FRESHWATER ECOSYSTEMS OF EUROPE

An Educational Approach

SUPPORTING MATERIAL FOR TEACHERS' TRAINING SEMINARS
(TEXTBOOK & GUIDELINES)

Education and Culture
Socrates

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COORDINATION

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PREFACE

The way we manage our freshwater resources is becoming more important every year as water is essential for life on earth. This fact was recognized by the United Nations when they designated the year 2003 as the World Year of Fresh Water. The ever increasing human demands for water and the rapid deterioration of water quality in many areas, threaten freshwater ecosystems. Freshwater resources are also closely connected and threatened by climatic changes. For this reason it is essential that people and especially youth, are introduced to these issues, understand the close connection between water quality and human life quality and learn to value freshwater ecosystems.

The 3rd World Water Forum in Kyoto (2003) produced the World Water Development Report, setting out a framework for the sustainable exploitation of fresh water resources. By careful management we can protect freshwater ecosystems while still exploiting them for our human needs. However, to do this successfully, we must understand all the demands and constraints on freshwater ecosystems and manage them to enhance our lives and to protect biodiversity.

"Freshwater Ecosystems of Europe: An Educational Approach" has been produced with the kind support of the European funded project CONFRESH (226682-CP-1-2005-1-GR-COMENIUS-C21). A team of teachers, scientists and other specialists, have worked together to provide up to date knowledge on European freshwater ecosystems to schools of Secondary Education. This pack provides detail chapters on every aspect of freshwater ecosystems in the hope that teachers around Europe will use this resource to promote the understanding and protection of these environments and their sustainable use. Our specific aims are to:

- Provide an integrated teaching material, including a textbook and activities, which present a comprehensive view of European freshwater ecosystems.
- Highlight the peculiarities of freshwaters in different European areas.
- Provide an interdisciplinary teaching material, meeting the needs of European schools' curricula.
- Present case studies outlining human interventions in various freshwater ecosystems.
- Publicize the innovative and effective strategies adopted by European Union under the 60/2000 Water Framework Directive (WFD), for the protection and enhancement of European fresh water ecosystems.
- Give pupils hands-on experience of scientific investigations centered on scientific observation and recording.
- Enable pupils to assess the ecological quality of a freshwater ecosystem in their area based on the outlines of WFD. Through study, pupils will become freshwater advocates and champion's sustainable management and development of this uniquely important resource.

“Freshwater Ecosystems of Europe: An Educational Approach” is available in printed and electronic form and consists of two parts:

Part A. Pupils’ pack that includes:

- Textbook.
- Activities for the classroom.
- Worksheets for the field.
- Identification Cards of Aquatic Invertebrates for use in the field or in the lab.
- CD Rom with a case study.
- Evaluation sheets.

Part B. Teachers’ pack that includes:

- Teachers’ pack.
- Suggestions for the implementation of the pupils’ pack in the school curricula.
- Evaluation sheets.

“Freshwater Ecosystems of Europe: An Educational Approach” is a comprehensive educational material that:

- Provides an overview of European freshwater ecosystems while giving details of particular issued faced in certain regions.
- Offers opportunities and support for specialist and non specialist teachers to introduce their students to freshwater ecosystems in an interdisciplinary approach.
- Includes field and class activities, addressed to and to be carried out by the pupils themselves. This develops team work and cooperation.

Dr. Voreadou Catherina
Coordinator of CONFRESH project

GUIDELINES FOR THE TEACHERS

Pupils' and Teachers' packs consist of a textbook with seven (7) chapters. Chapters one (1) to six (6) give essential scientific information on the freshwater ecosystems. The final chapter introduces a cultural element, connecting art with water and gives ideas for theatrical activities.

Most of the chapters in Pupils' Pack are followed by class activities which are based on the textbook.

Field activities occur in chapters three (3), four (4), five (5) and six (6). In order to gain sufficient results from the field, preliminary work should be carried out in class. Identification Cards of Aquatic Invertebrates are also a necessary tool for the field as well as for the lab activities. They provide pupils with interesting information on the morphology and ecology of aquatic invertebrates.

The case study enables pupils to investigate a real endangered freshwater ecosystem and see how it can be restored and managed in a sustainable way.

Teachers' pack provides detailed support for teachers to initiate the study of freshwater ecosystems in their classroom. The material would also be used in the training seminars that will be hosted by the CONFRESH team (please visit www.nhmc.uoc.gr/confresh for details).

The material has a strong interdisciplinary character. It can easily be implemented across the school curricula and is especially relevant to Biology, Geography, Geology and Environmental Science. Its use can be implemented in several ways and time periods during one or more school years. It can also be useful to actions and projects of School Environmental Education.

