ponds. Such algae, when in excess, not only covers concrete structures, but also gives an unpleasant odour to the water and the fish living in it. An extreme accumulation of cyanobacteria in waters is responsible for the unpleasant mud flavour of inland fish.

CAUSES OF AND PROPOSED ACTIONS AGAINST INVASIVE GROWTH OF CYANOBACTERIA

During the day, the increased growth of cyanobacteria can raise the oxygen concentration up to 200 percent while causing serious oxygen shortage during the night. The reason for this harmful, excessive growth of cyanobacteria is that inorganic nitrogen in the water accessible for the desired unicellular green algae is completely consumed (i.e. it is missing). As cyanobacteria can fix and use elementary nitrogen from the air, they can occupy eutrophic waters where inorganic nitrogen is missing. Therefore, they can dominate other useful species of phytoplankton. When such problems are experienced, microscopic examinations help to identify the family, genus or even species of cyanobacteria.

Protection against cyanobacterial bloom should be implemented in two steps.

1st step is the eradication or reduction of algae (Molnár et al., 2015) by using one of the below materials:

- Quicklime -200 kg/ha should be distributed in three portions in strips over the water surface. Do not use at high pH.
- Calcium hypochlorite or bleaching powder ($Ca(OCl)_2$) – should be used in basic waters, when 7-10 kg/ha is distributed in strips over the water surface, repeated maximum three times in four- or five-day intervals.
- Copper sulphate ($CuSO_4$) – should be used in a total yearly quantity of 8-10 kg/ha which is divided and distributed evenly over the pond water surface in three equal portions when needed, with intervals of three to four weeks.
- Straw – a recently discovered and tested environmentally friendly technique for the eradication of phytoplankton blooms (Tamás *et al.,* 2008, Stiller, 2012; Horváth, 2015). Maximum 5 000 kg/ha/season should be used in 90–500 kg/ha doses.

2nd step is the application of nitrogen fertilizers: When enough inorganic nitrogen is accessible for unicellular green algae, they will become dominant due to their vitality and competitiveness. When the aquatic environment is favourable for unicellular green algae, cyanobacteria have no chance to get space and dominance. Applicable quantities of nitrogen fertilizers vary based on the brand used. Final dosing should be based on a joint investigation of phytoplankton and the quality and quantity of nitrogen forms in the water (Sections 4.3 and 4.4).

Unicellular green algae

This very large group includes single-celled *eukaryotic** algae, similarly to protozoans. Unicellular green algae presented in Figure A2-2 are very important phytoplankton as they are responsible for primary production and so are the base of *natural fish production**.

Though unicellular green algae are directly consumed by filtrating fish species listed in Annex 3, their real importance in the aquatic food pyramid is that these autotrophic organisms also serve as food for heterotrophic plankton (i.e. zooplankton), which are widely consumed by many different fish species.

Occasionally, these organisms form blooms: rapid population explosions in response to changing seasons and nutrient availability such as nitrogen and phosphorus.

Filamentous algae

Filamentous algae are colonies of microscopic single-celled green algae. They form long, visible, free-floating chains with thread- or mesh-like filaments (Figure 5-3 and A2-2). Sometimes they attach to objects. Their role in fisheries and fish culture is ambiguous. They are consumed by some herbivorous fish species and provide shelter not only for young fish but also larger ones, including broodfish. However, their extensive growth in waters makes fishing difficult or even impossible. In addition, they compete for nutrients with more useful phytoplankton.

FIGURE 5-3
Naked-eye view of filamentous algae

Sources: http://www.unl.edu/ and http://www.pondalgaesolutions.com/pondweedrakes.html.

SAMPLING AND EVALUATING PHYTOPLANKTON

Microscopic investigation of samples – Phytoplankton groups are sampled with a vessel of about 100 ml with a cap to close it hermetically. This vessel is dipped into the water just below the water surface. The sample can be conserved for years with a few drops of potassium iodide solution which should be added until the colour of the sample becomes light brown. As evaluation is done on a cross-gridded slide under a microscope, it is recommended that the samples be sent to a specialized laboratory. The evaluation includes the estimation of the total number of algae cells (should be below 100 million/l) and the proportion and dominant species of cyanobacteria, unicellular green algae and other algae of the phytoplankton. From these groups, the most advantageous is when green algae is the dominant species. Papp and Fürész (2003) rank the proportion of green algae as follows:

- excellent if above 40 percent
- good if 30–40 percent
- moderate if above 20 percent
- weak if 10–20 percent
- bad if below 10%.

Measuring Chlorophyll a – This technique for determining phytoplankton requires specialized knowledge and skills, as well as a well-equipped laboratory. The pigment cells of sampled algae are extracted and the received substrate analysed with a photometrical technique. Chlorophyll a is suitable for estimating trophity: water is oligotrophic if the Chlorophyll a content is around 0–2 μg/cm^2, mesotrophic if it is around 2–6 μg/cm^2 and eutrophic if it is above 6 μg/cm^2 (Ács and Kiss Keve, 2004).

What to do

- If the concentration of unicellular green algae is low, apply manure/fertilizers in usual doses.
- In the case of algal bloom, remove the algae as detailed in Section 4.7.

Zooplankton

Zooplankton consists of heterotrophic planktonic organisms (i.e. animals). The most zooplankton for fish production are protozoans, rotifers, cladocerans and copepods.

The importance of these organisms varies by species, age and size of fish. Most of the first food of fish larvae consists of protozoans, rotifers, freshly hatched small *parthenogenetic** specimens of cladocerans and different larval forms (e.g. *nauplius**) of copepods (Nagy, 1989). The development stages of these zooplankton organisms are shown in Figures A2-6, A2-7 and A2-8.

As the mouth of developing fish larvae grows, they become capable of grabbing and feeding on larger, fully grown adult members of planktonic crustaceans, which are a natural food for many different fish species (Annex 3).

Protozoans

Protozoans can be found in all types of surface waters (Figure A2-4).

Rotifers

Rotifers are tiny worms that received their name after their characteristic, rotating movement (Figure A2-5). They play an important role as the first natural food for many fish larvae. In the case of rotifers, it is their size (width 20-40 µm, length 60-150 µm) rather than their nutritive value which makes them an indispensable first food. They have a reduced nutritive value because a considerable part of their body is built from hard, indigestible materials (Nagy, 1989). As rotifers are not the ideal first food for fish larvae, it is important to create conditions in the nursery ponds which will help stocked larvae to quickly pass their first phase of life, after which they increasingly become able to feed on larger zooplankton (young and small specimens of Cladocerans and Copepods (Figures A2-6 and A3-7).

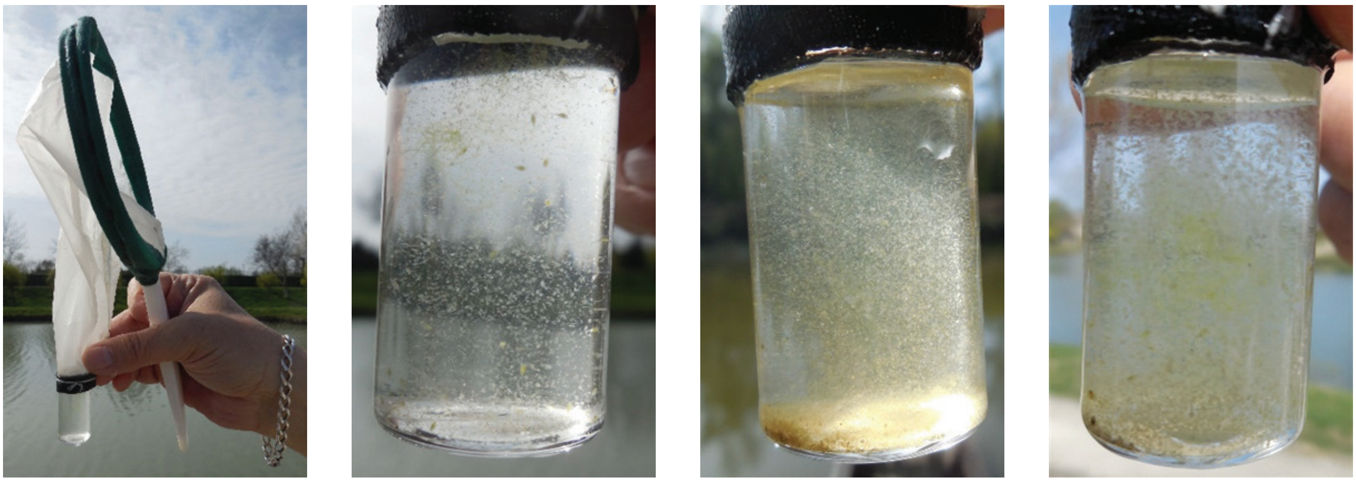
Cladocerans

Among planktonic crustaceans, cladocerans (Figure A2-6) are filtrating organisms, feeding mainly on unicellular green algae. They can produce large numbers of small, asexual eggs stored under their shields until hatched. From these eggs, entirely identical offspring will hatch, which develop to the size of adults after some shedding.

Cladocerans play a crucial role in the life of larvae and young fish. They provide a higher nutritive value for fish. Depending on the water temperature, their lifecycle lasts only for a few days. Therefore, they are represented by a wide range of different sizes within zooplankton. This allows feeding larvae to catch and swallow the ones proportional to the size of their mouth (Nagy, 1989).

They can propagate both *sexually** and *asexually**. When conditions are favourable, they form a practically all-female population, which is a guarantee for mass development and continuous presence in the water. As living conditions deteriorate, males also appear. After mating (i.e. *sexual reproduction**), females produce larger dormant eggs in a much smaller quantity. These remain unhatched until environmental conditions become favourable again. The dormant eggs hatched mainly by females, will asexually produce progeny if conditions remain favourable (Figure A2-6).

FIGURE 5-4
Judgement of zooplankton by the naked eye



A A1 A2 A3

The first naked-eye view of a plankton sample provides good, reliable information.

(A) The phial should be viewed against sunlight as demonstrated. (**A1**) Sample of a pond with a modest quantity of mixed zooplankton. A pond with rich zooplankton life in which rotifers (**A2**) and plankton crustaceans (**A3**) are dominant.

Copepods

Copepods are also important fish food organisms. These planktonic crustaceans propagate exclusively in a sexual way, is a slower process than the asexual one. Therefore, a nursery pond freshly inundated with plankton-poor water will first produce rotifers, then cladocerans and later on copepods.

Among copepods, there are predator species which may be harmful for the small, newly stocked carp and pikeperch feeding larvae. In the case of pike and European catfish, there is no such danger. The mouth of their feeding larvae is large enough to grab and swallow larger organisms, such as adult planktonic crustaceans.

After sexual reproduction, the lifecycle of copepods is rather complicated (Figure A2-7). Usually they reach the adult form after 4–6 nauplius and 6–8 copepodic larval stages. Though the adult form of some predator copepods may be dangerous for fish larvae that have just started to feed, their first larval forms are very suitable food for them. Adult forms of copepods are an abundant food source for the developing fry of all fish species and for adults of the filtrating and zooplankton-consuming species.

SAMPLING AND EVALUATING ZOOPLANKTON

Sampling of zooplankton is the best rapid field technique to determine the water productivity. Zooplankton is usually sampled with a plankton net (Annex 4). To get a realistic picture of zooplankton life, the mesh size of the net should be 60 µm.

In fish ponds where plankton life is rich, it is enough to filter about 20 litres of water, while in rivers and oligotrophic waters 100–400 litres of water should be filtered through a plankton net. If the sample is examined under a microscope, plankton should be treated with a few drops of absolute alcohol (96 percent) or formalin. The same procedure should be followed when the volume of zooplankton in the sample needs to be determined by settling the sample in a calibrated tube.

For practical reasons, it is recommended to always filter the same quantities of water in a similar way. This will allow to judge and compare samples in a uniform manner.

Methods can be different depending on the aim of the evaluation. Either a rapid estimation is required, or a detailed examination of the zooplankton is needed. Though checking the vial of the plankton net enables a preliminary estimation of the status of zooplankton (Figure 5-4), a more detailed protocol will ensure a more exact evaluation:

- For a rapid estimation of the quantitative and qualitative states of zooplankton a 10- or 20-fold loupe or a textile magnifier should be used (Annex 4).
- Besides smaller organisms, such as protozoans and rotifers, a microscopic examination of a sample will also allow the observation of different developmental stages of planktonic crustaceans.
- When the quantity of zooplankton should be determined in an exact way, the sample should be settled in a calibrated laboratory tube.

Zooplankton samples will help to decide whether the state of plankton is poor, acceptable, good or excellent. Checking the developmental stages of crustaceans will make judgements more exact.

Evaluation and possible actions

- Rich and diverse zooplankton life indicates healthy and productive aquatic life. If the volume of zooplankton is about 5–10 ml per 100 litres of water, the status of zooplankton is excellent, especially if the range and size of dominant species are also suitable for the current fish stock.
- A less dense zooplankton (below 0.5–1 ml per 100 litres of water) or the appearance of dormant eggs of cladocerans in the production season indicates that the nutrient and food resources of zooplankton have been used up. They should be supplemented with manure/fertilizer (quantities are based on the species of fish and period of the season).
- In intensive nursery ponds, inoculation of a few buckets of dense plankton collected from a suitable source will help the restoration of a healthy plankton life.

Nekton

Nekton consists of all those organisms capable of intensive swimming or moving in the water column independently of currents. These include ringed worms, large insects, their larvae and fish.

Crustaceans and insects and their freely moving larvae are visible everywhere in surface waters. These include large crustaceans (Figure A2-8), larvae and pupa of mosquitos and chironomids (Figure A2-9), nymphs of flies (Figures A2-10, A2-11 and A2-12), bugs, beetles and their larvae (Figures A2-13, A2-14 and A2-15).

Obviously, fish are the most important group of nekton for fisherfolk and fish producers. Fish can be sampled for many different reasons. The ways of sampling vary by species and age groups, as summarized in Table 5-1.

TABLE 5-1
Fish-catching methods and their suitability for sampling

Catching fish alive	Catching fish dead
Draining water is a widely used technique when a water body is planned to be fully harvested. In pond culture, fish are harvested alive when there is still water in the pond, while the objective in smaller pools is to strand fish before they are collected. This technique allows very detailed information to be obtained when fish stocks are accurately measured.	
Anaesthesia or stunning is used in well-known, tested quantities to reduce stress during fish handling. In this case, fish are not killed only stunned. Fish caught in this way can be well sampled.	**Execution with natural fish poisons (rotenone)** is a widely used technique to catch fish in sub-Saharan Africa, when native plants containing fish poison are used.
Using **hooks or hooks with bait** are widely practiced ancient ways of catching fish. The size of hooks and types of bait determine the range of species and size of fish to be caught. As not all species and sizes can be caught with this technique, it is less suitable for reliable sampling of fish stocks.	Using **hooks or hooks without bait** is a technique banned in many countries, because grappling hooks are cruel as causes considerable injuries for fish. Even if the fish can escape, they will likely die later because of injuries and/or secondary infections.
While there are situations when groping and **catching fish by hand** is possible, this technique is not suitable for sampling fish.	Using **spears, harpoons, and hand hooks** –is efficient, especially in the propagation season, though they are banned in many countries.
Trapping fish in baskets, Fyke nets, barriers and labyrinths are ancient devices for catching fish. These are usually suitable for catching fish alive and in good condition. It is a suitable technique for sampling fish.	
Passive netting is when a gill net is set and used near the bottom, surface or across the entire water column. It is a good but radical way of sampling according to size and species. It is a suitable technique for sampling fish.	
Fish aggregating devices (FADs) have been used for centuries both in marine and inland waters. The simplest one is when a pile of tree branches is placed in the water creating a place for fish to gather. This is less suitable for sampling.	
Active netting using drag nets, lift nets, etc., is the most effective way of sampling if nets with the right mesh size are selected. This is a suitable technique for sampling fish.	
Electrical fishing is an accurate and effective way of sampling or controlling fish stocks. As this technique is frequently, misused it is widely banned in many countries.	**Using explosives** is one of the cruellest ways of catching fish as it leaves wounded, dying fish behind. In addition, it is also highly dangerous for the person using them.

Source: Based on Bíró (2011).

SAMPLING OF YOUNG FISH AND INSECTS FROM NEKTON

Many of the insects and/or their larvae prey on young fish (Figures A2-11, A2-12, A2-13, A2-14 and A2-15). Therefore, the sampling of these insects and their larvae/nymphs is important, especially in nursery ponds.

Sampling of growing fish larvae and fry is done with fine-mesh nets (small seines, hand nets, scoop nets or smaller lift nets made of either soft or stiff mosquito nets) as presented in Annex 4.

These nets are also able to catch insects and their larvae/ nymphs. Consequently, a clear diagnosis of presence of insects predators can also be established while sampling young fish.

It is a daily task to check the status of growing fish larvae and fry, when an unusual progression of harmful insects and their larvae can be detected.

What to do

- Prevention is very important. Strictly observe fry-rearing technologies, for example keep ponds dry before stocking and filling them with fresh water containing reduced or poor zooplankton life. This will help to prevent a too early and extensive development of harmful copepods, larger insects and their larvae/ nymphs.
- In the case of emergency, insects and their larvae/nymphs will need to be eradicated with *authorized chemicals** tested before use. As approved chemicals (in this case the list of approved selective insecticides) are frequently changing, no brands are named here.

SAMPLING LARGER FISH

Observing the movement of fish or their feeding during the production season will provide a good assumption about the possible size and structure of a fish stock, especially in densely populated waters and ponds. It will also provide help in sampling.

During the winter, fish hibernate and their location needs to be known for sampling purposes.

All types of fishing methods are suitable for a reasonably accurate sampling of fish stocks. However, their suitability for obtaining reliable figures is different (Table 5-1). Both the method and equipment used in the sampling are determined by fishing techniques, targeted fish species and age groups.

5.2.3 Biotekton and benthos

A diverse aquatic life can be observed on any reasonably firm surfaces in waters. Such surfaces can be mud, stones, concrete and earth structures (e.g. monks and dikes) or any other objects under the water. Life developed on them is called benthon. Benthon consists of two main groups of living organisms: benthos which is the flora and fauna of the bottom, and biotekton which involves all organisms living on any surface submerged in waters other than the bottom. Depending on fish species, both benthos and biotekton can play an important role in inland fisheries and pond fish culture.

Biotekton

Biotekton consists of bacterial colonies, algae (Figure A2-2), sponges, rotifers attached to water plants and other substrates, snails (Figure A2-17), etc. For certain fish species, biotekton can be a major source of their natural diet (Table A3-4).

Benthos

Benthos contains different colonies of bacteria, algae, rotifers, larvae of mayflies, stoneflies and dragonflies, chironomid larvae and worms like tubifex, snails and others (Annex 2). For many fish species that are bottom feeders, including the most widely cultured common carp, and small cyprinids like breams and crucian carp, benthos is the second most important natural food for them after the plankton.

SAMPLING AND EVALUATING BIOTEKTON AND BENTHOS

Biotekton is not examined precisely but only observed to a certain extent in order to evaluate water productivity through the condition and thickness of the living cover (e.g. biotekton).

Benthos sampling is done for research purposes. It is done with a standard FBA pond net of 1 mm mesh size (Annex 4). The sample taken should be washed through a fine mesh sieve.

5.2.4 Macrovegetation in waters

Box 5-3: Biological control of macrovegetation

There are only a few fish species that feed on macrovegetation. Some of these species are tropical ones and some others are too small to consume considerable quantities. Only grass carp can grow fast and to a large size on this diet and their consumption is considerable. This is especially true when fish are larger than 0.3–0.5 kg and the water temperature is above 22 °C. As other animals grass carp also has preferences. They consume different waterweeds with varied preferences (Table A2-1).

As demonstrated in Figure A2-3, there are three easily distinguishable groups of aquatic macrovegetation (called phytal):

- Floating plants with roots in the water. Some of them remain under the water surface during their entire life, while others emerge and float over the water surface or grow even further, much above it.
- Plants rooted in the bottom that remain submerged.
- Plants rooted in the bottom that grow over the water surface. These are typical marsh plants.
- Biotopes populated with macrovegetation have a very diverse life, which includes bacteria, phytoplankton, zooplankton, algae, insects and their larvae, molluscs, reptiles, fishes, amphibians and mammals. These organisms find both food (prey) and shelter within the macrovegetation (Figure A2-1).

Macrovegetation has a different role in natural and manmade lakes and intensive fish ponds. In shallow lakes, macrovegetation cover can be as large as 75–90 percent. It forms very valuable ecosystems by providing food and shelter for a wide range of protected populations of plants and animals. In fish ponds, however, only a limited quantity of macrovegetation is advantageous. Reed-protecting dikes or waterweed providing shelter for fish can be advantageous, but their excessive growth is not desirable, because:

- They compete with phytoplankton for nutrients.
- They can make fishing difficult or impossible.

CONTROL OF MACROVEGETATION

If waterweeds are overpopulated, they consume most of the plant nutrients and block the penetration of sunlight into the water. As presented earlier in Section 5.2.1, categories of the ratio of waterweed coverage of the water surface are as follows:

- Below 5 percent of total water surface, the situation is negligible.
- Between 5 and 25 percent, the situation is acceptable.
- Between 25 and 50 percent, the situation becomes abnormal and should be dealt with.
- Between 50 and 75 percent, coverage becomes excessive, which calls for immediate action.

The amount of unwanted macrovegetation, such as reeds, sedges and bulrushes can be reduced in three ways:

- Chemically, which is not recommended.
- Mechanically, with special pond equipment and machines.
- Biologically, by stocking different sizes and age groups of herbivorous fish species in a number proportional to the extent of the coverage and dominant species of waterweeds (Box 5-3). This number may vary between 50 and 500 grass carp/ha of different age groups. Table A2-1 provides information on the acceptance of most common aquatic macrovegetation.

6. APPLICATION OF METEOROLOGY IN INLAND FISHERIES AND FISH CULTURE

It is widely known that meteorology – processes and atmospheric phenomena – has both direct and indirect effects on waters, fish species and fish stocks. It is very difficult to understand the effects of meteorology (the climate and weather of a region) on waters and fish stocks without a concise review of climate change and its effects on inland fisheries and aquaculture (Box 6-1).

Weather is the status of the atmosphere at a certain place. Because of the continuous movement of air masses with different temperature and humidity, weather changes constantly. Such masses of moving air are called *fronts**, which cause changes in the weather in general and changes in air temperature (water temperature), precipitation, evaporation, winds, air pressure etc..

According to the World Meteorological Organization (WMO), climate/weather/hydrology and climate/weather/water quality are the two guiding sets of aspects which makes it easier to understand how meteorology, and more precisely agrometeorology, should be applied in inland fisheries and fish culture (Boyd *et al.,* 2012).

Box 6-1: Effects of climate change on inland fisheries and aquaculture

The National Aeronautics and Space Administration (NASA) lists five key indicators of climate change:

- increasing carbon dioxide in the atmosphere
- rising global temperature
- melting of Arctic Sea ice
- melting of land ice
- rising sea level.

These indicators are important for understanding current changes in the global hydrological cycle, which has easily detectable direct effects on inland fisheries and fish culture.

The US Environmental Protection Agency (EPA) indicators are more specific and relevant in the case of fisheries:

- Weather and climate changes manifesting in extreme figures:
  - extreme temperatures
  - heavy precipitations and droughts.
- Altering water resources due to changing snow and ice conditions:
  - shrinking *glaciers**
  - unusually thick ice[5] on lakes
  - extreme snow falls, changing snow covers and snowpack.
- Indicators directly related to agriculture:
  - changing stream flows
  - changing length of the growing season
  - changing leafing and blooming data in agriculture and *phenological response** of both fish and their natural food organisms
  - changing bird wintering ranges.

According to the WMO, extreme weather events such as floods, droughts, hurricanes and unseasonable temperatures can adversely influence water quality and have a negative impact on fisheries and fish culture (Boyd *et al.,* 2012).

Climate, weather and hydrology

As outlined by the WMO in 2012, results of fisheries and fish culture are greatly influenced by the *hydrology** of the region of location (Boyd *et al.,* 2012). Managers should be familiar with and regularly monitor local hydrological conditions which are formed and characterized by precipitation, evaporation, overland flow or surface runoff and hydroclimate.

- **Precipitation** – The depth of precipitation falling into a water body can be measured in a gauging station and provides direct information for managers. Information (reports) on current and expected precipitation (forecasts) is available form national meteorological and agrometeorological services.
- **Evaporation** – In general, evaporation of standing waters is estimated by multiplying Class A pan evaporation value by 0.7.[6] This value is measured so it can be received from meteorological stations. If no such information services are available, individual solutions (setting up a pan evaporator as presented in Eijkelkamp Agrisearch Equipment, 2009) could be considered.
- **Overland flow** or **surface runoff** – Watershed areas can affect overland flows and runoffs, which is especially important in the case of reservoirs and barrage ponds fed with rain, stream or river water. These hydrological figures are important for planning and are extensively available at meteorological and hydrological stations. Overland flows and runoffs are often responsible for eutrophication and contaminations by washing plant nutrients and/or toxicants into the water. For these reasons, the follow-up of such data is important.

[5] Thick ice and lower water level can result in smaller areas of suitable wintering locations (Thorpe *et al.,* 2011).

[6] In particular, pan coefficient may range between 0.7 and 0.9 according to the season, actual area and depth.

- **Hydroclimate** is the influence of climate on water availability. When more rain falls than water evaporates, excess water either infiltrates the soil or runs off the surface as a stream. In dry regions, the amount of rain does not meet the demand of evaporation. In such regions there are no streams, only temporary runoffs at times of unusually huge rains.

Different hydrological and meteorological data and information are usually available, which, together with individual observations, enable a reliable calculation of water budget, that is water balance and the yearly distribution of "received" and "lost" water.

Climate, weather and water quality

There is a complex relationship between climate, weather and the water quality of surface inland waters.

- **Solar radiation** and **air temperature** are directly responsible for the quality and intensity of aquatic life. Together with **air pressure** and **winds,** they also influence the oxygen content of waters.
- **Heat exchange** between air and water, seasonal and daily **heat stratification of water layers** and **icing** are those phenomena which can be foreseen, if relevant meteorological data are followed up daily.
- **Precipitation**, **evaporation** and **runoffs** may change halobity, trophity and saprobity of waters, while **winds** and **fronts** (i.e. sudden differences in **air pressure**) may cause changes in deeper water layers and in oxygen concentration, and may also be responsible for the release of toxic gasses from the mud.

FIGURE 6-1
Meteorological data on the web – examples of national services

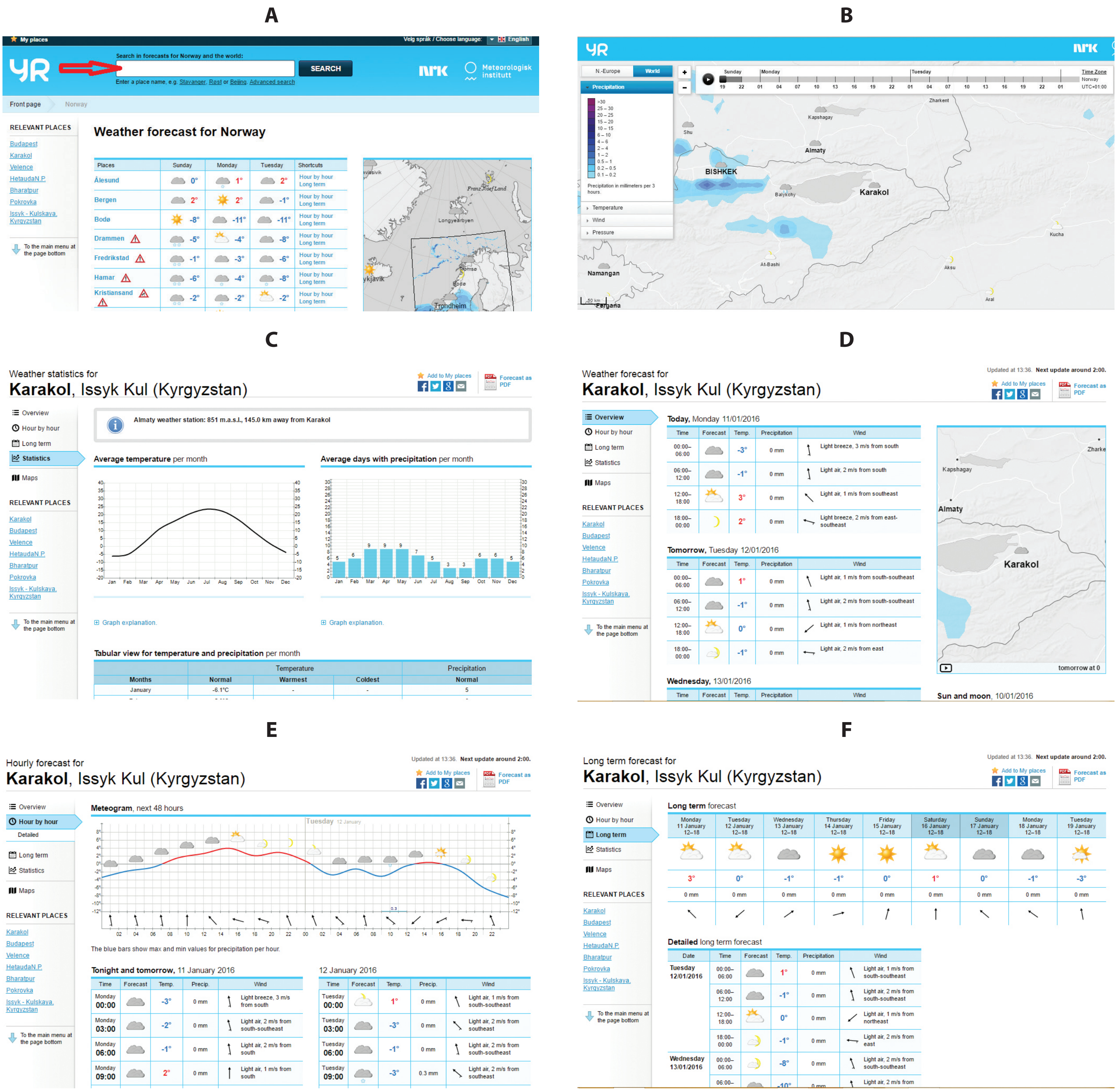
An example of meteorological (left) and agrometeorological (right) services: (http://www.met.hu).

The examples shown in Figure 6-1, together with the short inventory of physical, chemical and biological water qualities discussed in previous chapters, prove that meteorology has a major role to play in the management of fisheries and fish culture. Data and information supplied on a daily basis by national and international meteorological and agrometeorological services are crucial.

Availability of meteorological and agrometeorological data and information

There is a wide range of national meteorological information and data regularly broadcasted on radio and television. Today, the Internet is an important source of meteorological information and data; there are numerous national and international websites providing knowledge on different, specific parts of the subject. Figures 6-1 and 6-2 are examples of how national and international services can appear on a computer screen.

FIGURE 6-2
Meteorological data on the web – examples of international services



(**A**) Searching for a specific location (the example of the website of the Norwegian Meteorological Institute: http://www.yr.no/place/Norway/. The search field is indicated by the red arrow. (**B**) Precipitation map of a specific location. (**C**)Average monthly temperatures and precipitation. (**D**) Short-term weather forecast. (**E**) Hourly weather forecast. (**F**) Long-term weather forecast.

7. SUMMARY AND CONCLUSIONS

There is a well definable set of water properties which, together with some important meteorological data, should be checked and followed up by field staff in fisheries and fish farms. A list of these water properties and meteorological data is presented in Table 7-1.

TABLE 7-1
Inventory of water properties and meteorological data to be followed up by field staff

Type of properties and data	Followed up by	Related information to be found in
Physical Qualities		
1. Transparency	**Manager**	**Section 4.1**
2. Temperature	**Manager**	**Section 3.2 and Annex 4**
3. Icing	**Manager**	**Section 3.2**
Chemical Qualities		
4. Conductivity and TDS	Specialist	Section 3.3 and Annex 4
5. pH	**Manager**	**Section 3.4 and Annex 4**
6. Alkalinity	Specialist	Section 3.5 and Annex 4
7. DO and **oxygen saturation**	**Manager**	**Section 4.2 and Annex 4**
8. Nitrite	**Manager**	**Section 4.3, 4.4 and Annex 4**
9. Nitrate	**Manager**	**Section 4.3, 4.4 and Annex 4**
10. Phosphorus, orthophosphate	**Manager**	**Section 4.3 and Annex 4**
11. Ammonium and free ammonia	**Manager**	**Section 4.4 and Annex 4**
12. Hydrogen sulphide	Specialist	Section 4.4 and Annex 4
Biological Qualities		
13. Phytoplankton (microscopic analyses)	Specialist	Section 5.2 and Annex 2
14. Chlorophyll a	Specialist	Section 5.2
15. Zooplankton (loupe)	**Manager**	**Section 5.2, Annexes 2 and 4**
16. Zooplankton (microscope)	**Manager**	**Section 5.2, Annexes 2 and 4**
17. Insects in the nekton	**Manager**	**Section 5.2, Annexes 2 and 4**
18. Fish stocks	**Manager**	**Section 5.2 and Annex 3**
19. Benthos	Specialist	Section 5.2
20. Macrovegetation	**Manager**	**Section 5.2**
Meteorological data		
21. Short/long-term weather forecast – temperature	**Manager**	**Chapter 6**
22. Short/long-term weather forecast – precipitation	**Manager**	**Chapter 6**
23. Short/long-term weather forecast – sunny days	**Manager**	**Chapter 6**
24. Short/long-term weather forecast – fronts	**Manager**	**Chapter 6**
25. Evaporation, radiation and winds	**Manager**	**Chapter 6**

7.1 Surveys, samplings and tests to be completed by managers

The actual size of waters, together with water balance, is important information, indispensable for managers of both fisheries and pond fish farms (Table 7-2).

Knowing these parameters is essential for planning and evaluating results.

Regarding waters, a wide range of physical, chemical and biological properties can and should be inspected and analysed by managers (Table 7-1).

In addition, some simple observations should also be done by checking the odour and clarity of water as well as foam development when water is shaken in a plastic bottle, which is a sign of decomposing organic materials or detergents in the water (Fürész and Papp, 1995).

TABLE 7-2
Essential information on water bodies used for fisheries and aquaculture

Parameters	Max.	Mean	Min.
Applicable for all types of standing waters			
Water supply (m^3/min, m^3/h or m^3/day)			
Area (ha)			
Length (m)			
Width (m)			
Depth (m)			–
Daily fluctuation of water level (m)			
Weekly fluctuation of water level (m)			
Monthly fluctuation of water level (m)			
Seasonal fluctuation of water level (m)			
Applicable for water reservoirs			
Daily discharge of water in spring (m^3)			
Daily discharge of water in summer (m^3)			
Daily discharge of water in autumn (m^3)			
Daily discharge of water in winter (m^3)			

7.2 When expert assistance is required

An important part of the work of water specialists is to complete an overall survey of water bodies to be able to judge the current status of the water body and its fish production potential. This review should include a detailed characterization of physical, chemical and biological water qualities.

Often, water samples are taken and sent to a laboratory for checking. Samples should be collected in clean, large, one litre plastic bottles rinsed with the sampled water before sampling. It is important to completely fill the bottle without leaving air bubbles. Each bottle sent to a laboratory should be labelled as described in Box 7-1.

Box 7-1: Data and information on water samples

Each bottle of water samples should be labelled as follows:

Sample number, date, name of the farm/water body, name of the owner, address, phone and/or email, case history, number/indication of the fish pond or water body within a farm where the sample was taken.

If more samples are taken from the same water body, the exact locations should also be indicated (Molnár *et al.*, 2015).

As a conclusion, specialists are required to check water quality parameters listed in Table 7-1 on a regular basis and contact specialists in the case of an emergency, when water pollution is suspected, or mass mortality is observed.

GLOSSARY

Aerobic organism or **aerobe** – an organism which requires free oxygen for life and growth.

1	bar	=	0.9869	atm	=	~ 1	atm
1	bar	=	29.5300	"Hg	=	750.0616	mmHg
1	atm	=	29.9213	"Hg	=	759.9999	mmHg

Air pressure – weight of air above an object which exerts a force called pressure. Variations in pressure lead to the development of winds that play a significant role in shaping daily weather (http://ww2010.atmos.uiuc.edu). In front of warm fronts, air pressure reduces, while in the case of cold fronts it increases. Air pressure is most frequently expressed in terms of bar (bar), atmosphere (atm), millimetre Mercury (mmHg) and inch Mercury ("Hg).

pH	12	11	10	9	8	7
NH_3+NH_4^+ (mg/l)	1	1.05	1.54	5.55	33.3	100

Ammonia –a colourless gas with a strong pungent odour. Ammonia reacts with water to form a weak base. The term ammonia refers to two chemical species which are in equilibrium in water; i.e. the un-ionized, free ammonia (NH_3) and the ionized ammonia (NH_4^+). Tests for ammonia usually measure total ammonia (NH_3 plus NH_4^+). Toxicity to ammonia is primarily attributable to the un-ionized form (NH_3) named free ammonia. In general, more NH_3 and greater toxicity exist at higher pH (http://www.water-research.net/index.php/ammonia-in-groundwater-runoff-and-streams). Accordingly, free ammonia (NH_3) and ammonium ions (NH_4^+) together represent the total ammonia (NH_3 + NH_4^+) content of water. Even a concentration of 0.1 mg/l is poisonous to fish. The toxicity of total ammonia changes by pH as presented in the table. Accordingly, the higher the pH the less amount of total ammonia is enough to kill fish.

Anadromous – fish species which migrate from marine waters into fresh waters to spawn (e.g. trout, salmon).

1 m	=	10 x 10^{-8}	Å	=	100 000 000	Å
1 m	=	10 x 10^{-6}	µm	=	1 000 000	µm
1 Å	=	10^{2}	µm	=	100	µm

Angstrom (Å) –a unit of length used for submicroscopic objects and organisms.

Anion – a negatively charged ion.

Aquifer –an underground water reservoir where groundwater is stored.

Assimilation – the entire process of plant nutrition, including both photosynthesis and the absorption of inorganic plant nutrients.

Asexually –*asexual reproduction**

Asexual reproduction – a form of reproduction which happens without the fusion of male and female gametes (egg and sperm). Thus, the offspring will be the same as the parent.

Atomic mass – the mass of an atom or molecule of a chemical element expressed in atomic mass units.

Authorized chemicals – chemicals that need specific permission from competent governmental authorities to be used.

Autotrophic organisms – organisms that synthetize nutrients and build up their bodies from simple inorganic substances.

Biosynthesis – a process where complex molecules are produced from simple ones within a living cell or organism.

Biotope – An environmental region characterized by certain conditions and populated by characteristic plants and animals (Allaby, 1994). In other words a region uniform in environmental conditions and in its populations of animals and plants for which it is the habitat https://www.merriam-webster.com/. In this publication biotope is a well-definable area/part of a water body (*habitat**) which can be associated with a particular ecological community of living organisms.

Brackish water – a mixture of sea and fresh water common in estuaries and lagoons where sea and fresh water meet and mix. Its salt (NaCl) content varies between 0.05 and 3.0 percent.

Brown motion – a random motion of particles suspended in water, caused by the collision with the molecules of the medium.

Buffer capacity or more precisely **pH buffer capacity** – the major buffering mechanism in most fresh waters which relies on the CO_2 –HCO_3^- –CO_3^- equilibrium system (Wetzel, 1983).

Cage culture – a technology suitable for an intensive production of fish in different floating compartments prepared from nets or grids. Cages are few metres deep and can be located in rivers, lakes, reservoirs or even in fish ponds. Cage culture is based on the same principles as tank culture. Fish in the cages are fed with a biologically complete diet. Water quality in a cage is maintained by a continuous exchange of water which can naturally be ensured by the stream of rivers, currents caused by winds or the movement of fish in the cages. Production is calculated in unit volume (number of fish/m^3 or kg/m^3). If cages are placed in fish ponds, unused feed is utilized by fish outside the cages, while faeces are ideal manure to increase natural fish food production of ponds. However, long-term accumulation of faeces under the cages may cause oxygen depletion and deterioration of water quality. Therefore, cages should not be fixed at the same part of the pond for a long period of time. It is a rule of thumb that fish production in cages placed in a fish pond cannot be more than the carrying (i.e. fish production) capacity of the pond stocked with free swimming fish.

Catadromous – fish species which migrate from fresh water to marine water to spawn (e.g. eel).

Cation – a positively charged ion.

Chemical oxygen demand (COD) – an indicator that shows the oxygen consumption of a chemical process when all organic and inorganic materials found in a water sample are oxidized.

Colloids – homogenous, non-crystalline substances consisting of large molecules or ultramicroscopic particles which are evenly dispersed in another substance.

Colour of water – derives from different chemical components and suspended or dissolved materials in the water. It can also be determined by the colour of planktonic organisms which live in it. If water is full of phytoplankton, its colour will likely be green, which, to a certain extent, refers to the productivity of pond water.

Condensation – a process whereby water vapour of the atmosphere is changed into liquid. In the atmosphere, condensation may appear as clouds or dew. Condensation is also responsible for water appearing on the exterior of cold cans or bottles. Condensation is not the result of one particular temperature but the difference between two temperatures: air temperature and dew point. Dew point is the temperature at which dew forms. This is the point of temperature where air becomes saturated when being cooled. Any additional cooling will cause the condensation of water vapour. When air temperature and dew point are equal, foggy conditions will appear. Condensation is the opposite of evaporation. Since water vapour has a higher energy level than liquid water, when condensation occurs, excess energy is released in the form of heat. This release of heat fosters the formation of hurricanes (http://www.srh.noaa.gov/).

Convectional current –the transference of heat within water caused by the movement of warmer, less dense water to cooler areas.

Culture-based fishery (CBF) –a widely practised fish culture technique, mainly used when the natural balance of reproduction of different fish species is blocked or inadequate. As a result, the water body is regularly stocked. In such cases, stocking is based on the real fish production capacity of a certain water body.

Diadromous – fish species which migrate between marine waters and fresh waters.

Diapause – a period of suspended development of an organism.

Diffusion – mixing, the movement of molecules from high concentration areas to low concentration ones.

Dissimilation –the opposite of assimilation, a metabolic breakdown of complex organic molecules into simple ones while energy is released. During the process, oxygen is consumed, and carbon dioxide is produced in green plants.

Ecological – *Ecology**

Ecology – a scientific study or analysis on the relationships of organisms to each other and to their physical surroundings.

Ecosystem – a community of living organisms and their interactions with the environment.

Emulsion – a fine dispersion of one liquid within another liquid, when the two liquids do not enter into a chemical reaction with each other.

Epilimnion – the upper/top-most layer of a thermally stratified lake.

Eurythermal – an organism that can tolerate a wide range of temperatures.

Eutrophic – a water rich in plant nutrients, resulting in a dense aquatic life.

Eutrophication – a process by which a water body becomes rich in dissolved plant nutrients that stimulate the growth of aquatic plant life and the life of organisms feeding on them. Rich aquatic life is important in fish ponds, hence its development is supported by regular manure and/or fertilizers.

Evaporation – a process by which a substance changes from liquid to gas phase. In meteorology, the most common substance is water. For the process of evaporation energy is required. Energy can come from any source: the sun, the atmosphere, the earth, or objects on the earth. Only pure water can evaporate; contaminants and salts are left behind. As a result, the lake waters become more saline. (http://www.srh.noaa.gov/).

Eukaryotic cells – organisms with a cell or cells containing membrane-bound organelles, for example a proper nucleus.

Fauna – animals of a particular region or habitat.

Fish culture systems – systems of cultivating fish. The main fish culture systems are pond culture, tank culture, *cage culture** and culture-based fisheries (CBF).

Fisheries – (a) a place where fish are caught or reared; (b) the management of catching fish in natural and manmade waters.

Flora – plants of a particular region or habitat.

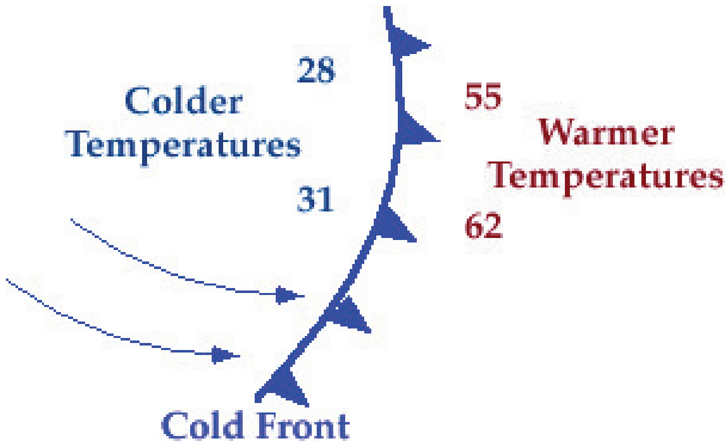
Fresh waters – usually inland water bodies such as lakes, ponds, streams and rivers. As indicated in Table 3-1 their dissolved salt content is below 500 mg/l (Felföldy, 1974).

Front – a boundary between air masses of different temperature, humidity and density. A **cold front** is defined as the transition zone where a cold air mass replaces a warmer one. Air behind a cold front is noticeably colder and drier (http://ww2010.atmos.uiuc.edu). Hours before the arrival of a cold front, the temperate rises. With a **warm front**, the arriving warmer mass of air slips upward over the colder mass of air which, being heavier, later stretches over the ground. In the region located in front of a warm front, *air pressure** reduces (http://www.meteoline.hu/?m=210).

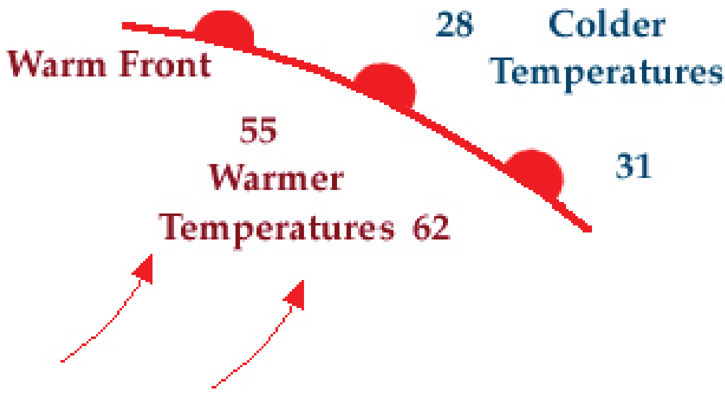
Groundwater – all waters beneath ground surface (http://eur-lex.europa.eu/legal-content/EN).

Generative growth – development/growth of the sexual organs and products of plants.

Mapping a cold front



Mapping a warm front



(http://ww2010.atmos.uiuc.edu)

Glacier – a very slowly moving mass of ice formed by the accumulation and compaction of snow in mountains. Glaciers form near sea level at pools, but the elevation of their location increases by latitude towards the Equator (Figure A1-2). Therefore, glaciers develop in high mountains located in temperate and subtropical climatic regions. An important characteristic of glaciers is that they can buffer water resources in entire regions; winter precipitation deposited in glaciers provides a steady and even water supply during summers in dry regions, like Central Asia.

Habitat – the living place of organisms or communities described by its biotic and abiotic characteristics (Allaby, 1994).

Heat – a form of energy deriving from the motion of molecules. The relationship between heat added and changes in water temperature can be expressed with the simple equation shown.

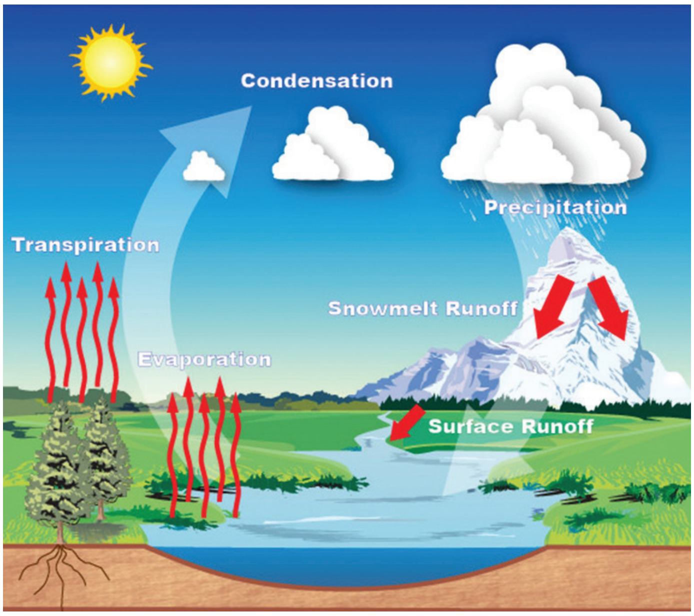
$$Q = c * m * T$$

Where: **Q** = "heat added", **c** = "specific heath"
m = "mass", **T** = "change in temperature"

Heterotrophic organisms – those organisms that can only obtain nutrients from complex organic substances.

Hibernate – to spend the winter in a dormant state; term is used both for plants and animals.

Hydrological cycle – the continuous circulation of water within the earth-atmosphere system. In other words, hydrological cycle is the motion of water from the ground to the atmosphere and back. Most important processes of water cycle are; *evaporation**, *transpiration**, *condensation**, *precipitation** and *runoff** (http://www.srh.noaa.gov).



Source: http://www.ei.lehigh.edu/learners/cc/images/waterCycle.jpg.

Hydrogen sulphide – a colourless gas that smells like rotten eggs. Sulphur-reducing bacteria, which use sulphur as an energy source, are the primary producers of large quantities of hydrogen sulphide. These bacteria chemically change natural sulphates in water to hydrogen sulphide. Sulphur-reducing bacteria live in oxygen-deficient environments such as deep wells, plumbing systems, water softeners and water heaters (http://www.water-research.net/index.php/sulfur). These bacteria usually flourish in the mud. In water, hydrogen sulphide molecules dissociate into hydrogen sulphide (HS^-) and sulphide (S^{2-}) ions. Their relative concentrations depend on the pH of water. The concentration of hydrogen sulphide increases when pH decreases (i.e. acidity increases). At pH 7.4, about one-third of hydrogen sulphide is undissociated while most of the remaining exists as mono-hydrogen sulphide anion.

The sulphide is present in higher concentrations above pH 10. In well-aerated water, hydrogen sulphide is immediately oxidized to sulphates and then to elemental sulphur in a biological way. In anaerobic waters, a microbial reduction of sulphate to sulphide can also occur (WHO, 2003).

pH	8.2	7.4	6.1	5.2
H_2S (mg/l)	8.0	3.3	0.95	0.55

Undissociated hydrogen sulphide is more toxic. Its lethal concentrations for young carps are presented in the table (Dévai and Dévai, 1979).

Hydrology –a science that deals with the properties, distribution, and circulation of water on and below the Earth's surface and in the atmosphere (Merriam-Webster, 2016).

Hypolimnion – the lower layer of a thermally stratified lake.