Dr. Voreadou Catherina
Coordinator of CONFRESH project
GUIDELINES FOR THE TEACHERS

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WATER

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1. Water - the essential element for life

The most important element for all life is water. Water in the natural environment is defined as water in all its various states - in the atmosphere, on the land and in water bodies. The majority of processes in the nature depend on water or on the aquatic environment. Water creates and maintains life in every ecosystem. As a result, water is of primary importance to all living things.

1.1 Water molecule structure

Water is a tiny V-shaped symmetric molecule with the chemical formula H_2O. It is the simplest compound made up of the two most common elements in the Universe (Fig.1) - two hydrogen (H) atoms attached to a relatively heavy oxygen atom (O).

A covalent chemical bond consists of a pair of electrons shared between two atoms (Fig.1). In the water molecule H_2O, the single electron of each H is shared with one of the six outer-shell electrons of the oxygen, leaving four electrons which are organized into two non-bonding pairs (e.g. Chaplin, 2001; Finney, 2001).

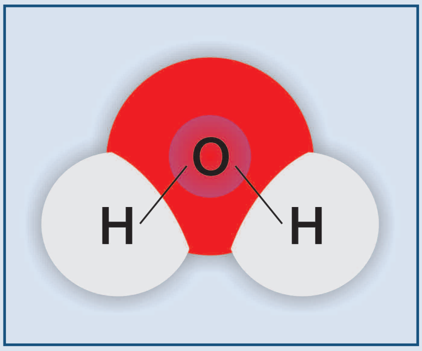


Fig. 1. The molecular structure of water: the approximate shape and electrical charge distribution of water. The larger oxygen atom attach to two smaller hydrogen atoms. Note that the average electron density distribution around the oxygen atom is about 10x higher than around the hydrogen atoms - after Chaplin (2000).

The side with the hydrogen atoms is positively charged, and attracts the oxygen side - of a different water molecule - which is negatively charged. H_2O molecules attract each other through the special type of dipole-dipole interaction known as hydrogen bonding.

The H_2O molecule is electrically neutral, but the positive and negative charges are not distributed uniformly, as seen in Fig.1 (the action in colour from green to purple).

Additionally, the molecular polarization of the H_2O molecule may be electrical (caused by the redistribution of its electrons), geometric (caused by changes in the bond lengths and angles) and/or orientational (caused by the rotation of the whole molecule), as seen in Fig.1. Despite its small size, water molecule is amazingly complex. This molecular structure of water molecule (dipole) influences how many substances dissolve in water. Water is called the "universal solvent" because it dissolves more substances than any other liquid. This means that wherever water goes, either through the ground or through our bodies, it carries along valuable chemicals, minerals, and nutrients. The substances that will mix well and dissolve in water (e.g. salts) are known as "hydrophilic" substances (having a strong affinity for water). It refers to a physical property of a molecule that can transiently bond with water through hydrogen bonding. This is thermodynamically favorable, and makes these molecules soluble not only in water, but also in other polar solvents. The polar substances dissolved in water are referred to as "aqueous". The substances that do not mix well with water (e.g. fats and oils), are known as "hydrophobic" (water-fearing) components. Hydrophobic molecules tend to be non-polar and thus prefer other neutral molecules and nonpolar solvents. Hydrophobic molecules in water often cluster together.

1.2 Water's physical and chemical properties

Water is unique because it is the only natural substance that is found in all three states: liquid, solid (ice), and gas (water vapor, steam) at the temperatures normally found on Earth (Fig.2, Fig. 3).

Water is distinctive among the more than 15 million known chemical substances in that its solid form ice is lighter (less dense) than the liquid. This explains why ice floats on liquid water. The maximum density (weight) of water is reached at 4 degrees Celsius (Fig. 4). It becomes less dense at both higher and lower temperatures. The density of water is approximately 1 gram per cubic centimeter. With a density of approximately 0.917 grams per cubic centimeter ice floats on water.

The plot at Fig. 4 shows how the volume and density of water varies with the temperature - the large increase (about 9%) on freezing shows why ice floats on water and why pipes burst when they freeze. The expansion between -4° and 0° is due to the formation of larger clusters. Above 4°,