Ion – an atom or molecule with a net electronic charge through loss or gain of electron(s). With a negative charge, it is called *anion**, with a positive charge, it is called a *cation**.

Labyrinth fish – fish species with a special organ, known as a labyrinth, which allows the fish to breathe air from the atmosphere at the surface of the water. Both ornamental (betta, gourami, paradise fish, etc.) and commercial fish species (African and Asian catfish, pangasius, etc.) belong to this group.

Metalimnion – the layer of a temperature gradient between the epi- and hypolimnion of a water body, also called thermocline.

Micron or micrometre (µ or µm) – a unit of length used to measure microscopic objects and organisms, as well as the mesh size of plankton nets.

1 m	=	10×10^{-6}	µm	=	1 000 000	µm
1 mm	=	10×10^{-3}	µm	=	1 000	µm
1 Å	=	10^{2}	µm	=	100	µm

Mineralization – conversion of an organic substance into an inorganic one or mineral.

Minimum withdrawal period – the minimum required period for the degradation of a chemical. When testing and using a new chemical for treating fish diseases, it is essential to consider the average daily water temperature. If the selected chemical is not specifically licensed for fish, only for other animals, the product can only be used when strictly adhering to the minimum withdrawal period of 500 days, or more precisely 500 D° (day degree). The exact days are calculated as follows: 500 divided by the average daily water temperature, i.e. by day degree (D°). Accordingly, the withdrawal period is 100, 50, 25 or 20 days when the average daily water temperature is 5, 10, 20 or 25 °C (Molnár *et al.*, 2015).

Natural fish food organisms – a collective name for aquatic living organisms and materials (seeds, detritus, etc.) produced naturally that are consumed by fish.

Natural fish production – fish production developing from the natural food productivity of the pond. The term is mainly used in pond fish culture where energy-rich grains are used as supplementary feed to increase fish production. Consequently, the total production is made up of two components: natural fish production and feeding.

Nauplius – the first larval stage of many crustaceans. It has an unsegmented body and only one eye.

Nekton –all organisms capable of intensive swimming or moving in the water column independently of currents, including ringed worms, large insects and their larvae, as well as fish.

Organelle – an organized or specialized part of a living cell that has a specific function.

Orthophosphate –*phosphorus**

Ovulation –when eggs become free within the ovary. After ovulation, eggs are released during spawning or can be stripped.

Oxygen-consuming gasses –gasses which reduce dissolved oxygen (DO) in water. For example, hydrogen sulphide is one of these gasses.

Oxygen saturation – difference between the actual and potential DO content expressed in percent. It shows the extent of saturation.

Parthenogenetic – reproduction from a specific gamete (mostly from a female reproductive cell) without fertilization.

Phenological response –*phenology**

1‰ = 1 mg/l or 1 ml/l	**1%** = 10 mg/l or 10 ml/l

Phenology – study of cyclic and seasonal biological *phenomena** of plant and animal life in relation to climatic conditions.

Phenomena – plural form of phenomenon; a fact or situation observed to exist or happen, especially when it is unusual or difficult to understand or explain fully.

Phosphorus –the most important element in the flow of energy of aquatic living organisms. Pure, "elemental" phosphorus (P) is rare in waters, where it usually exists as part of a phosphate molecule (PO_4). Phosphorus in aquatic systems can occur in inorganic and organic phosphate forms. Animals can use both organic and inorganic phosphate. Both organic and inorganic phosphorus can be dissolved or suspended in water (attached to particles in the water column). From inorganic phosphorus, the soluble orthophosphate forms ($H_2PO_4^{3-}$, HPO_4^{2-}, PO_4^{3-}, $FeHPO_4^{+}$, $CaH_2PO_4^{+}$) are accessible for plants. Orthophosphate is built into organic compounds in plants. Organic phosphate consists of a phosphate molecule associated with a carbon-based molecule, as in plant or animal tissues. After the termination of life organic phosphate is decomposed into orthophosphates by bacteria (EPA 2015).

Photosynthesis –process by which green plants use light/solar energy to synthetize organic materials/nutrients from carbohydrate and water.

Phytoplankton – collective name for microscopic plants in plankton.

Plankton – collective name for floating and drifting tiny, microscopic organisms in waters.

Poikilotherm organisms –organisms, such as fish and their food organisms, that cannot regulate their body temperature and are strongly influenced by the temperature of the environment.

Pond culture – a fish culturing method when fish and their natural food organisms are reared in the same water body. For the best possible utilization of natural fish-food production capacity of a pond, fish species of different feeding habits and food spectrums are stocked and grown together.

pH buffer capacity – the amount of a strong acid or base necessary to change the pH of 1 litre of a solution by 1. It relies on the CO_2 –HCO_3^- –CO_3^- equilibrium system, which is the major buffering mechanism in most fresh waters (Wetzel, 1983).

ppm – 1 ppm = 1 mg/m^3 or 1 ml/m^3

ppt – 1 ppt = 1mg/l or 1 ml/l

Precipitation – occurs when tiny condensation particles grow too large through collisions and coalescences for the rising air to support and thus fall to Earth. The main forms of precipitation are rain, hail, snow or sleet. It is a primary way to receive fresh water on Earth. On average, the world receives about 38½" (980 mm) of precipitation each year, both in oceans and on land masses (http://www.srh.noaa.gov/).

Runoff – occurs when there is an excessive precipitation and the ground becomes saturated (cannot absorb water any more). Rivers and lakes are the results of runoffs. There is some evaporation from runoffs into the atmosphere but most part of the water in rivers and lakes returns to the oceans. If runoff water flows into a lake with no outlet, then evaporation is the only way for the water to return to the atmosphere (http://www.srh.noaa.gov/).

Sexually –*sexual reproduction**

Sexual reproduction –happens with the fusion of a mature haploid male and female germ cell.

Stenothermal – ability to live in or tolerate only a small/narrow range of temperature.

Sublimation – transformation of a solid substance directly into vapour when receiving heat (being heated).

Surface waters – all inland waters except groundwaters, transitional, i.e. brackish waters and coastal waters (EUR-Lex, 2000).

Suspension – a mixture containing solid, filterable particles that are dispersed in a fluid. In suspensions, fluid does not enter into a chemical reaction with suspended particles.

Thermocline –*metalimnion**

Transpiration – the evaporation of water from plants. In most plants, transpiration is a passive process mostly controlled by the humidity of atmosphere and moisture content of soil (http://www.srh.noaa.gov/).

Trophity – extent of the primary organic matter production of waters.

Trophic level –level an organism holds in the food pyramid (e.g. producers, primary, secondary or tertiary consumers).

Turbidity –the measure of relative clarity of a liquid. Turbidity of waters can be the result of mechanical (*suspended** materials), chemical (*colloids**) and biological (*plankton**) effects.

Vegetative growth – growth of the body of plants.

Zoobenthos –collective name of animals living in benthos. More explanation see at: http://www.fao.org/faoterm/en/.

Zooplankton –collective name of animals in plankton.

REFERENCES

Ács É. & Kiss Keve T. 2004. *Algalógiai Praktikumok*. Budapest, ELTE Eötvös Kiadó. 361 pp.

Allaby, M. 1994. – The Concise Oxford Dictionary of Ecology. Oxford University Press.

Allen R.G., Pereira L.S., Raes D. & Smith M. 1998. – *Crop evapotranspiration – Guidelines for computing crop water requirements.* FAO Irrigation and drainage paper No. 56. FAO, Rome. (also available at http://www.fao.org/docrep/X0490E/x0490e00.htm#Contents and http://www.fao.org/docrep/X0490E/x0490e08.htm).

Apperson, C., Waldvogel, M., & Bambara, S. 2016. Biology and control of non-biting aquatic midges. Extension Entomology, Insect Note – ENT/rsc-15. North Carolina State University [online]. Raleigh, NC, USA. [Cited: 2016]. http://entomology.ces.ncsu.edu/depts/ent/notes/Urban/midges.htm.

Arofanatics. 2015. Life cycle of daphnia [online]. http://www.arofanatics.com/forums/showthread.php?t=390789.

Berka, R. 1989. *Inland capture fisheries of the USSR***.** FAO Fisheries Technical Paper No. 311. Rome, FAO. 143 pp. (also available at http://www.fao.org/inland-fisheries/tools/detail/en/c/1150318/).

Bíró, P. 1979. Bevezetés a halpopulációk dinamikájába. Debrecen, Hungary, Oktatási segédanyag.

Bíró, P. 2011. Vizsgálati módszerek és értékelő eljárások a halbiológiában. Debrecen, Hungary, Debrecen University Press. 272 pp.

Clegg, J. 1967. *The Observer's Book of Pond Life*. London, Frederick Warner & Co., Ltd.

Csányi, B., Szekeres, J., Zagyva, A. & Várbíró G. 2012. Vízi makrogerinctelen módszertani útmutató, Készült a Víz Keretirányelv monitoring vizsgálatait végző hidrobiológusok részére [online]. http://www.kornyezetvedok.hu/vgt/vgt2/orszagos/6_1_hatter-anyag_Makrozoobentosz_Modszertani_utmutatoVGT2.pdf.

Devai, Gy., Nagy, S.A., Wittner I., Aradi, Cs., Csaba Z. & Toth, A. 1998. Vizi és vizes élőhelyek sajátosságai és típusai. KLTE, Department of Ecology, Hydrobiological Team [online]. Debrecen, Hungary. [Cited: 2016]. http://ttmk.nyme.hu/fldi/Documents/Korponai%20J%C3%A1nos/hidrobiol%C3%B3gia/vizek_es_vizes_elohelyek_tipologiaja.pdf.

Dévai, I. & Dévai, Gy. 1979. A víz fizikai és kémia tulajdonságai. Debrecen, Hungary, Kossuth Lajos University.74 pp.

Dictionary.com. 2015. Definitions. In: *Dictionary.com* [online]. New York. [Cited: 2016]. http://dictionary.reference.com/.

Downing, J.A. 2015. Chapter 4: Sampling of the benthos of standing waters. [Cited: 2016]. http://www.public.iastate.edu/~downing/tier%202/jadpdfs/1984%20Downing%20Sampling%20the%20benthos%20of%20standing%20waters.pdf.

Eijkelkamp Agrisearch Equipment. 2016. Evaporation pan. In: *Eijkelkamp Agrisearch Equipment* [online]. Giesbeek, the Netherlands [Cited: 2016]. http://www.kean.edu/~csmart/Hydrology/Lectures/Evaporation_pan.pdf.

Encyclopedia Britannica. 2019. Biological production. In: *Encyclopedia* Britannica [online]. Chicago. https://www.britannica.com/science/biological-productivity.

EPA. 2015. The phosphorus. In: *United States Environmental Protection Agency* [online]. Washington, DC. [Cited: 2016]. http://water.epa.gov/type/rsl/monitoring/vms56.cfm.

EUR-Lex. 2000. Establishing a framework for Community action in the field of water policy, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 [online]. Brussels. [Cited: 2016]. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060&qid=1480150356759.

European Commission. 2006. EU intervention in inland fisheries "Studies linked to the implementation of the European Fisheries Fund". Framework contract N° FISH/2006/09 (Lot N°3) European Commission, Directorate for Maritime Affairs and Fisheries, EU wide report – final version.134 pp. https://ec.europa.eu/fisheries/sites/fisheries/files/docs/publications/inland_fisheries_en.pdf.

Fairfax Water. 2015. Explanation of water hardness. In: *Fairfax County Water Authority, Water Quality Authority* [online]. Fairfax, VA. [Cited: 2016]. https://www.fairfaxwater.org/faq/how-hard-our-water.

Farlex. 2015. Inland waters. In: *The Free Dictionary* [online]. Hundington Valley, PA. [Cited: 2016]. http://legal-dictionary.thefreedictionary.com/Inland+Waters.

Felföldy, L. 1974. A biológiai vízminősítés. *Vízügyi hidrobiológia* 3:242.

Felföldy, L. 1981. *A vizek környezettana. Általános hidrobiológia*. Budapest, Mezőgazdasági Kiadó,. 290 pp.

Finch, J. & Calver, A. 2008. *Methods for the quantification of evaporation from lakes.* Prepared for the World Meteorological Organization's Commission for Hydrology [online]. Wallingford, UK. [Cited: 2016]. http://nora.nerc.ac.uk/14359/1/wmoevap_271008.pdf.

Flanagan, S.M., Nielson, M.G., Robinson K.W., & Coles J.F. 2015. *Water Quality Assessment of the New England Coastal Basins in Maine, Massachusetts, New Hampshire, and Rhode Island: Environmental Settings and Implications for Water Quality and Aquatic Biota.* Water Resources Investigations Report 98-4249 [online]. Washington, DC. [Cited: 2016]. http://pubs.usgs.gov/wri/wri984249/pdf/6ecological.web.pdf.

Fondriest.com. 2015. Fundamentals of Environmental Management – What is pH? In: *Fondriest Environmental Inc.* [online]. Fairborn, USA. [Cited: 2016]. http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/#p1.

Fondriest.com. 2016. Fundamentals of environmental measurements. In: *Fondriest Environmental Inc.* [online]. Fairborn, USA. [Cited: 2016]. http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/.

Fürész, Z. & Papp, K. 1995. ***A víz, a vízminőség és vízvizsgálatok***, MOHOSZ, Horgászati és Halgazdálkodási Osztály. 87 pp.

GOV.UK. 2015. – Categorization of waters [online]. London. [Cited: 2016]. https://www.gov.uk/guidance/inland-waterways-and-categorisation-of-waters.

Government of British Columbia. 2015. Ministry of Environment, Environmental Protection Division [online]. Victoria, Canada. [Cited: 2016]. http://www.env.gov.bc.ca/wat/wq/BCguidelines/temptech/temperature.html.

HACH. 2015. Hardness Guide. [online]. Loveland, USA. [Cited: 2016]. http://www.hach.com/hardnessguide.

Haw River Watch. 2015. *Part 5: Identifying Macroinvertebrates, A citizen water quality Project of Haw River Assembly* [online]. Haw River. [Cited: 2016]. http://hawriver.org/wp-content/uploads/2013/02/RW-Pres-5-ID-Macros_20100513_web.pdf.

Hepher, B. & Pruginin, Y. 1981. *Commercial Fish Farming with Special Reference to Fish Culture in Israel.* Chichester UK, John Wiley & Sons. 261 pp.

Horváth L. & Pékh Gy. 1984. *Haltenyésztés, Tógazdasági halászmesterek könyve*. Budapest, Mezőgazdasági Kiadó. 173 pp.

Horváth L. & Tamás G. 1981. I*vadéknevelés – Szaporító és ivadéknevelő halászmesterek könyve*. Budapest, Mezőgazdasági Szakmunáskönyvtár, Mezőgazdasági Kiadó. 182 pp.

Horváth, L. 2000. *Fish Biology and Fish Culture*. Budapest, Mezőgazda Kiadó. 440 pp. (written in Hungarian).

Horváth, L. 2015. *Gabonaszalma eredetű cellulóz bevitel a halastavi anyagforgalomba az alga túlszaporodás korlátozására***.** 15 Halászati Tudományos Tanácskozás NAIK HAKI [online]. [Cited: 2016]. http://hakinapok.haki.hu/.

Howels, C. 2015. Life cycle of diving beetle. In: *Australian Museum* [online]. Sydney. [Cited: 2016]. http://australianmuseum.net.au/image/diving-beetle-life-cycle.

Lavens, P. & Sorgeloos, P. (eds). 1996. *Manual on the production and use of live food for aquaculture.* FAO Fisheries Technical Paper. No. 361. Rome, FAO. 295 pp. (also available at ftp://ftp.fao.org/docrep/fao/003/w3732e/w3732e00.pdf).

Merriam-Webster. 2016. Definition of hydrology. In: *Merriam-Webster* [online]. Springfield, USA. [Cited: 2016]. http://www.merriam-webster.com/dictionary/hydrology.

Ministry of British Columbia. 2015. *Ambient water quality guidelines for temperature: overview.* Environment Protection Division [online]. [Cited: 2016]. https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines.

Moczár, L. 2005. *Vizi gerinctelen állatok határozója*. Budapest, Agroinform Kiadó, 98 pp.

Moiseenko, T.I. 2015. *Types and properties of water – Vol. II – Biological properties of freshwater bodies.* Water Problems Institute RAS, Russia. [Online]. Paris. [Cited: 2016]. http://www.eolss.net/sample-chapters/c07/e2-03-04-03.pdf.

Molnár, K., Székely, C. and Láng, M. 2019. Field guide to the control of warmwater fish diseases in Central and Eastern Europe, the Caucasus and Central Asia. FAO Fisheries and Aquaculture Circular No.1182. Ankara, FAO. 124 pp. License: CC BY-NC-SA 3.0 IGO http://www.fao.org/3/ca4730en/ca4730en.pdf.

Molony, B. 2001. Environmental requirements and tolerance of Rainbow trout (*Oncorhynchus mykiss*) and Brown trout (*Salmo trutta*) with special reference to Western Australia: A review. Fisheries Research Report No. 130, Department of Fisheries, Government of Western Australia [online]. [Cited: 2016]. http://www.fish.wa.gov.au/Documents/research_reports/frr130.pdf.

Nagy S.A., Grigorszky I., Wittner I. & Dévai Gy. 2007. A halastavi halhústermelés ökológiai alapjai. In Cs. Hancz (ed). *Haltenyésztés.* Kaposvár, Hungary, Kaposvári Egyetem Állattudományi Kar. pp. 15-39 (also available at http://real.mtak.hu/4136/).

Nagy, S.A. 1998. – *Importance of the qualitative changes of zooplankton in fish pond and natural waters*. Kossuth Egyetem Kiadó, Debrecen, pp.131. (PhD dissertation written in Hungarian).

Nagy, S.A. 2013a. *Hydro-ecology – Thermal Waters*. University of Debrecen [online]. Debrecen, Hungary. [Cited: 2016]. http://www.tankonyvtar.hu/en/tartalom/tamop412A/2011_0025_kor_2/ch15s02.html).

Nagy, S.A. 2013b. *Hydro-ecology – Salinity of Waters.* University of Debrecen [onnline]. Debrecen, Hungary. [Cited: 2016]. http://www.tankonyvtar.hu/en/tartalom/tamop412A/2011_0025_kor_2/ch15.html.

Nagy, S.A. 2013c. *Hidroökológia; A trópusi vizek működési sajátosságai.* University of Debrecen [online]. Debrecen, Hungary. [Cited: 2016]. http://www.tankonyvtar.hu/hu/tartalom/tamop412A/2011_0025_kor_2/ch04s05.html.

Olivero-Sheldon, A., Jospe, A. & Anderson, M.G. 2014.Northeast Lake and Pond Classification System. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office [online]. Boston. [Cited: 2016]. https://easterndivision.s3.amazonaws.com/Freshwater/Northeast_Lake_and_Pond_Classification.pdf.

Ördög, V. 2000. In L. Horváth. *Halbiológia és Haltenyésztés.* Budapest, Mezőgazda Kiadó. 220 pp.

Papp, K. & Fürész, Gy. 2003. *Vízminőség, vízvizsgálatok*. Kaposvár, Hungary, Magyar Országos Horgász Szövetség.104 pp.

Pidwirny, M. & Jones, S. 2014. Chapter 8. Introduction to the hydrosphere. Physical properties of water. In: *Fundamentals of Physical Geography.* Okanagan, Canada, University of British Colummbia. (also available at http://www.physicalgeography.net/fundamentals/8a.html).

Prophet, C. 2015. Stream ecology. *The Kansas School Naturalist,* 52(1). [online]. [Cited: 2016]. http://www.emporia.edu/ksn/v52n1-may2005/.

Rahman, M.S. 1992. *Water Quality Management in Aquaculture*. Dhaka, Bangladesh, BRAC Printer. 84 p.

Révész, B. 2003. A Balaton felszínközeli klímája, Természettudományi Kar, Meteorológiai Tanszék [online]. Budapest, Eötvös Tudományegyetem. [Cited: 2016]. http://nimbus.elte.hu/.

Ribiánszky, M. & Woynarovich, E. 1962. *Hal, halászat, halgazdálkodás.* Budapest, Mezőgazdasági Kiadó. 310 pp.

Robinson, K.W., Flanagan, S.M., Ayotte, J.D., Campo, K.W., Chalmers, Ann, Coles, J.F. & Cuffney, T.F. 2004. *Water quality in the New England Coastal Basins – Maine, New Hampshire, Massachusetts, and Rhode Island, 1999–2001*. U.S. Geological Survey Circular 1226, 38 pp. (also available at http://pubs.usgs.gov/circ/2004/1226/).

Stiller, É. 2012. *Az árpaszalma és alkalmazása a vizek algásodásának visszaszorítására.* Tervezési feladat, biomérnök, BSc. Budapest, Budapesti Műszaki és Gazdaságtudományi Egyetem [BSc dissertation].

Study.com. 2015. Springs; definition, formation and types. In: Study.com [online]. [Cited: 2016]. Mountain View, USA. http://study.com/academy/lesson/springs-definition-formation-types.html.

Taghvaeian, S., & Sutherland, A. 2015. *Evaporation Losses from Shallow Water Bodies in Oklahoma*. Oklahoma Cooperative Extension Service Fact Sheet. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-9525/BAE-1529web.pdf.

Tamás, G. & Horváth, L. 1972. A növényevő ivadék indító természetes táplálékának előállítása üzemi méretekben. *Halászat*, 18:56-57

Tamás, G. & Horváth, L. 1976. – Growth of cyprinids under optimal zooplankton conditions. *Bamidgeh Bull. for Fish Culture,* 25(3):30-36.

Tamás, G., Ördögh, V., Csorbai, B., Urbányi, B., Béres, B. & Horváth, L. 2008. *Gabonaszalma eredetű cellulóz bevitel a halastavi anyagforgalomba az alga túlszaporodás korlátozására.* Presentation given at Szent István Egyetem, Halgazdálkodási Tanszék (also available at http://hakinapok.haki.hu/tartalom/2008/Horvath.pdf).

Thorpe, A., Whitmarsh, D., Drakeford, B., Reid, C., Karimov, B., Timirkhanov, S., Satybekov, K. & Van Anrooy, R. 2011. *Feasibility of restocking and culture-based fi sheries in Central Asia*. FAO Fisheries and Aquaculture Technical Paper. No. 565. Ankara, FAO. 106 pp. (also available at http://www.fao.org/docrep/016/ba0037e/ba0037e.pdf).

Tortajada, A.M., Carmona, M.J., & Serra, M. 2013. Typical life cycle of monogonont rotifers. *PLOS ONE.* Figure. [online]. [Cited: 2016]. https://figshare.com/articles/_Typical_life_cycle_of_monogonont_rotifers_/543245.

United Utilities. 2015. Water hardness. In: United Utilities [online]. [Cited: 2016]. http://www.unitedutilities.com/documents/WaterhardnessFactSheet.pdf.

USGS. 2015. Water, the Universal Solvent. U.S. Geological Survey (USGS) [online]. Reston, USA. [Cited: 2016]. http://water.usgs.gov/edu/solvent.html.

USGS. 2016. How much water is there on, in, and above the Earth? U.S. Geological Survey (USGS) [online]. Reston, USA. [Cited: 2016]. http://water.usgs.gov/edu/earthhowmuch.html.

UTAS. 2015. Zooplankton. In: University of Tasmania [online]. Hobart, Australia. [Cited: 2016]. http://www.imas.utas.edu.au/zooplankton/image-key/copepoda.

Vanden Pol, E. 2015. Dragonfly life cycle. In: Learning about life cycles [online]. [Cited: 2016]. https://sites.google.com/site/mrsvandenpollifecycles/life-cycle-research-project/dragonfly/dragonfly-life-cycle.

Wetzel, R.G. 1983. *Limnology*, Second Edition. New York, CBS College Publishing, pp. 767.

Whitney, R.J. 1942. *Diurnal fluctuation of oxygen and pH in two small ponds and a stream*. Birmingham, UK, Zoology Department, University of Birmingham. (also available at http://jeb.biologists.org/content/jexbio/19/1/92.full.pdf).

WHO. 2003. Hydrogen Sulphide in Drinking-Water – Background Information for Developing Drinking-Water Quality. In: *Guidelines for Drinking-Water Quality*, 2nd ed. Vol. 2. Health criteria and other supporting information. Geneva, World Health Organization, Geneva, 1996. http://www.who.int/water_sanitation_health/dwq/chemicals/en/hydrogensulfide.pdf.

WMO. 2012 – Chapter 13 Application of Agrometeorology to Aquaculture and Fisheries In: C.E. Boyd, H. Pine, J. Ferraz de Queiroz, I. Dontwi, G. Tucker, & M. Van Der Ploeg. *Guide to Agricultural Meteorological Practices* (Weather-Climate-Water), WMO-No. 134. http://www.wmo.int/pages/prog/wcp/agm/gamp/gamp_en.php http://www.wamis.org/agm/gamp/GAMP_Chap13.pdf and http://www.wmo.int/pages/prog/wcp/agm/gamp/documents/WMO_No134_en.pdf.

WMO. 2015. METEOTERM, the WMO terminology database [online]. [Cited: 2016]. https://www.wmo.int/pages/prog/lsp/meteoterm_wmo_en.html.

Woods Hole Oceanographic Institution. 2015. Phytoplankton [online]. [Cited: 2016]. http://www.whoi.edu/main/topic/phytoplankton.

Woynarovich, A. 1988. *A Magyar Nagyüzemi Előnevelt Ivadéktermelési Technológia Alkalmazási Lehetőségei Brazíliában.* Debrecen, Hungary, Debreceni Agrártudományi Egyetem, Mezőgazdaságtudományi Kar, Állattenyésztési és Termeléstechnológiai Intézet [PhD thesis].

Woynarovich, A., Bueno, P.B., Altan, Ö., Jeney, Zs., Reantaso, M., Xinhua, Y. & Van Anrooy, R. 2011. *Better management practices for carp production in Central and Eastern Europe, the Caucasus and Central Asia*. FAO Fisheries and Aquaculture Technical Paper No. 566. Ankara, FAO 2011. 153 pp. (also available at http://www.fao.org/docrep/016/i2409e/i2409e.pdf).

Woynarovich, A., Hoitsy, G. & Moth-Poulsen, T. 2011. *Small-scale rainbow trout farming.* FAO Fisheries and Aquaculture Technical Paper No. 561. Rome, FAO. 2011. 81 pp. (also available at http://www.fao.org/docrep/015/i2125e/i2125e.pdf).

Woynarovich, A., Määttä, V., Fersoy, H. & Moth-Poulsen, T. 2015. *Regional practices: stocked and farmed inland fish species and types of their hatcheries.* FAO CACFish Regional Workshop on Inland Fish Hatchery Management, Bishkek, 27–30 October 2014.

Woynarovich, A., Moth-Poulsen, T., & Péteri, A. 2010. *Carp polyculture in Central and Eastern Europe, the Caucasus and Central Asia: A manual.* FAO Fisheries and Aquaculture Technical Paper. No. 554. Rome, FAO. 2010. 73 pp. (also available at http://www.fao.org/docrep/013/i1794e/i1794e00.htm).

Woynarovich, A., Reja, M.A., Akhand, M R.I., Islam, M.M., Sarker, R.K., Thomsen, S., Moth-Poulsen, T. & Khaleque, M.A. 2003. *MAEP Fish Farmers' Manual – Fish production in pond*. Danida, Bangladesh, Mymensingh Aquaculture Extension Project. 82 pp.

Woynarovich, E. 1975. *Elementary Guide to Fish Culture in Nepal*. FAO, Rome. 138 pp.

Woynarovich, E. 1985. *Manual de Piscicultura – Divisão de Piscicultura e Pesca*. Brasília, Codevasf. 71 pp.

Wurts, W.A. 2004. *Understanding water hardness.* Princeton, KY, USA, Kentucky State University Cooperative Extension Program. (also available at https://wkrec.ca.uky.edu/files/hardness.pdf). **YSA.** 2015. *The Basics of Chlorophyll Measurement.* YSI Technical Note [online]. Yellow Springs, USA, YSI. [Cited: 2016]. https://www.ysi.com/File%20Library/Documents/Technical%20Notes/T606-The-Basics-of-Chlorophyll-Measurement.pdf.

ANNEX 1

SOME PRACTICAL CLASSIFICATIONS OF WATERS

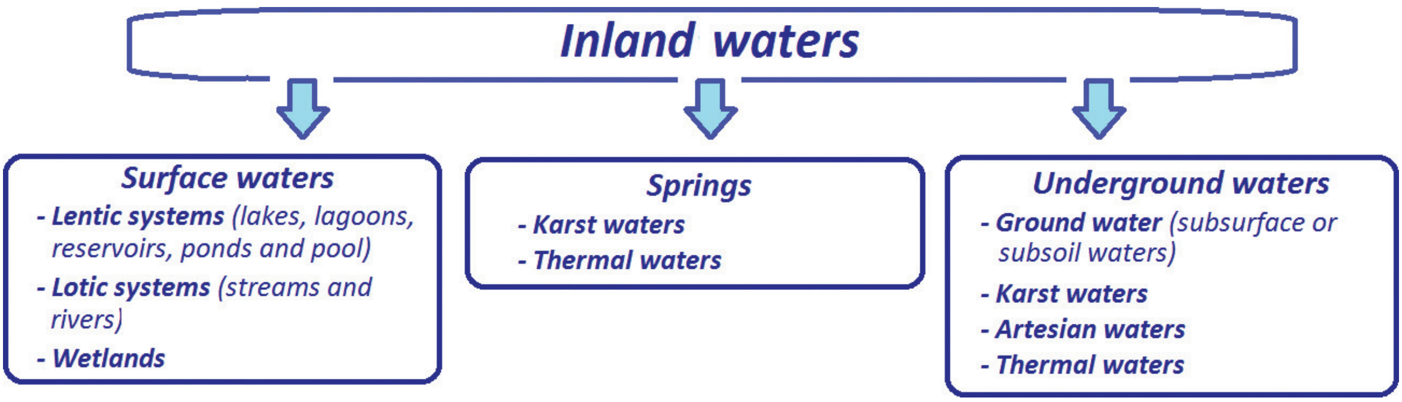
Of the numerous classifications and groupings of waters, some practical ones relevant to this publication are presented in this annex.

TABLE A1-1
Estimation of global water distribution[7]

Type of water	Water volume, in cubic kilometres	Percent of fresh water	Percent of total water
1. Oceans, seas and bays	**1 338 000 000**	**–**	**96.54**
2. Ice caps, glaciers and permanent snow	**24 064 000**	**68.7**	**1.74**
3. Groundwater	**23 400 000**	**–**	**1.69**
3.1. Fresh	10 530 000	30.1	0.76
3.2. Saline	12 870 000	–	0.93
4. Soil moisture	**16 500**	**0.05**	**0.001**
5. Ground ice and permafrost	**300 000**	**0.86**	**0.022**
6. Lakes	**176 400**	**–**	**0.013**
6.1. Fresh	91 000	0.26	0.007
6.2. Saline	85 400	–	0.006
7. Atmosphere	**12 900**	**0.04**	**0.001**
8. Swamp water	**11 470**	**0.03**	**0.0008**
9. Rivers	**2 120**	**0.006**	**0.0002**
10. Biological water	**1 120**	**0.003**	**0.0001**

Source: USGS (2015).

FIGURE A1-1
Main groups of inland waters



Source: Dévai *et al.* (1998).

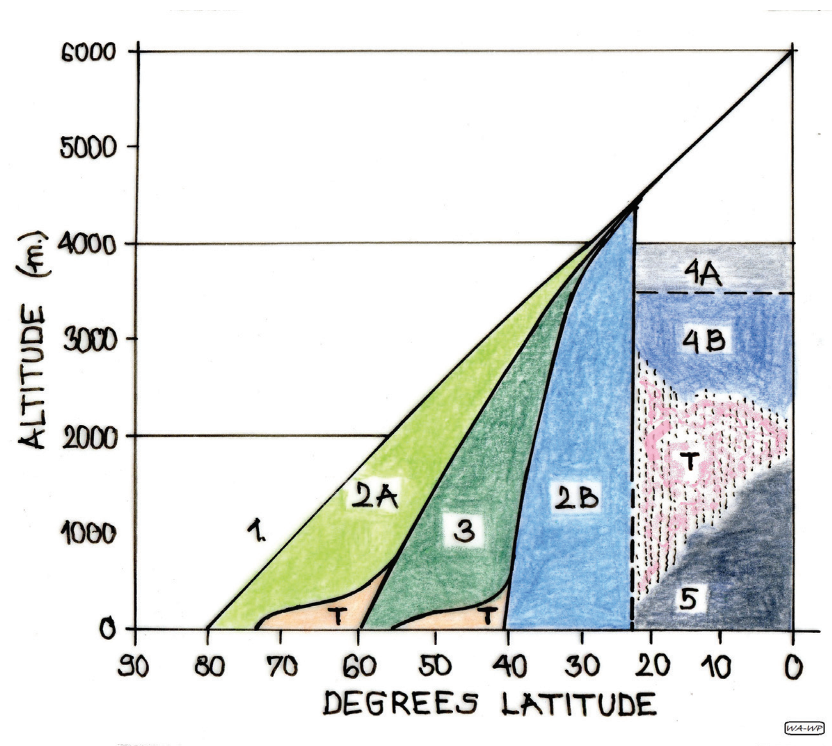
[7] Percent figures are rounded.

TABLE A1-2
Classification of lakes by their thermal characteristics

Type of lake	Description	Climatic zones			
		Cold	Temperate	Sub-tropic	Tropic
1. Amictic	Covered with ice year-round	Yes			
	Highly saline inland waters		Yes	Yes	Yes
2. Monomictic	Cold – water temperature below 4 °C year-round. There is only one period of circulation in the summer at or below 4 °C.	Yes			
	Warm – water temperature above 4 °C year-round. These waters circulate at or above 4 °C about in winter.		Yes	Yes	Yes
3. Dimictic	Bottom and surface waters change place twice a year.		Yes		
4. Polymictic	Cold – one period year-round				High-altitude lakes
	Warm – one period year-round				Yes
5. Oligomictic	Warm year-round – there is practically no stratification				Yes

Source: Wetzel (1983).

FIGURE A1-2
Schematic arrangement of thermal lake types with latitude and altitude



1) Amictic (e.g. very few Artic lakes).

2A) Cold monomictic (e.g. Artic and mountain lakes).

3) Dimictic (e.g. cool temperate regions of the world).

2B) Warm monomictic (e.g. lakes of the warm regions of temperate zones particularly those influenced by oceanic climates and mountainous area of subtropical zones).

4A) Cold polymictic (e.g. lakes of moderate depth on high altitude of equatorial regions).

4B) Warm polymictic (e.g. lakes with frequent circulation on equatorial tropics with small variation in annual water temperature).

5) Oligomictic (e.g. lakes of the tropics without stratification).

T: Transition regions. (Based on Wetzel, 1983)].

TABLE A1-3
Summary of classification attribute and threshold definitions

Class	Definition	Direct measures to be used
Trophic	National Lake Assessment break in Chlorophyll a: **1. Oligotrophic**: ≤ 2 µg/l **2. Mesotrophic**: > 2-7 µg/l **3. Eutrophic**: > 7-30 µg/l **4. Hypereutrophic**: > 30 µg/l	Chlorophyll a (in July and August).
Alkalinity	**1. High alkalinity**: ≥ 50 mg/l $CaCO_3$ **2. Medium alkalinity**: ≥ 12.5 and < 50 mg/l $CaCO_3$ **3. Law alkalinity**: < 12.5 mg/l $CaCO_3$	Milligram per litre of $CaCO_3$ < 2 m depth of water.
Temperature	Presence of greater than 1 metre of following habitat through the summer: **1. Very cold**: < 12.8 °C and ≥ 5 mg/l DO **2. Cold**: 12.8 °C ≤ 18 °C and ≥ 5 mg/l DO **3. Cold-cool**: > 12.8 °C ≤ 21 °C and ≥ 4 mg/l DO or indicator fish – non-reproducing brook trout, holdover or reproduction of brown trout, kokanee, smelt. **4. Warm**: > 21 °C	Temperature and DO depth profiles from July to August. Indicator fish reproduction.
Depth	**Ponds** versus **lake** threshold **1. Oligotrophic**: 9.14 m (30 ft.) **2. Mesotrophic**: 6.10 m (20 ft.) **3. Eutrophic** and h**ypereutrophic**: 3.05 m (10 ft.) Ponds have light penetration to the bottom and light penetration is dependent on the trophic state as shown.	Depth of light penetration in metres (and feet).

Source: Sheldon *et al.* (2014).

TABLE A1-4
Trophity of inland waters under temperate climate and their potential fish production capacities

Main categories of waters	Description	Potential fish production (kg/ha/yr.)
Brown acidic (dystrophic) waters	Poor in natural fish food and poor in oxygen.	–
Less productive (oligotrophic) waters	Cold waters that do not warm up over 14–15 C°, poor in natural fish food, rich in oxygen. Transparency: above 8–4 m.	1–15
Medium productive (mesotrophic) waters	Less warming-up water, medium in natural fish food, well supplied with oxygen. Transparency: between 4 and 2 m.	15–100
Productive (eutrotrophic) waters and extensive fish ponds	These waters warm up in summers with seasonal and daily problems with oxygen content. Transparency: between 2 and 0.5 m	100–200
Very productive (hypertrophic) waters and intensive fish ponds	These waters warm up in summer with seasonal and daily problems with oxygen content. Transparency: low 0.5–0.25 m	above 200

Source: Based on Berka (1989).

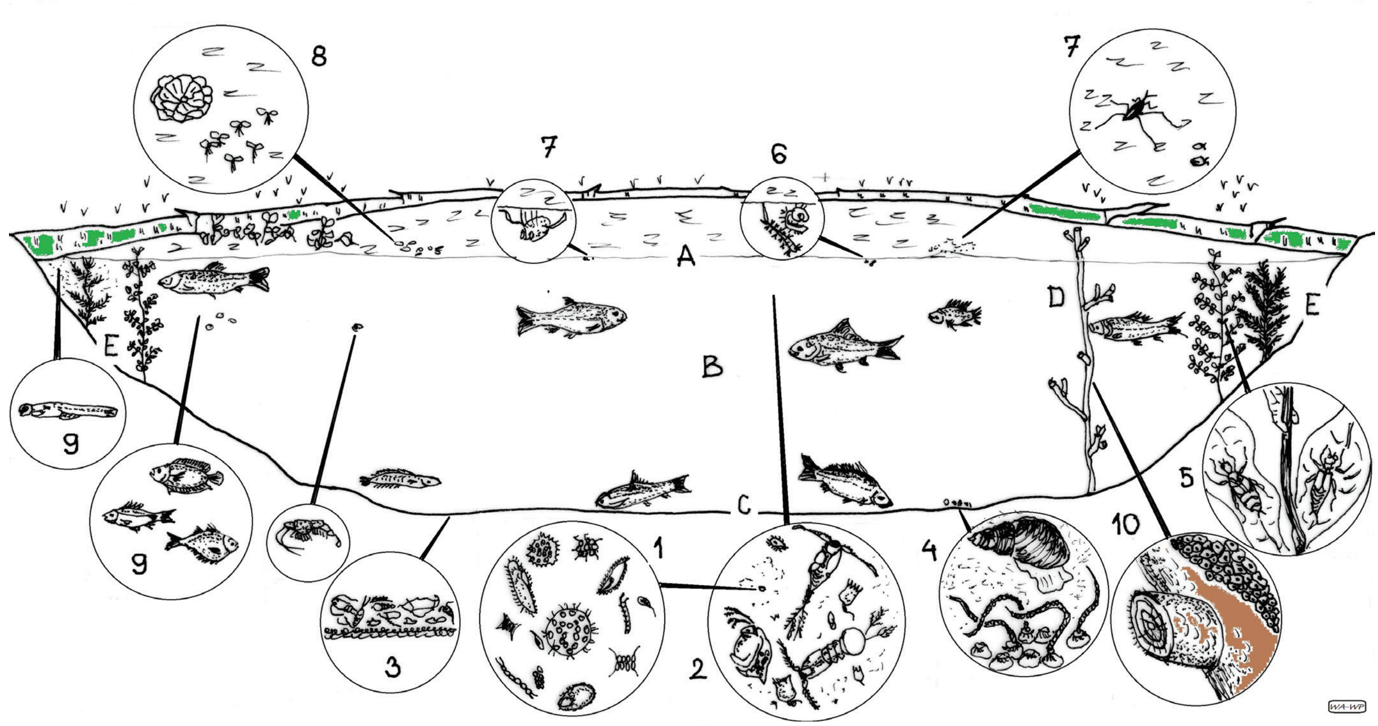
AQUATIC ORGANISMS IMPORTANT FOR INLAND FISHERIES AND POND FISH CULTURE

There are certain groups of aquatic organisms which are especially important for fish. One part of them serves directly or indirectly as fish food, whereas others prey on fish, especially on their smaller and younger age groups. These aquatic organisms are as follows[8]:

- **Plants,** including (1) phytoplankton, (1) mosses and (1) water weeds.
- **Animals,** including (1) protozoans, (2) worms (rotifers, flat and ringed worms), (3) molluscs (snails and bivalves), (4) crustaceans (plankton crustaceans, shrimp and crayfish), (5) insects (midges, flies, water bugs and water beetles) and (6) vertebrates (fish, amphibians, reptiles, water birds and water mammals)

There are also other practical groupings of aquatic organisms. One of them is presented in Figure A2-1 where the organisms are categorized according to the biotope in which they typically live and feed from.

FIGURE A2-1
Biotopes of inland standing waters and their typical natural fish food organisms



(A) Water surface – (7) Bugs (Figure A2-13), (8) Floating water weeds (Figure A2-3).

(B) Water column – (1) Phytoplankton (Figure A2-2) and protozoans (Figure A2-4), (2) Rotifers (Figure A2-(5), cladocerans (Figure A2-6) and copepods (Figure A2-7), as well as large crustaceans (Figure A2-8),

(C,D, E) Biotekton and bottom – (3) Detritus of dead organisms, (4) Ringed worms (Figure A2-16) and molluscs (Figure A2-17) and macrovegetation (Figure A2-3), (5) Periphyton.

One or more biotopes during a lifecycle – (6) Midges: mosquitos and chironomids (Figure A2-9), (5) fly larvae and pupae (Figure A2-10), mayflies (Figure A2-11), damselflies and dragonflies (Figure A2-12), bugs (Figure A2-13) and beetles and their larvae (Figure A2-14 and Figure A2-15).

Water and shore – Frogs (Figure A2-18).

Source: Based on Woynarovich *et al.* (2003).

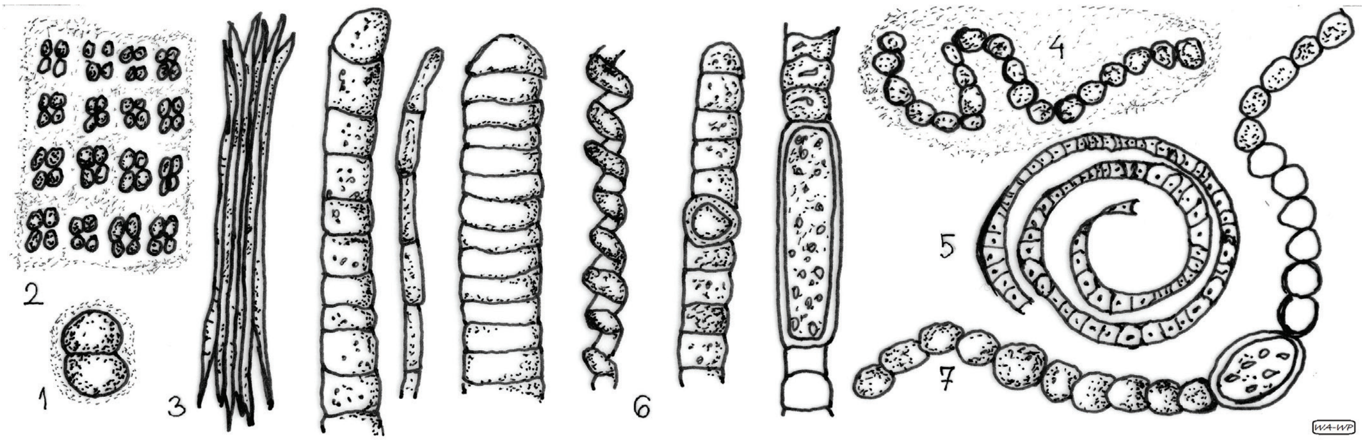
In the subsequent figures, widely found species of aquatic organisms are presented and described.

[8] Bacterioplankton and bacteria which cover microscopic organic particles are both a food source of zooplankton.

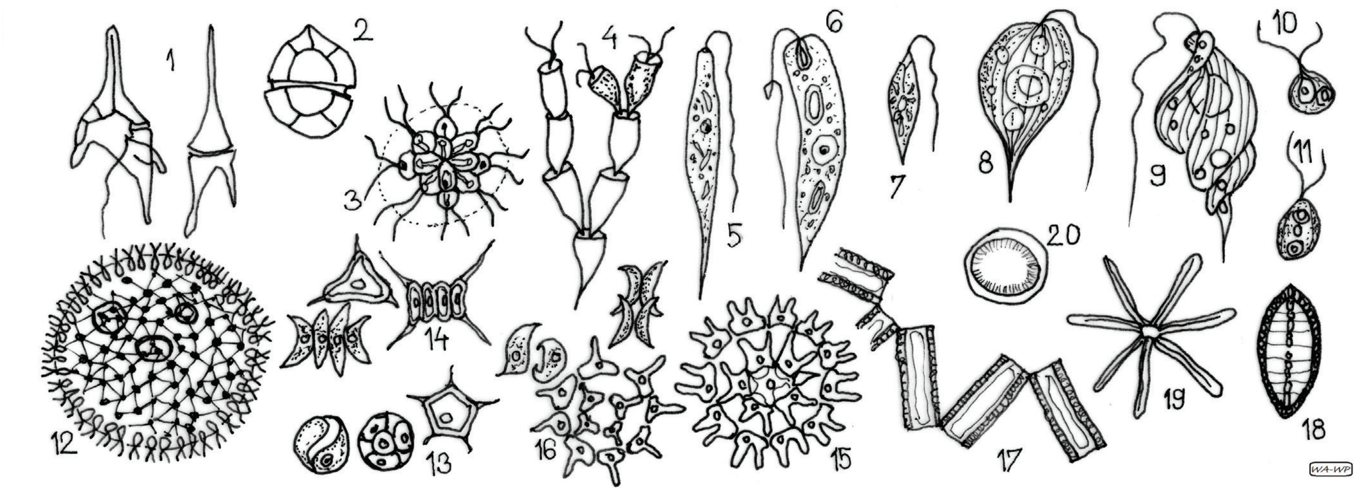
Phytoplankton and mosses

Most of the unicellular green algae are food for plankton crustaceans, while their large species and specimens are filtered also by filter-feeding fish out of which silver carp (*Hypophthalmichthys molitrix*) and Nile tilapia (*Oreochromis niloticus*) are the most frequently cultured species. Silver carp in particular is frequently used both to utilize algae and to control/prevent algae blooms biologically. In addition, it is the cheapest way to produce fish protein for human consumption (Box 5-1).

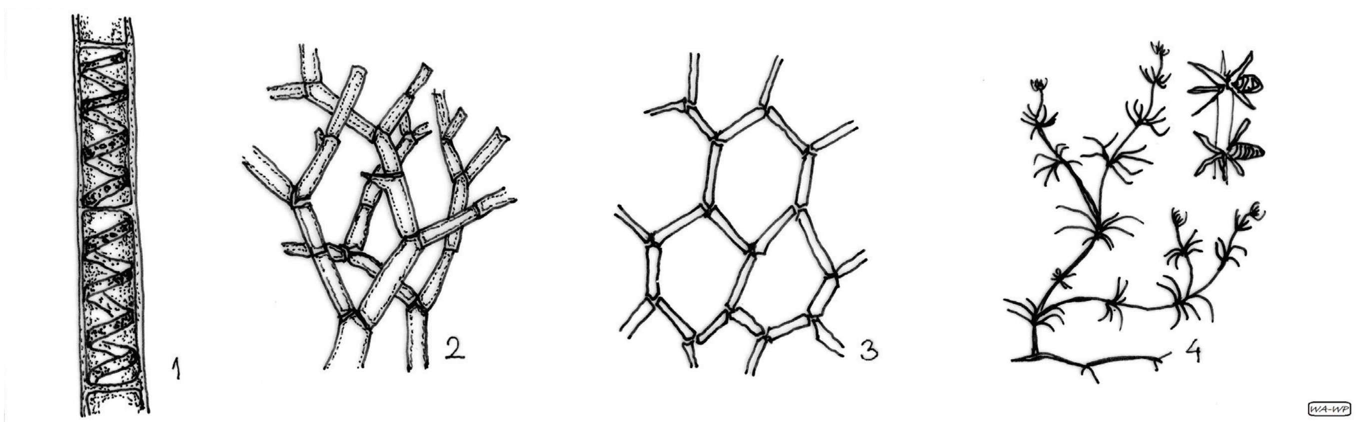
FIGURE A2-2
Phytoplankton



The most frequent cyanobacteria: (**1**) Chroococcus (cell size: 7-10 µm), (**2**) Merismopedia (cell size: 1.5 µm), (**3**) Aphanizomenon (cell size: 5 x 100 µm), (**4**) Nostoc, (**5, 6** Oscillatoria, (**7**) Anabaena (cell size: 4 x 50 µm). Source: Based on Woynarovich (1985).



Unicellular green algae: (**1, 2**) Dinoflagellates, (**3**–**11**) Chlorophytes, (**12**–**16**) Chlorophytes, (**17**–**20**) Diatoms. Source: Based on Woynarovich (1985).

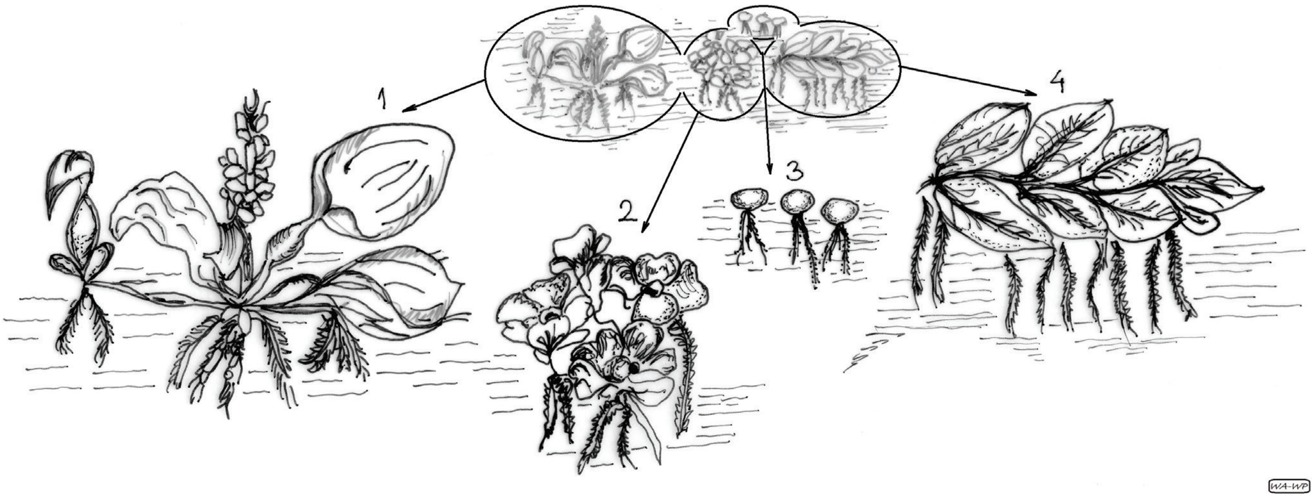


(**1**–**3**) Filamentous algae. (**4**) Chara. Source: Based on Woynarovich (1985).