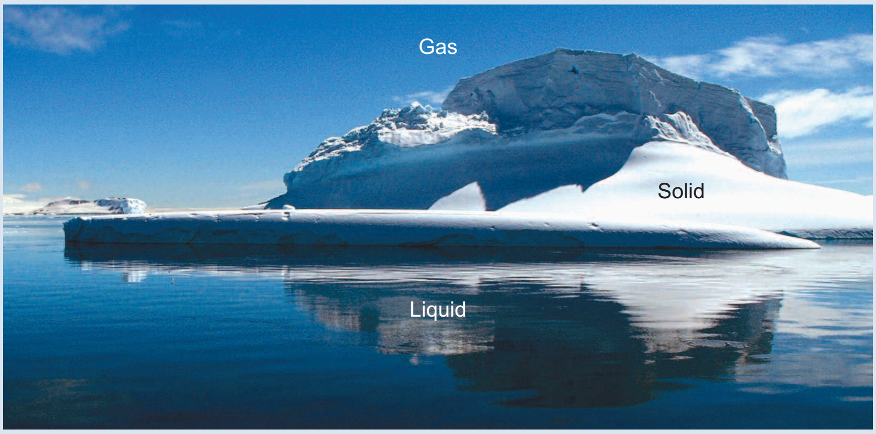


Fig. 2. Water occurring in three states in natural environment. Photo by P. Pinto

thermal expansion sets in as thermal vibrations of the O-H bonds becomes more vigorous, tending to push/shove off the molecules farther apart. Water's freezing point is 0° on the Celsius scale, and 100°C is water's boiling point.

Water has a very high heat of vaporization. The heat is needed to break the hydrogen bonds between water molecules to enable them to vaporize (at 100 degrees Celsius). When water molecules vaporize in this way, they carry with them a parcel of heat.

On a grander scale, when water molecules vaporizes from the ocean surface they carry heat away from the ocean, and this helps to control and regulate the world's climate. As a consequence, most of the water on Earth contained in the oceans and the high heat capacity of this large volume of water (1.35 million cubic kilometers) buffers the Earth surface from large temperature changes. The oceans absorb huge amounts of solar energy and ocean currents transport this heat from the equator toward the Poles.

Water has a very high surface tension. The cohesive forces between molecules drawn into a liquid are shared with all neighboring water atoms but those on the surface have no neighboring atoms above, and exhibit stronger attractive forces upon their nearest neighbors on the surface (see Fig.5 A). This enhancement of the intermolecular attractive forces at the surface is called surface tension. Water surface "film" can be used as a habitat for some aquatic insects, e.g. pond skater, because their weight is not enough to break through the surface (Fig. 6).

Surface tension is also responsible for the shape of liquid droplets (Fig. 7). Although easily deformed, droplets of

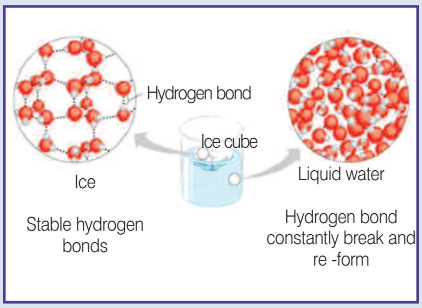


Fig. 3. Differing molecule states of water.

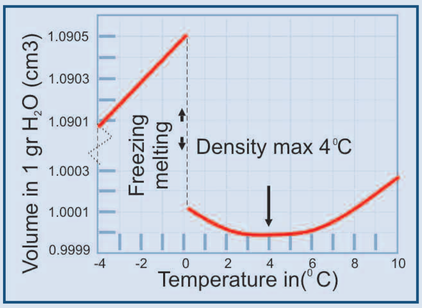


Fig. 4. The plot of relationships between the water density and the temperature.

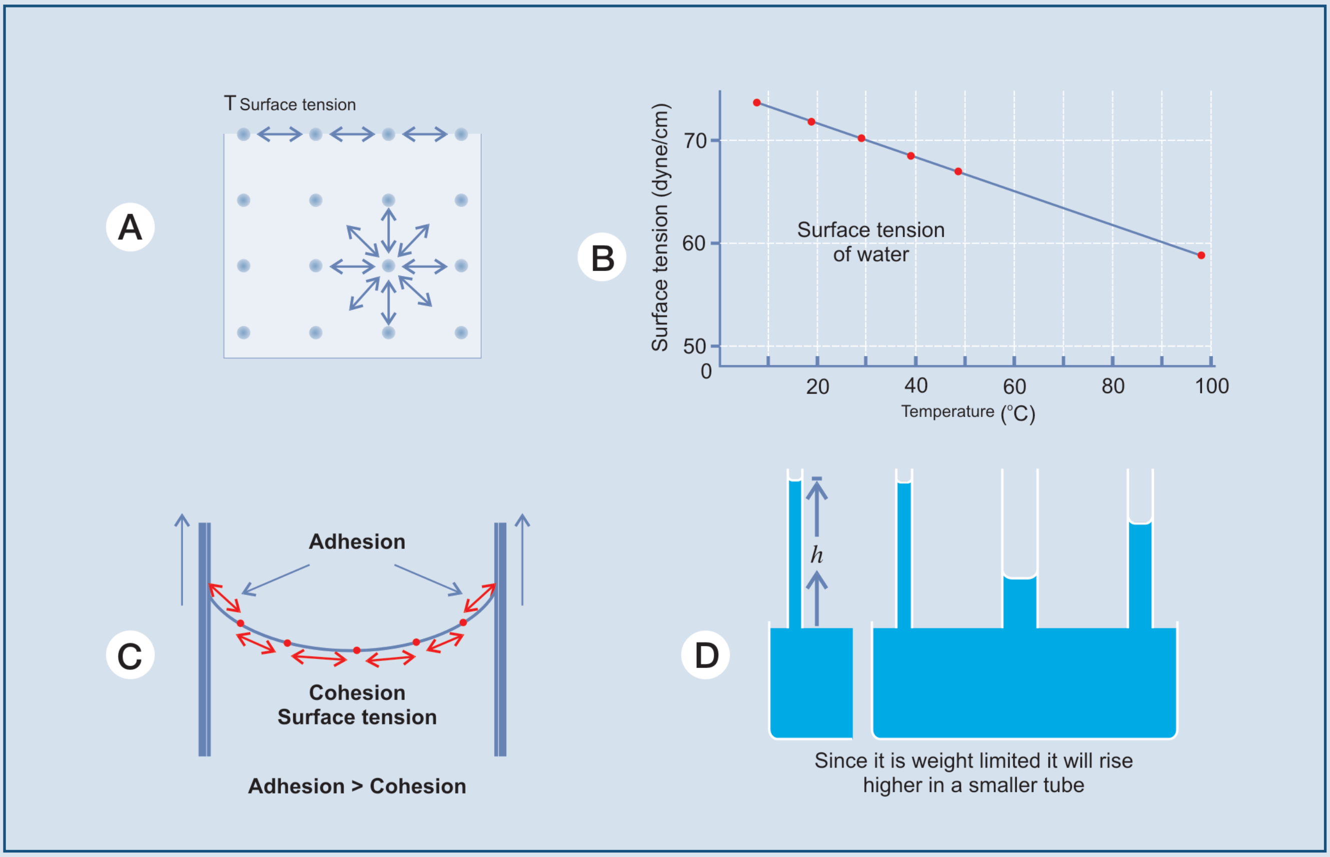


Fig. 5. (A) Illustration of the surface tension forces: the strong cohesive forces between molecules on the water surface (B) The plot of the negative correlation between surface tension and water temperature; (C) The scheme illustrates the forces involved in capillary action. A liquid climbs up a capillary tube without external pressure - capillary action occurs when the adhesion to the walls is stronger than the cohesion forces between the liquid molecules; (D) The height h to which capillary action will lift water depends upon the weight of water which the surface tension will lift.

water tend to be pulled into a spherical shape by the cohesive forces of the surface layer and gravity.

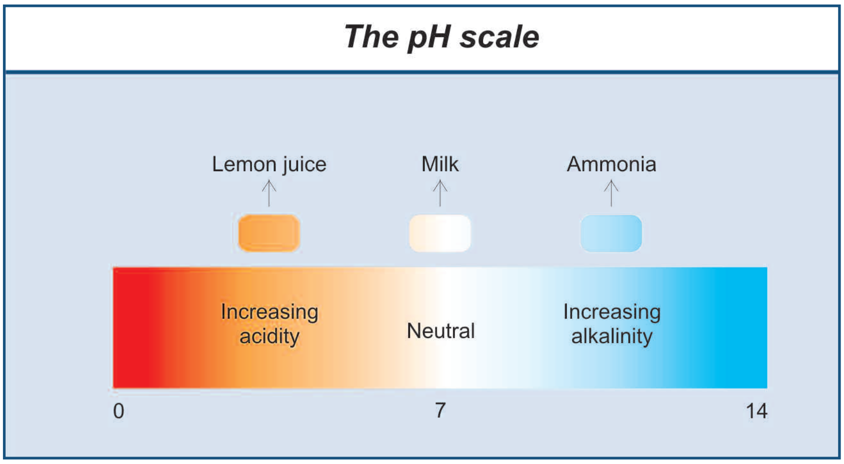
Fig. 6. Water striders (family Gerridae) skate along the surface of ponds. Like snowshoes, their modified leg tips prevent these insects from breaking the water's surface tension. Photo by R. Jaskula

The surface tension of water also decreases significantly as the temperature rises (Fig. 5 B). Consequently, hot water is a better cleaning agent because the lower surface tension makes it a better "wetting agent" to get into pores and fissures.

Surface tension is also responsible for capillary action. Capillary action is the result of adhesion and surface tension. Adhesion of water to the walls of a vessel will cause an upward force on the liquid at the edges and result in a meniscus which turns upward. The surface tension (cohesion forces) acts to hold the surface intact, so instead of just the edges moving upward, the whole liquid surface is dragged upward (Fig. 5 C, D).