Water weeds

Many of the water plants are partly or entirely consumed by herbivorous and omnivorous fish, such as grass carp (*Ctenopharyngodon idella*), Redbreast tilapia (*Tilapia rendalli*), common carp (*Cyprinus carpio*) and bream (*Abramis brama*).

FIGURE A2-3
Waterweeds



Floating waterweeds: (**1**) Water hyacinth (*Euchornia sp.*). (**2**) Water lettuce (*Pistia sp.*). (**3**) Duckweed (*Lemna sp.*). (**4**) Butterfly fern (*Salvinia sp.*). Source: Based on Woynarovich (1985).

Submerging waterweeds: (**1**) Miriophillum. (**2–4**) Potamogeton. (**5**) Elodea. (**6**) Cabomba. Source: Based on Woynarovich (1985).

Emerging water weeds: (**1**) Common reed (*Phragmites sp.*). (**2**) Most sedges (*Carex sp.*) are perennial. (**3**) Bulrush (*Typha sp.*) is a waterside plant. Source: Based on Woynarovich (1985).

TABLE A2-1
Consumption preferences of grass carp

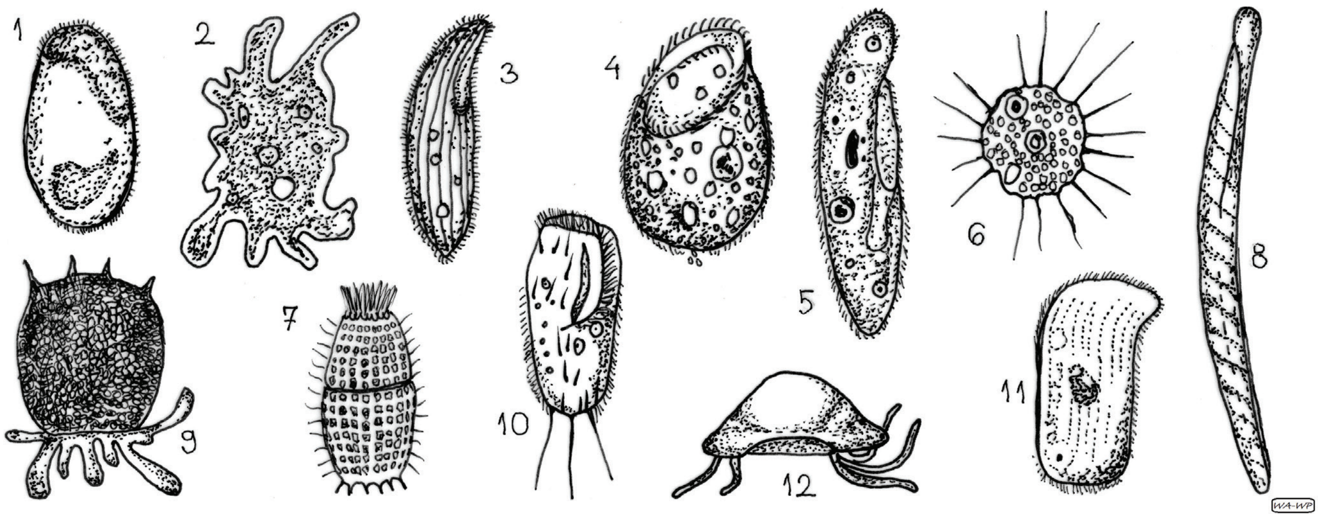
Latin name of waterweeds	Preference*	Latin name of waterweeds	Preference
Hornwort *(Ceratophyllum sp.)*	4	**Pondweed** *(Potamogeton lucens)*	4
Chara sp.	4	**Pondweed** *(Potamogeton natans)*	4
Cladophora sp.	4	**Pondweed** *(Potamogeton pectinatus)*	3
Canadian pondweed *(Elodea sp.)*	4	**Pondweed** *(Potamogeton perfoliatus)*	4
Common frogbit *(Hydrocharis sp.)*	3	**Water crowfoot** *(Ranunculus sp.)*	1
Water iris *(Iris sp.)*	2A	**Sedge, rush** *(Schoenoplectus sp.)*	3
Water milfoil *(Myriophyllum sp.)*	4	**Water-parsnip** *(Sium latifolium)*	3
Spiny water-nymph *(Najas marina)*	4	**Blanket weed** *(Spirogyra sp.)*	4
Reed *(Phragmites sp.)*	3A	**Water caltrop** *(Trapa natans)*	3
Water smartweed *(Polygonum sp.)*	2	**Reed mace** *(Typha angustifolia)*	2A
Pondweed *(Potamogeton crispus)*	3	**Reed mace** *(Typha latifolia)*	3A

* Rate 4: Consumed within 8 hours with a huge appetite. Rate 3: Consumed within 24 hours with a medium appetite (3A: hard stems were not consumed). Rate 2: Consumed within 48 hours (2A: hard stems were not consumed). Rate 1: Only 25–30 percent consumed (Antalfi and Tölg, 1972).

Zooplankton

Zooplankton consist of protozoans, rotifers and plankton crustaceans, of which the most important natural fish food organisms belong to cladocerans and copepods. Zooplankton, especially rotifers and smaller development stages of plankton crustaceans, are the first natural fish food of the just-feeding larvae of practically all freshwater fish species. There are also zooplankton feeder species: for example, bighead carp (*Hypophthalmichthys nobilis*), catla (*Catla catla*), tambaqui (*Colossoma macropomum*) and many of the omnivorous fishes consume zooplankton during their entire life.

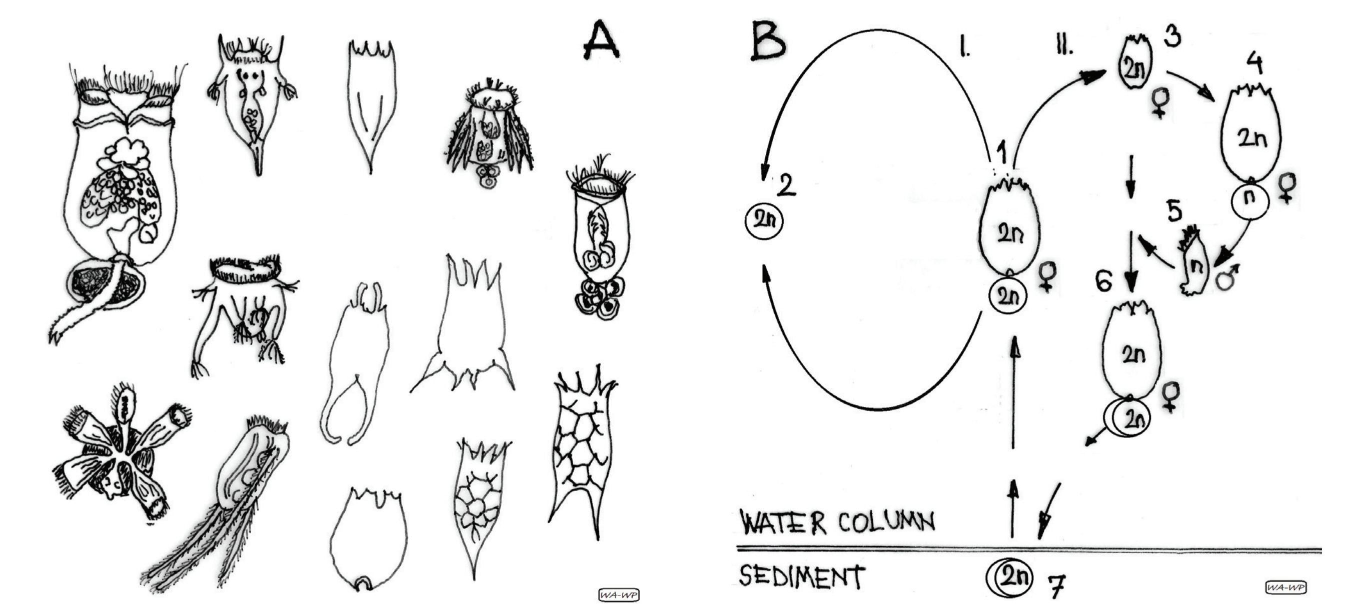
FIGURE A2-4
Zooplankton – Protozoans



These single-celled microscopic animals (cell size: 50–300 μm) develop among decaying plants and hay infusions. They serve well as the first food of feeding larvae of most warmwater fish species. If conditions are favourable, the generation time varies between 6 and 24 hours at 20–25 °C water temperature.

(**1**) *Colpidium* (ciliate) is the first organism of hay infusions. (**2**) *Amoeba* occurs most frequently on pond mud. (**3**) *Loxodes* occurs in infusions. (**4**) *Bursaria* occurs in pools. (**5**) *Paramecium* (ciliate) appears in decaying vegetation but also develops in hay infusions. (**6**) *Actinophrys* develops among water plants in ponds. (**7**) *Coleps* can be found among decaying plants. (**8**) *Spirostomum* is found around decaying leaves. (**9**) *Diffugia* is found in pond mud. (**10**) *Stylonchia* is found among decaying vegetation and old hay infusions. (**11**) *Chilodon* is found among decaying vegetation. (**12**) *Arcella* is found in mud or on pond mud. Source: Based on Clegg (1967).

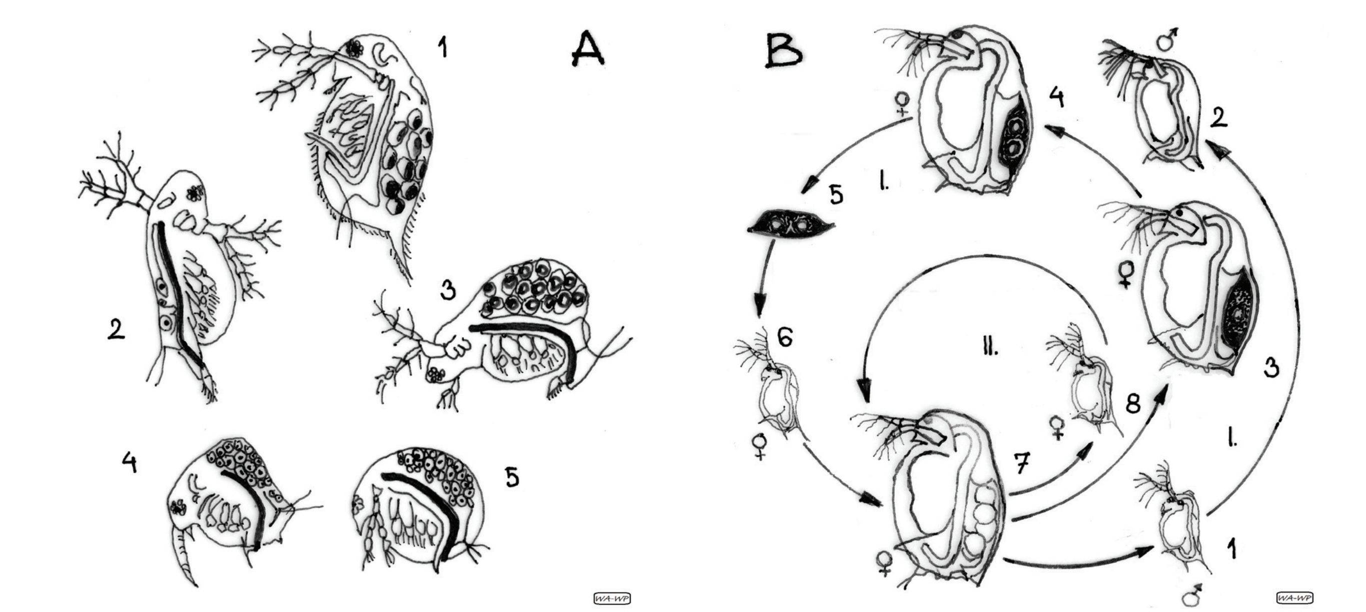
FIGURE A2-5
Zooplankton – Rotifers



A. Typical shapes of rotifers (based on Woynarovich, 1985). Their size varies between 90 and 250 µm (http://rotifersolutions.com/?p=51). Their life span is between 3.4 and 4.4 days at 25°C. Larvae become adult after 0.5 to 1.5 days. Females start to lay eggs approximately every four hours. Females can produce ten generations of offspring (Lavens & Sorgeloos, 1996).

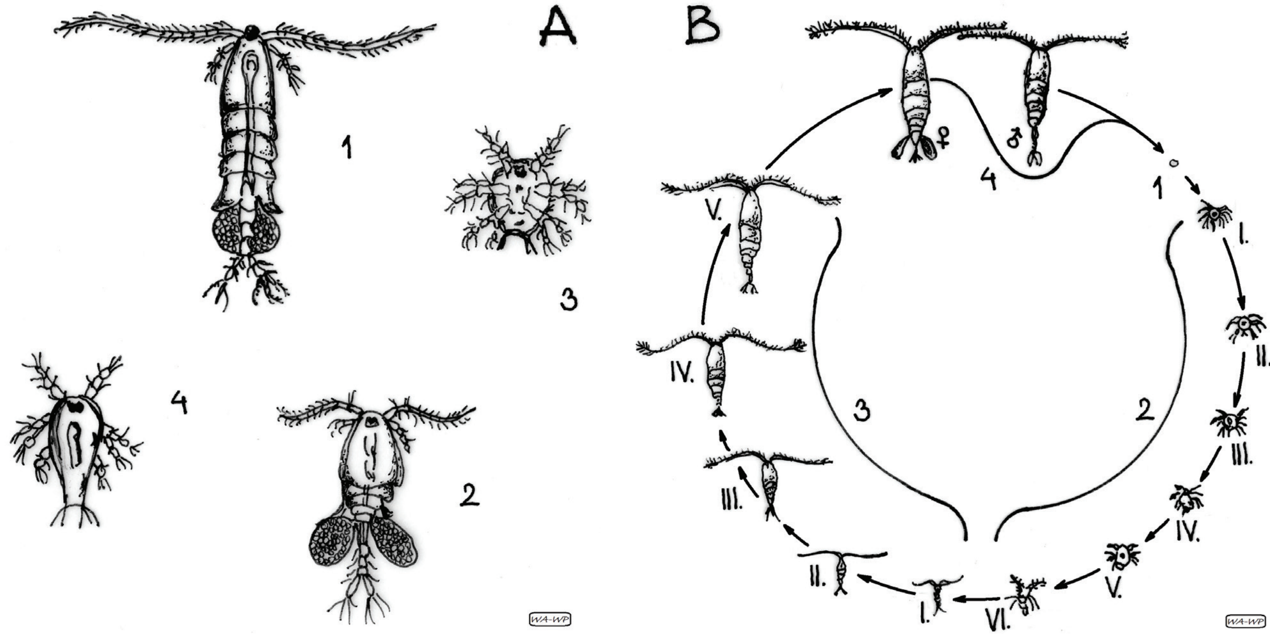
B. Lifecycle of a rotifer (*Brachionus plicatilis*): I. Asexual phase which lasts until environmental conditions are favourable. (**1**) Asexual female. (**2**) Asexual eggs, II. Sexual phase occurs when conditions become unfavourable. (**3**) Young sexual female. (**4**) Sexual female produces (**5**) male. (**6**) Sexual female produces *diapausing** egg. (**7**) Diapausing egg. Source: Based on Tortajada *et al.* (2013).

FIGURE A2-6
Zooplankton – Cladocerans



Cladocerans are the third group of zooplankton organisms which appear in a freshly filled pond with clear water. **A.** Typical cladocerans: (**1**) Daphnia (size: 0.2-5 mm), (**2**) Diaphanosoma (size: 0.8-1.2 mm), (**3**) Moina (size: 0.2-2 mm), (**4**) Bosmina (size: 0.2-1 mm), (**5**) Chidorus (size of male: 0.2 mm, female: 0.3-05 mm) (based on Woynarovich, 1985) **B.** Lifecycle of a cladoceran (*Daphnia magna*) I. Sexual cycle starts when environmental conditions become unfavourable. (**1**) At this time a parthenogenetic son is produced. (**2**) The male matured to mate. (**3**) A haploid egg is produced and (**4**) mating with the male occurs. (**5**) The sexual egg produced is dormant until conditions become favourable to hatch after diapause. (**6**) The female is produced. (**7**) When conditions are favourable, the asexual cycle starts, while in the case of an unfavourable environment a male is produced. II. Parthenogenetic cycle: (**8**) A parthenogenetic daughter is produced. Parthenogenetic cycles go on until conditions are favourable (www.arofanatics.com).

FIGURE A2-7
Zooplankton – Copepods



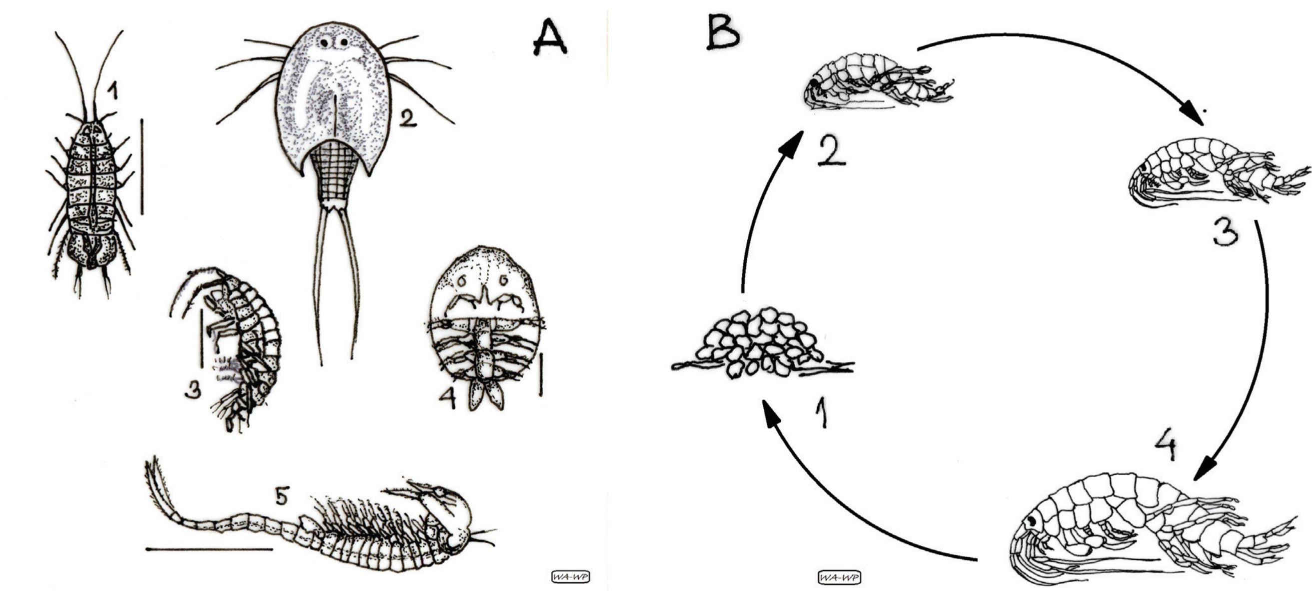
A. Typical nauplii and copepodic stages: (**1**) Diaptomus adult (size: 1.5-2 mm), (**2**) Cyclops adult (size: 1-1.5 mm), (**3**) Cyclops larvae and (**4**) Diaptomus larvae**.**

B. Copepods last about 3-6 days when water temperature is about 20-25 °C. Lifecycle: (**1**) Egg. (**2**) Nauplii stages. (**3**) Copepodic stages. (**4**) Adults that mate (http://science.kennesaw.edu/).

Larger water crustaceans

Within this group, there is a wide range of crustaceans. Discounting the parasitic ones, they are an important food source both for the developing young and the adult specimens of many different fish species, including predator and omnivorous species.

FIGURE A2-8
Larger water crustaceans



A. (**1**) Water louse (*Asellus sp.*) (size: about 20 mm). (**2**) Apus (*Triops sp.*) (size: about 20 mm). (**3**) Freshwater shrimp (*Gammarus*) (size: about 30 mm). (**4**) Fish louse (*Argulus sp.*) (size: about 7 mm). (**5**) Fairy shrimp (*Chirocephalus sp.*) (size: about 20 mm) (Clegg, 1967).

B. Lifecycle of gammarus: (**1**) eggs, (**2–3**) developing gammarus with regular shedding, (**4**) adult (http://amphipods.weebly.com/lifecycle.html).

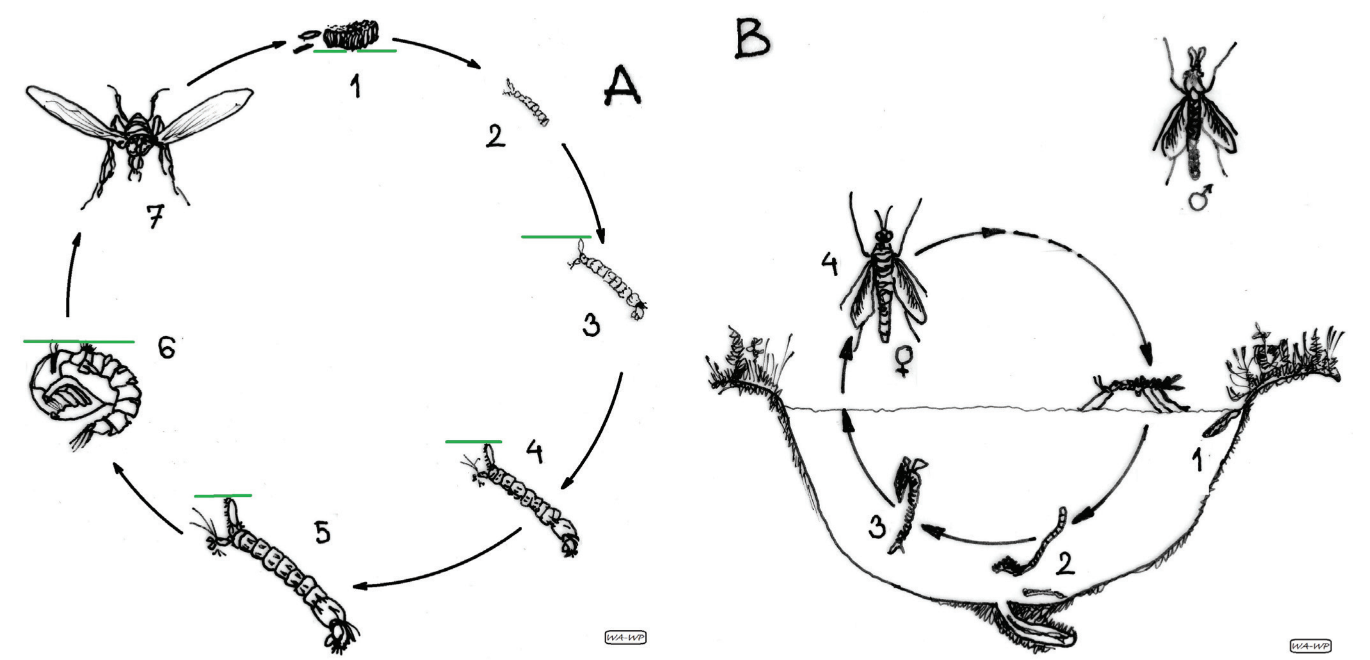
Water insects

Insects are terrestrial animals. Their imagoes (i.e. adults) are fully adapted to terrestrial life. Still some orders of insects play a significant role in the aquatic ecosystems of inland waters, including fish ponds, as many of them have partly or entirely adapted to aquatic life.

- Partly aquatic insects lay eggs into the water where they develop until reaching fully developed adult stage, when they leave the water. Adult insects leaving waters often remove considerable quantities of organic materials from the water. The important insects for fisheries and fish culture which live and develop in the water until becoming full developed adults include:
  - Mosquitos and chironomids. The larvae of chironomid live on organic detritus in the mud and are a valuable main or occasional natural fish food for many fish species.
  - Mayflies, damselflies and dragonflies. Damselfly and dragonfly nymphs live for one or two years and prey on fish larvae and the developing fry of many fish species. However, the same nymphs are also a valuable food for many larger or adult fish.
- Fully aquatic insects

  Water bugs and water beetles are fully adjusted to aquatic life. All their development stages including imago live in water. Depending on species and size, they are fish food, but are also dangerous for developing fish larvae and fry as they prey on them.
  - Fully developed water bugs are capable of attacking fish or other small animals including tadpoles, frogs and smaller water snakes.[9]
  - True water beetles are mainly carnivorous both in their larval and adult stages and are dangerous for fish larvae and fry.