BOX I. THE MAIN PHYSICAL AND CHEMICAL CHARACTERISTICS OF WATER

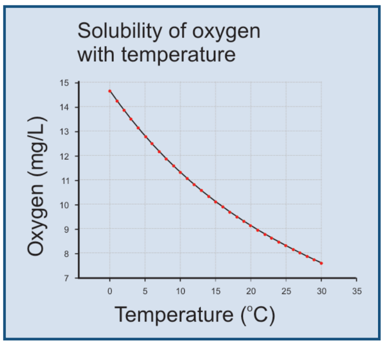
The results of any single measurement of a water's properties should be always considered over time (24 hours, a week, season, etc.) in the temporal scale, and also in the natural hydrochemical background of the water body (e.g. pH of 5.5 is acid but it might be normal, seasonal state for a mountain creek).



pH is a measure of how acidic/alkaline water is. This mean the relative amount of free hydrogen and hydroxyl ions in the water. Pure water has a neutral pH of 7. The range goes from 0 - 14. pHs of less than 7 indicate acidity (water has more free hydrogen ions), whereas a pH of greater than 7 indicates a alkalinity/basicity (water has more free hydroxyl ions). Since pH can be affected by chemicals in the water, pH is an important indicator of water that is changing chemically. Pollution can change water's pH, which in turn can harm animals and plants living in the water. pH can be accessed using litmus paper.

Water temperature - temperature can affect the ability of water to hold oxygen as well as the ability of organisms to resist certain pollutants.

A lot of water is used for cooling purposes in power stations that generate electricity (water has a high specific index - can absorb a lot of heat before begins to get hot). The power stations generally release warmer water back to the environment. The temperature of the released water can affect habitats down stream.



Conductivity is a measure of the ability of water to conduct an electrical current. It is highly dependent on the amount of dissolved solids (such as salt) in the water. Pure water, such as distilled water, will have a very low conductivity, and sea water will have a high conductivity. Rainwater often dissolves airborne gasses and airborne dust while it is in the atmosphere, and thus often has a higher specific conductivity than distilled water. Specific conductivity is an important water-quality measurement because it gives a good idea of the amount of dissolved material in the water.

Turbidity is the amount of particulate matter that is suspended in water. Turbidity measures the scattering effect that suspended solids have on light: the higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid include: clay, silt , fine organic and inorganic matter, soluble organic compounds, plankton, microscopic organisms, and pathogens.

Dissolved oxygen - although water molecules contain an oxygen atom, this oxygen can not be used by aquatic organisms for respiration. A small amount of free oxygen is actually dissolved in water (up to about ten molecules of oxygen per million of water). This dissolved oxygen is needed for respiration by zooplanktonic animals, invertebrates and fishes. Rapidly moving water, such as in a mountain stream or large river, tends to contain a lot of dissolved oxygen, while stagnant water contains lower concentrations. Bacteria in water can consume oxygen as organic matter decays. The pollution in our lakes and rivers can cause a reduction in the level of oxygen.

Photo by G. Kosmala

1.3 Water for human health

Liquid water is essential for life. It is the most important element throughout the living world. In particular, we cannot live without water for more than about 100 hours, whereas other nutrients may be neglected for weeks or months. Until recently, water has been taken for many different, unlimited human applications and treatments, and no other element is more essential or needed in a great quantity.

Water balance			
Water input, ml day^{-1}		Water output, ml day^{-1}	
Drinks	1500	Urine, faeces	1600
Food	700	From skin, sweat	500
Metabolic water	300	Respiration	400

Table 1. Water input and output values for an adult in a temperate climate (after Stirling & Parsons, 2000).

BOX II. WATER FOR OUR HEALTH

Without water, your body also would stop working properly. Your body is about two thirds water, and a person can't survive for more than a few days without it. Why? Your body has lots of important jobs and it needs water to do many of them. For instance, your blood, which contains a lot of water, carries oxygen to all the cells of your body. Without oxygen, those tiny cells would die and your body would stop working. Water is also in lymph, a fluid that is part of your immune system, which helps you fight off infection. You need water to digest your food and get rid of waste, too. Water is needed for digestive juices, urine (pee), and poo. And you can bet that water is the main ingredient in perspiration sweat. In addition to being an important part of the fluids in your body, each cell depends on water to function normally. However, your body doesn't get water only from drinking water or milk. Lots of foods contain water, such as fruits and vegetables. When your body doesn't have enough water, you became dehydrated. Each day humans must replace 2.4 liters of water, some through drinking and the rest taken by the body from the foods eaten.

The water content of our bodies varies and is variable between individuals - from above about 60% as a child, 50-59% as an adult (body water is distributed between the cells and the extracellular fluid). The role of water is crucial both for body's metabolism and its ability to transport all the components. The carbohydrates and proteins that our bodies use as food are incorporated in metabolic processes and transported by water in the bloodstream. No less important is the ability of water to transport waste material out of our bodies. Water balance in humans has been studied and modeled (Stirling & Parsons, 2000). Electrolyte intake and output (total ionic solutions of acids, bases or salts) are closely linked, both to each other and the hydration status. All values will vary with diet, activity and climate. Typical values for an adult in a temperate climate are given at Table 1.

1.4 Water as an environment for life

Water is of major importance to all living things. Water possesses particular properties that sustain life, therefore no other liquid can replace water in or outside an organisms body.

These properties are connected with the physical and chemical structure of the water molecule and are brought about by the hydrogen-bonded environment particularly evident in liquid water, as freshwater ecosystems.

Generally, the coexistence of the solid, liquid, and gaseous phases of water on Earth is vital to existence of life on Earth. If the Earth's location in the solar system were even marginally closer to or further from the Sun (a million miles or so), the conditions which allow the three forms to be present simultaneously would be far less likely to exist. Additionally, Earth's mass allows gravity to hold an atmosphere. Water vapour and carbon dioxide in the atmosphere provide a greenhouse effect which helps maintain a relatively steady surface temperature, and climate. Water is also an invaluable resource to human societies - for cleaning and waste removal, for energy generation, for food production, for cooling and heating, for transportation, and for recreation.

Rational water use, with a view to the long-term needs of other consumers, both human and otherwise, should be sustainable. Therefore, we have to study the role of water in our lives and learn more about the functioning of our freshwater ecosystems. Only with better knowledge and understanding we can undertake ecologically-sound tasks for water protection, and sustainable management.

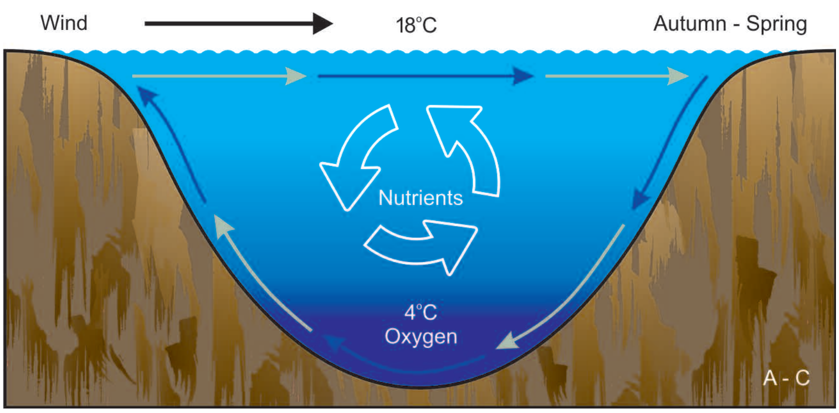
BOX III. HOW WATER BEHAVES AT DIFFERENT TEMPERATURES IN LAKES?

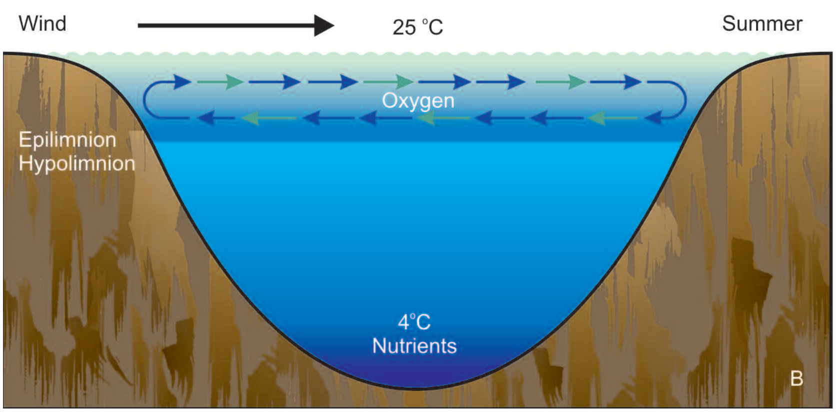
For the most part, as water increases in temperature it becomes less dense. Conversely, water becomes denser as it decreases in temperature. The exception to this rule is that water reaches its maximum density at approximately 4˚ Celsius.
Below 4˚C, as water cools, the number of water molecules joined together by hydrogen bonds increases to form loose clusters of ice. The molecules in ice form a very structured, open framework, so ice itself is less dense than water and, consequently float on it. With this concept in mind we can consider seasonal or thermal stratification within lakes.

During the spring (A) - after the ice melts on a lake, the lake water is generally the same temperature from the surface to the bottom. Wind blowing across the surface encourages the water to circulate and mixing. Surface water is pushed to the lake bottom and bottom water rises to the surface. This circulation allows relatively large amounts of oxygen to reach the bottom of the lake. The mixing of lake water at this time of year is called the spring overturn.