FIGURE A2-9
Water insects – mosquitos and chironomids

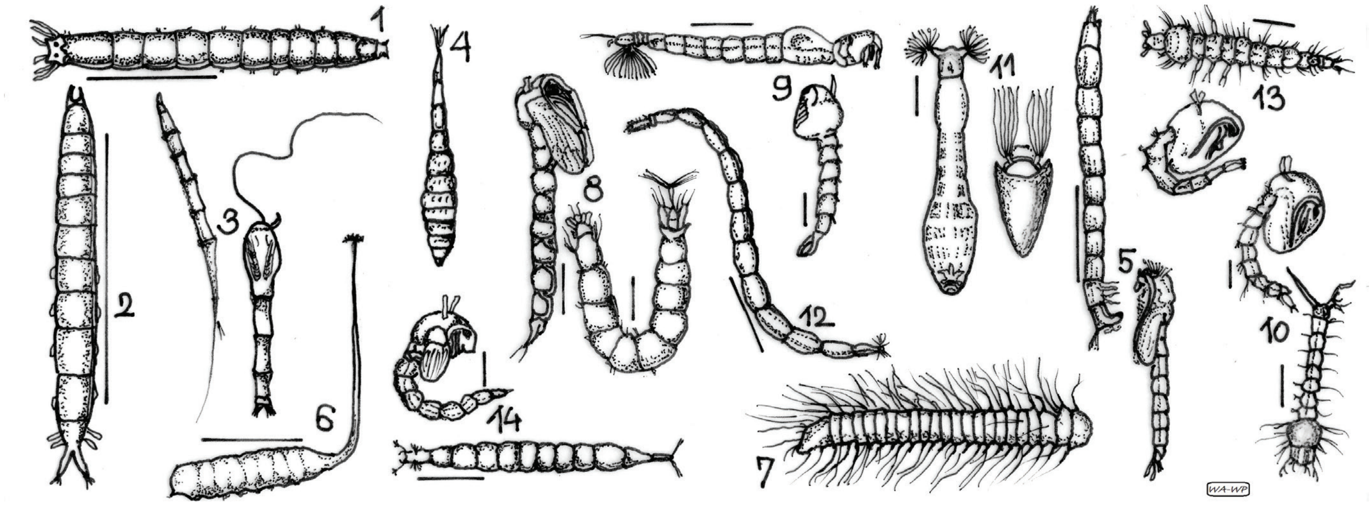


(A) Lifecycle of mosquitos lasts about 10-14 days at 20-25 °C temperature. Generalized lifecycle of mosquitos (all life stages are linked to the water surface):. (**1**) raft of eggs, (**2**) first larvae stage, (**3**) second larvae stage, (**4**) third larvae stage, (**5**) fourth larvae stage, (**6**) pupal stage, (**7**) adult flies out of the water. Source: Based on http://www.malaria.com/.

(B) Generalized lifecycle of chironomids: **(1**) egg mass (time to hatch: 3-7 days), (**2**) larvae (length: 2-7 weeks), (**3**) pupa (length: 3 days), (**4**) adult female (length: 3-5 days)**.** Source: Based on Apperson *et al.* (2006)**.**

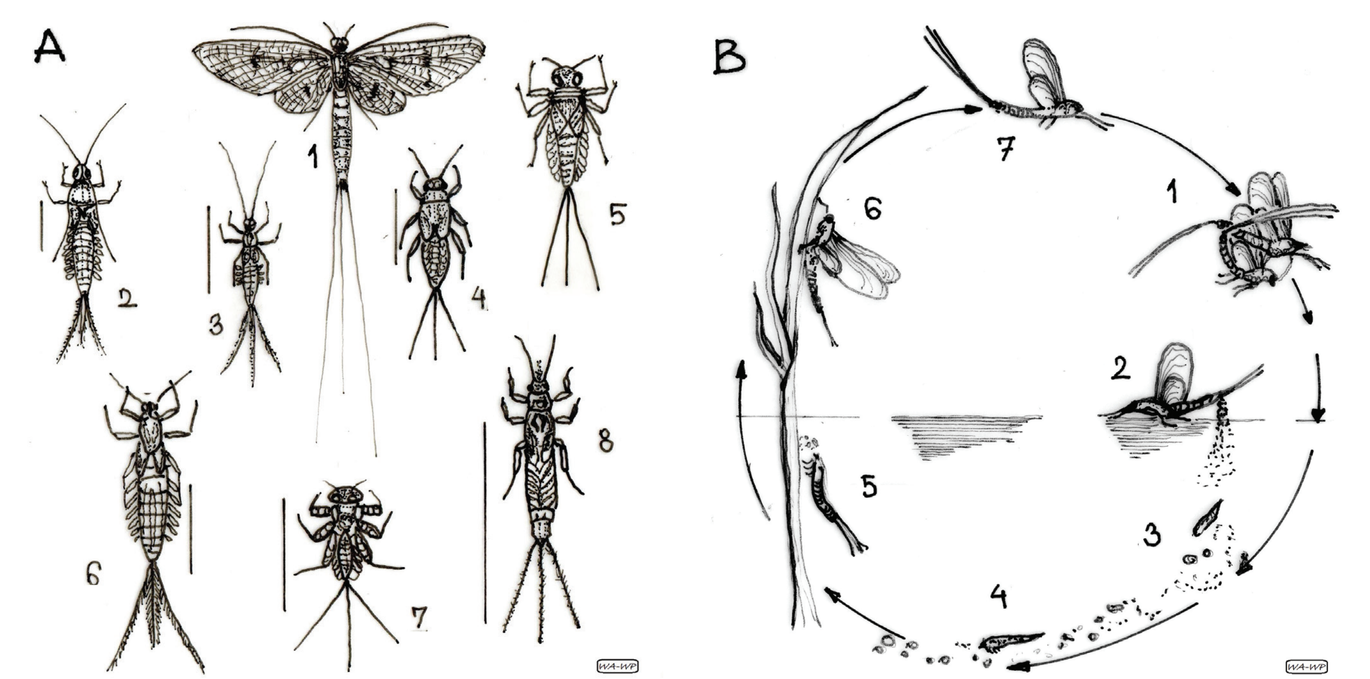
[9] https://www.youtube.com/watch?v=HjRoGyRE5z0.

FIGURE A2-10
Water insects – Fly larvae and pupae



(**1, 2**) Terrestrial larvae of crane flies pass the larval stage in mud, under stones in streams and in the nearby damp earth. (**1**) *Tipula*. (**2**) *Pedicia*. (**3**) Larvae and pupa of Ptychoptera. The larvae live in the mud. (**4**) Larvae of the soldier fly *Stratiomys* hang suspended from the water surface-film. (**5**) Pupa and larvae of the midget *Chironomus* are called "bloodworms" and are very common in ponds. There are many species, some of which live in the mud, others in the plant tissue or swimming freely. (**6**) Larvae of the drone fly *Eristalis*, also called "rat-tailed maggots", are found in black mud. (**7**) Larvae of crane fly *Phalacrocera*. They live among the sphagnum moss in bog pools. (**8**) Pupa and larvae of the midge *Dixa* live in ponds among vegetation near the surface. (**9**) "Phantom larva" and pupa of the midge *Chaoborus* live in lakes, ponds and shady pools. (**10**) Pupa and larvae of the gnat *Culex*. (**11**) Larvae and pupa of the blackfly, *Simulium*. (**12**) Larvae of the biting midge, *Ceratopogon*. (**13**) Larvae and pupa of the mosquito, *Anopheles*. (**14**) Pupa and larvae of the midge *Tanypus*. Source: Based on Clegg (1967).

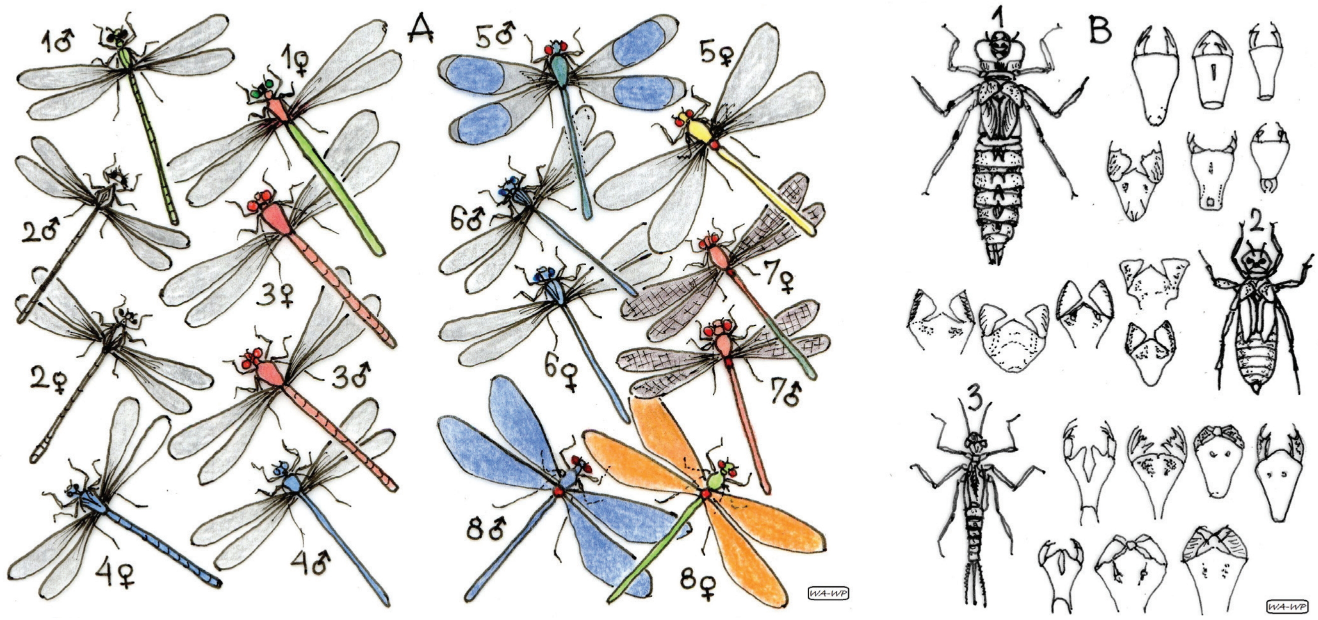
FIGURE A2-11
Water insects – Mayflies



A. (**1**) Mayfly or green drake (*Ephemera sp.*). The adult insect emerges in late May or early June. (**2**) Pale watery dun (*Centroptilum sp.*) found widely among the waterweeds. (**3**) Pond olive (*Cloeon sp.*). (**4**) Blue-winged olive (*Ephemerella sp.*). (**5**) Olive upright (*Rhithrogena sp.*). (**6**) Large dark olive (*Baetis sp.*) common in fast-moving waters. (**7**) Late March brown (*Ecdyonurus sp.*) common in streams and ponds. (**8**) Mayfly or green drake (*Ephemera sp.*). Source: Clegg (1967).

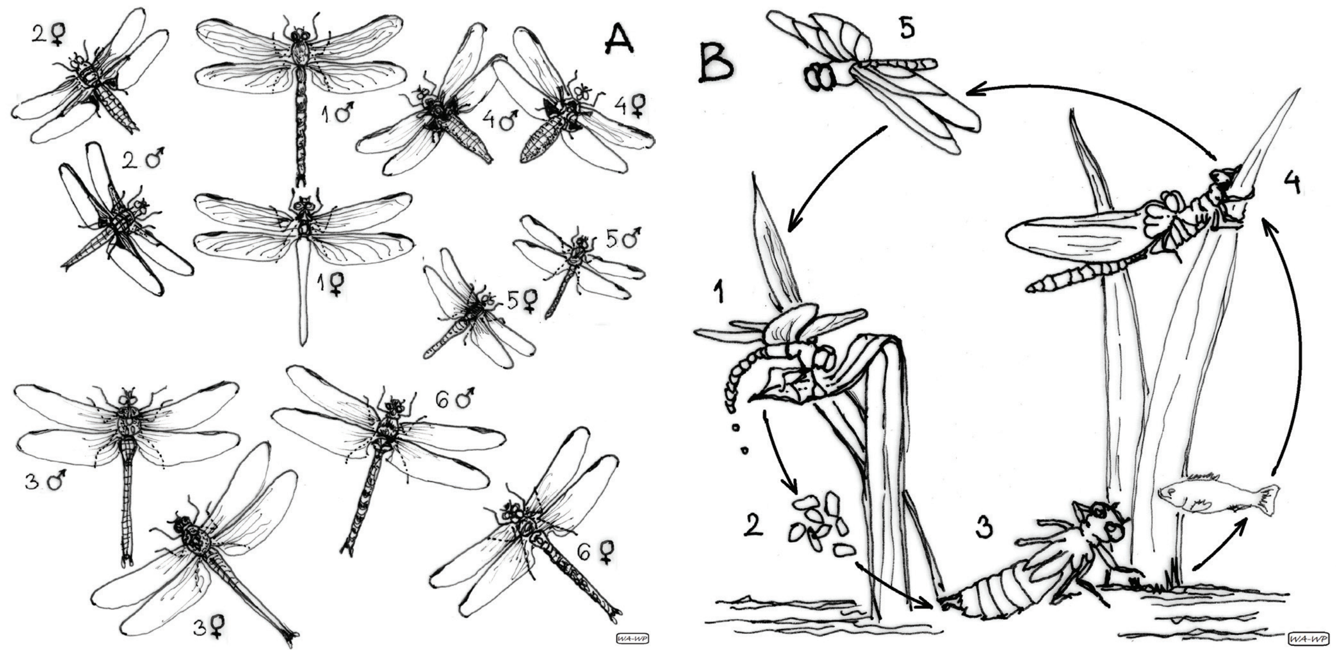
B. Though the adult life of the mayfly is very short, the entirely aquatic nymphal stage may last years. Lifecycle of a mayfly: (**1**) mating, (**2**) laying eggs. (**3, 4**) larval stage, (**5**) immature form; nymph, (**6**) sub-imago, (**7**) imago (adult). Source: http://what-when-how.com/.

FIGURE A2-12
Water insects – Damselflies and dragonflies



Damselflies and dragonflies occur near/around rivers, canals, lakes and ponds. **A.** Typical damselflies: (**1**) Green lestes (*Lestes sp.*). (**2**) Common ischnura (*Ischnura sp.*). (**3**) Large red damselfly (*Pyrrhosoma sp.*), often the first dragonfly of the season[4] and remains on from the beginning of May to the end of August. (**4**) Common coenagrion (*Coenagrion sp.*) found between the end of May and the middle of August. (**5**) Banded agrion (*Agrion sp.*), a common Eurasian species. (**6**) Common blue damselfly (*Enallagma sp.*) found between mid-May and mid-September. (**7**) Small red damselfly (*Ceriagrion or Pyrrhosoma sp.*) found from early June to early September. (**8**) Demoiselle agrion (*Agrion sp.*) found between the end of May and the end of August. Source: Clegg (1967).

B. Damselfly and dragonfly nymphs: (**1**) Long-bodied dragonfly nymphs and their distinctive masks. (**2**) Short-bodied dragonfly nymphs and their distinctive masks. (**3**) Slender-bodied damselfly nymphs and their distinctive masks. Source: Clegg (1967).

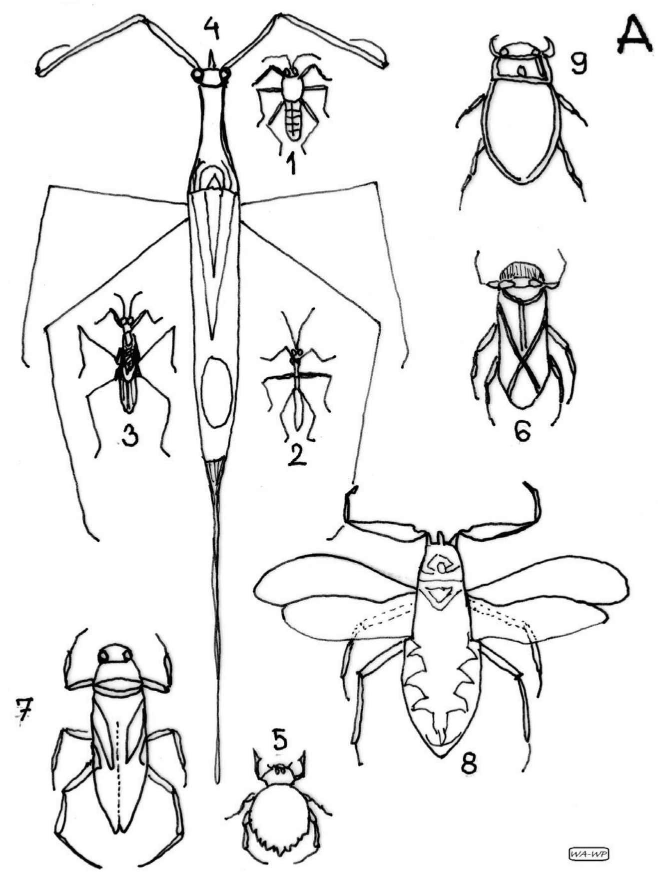


A. Typical dragonflies: (**1**) Brown aeshna (*Aeshna sp.*) found between mid-July and the end of September. (**2**) Golden-ringed dragonfly (*Cordulegaster sp.*) found between mid-June and early September. (**3**) Common Aeshna (*Aeshna sp.*) and relatives: **4**) **5**) **6**). Source: Clegg (1967).

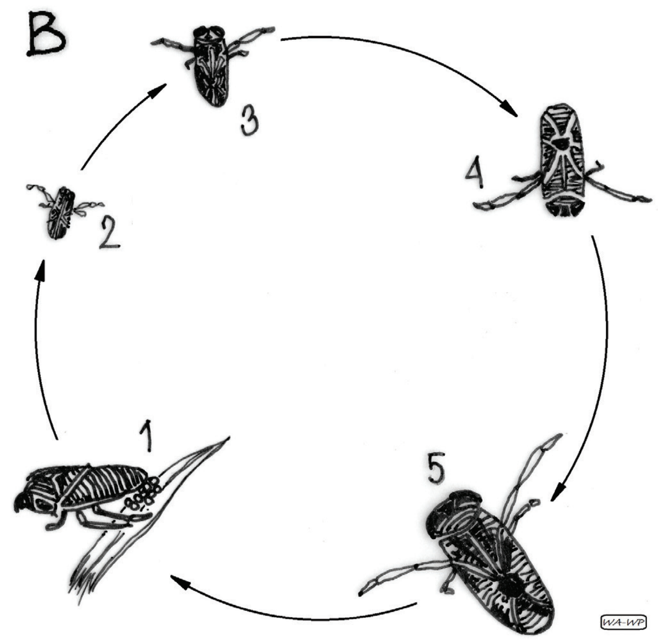
B. Lifecycle of a dragonfly: (**1**) laying eggs, (**2**) hatching eggs, (**3**) nymph – one of the most aggressive predators for developing fry, (**4**) moult, (**5**) adult. Source: Based on http://www.education.com/.

[10] Observations in this section on when insects can be seen apply to temperate climates.

FIGURE A2-13
Water insects – Bugs

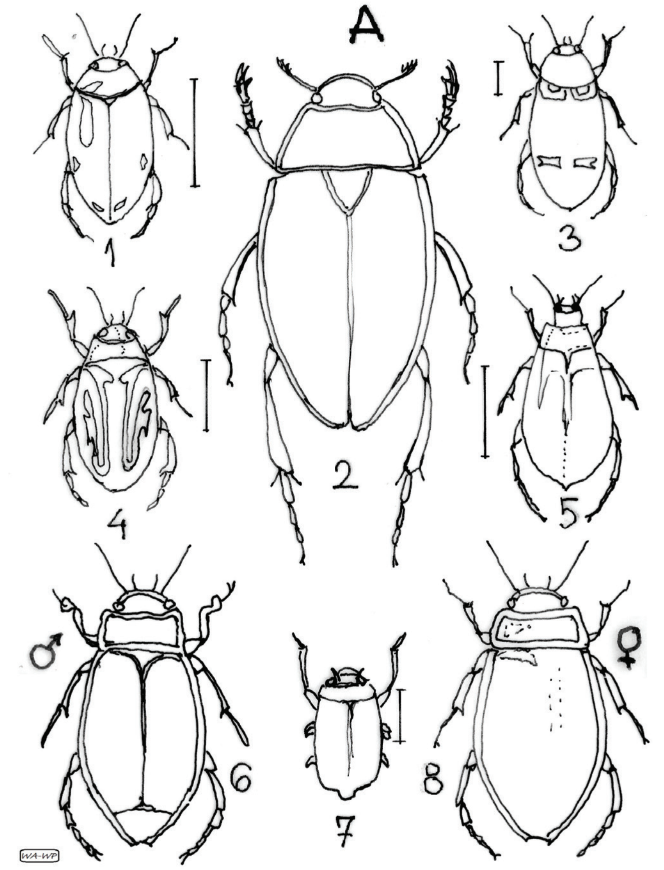


A. Surface-film dwellers: (**1**) Water cricket (*Velia sp.*). (**2**) Water measurer (*Hydrometra sp.*). (**3**) Pond skater (*Gerris sp.*). Underwater dwellers: (**4**) Long water scorpion (*Ranatra sp.*). (**5**) *Aphelocericus sp.* (**6**) Lesser water boatman (*Corixa sp.*). (**7**) Water boatman (*Notonecta sp.*). (**8**) Water scorpion (*Nepa sp.*). (**9**) Creeping water bug (*Ilyocoris sp.*). Source: Clegg (1967).

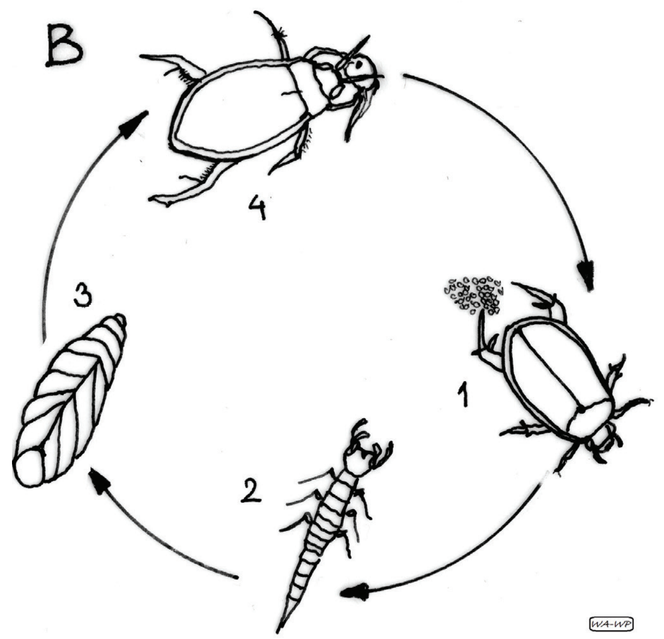


B. Lifecycle of water boatman: (**1**) eggs, (**2-4**) moulting stages, (**5**) adult.
Source: http://www.kidfish.bc.ca/waterboat_cycle.htm.

FIGURE A2-14
Water insects – Beetles

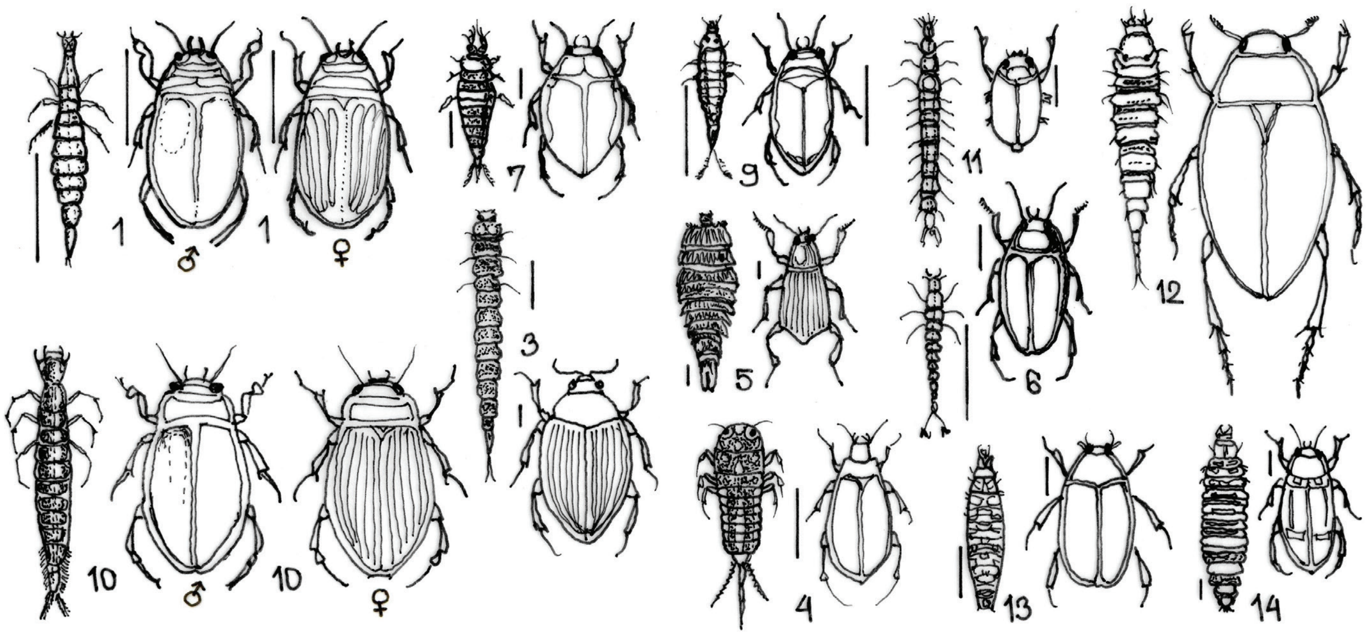


A. Typical water beetles: (**1**) The mud dweller, *Ilybius sp.* (**2**) Great silver beetle, *Hydrophilus sp.* (**3**) *Laccophilus sp.* (**4**) *Platumbus sp.* (**5**) The screech beetle, *Hydrobia sp.* (**6, 8**) Female and male of great diving beetle (*Dytiscus sp.*) are aggressive carnivore. (**7**) Whirling beetle (*Gyrinus sp.*). Source: Clegg (1967).