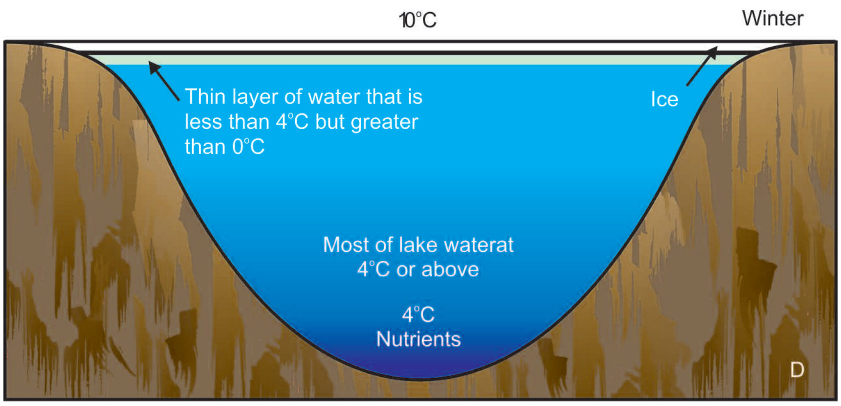
During the summer (B) - the surface water layer of the lake absorbs heat, and forms a heated layer called the epilimnion. This layer floats above the colder, deeper and denser water called the hypolimnion. In the summer, these layers remain distinct: only the water in the upper layer (epilimnion) benefits from wind driven circulation, leaving the lower layer (hypolimnion) almost stagnant. Without mixing to provide dissolved oxygen, the lake bottom, lacking enough light for photosynthesis to occur, tends to have a very limited supply of oxygen during the summer. Respiration by animals and bacteria can deplete the dissolved oxygen at the bottom of the lake even further. A stratified lake of this nature is said to be in the summer stagnation.

The lake water in the autumn (C) has generally uniform temperatures (about 4˚C), and wind can thoroughly mix the water. Surface water, which is in direct contact with the cold air, gets cooled faster than the water below. This cold, dense water sinks and further helps to mix the lake. Once more oxygen and nutrients are replenished throughout the water column. This process is called the autumn overturn.





During the winter (D) - the surface water is eventually cooled below 4˚C. At this point, the water no longer sinks. The water molecules begin to align themselves (form more hydrogen bonds) to solidify. As water temperatures at the surface reach 0˚C, ice begins to cover the surface of the lake. Ice cover prevents mixing. However, stratification can occur. A layer of low density water colder than 4˚C, but warmer than 0˚C forms just under the ice. Below this water, the remainder of the lake water is usually near 4˚C. At this point, a lake is said to be in the winter stagnation.



2. Earth's hydrosphere

Fig. 7. As seen from space, one of the most unique features of our home planet is the water, in both liquid and frozen forms, that covers approximately 71% of the Earth's surface.

2.1 Unique features of Earth

The hydrosphere includes all water on Earth. The abundance of water on Earth is a unique feature that clearly distinguishes our "Blue Planet" from others in the solar system (71% of the earth is covered by water, Fig. 7). Not a drop of liquid water has yet been found anywhere else in the solar system. It is because the Earth has just the right mass, the right chemical composition, the right atmosphere, and is the right distance from the Sun (the "Goldilocks" principle) that allows water to exist mainly as a liquid. However, the molecular structure of water and the range of surface temperatures and pressures of our planet enable water to exist in all three states.

2.2 Earth systems

The hydrosphere interacts with, and is influenced by, all the other earth systems, the lithosphere and atmosphere. The water of the hydrosphere is distributed among several different stores found in the other spheres (Fig. 8). The living world, or biosphere, links all the other spheres enabling water to move between the hydrosphere, lithosphere and atmosphere mainly by transpiration, the movement of water though plants from root to leaves.

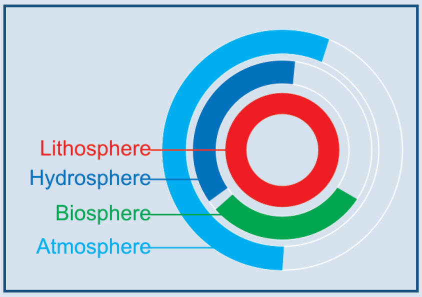


Fig. 8. Earth Spheres/Systems.

2.3 Global water distribution

About 97% of all water is in oceans (Fig. 9). As a result, freshwaters are a very precious resource, and there are many beneficial reasons to save the water.

Fig.10. shows the distribution of the three percent of freshwaters: (1) the majority - about 69 percent, is locked up in glaciers and icecaps, mainly in Greenland and Antarctica; (2) the remaining freshwater is ground water and only about 0.3 percent is contained in rivers and lakes.