B. Lifecycle of a diving beetle (*Dytiscus sp.*): (**1**) eggs, (**2**) Larvae, (**3**) pupa, **4**) adult.
Source: http://australianmuseum.net.au/.

FIGURE A2-15
Water insects – Beetles and their larvae

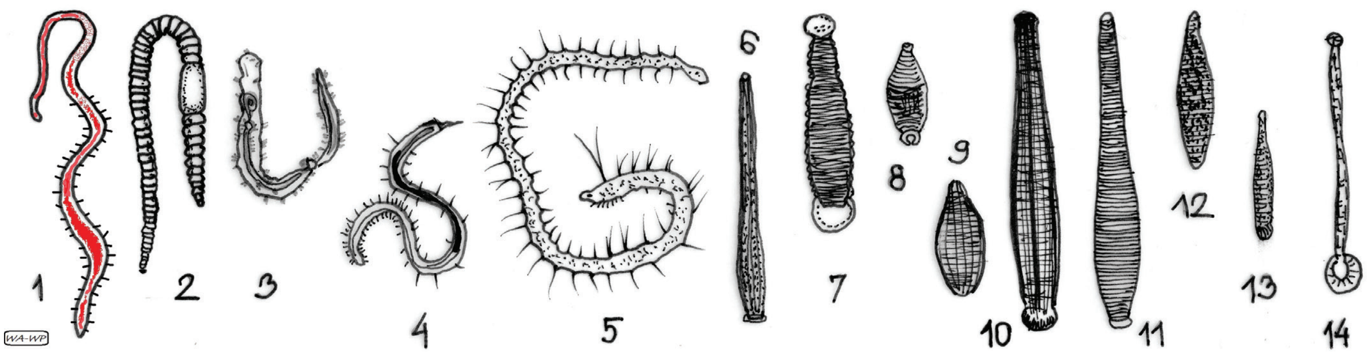


(**1**) *Acilius sp.*, a relative of the great diving beetle. (**3**) *Haliplus sp.*, whose larvae feed on filamentous algae. (**4**) Screech beetle (*Hygrobia sp.*). (**5**) *Helmis sp.*, whose larvae are found under stones. (**6**) *Agabus sp.* common in waters. (**7**) *Hypydrus sp.* (**9**) *Ilybus sp.* (**10**) Great diving beetle (*Dytiscus sp.*). (**11**) Whirling beetle (*Gyrinus sp.*). (**12**) Great silver beetle (*Hydrophilus sp.*). (**13**) *Hydrobius sp.* (**14**) *Laccobius sp.* Source: Based on Clegg (1967).

Worms

Worms are important organisms in aquatic ecosystems as they are either external/internal parasites or are a valuable natural food for fish.

FIGURE A2-16
Ringed worms



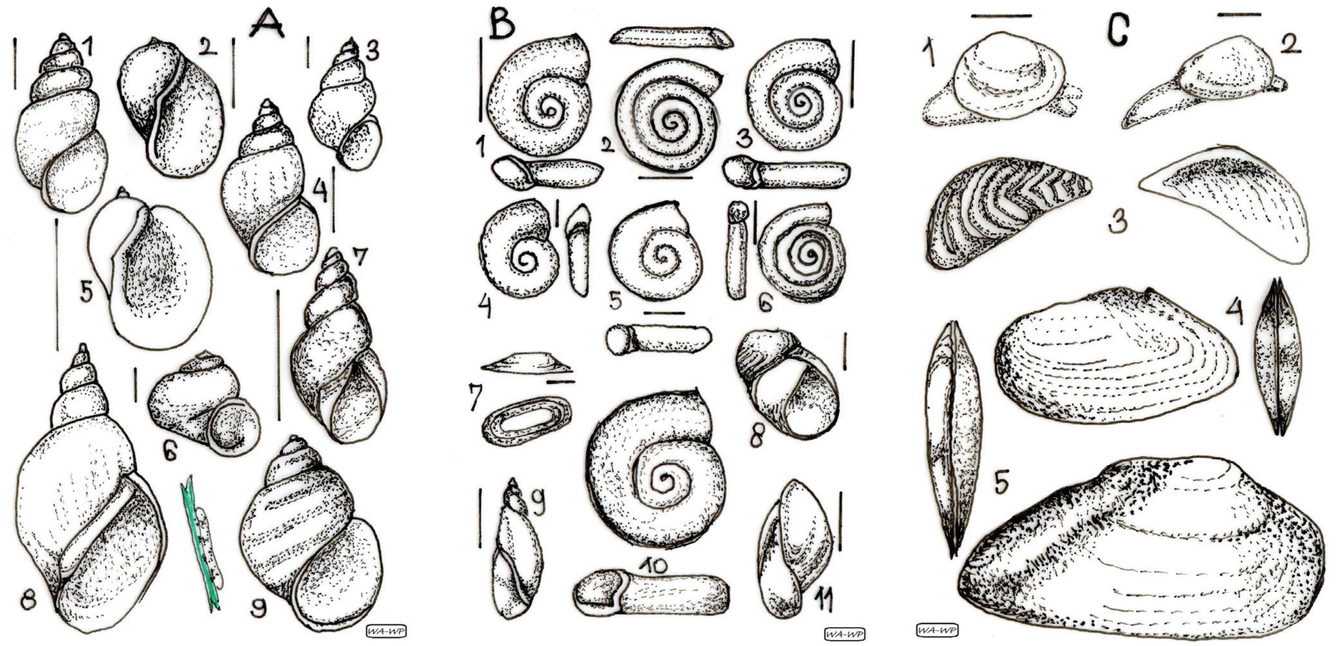
Semiaquatic and aquatic earth worms (Oligotchaeta): (**1**) Tubifex (*Tubifex tubifex*). (**2**) White or pot worms (*Enchytraeus sp.*). (**3**) *Aeolosoma sp.*. (**4**) *Stylarria sp.*. (**5**) *Nais sp.*

Leeches (Hirudinea): (**6**) *Dina sp.* (**7**) *Cystobranchus sp.* (**8**) *Helobdella sp.* (**9**) *Glassiphonia sp.* (**10**) *Hirudo sp.* (**11**) *Haemopis sp.* (**12**) *Theroomyzon sp.* (**13**) *Piscicola sp.* Source: Based on Moczár (2005).

Molluscs

This large group of aquatic organisms includes gastropods, snails, limpets, bivalves and mussels. Snails and mussels are more important as they are food competitors of fish, but their specimens are consumed by common carp (*Cyprinus carpio*) and by other bottom-feeder fish species. In addition, there are fish species such as Tambaqui (*Colossoma macropomum*) which feed mainly on snails and mussels whenever they can find them.

FIGURE A2-17
Molluscs

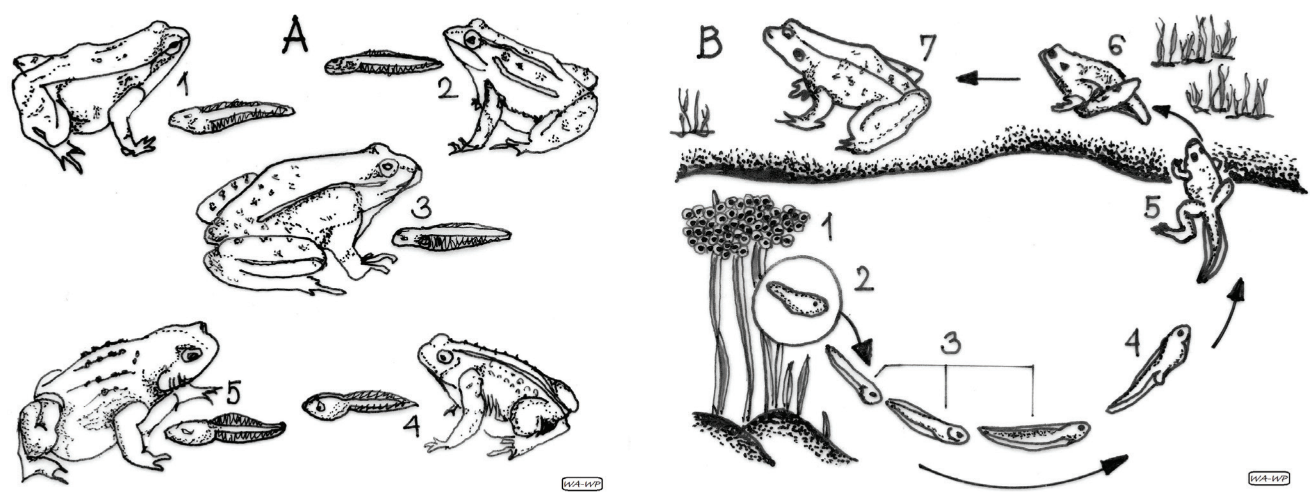


Water snails: **A**. (**1**) Dwarf pond snail. (**2**) Wandering snail. (**3**) Spire shell. (**4**) Common Bithynia. (**5**) Ear pond snail. (**6**) Valve snail. (**7**) March snail. (**8**) Great pond snail. (**9**) Freshwater winkle. **B**. (**1**) Keeled ramshorn. (**2**) Whirlpool ramshorn. (**3**) The ramshorn. (**4**) Flat ramshorn. (**5**) White ramshorn. (**6**) Button ramshorn. (**7**) Lake limpet. (**8**) The netrite. (**9**) Moss bladder snail. (**10**) Great ramshorn. (**11**) Bladder snail. **C.** Orb- and pea-shells: (**1**) Horny orb-shell. (**2**) River pea-shell. (**3**) Zebra mussel. (**4**) Swan mussel. (**5**) Duck mussel. Source: Based on Clegg (1967).

Amphibians

Frogs and toads are important amphibians for fisheries and fish culture. Their developing tadpoles are both serious food competitors and predators for young fish while adult frogs feed on fish. As they are especially harmful in nursery ponds, such ponds should be kept dry when they are not used.

FIGURE A2-18
Frogs and toads



A. (**1**) Common frog, *Rana temporaria* is known as grass frog or brown frog. Frogs breed as soon as they emerge from hibernation. The tadpoles take about 12 weeks to complete their metamorphosis. (**2**) Edible frog, *Rana esculenta*. (**3**) Marsh frog, *Rana ridibunda*. (**4**) Natter jack toad, *Bufo calamita*. The tadpoles complete their metamorphosis in about 6-8 weeks. (**5**) Common toad, *Bufo*. The eggs are laid in strings often 3-4 metres long. The tadpole stage lasts about 8-12 weeks. Source: Clegg (1967).

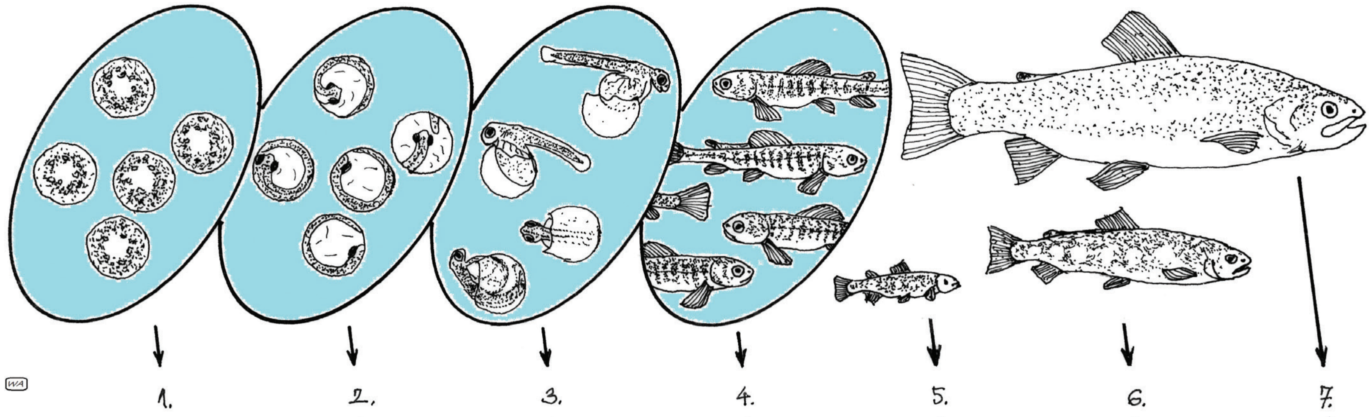
B. The lifecycle of frogs lasts about 12-16 weeks under temperate climate. Lifecycle: (**1**) eggs (6-21 days), (**2**) embryo (7-10 days), (**3**) tadpole, (**4**) front legs break through, (**5**) start of pulmonary breathing, (**6**) tadpole frog, (**7**) adult frog Source: http://www.infovisual.info/02/029_en.html.

TABLES OF ENVIRONMENTAL REQUIREMENTS OF SELECTED COMMERCIALLY IMPORTANT FISH SPECIES

There are general and specific environmental conditions which fish and fish stocks require to survive and grow. This is a rather complicated point because the diversity of fish species, hence their requirements regarding physical, chemical and biological qualities of water, is so wide-ranged that without certain groupings, no clear answers can be provided.

The situation is more diverse when the required environmental conditions are established for the different development stages of fish illustrated in Figure A3-1. Spawning females and males, laid eggs, developing embryos, non-feeding and just-feeding fish larvae, growing fry and fingerling, and sexually matured adult fish require a partly or entirely different ambience.

FIGURE A3-1
Development stages uniformly applicable for all freshwater fish species



(Woynarovich *et al.*, 2011.)

(**1**) Fertilized eggs. (**2**) Developing embryos. (**3**) Hatching non-feeding larvae. (**4**) Just-feeding and feeding larvae. (**5**) Advanced fry. (**6**) Fingerling. (**7**) Grown/sexually matured adult fish.

Today, many governments set standards for water quality required for the different types of waters in which fisheries and fish culture take place. Tables A3-1 and A3-2 are presented as guidelines where no such standards have been set by national governments.

TABLE A3-1
Inventory of water parameters required for fisheries and fish culture – Trout species

Quality parameters	Required for growth	Required for survival	Acceptable ranges	Lethal
Temperature (°C)	10-22 10-16 optimum	20-25	5-10 17-20	above 25
pH	7.0-8.0	6.0-7.0 8.0-9.0		
Dissolved oxygen – O_2 (mg/l)	at and above 7	below 7		
Salinity (‰)		0-30		
Calcium hardness (mg/l)	50-300	300-400		
Ammonium ion – NH_4+ (mg/l)				
Free ammonia – NH_3 (mg/l)	below 0.0125	below 1.8		
Nitrite ion (mg/l)	below 0.000012	below 0.23		
Nitrate ion (mg/l)	below 0.025	below 0.25		
Zink (mg/l)	below 3.01		0.1-10	
Aluminium (mg/l)			0-71	
Cadmium (µg/l)			0-5	
Iron (nmol/l)				2 500
Copper (µg/l)			55	

Source: Based on Molony (2001).

TABLE A3-2
Inventory of water parameters required for fisheries and fish culture – Warmwater species

Quality parameters	Minimum	Required range	Maximum	Lethal
pH	6.5	6.5-8.0	8.5	<4.0-4.5 – >10.0-10.5
Dissolved oxygen – O_2 (mg/l)	4*	5-12*		Species dependent
Oxygen saturation (%)	50	above 70*		Species dependent
Conductivity (µS/cm)	250*	800 (1 000-2 700*)	6 000*	Species dependent
Salinity (‰)		0.5–1.5	5.0000	Species dependent
Hardness (ppm)	100	120–180	300	
Ammonium ion – NH_4+ (mg/l)		< 1.0	2.5	pH dependent
Free ammonia – NH_3 (mg/l)			0.0200	pH dependent
Nitrite ion (mg/l)		< 0.1 (0.0*)	0.3 (0.2*)	
Nitrate ion (mg/l)		< 20 (1.0–10.0*)	40 (15*)	
Total nitrogen (mg/l)		2.5–10.0*	15*	
Chemical oxygen demand (mg/l)		8 (18–22*)	12 (30*)	
Orthophosphate ion (mg/l)		0.3 (0.6–1.8*)	2.0	
Hydrogen sulphide – H_2S (mg/l)			0.002	pH dependent
Total iron (mg/l)		0.003	0.005	0.9
Arsenic (mg/l)		0.05	0.1	
Zink (mg/l)		0.2	0.7	1.0
Mercury (mg/l)		0.0005	0.001	
Cadmium (mg/l)		0.003	0.004	0.005
Chlorine (mg/l)		0.01	0.02	0.1
Nickel (mg/l)		0.02	0.1	
Lead (mg/l)		0.01	0.0	0.1
Copper (mg/l)		0.2	0.022	1.0
Cyanide (mg/l)		0.01	0.1	
Total suspended material		1 000	1 500	

* Based on Horvath and Pékh (1984).

Source: Based on Papp and Fűrész (2003).

TABLE A3-3
Optimum temperature ranges of specific life history stages of salmonids and other coldwater species for guideline application

Species	Incubation	Rearing	Spawning
Trout			
Brown trout (*Salmo trutta*)	1.0-10.0	6.0-17.6	7.2-12.8
Cutthroat trout (*Oncorhynchus clarkii*)	9.0-12.0	7.0-16.0	9.0-12.0
Rainbow trout (*Oncorhynchus mykiss*)	10.0-12.0	16.0-18.0	10.0-15.5
Char			
Arctic char (*Salvelinus alpinus alpinus*)	1.5-5.0	5.0-16.0	4.0
Brook trout (*Salvelinus fontinalis*)	1.5-9.0	12.0-18.0	7.1-12.8
Bull trout (*Salvelinus confluentus*)	2.0-6.0	6.0-14.0	5.0-9.0
Dolly Varden (*Salvelinus malma*)	–	8.0-16.0	–
Lake trout (*Salvelinus namaycush*)	5.0	6.0-17.0	10.0
Grayling			
Grayling (*Thymallus thymallus*)			
Arctic grayling (*Thymallus arcticus*)	7.0-11.0	10.0-12.0	4.0-9.0
Whitefish			
Whitefish (*Coregonus lavaretus*)			
Lake whitefish (*Coregonus clupioformis*)	4.0-6.0	12.0-16.0	greater than 8.0
Mountain whitefish (*Prosopium williamsoni*)	less than 6.0	9.0-12.0	less than 6.0
Other species			
Burbot (*Lota lota*)	4.0-7.0	15.6-18.3	0.6-1.7
White sturgeon (*Acipenser transmontanus*)	14.0-17.0	–	14.0

Source: Based on Ministry of British Columbia (2015).

TABLE A3-4
Typical feeding habits and food spectrum of selected commercially important fish species

English name	Scientific name	Typical feeding habit of adults	Typical food spectrum of adults
Coldwater species			
Arctic char	*Salvelinus alpinus*	Predator	Fish, insects
Broun trout	*Salmo trutta*	Predator	Fish, insects
Rainbow trout	*Oncorhynchus mykiss*	Predator	Fish, insects
Sevan trout	*Salmo ischchan*	Predator	Fish, insects
Cisco	*Coregonus sardinella*	Omnivorous	Zooplankton, insects
Peled	*Coregonus peled*	Omnivorous	Zooplankton, insects
Vendace	*Coregonus albula*	Omnivorous	Zooplankton, insects
White fish	*Coregonus lavaretus*	Omnivorous	Zooplankton, insects
Warmwater fish species			
Pike	*Esox lucius*	Predator	Fish
Pikeperch	*Sander lucioperca*	Predator	Fish
Volga pikeperch	*Sander volgense*	Predator	Fish
Bighead carp	*Hypophthalmichthys nobilis*	Zooplankton feeder	Zooplankton
Bream	*Abramis brama*	Omnivorous	Benthos
Common carp	*Cyprinus carpio*	Omnivorous	Benthos
Crucian carp	*Carassius auratus*	Omnivorous	Benthos
Grass carp	*Ctenopharyngodon idella*	Herbivorous	Macrovegetation
Silver carp	*Hypophthalmichthys molitrix*	Phytoplankton feeder	Phytoplankton
Stone moroko	*Pseudorasbora parva*	Omnivorous	Plankton, insects
Tench	*Tinca tinca*	Omnivorous	Benthos
European catfish	*Slurus glanis*	Predator	Fish, insects, birds
Tropical fish species			
Mrigal	*Cirrhinus mrigala*	Omnivorous	Benthos
Rohu	*Labeo rohita*		Biotekton
Catla	*Catla catla*	Zooplankton feeder	
African catfish	*Clarias gariepinus*		Fish, insects
Nile tilapia	*Oreochromis niloticus*	Omnivorous	Zooplankton, insects
Redbreast tilapia	*Tilapia rendalli*	Herbivorous	Water weeds, insects
Tambaqui	*Colossoma macropomum*	Omnivorous	Molluscs, fruits, zooplankton
Pacu	*Colossoma mitrei*	Omnivorous	Zooplankton, insects
Pirapitinga	*Colossoma bidens*	Omnivorous	Fruits, zooplankton
Curimata pacu	*Prochilodus marggravii*	Omnivorous	Benthos

Source: Based on Woynarovich *et al.* (2015).

TABLE A3-5
Favourable spawning environment and water temperature of selected commercially important fish species

English name	Scientific name	Type of water	Water temperature (°C)
Coldwater species			
Arctic char	*Salvelinus alpinus*	Streams and upper sections of rivers	
Broun trout	*Salmo trutta*	Streams and upper sections of rivers	
Rainbow trout	*Oncorhynchus mykiss*	Streams and upper sections of rivers	6–12
Sevan trout	*Salmo ischchan*	Streams and upper sections of rivers	4–10
Peled	*Coregonus peled*	Streams and lakes	0.5–3
Vendace	*Coregonus albula*	Lakes, brackish water	0.5–5
White fish	*Coregonus lavaretus*	Streams, lakes and brackish water	1–5
Warmwater fish species			
Pike	*Esox lucius*	Still waters	6–12
Pikeperch	*Sander lucioperca*	Still waters and slow-flowing sections of rivers	10–12
Volga pikeperch	*Sander volgense*	Still waters and slow-flowing sections of rivers	12–18
Bighead carp	*Hypophthalmichthys nobilis*	Upstream sections of river	22–24
Bream	*Abramis brama*	Still waters	16–20
Common carp	*Cyprinus carpio*	Still waters	18–22
Crucian carp	*Carassius auratus*	Anywhere	18–26
Grass carp	*Ctenopharyngodon idella*	Upstream sections of large rivers	22–24
Silver carp	*Hypophthalmichthys molitrix*	Upstream sections of large rivers	21–24
Stone moroko	*Pseudorasbora parva*	Anywhere	18–26
Tench	*Tinca tinca*	Still waters	20–22
European catfish	*Slurus glanis*	Still waters and slow-flowing sections of rivers	22–24
Tropical fish species			
Mrigal	*Cirrhinus mrigala*	Upstream sections of river	above 22
Rohu	*Labeo rohita*	Upstream sections of river	above 22
Catla	*Catla catla*	Upstream sections of river	above 22
African catfish	*Clarias gariepinus*	Anywhere	above 24
Nile tilapia	*Oreochromis niloticus*	Anywhere	above 24
Redbreast tilapia	*Tilapia rendalli*	Anywhere	above 24
Tambaqui	*Colossoma macropomum*	River	above 24
Pacu	*Colossoma mitrei*	River	above 22
Pirapitinga	*Colossoma bidens*	River	above 24
Curimata pacu	*Prochilodus marggravii*	River	above 22

Source: Based on Woynarovich *et al.* (2015).

TABLE A3-6
Key data of egg incubation of selected commercially important fish species

English name	Scientific name	Type of eggs	Diameter of swollen eggs (mm)	Length of incubation (D°)	Water temp. (°C)
Coldwater species					
Arctic char	*Salvelinus alpinus*	Not sticky			
Broun trout	*Salmo trutta*	Not sticky			
Rainbow trout	*Oncorhynchus mykiss*	Not sticky	4.2–5.8	312–330	6–12
Sevan trout	*Salmo ischchan*	Not sticky	4.3–5.8	340–360	6–8
Cisco	*Coregonus sardinella*	Not sticky	2.3–3.0	100–200	0.2–4
Peled	*Coregonus peled*	Not sticky	1.7–2.2	60–80	0.2–2
Vendace	*Coregonus albula*	Not sticky	1.5–2.0	60–90	0.2–2
White fish	*Coregonus lavaretus*	Not sticky	2.3–3.0	100–200	0.2–4
Warmwater fish species					
Pike	*Esox lucius*	Sticky	2.5–3.0	120–140	6–12
Pikeperch	*Sander lucioperca*	Sticky	1.0–1.5	110–120	10–12
Volga pikeperch	*Sander volgense*	Not sticky			12–18
Bighead carp	*Hypophthalmichthys nobilis*	Not sticky	3.7–5.3	26–32	22–24
Bream	*Abramis brama*	Sticky			16–20
Common carp	*Cyprinus carpio*	Sticky	1.5–2.5	60–70	18–22
Crucian carp	*Carassius auratus*	Sticky			18–26
Grass carp	*Ctenopharyngodon idella*	Not sticky	3.7–5.3	24–30	22–24
Silver carp	*Hypophthalmichthys molitrix*	Not sticky	3.7–5.7	24–30	22–24
Stone moroko	*Pseudorasbora parva*	Sticky			18–26
Tench	*Tinca tinca*	Sticky	0.6–0.7	60–70	20–22
European catfish	*Slurus glanis*	Sticky	3.0–4.0	50–60	22–24
Tropical fish species					
Mrigal	*Cirrhinus mrigala*	Not sticky	4–6	20–22	above 24
Rohu	*Labeo rohita*	Not sticky	4–6	20–22	above 24
Catla	*Catla catla*	Not sticky	4–6	20–22	above 24
African catfish	*Clarias gariepinus*	Sticky			above 24
Nile tilapia	*Oreochromis niloticus*	Not sticky			above 24
Redbreast tilapia	*Tilapia rendalli*	Not sticky			above 24
Tambaqui	*Colossoma macropomum*	Not sticky	4.0–4.3	about 24	above 24
Pacu	*Colossoma mitrei*	Not sticky	2.7–2.9	about 24	above 22
Pirapitinga	*Colossoma bidens*	Not sticky	about 4.0	about 24	above 24
Curimata pacu	*Prochilodus marggravii*	Not sticky	about 3.0	about 24	above 24

Source: Based on Woynarovich *et al.* (2015).

TABLE A3-7
Key data of rearing non-feeding larvae of selected commercially important fish species

English name	Scientific name	Type	Size of non-feeding larvae (mm)	Length of incubation (D°)	Water temp. (°C)
Coldwater species					
Arctic char	*Salvelinus alpinus*				
Broun trout	*Salmo trutta*				
Rainbow trout	*Oncorhynchus mykiss*	Freely lays on the bottom	14.0–14.5	312–330	6–12
Sevan trout	*Salmo ischchan*	Freely lays on the bottom	15–17	370–470	6–8
Cisco	*Coregonus sardinella*	Freely lays on the bottom			
Peled	*Coregonus peled*	Freely lays on the bottom	9.0–10.0	60–80	0.2–2
Vendace	*Coregonus albula*	Freely lays on the bottom	8.0–9.0	60–90	0.2–2
White fish	*Coregonus lavaretus*	Freely lays on the bottom	12.0–14.0	100–200	0.2–4
Warmwater fish species					
Pike	*Esox lucius*	First sticks to the substrate		100–120	8–12
Pikeperch	*Sander lucioperca*	Floats in the water column		100–110	10–12
Volga pikeperch	*Sander volgense*	Floats in the water column			12–18
Bighead carp	*Hypophthalmichthys nobilis*	Floats in the water column		60–70	22–24
Bream	*Abramis brama*	First sticks to the substrate			16–20
Common carp	*Cyprinus carpio*	First sticks to the substrate		60–70	18–22
Crucian carp	*Carassius auratus*	First sticks to the substrate			18–26
Grass carp	*Ctenopharyngodon idella*	Floats in the water column		60–70	22–24
Silver carp	*Hypophthalmichthys molitrix*	Floats in the water column		60–70	22–24
Stone moroko	*Pseudorasbora parva*	First sticks to the substrate			18–26
Tench	*Tinca tinca*	First sticks to the substrate		100–110	20–22
European catfish	*Slurus glanis*	Freely lays on the bottom		70–100	22–24
Tropical fish species					
Mrigal	*Cirrhinus mrigala*	Floats in the water column		60–70	above 24
Rohu	*Labeo rohita*	Floats in the water column		60–70	above 24
Catla	*Catla catla*	Floats in the water column		60–70	above 24
Tambaqui	*Colossoma macropomum*	Floats in the water column		60–70	above 24
Pacu	*Colossoma mitrei*	Floats in the water column		60–70	above 24
Pirapitinga	*Colossoma bidens*	Floats in the water column		60–70	above 24
Curimata pacu	*Prochilodus marggravii*	Floats in the water column		60–70	above 24

Source: Based on Woynarovich *et al.* (2015).

TABLE A3-8
Key data of feeding larvae of selected commercially important fish species

English name	Scientific name	Size of feeding larvae (mm)	Size of first food (µm)	Type of first food
Coldwater species				
Rainbow trout	*Oncorhynchus mykiss*	21–23	250–500	Larger zooplankton
Sevan trout	*Salmo ischchan*	21–24	250–500	Zooplankton, small benthos
Peled	*Coregonus peled*	9–10	50–150	Smaller zooplankton
Vendace	*Coregonus albula*	8–9	50–100	Smaller zooplankton
White fish	*Coregonus lavaretus*	12–14	100–200	Smaller zooplankton
Warmwater fish species				
Pike	*Esox lucius*	11–14	200–500	Larger zooplankton
Pikeperch	*Sander lucioperca*	5–6	50–200	Smaller zooplankton
Bighead carp	*Hypophthalmichthys nobilis*	6.0–6.5	50–250	Smaller zooplankton
Common carp	*Cyprinus carpio*	6–7	100–300	Smaller zooplankton
Grass carp	*Ctenopharyngodon idella*	6–7	50–250	Smaller zooplankton
Silver carp	*Hypophthalmichthys molitrix*	6–7	50–300	Smaller zooplankton
Stone moroko	*Pseudorasbora parva*			Small zooplankton
Tench	*Tinca tinca*	4.5–5.5	50–100	Smaller zooplankton
E. catfish	*Slurus glanis*	8–9	200–500	Larger zooplankton
Tropical fish species				
Mrigal	*Cirrhinus mrigala*		50–250	Smaller zooplankton
Rohu	*Labeo rohita*		50–250	Smaller zooplankton
Catla	*Catla catla*		50–250	Smaller zooplankton
African catfish	*Clarias gariepinus*		50–250	Zooplankton
Tambaqui	*Colossoma macropomum*		50–250	Smaller zooplankton
Pacu	*Colossoma mitrei*		50–250	Smaller zooplankton
Pirapitinga	*Colossoma bidens*		50–250	Smaller zooplankton
Curimata pacu	*Prochilodus marggravii*		50–250	Smaller zooplankton

Source: Based on Woynarovich *et al.* (2015).

ANNEX 4

INVENTORY OF EQUIPMENT, TEST KITS AND INSTRUMENTS USED FOR SAMPLING AND MEASURING THE PROPERTIES OF WATERS IN THE FIELD

Contents

1. Introduction.
2. Water thermometers.
3. Equipment of sampling and observing zooplankton, insects and fish.
   - 3.1. Plankton nets.
   - 3.2. Hand nets.
   - 3.3. Fish traps, nets and balances.
   - 3.4. Magnifiers and microscopes.
4. Test kits and instruments for measuring chemical properties of waters.
5. Conclusions on selection of tools for measuring chemical properties of waters.

FIGURE A4-1
Tools of field survey of water properties

1. Introduction

These days, practically all information about materials, equipment, kits and instruments necessary for sampling and measuring the physical, chemical and biological properties of waters is available on the Internet. Still, such information, often found in massive quantities, should be used with caution as it may be misleading. The information in this annex will help to find all necessary information to do a proper job.

2. Water thermometers

There seems to be an endless range of thermometers used for measuring water temperature. The main groups of water thermometers, presented in Figure A4-2, include:

- Bathroom thermometers are usually cheap, but often unreliable.
- Swimming pool thermometers are considered good and reliable.
- Spirit-filled aquarium thermometers are both good and affordable but should be checked for accuracy.
- Spirit- or mercury-filled laboratory thermometers are very good but not cheap; they are a good investment for those who want accurate readings.
- Digital thermometers can be a good choice, if they are accurate.

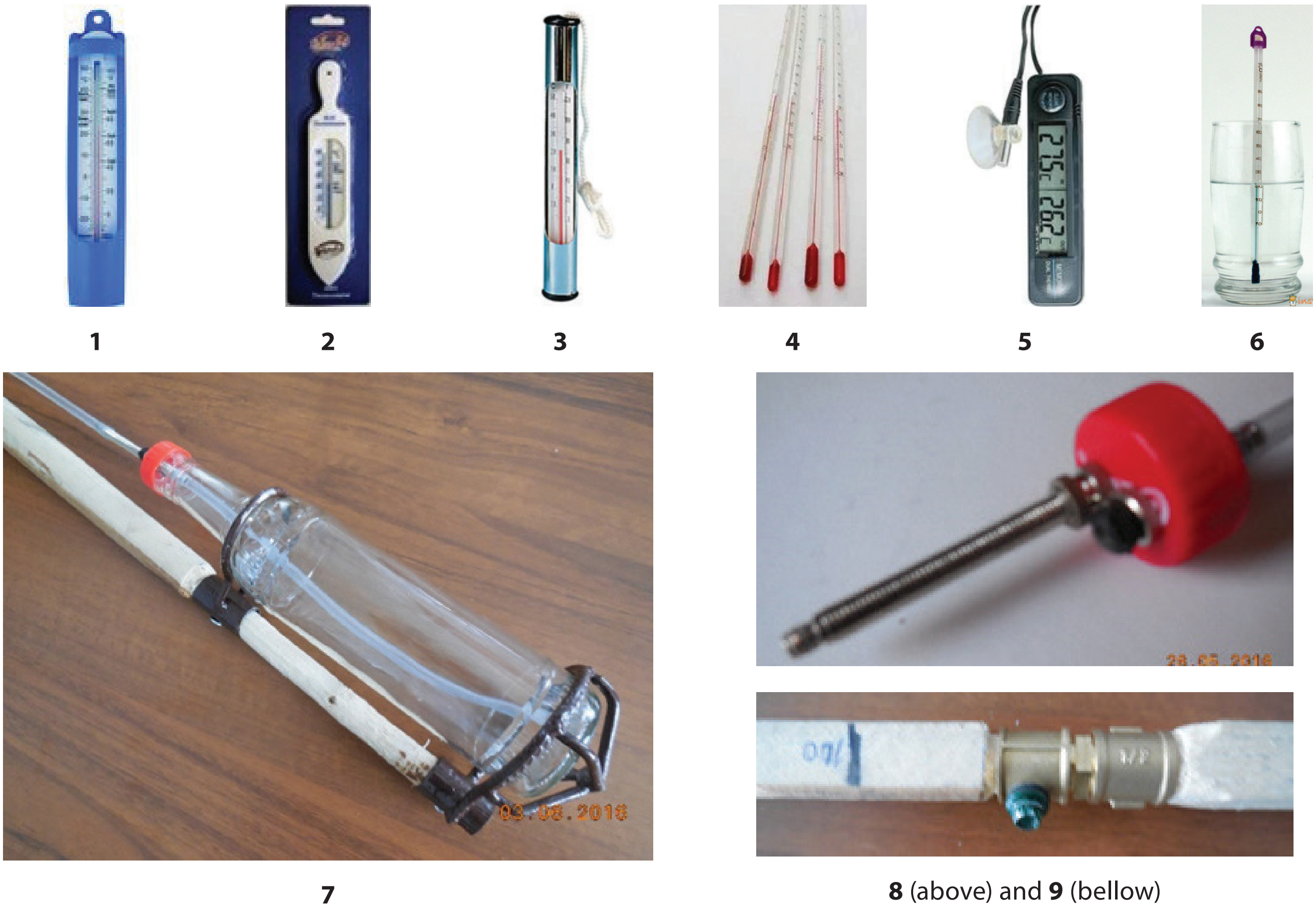
3. Equipment of sampling and observing zooplankton, insects and fish

3.1 Plankton nets

Plankton nets are usually "homemade". As demonstrated in Figure A2-3, the frame can be made from different materials. The sieve itself can be purchased from shops where sieve materials are sold for milling or printing companies.

The accurate way of taking a plankton sample is detailed in Chapter 5.2.2.

FIGURE A4-2
Different types of water thermometers and sampling equipment for deeper water



(1,2) Bathroom thermometers. (**3)** Swimming pool thermometer. (**4)** Spirit aquarium and water thermometers. This glass type thermometer needs a case made from a plastic tube, otherwise it will break. (**5)** Digital thermometer.

(6) For accurate reading, a sample should be taken with a small container/cup in which the thermometer is placed and can be read.

(7) For deep waters, a bottle fixed to a stick and equipped with a fine pipe is used. The bottle should be strong enough to resist water pressure while the sample is taken (Figure 3-6). (**8)** The fine tube is connected to a bicycle valve fixed through the bottlecap. Through this fine tube air is released from the bottle when it is at the required depth. (**9)** To reach depth beyond 2 metres, an additional stick should be bolted to the first one.

3.2 Hand nets

Hand nets (Figure A4-4) are used to check and follow up the population of aquatic organisms illustrated in Figures A2-8, A2-9, A2-10, A2-11, A2-12, A2-13, A2-14, A2-15 and A2-16. These nets, dipped into the shallow waters on the pond side or pulled through the macrovegetation, will help to catch both insects (and their different development stages) and fish larvae and fry.

The small-framed net with a long handle serves to check feed consumption in ponds but can also facilitate the sampling of benthos organisms illustrated in figures A2-16 and A2-17.

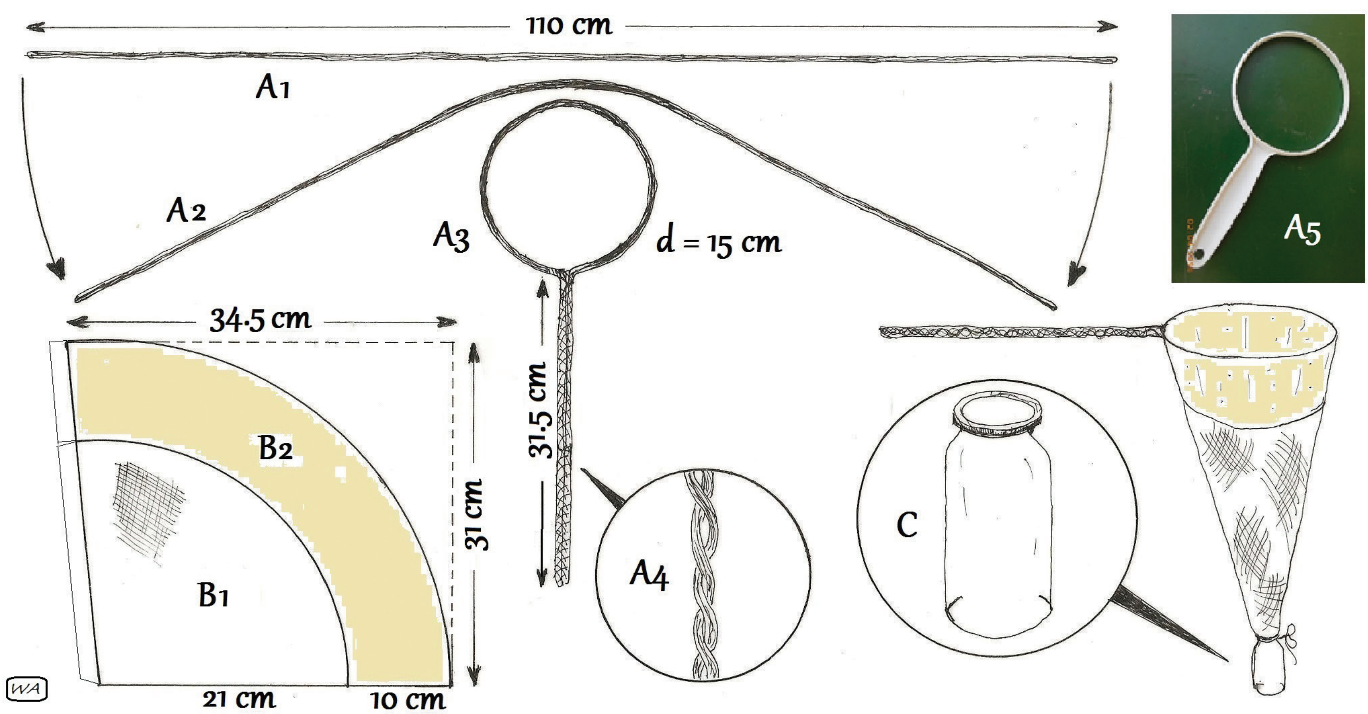
3.3 Fish traps, fishing nets and balances

The range of traps and nets sampling fish is so wide that it would be difficult to present all of them in this annex. Therefore, only three typical ones are shown in Figure A4-5.

At sampling, when fish are caught, they should be separated by species and size (groups of small, medium and large fish). If all the fish are of a similar size, there is no need to separate size groups. This is usually the case with fry and fingerling rearing.

Hand balances used by anglers (sport fishers) and sold everywhere that sells fishing equipment can be used.

FIGURE A4-3
Materials and steps for making a plankton net



A$_{1.}$ Take a stiff copper wire.

A$_{2.}$ Bend the wire around a large iron pipe (~ 15 centimetres in diameter).

A$_{3,}$ **A**$_{4.}$ This will give you a finished frame with a woven wire handle.

A$_{5,}$ **A**$_{6.}$ Alternatively, mount the plankton net on a suitable 15 cm diameter large plastic frame made from a widely available kitchen sieve and the mounted plankton net.

B$_1$/ The sieve (60-micron mesh size).

B$_2$/ A light cotton cloth strong enough to fix the sieve to the frame.

C/ The transparent glass phial (often a used antibiotic container).

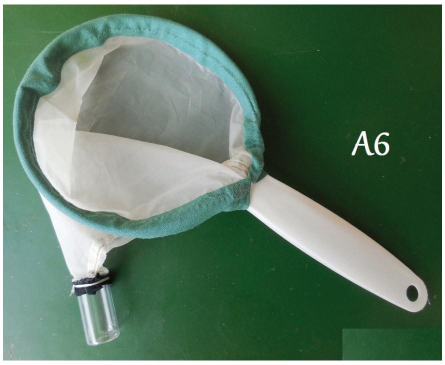
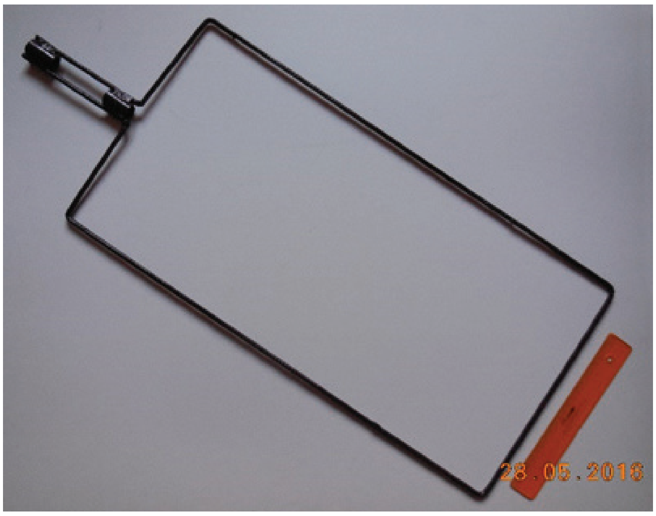


FIGURE A4-4
Hand nets for checking aquatic insects, young fish and benthos



1

2

3

4

(1) Frame (about 60 x 30 cm, max. 6 mm iron bar) of a hand net used to take samples of aquatic insects, insect larvae, fish larvae and fry. (**2)** Frame (about 25 x 25 cm, max. 6 mm iron bar) of a hand net affixed to a handle to take mud samples from the bottom of a pond. The same is used for checking feed consumption in ponds. (**3)** Both frames covered with a strong mosquito net. (**4)** A sample of insects and fish larvae being observed.

FIGURE A4-5
Selected gear for sampling fish

1

2

3

(1) A seine net used for catching fish. (**2)** A simple trap set with long wings to facilitate not only sampling fish, but also obtaining information about their movement. (**3)** A cast net widely used for checking/sampling fish.

3.4 Magnifiers and microscopes

Magnifiers

Hand magnifiers, as presented in Figure A4-6, are used in the field for having a closer look at zooplankton samples when the aim is to see and determine the main groups of organisms, such as rotifers, cladocerans and copepods. These magnifiers will work well, if they really magnify up to the value indicated on them:

- The best is a good quality 10-fold loupe used by jewellers. Such loupes are often in a set of two lenses (a 10-fold lens and a 20-folds lens) (No. 1 in Figure A4-6).
- The lens of magnifiers used by philatelists should be at least 6–8-fold (No 2 in Figure A4-6).
- Textile loupes standing in a thin layer of sample in a Petri dish help observe and estimate the proportion of the different members in the zooplankton. Textile loupes are also good for close observation of sieves, nets and textile used in fisheries and fish culture (No. 3 in Figure A4-6).
- Large standing loupes, like textile loupes, fix the distance of focus from the lens. This helps observations by those not skilled in using magnifiers (No. 4 and No. 5 in Figure A4-6). This type of magnifier is especially good for determining fecundity and observing the actual state of developing eggs.

FIGURE A4-6
Widely available magnifiers and loupes to be used in fisheries and fish culture

(1) Folding magnifier. (**2)** Hand magnifiers. (**3)** Textile loupe, which helps to estimate the size of observed objects and organisms. (**4, 5)** Stand magnifier and focusing stand magnifier.

Microscopes

FIGURE A4-7
Stereo microscope

A microscope does not belong to the set of basic field tools owned by a fishery or aquaculture manager, even though it is rather handy to have for observing fish eggs, and samples of plankton, insects, insect and fish larvae and parasites of fish. Microscopes are especially useful in fish hatcheries or/ and nurseries.

Expensive microscopes used for research are too good for field work. Cheap microscopes made for children/students are usually not good enough. So, when buying a microscope, the recommended type is one that magnifies a maximum of 500-fold and observes objects both in a Petri dish and on a slide (Figure A4-7).

4. Test kits and instruments for measuring the chemical properties of waters

For measuring the different chemical properties of water, both test kits and instruments are used on the field:

- Test kits, also called "quick or visual test kits", are used to check water quality parameters in the field, but there is also a well-established industry which produces test kits for aquarists (Table A4-8). These are equally useable in fisheries and fish culture, provided the test kits are reliable.
- The range of instruments developed for measuring water parameters is wide. Most of them are used for measuring a single parameter while others are suitable for measuring a set of different parameters.

FIGURE A4-8
Test kits developed for aquarists

GENUINE SOURCES OF INFORMATION AVAILABLE ON THE INTERNET

When surfing the Internet to find information about test kits and instruments for water analysis, it is worthwhile clicking on the homepages of recognized companies who produce and sell such tools.

Information on availability and suitability – Reputable companies offer not only the product, but also clear and understandable short explanations about the parameters which the test kit or instrument was developed to measure. This information helps in deciding what to buy.

Information on price – Even though prices from leading companies are often too expensive, this information helps to navigate the different prices offered and to compare them, keeping in mind that usually the cheapest one is the most expensive in the long run.

Conductivity, TDS and hardness

- Portable TDS meters (salinity and conductivity pens) and refractometers.
- Hardness test kits.

Note: Fish farms do not necessarily need such tools.

pH

- pH indicator test strips and pH visual test kits (Figure A4-8 shows options).
- Portable pH meters often built together with digital thermo- and DO meters.

Note: It is enough to have and use either a reliable indicator test strip or a visual test kit.

Alkalinity

- Alkalinity visual test kits and alkalinity meters.

Note: Fish farms do not necessarily need such tools.

DO (dissolved oxygen)

- Visual DO test kits (Figure A4-8 shows options) and portable DO and oxygen saturation meters often built together with digital thermo- and pH meters.

Note: It is usually enough to have and use a reliable visual test kit.

Nitrite and nitrate

- Visual test kits for both nitrite and nitrate (Figure A4-8 shows options).
- Portable nitrate meters.

Note: It is usually enough to have and use a reliable visual test kit in the field.

Phosphate

- Visual phosphate test kits (Figure A4-8 shows options) and portable phosphate meters.

Note: It is enough to have and use a reliable visual test kit.

Ammonium/ammonia

- Visual ammonium/ammonia test kits (Figure A4-8 shows options) and
- Portable ammonium/ammonia meters.

It is enough to have and use a reliable visual test kit.

Hydrogen sulfide

- Visual hydrogen sulfide test kits and portable hydrogen sulfide meters.

Note: Fish farms do not necessarily need such tools.

5. Conclusions on selection of tools for measuring chemical properties of waters

Making decisions about purchasing and using water analytical tools, i.e. whether to use test kits or instruments, is always difficult. But these decisions must be made. To facilitate an easy assessment of all aspects and ensure the best possible results, both in the short and long term, the following summary was compiled.

PROS AND CONS OF SELECTING AND USING TEST KITS OR INSTRUMENTS

Before deciding which type of tools to buy and use, the following aspects should be considered:

- Why these tools are needed and who will use and maintain them?
- Which is more important – accuracy or cost?

Test kits are cheaper, but also less accurate than some measuring instruments developed explicitly for field work. Instruments are very accurate and easy to use but are more expensive and require specialized regular maintenance (Box A4-1).

Consider making a systematic and thorough inventory of key aspects: [1] reasons and objectives, [2] financial and human resources and [3] range, reliability and price of available tools.

A basic set of water analytical tools is needed to check pH and DO, while an advanced set should include tools for checking nitrate, nitrite and phosphate. An advanced set, complemented by a tool for measuring ammonium/ammonia in water where it is likely to develop, will completely equip field staff.

Box A4-1: The predictable fate of many water analytical instruments

Fish farmers who receive support within the framework of a project, are often equipped with high-tech water analytical instruments. But the outcome is often discouraging:

- Neither the field situation nor the farmers' skills and preparedness justify the purchase/supply of such expensive instruments.
- The supplied instruments are very often the only ones in a country where the manufacturer does not have a presence, hence there is no skilled maintenance and service support. Even the supply of fresh calibration solutions become difficult.

As a result, many such instruments can be seen gathering dust in fish farms around the world.

ISBN 978-92-5-132142-3

9 789251 321423

CA7588EN/1/03.20