As a consequence, rivers and lakes provide most of the water we use for our everyday lives.

In recent years, as our community's demand on our water supply has increased, the availability of this valuable natural resource has decreased, making us more aware than ever before of the importance of employing water conservation measures in our day-to-day lives.

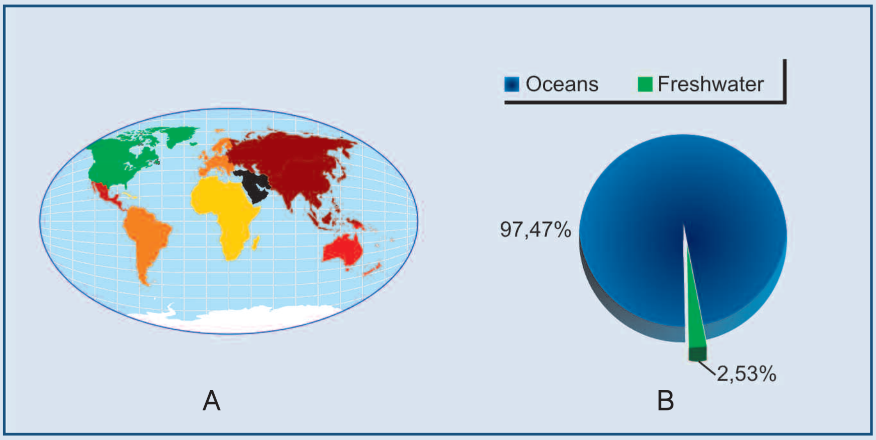


Fig. 9. Oceans (Pacific, Atlantic, Indian, Arctic) and continents (Europe, America, Africa, Asia, Australia, Antarctica). B. Distribution of Earth's water.

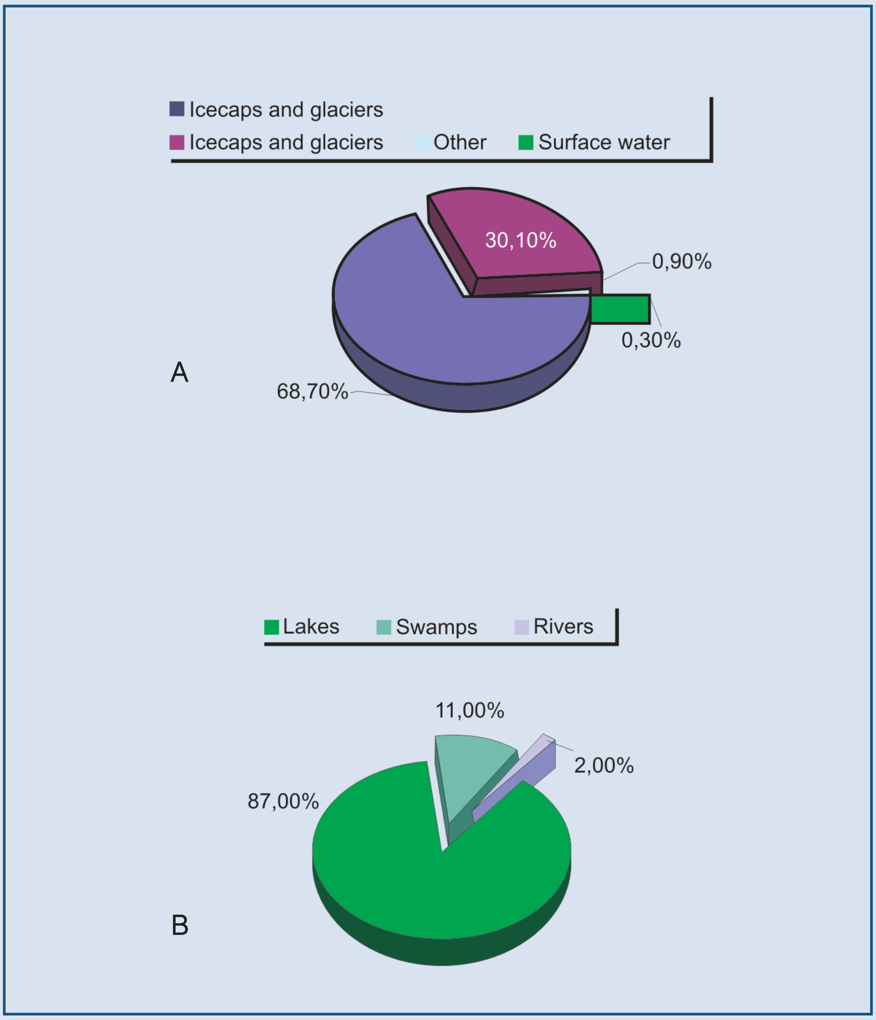


Fig. 10. Global water distribution; A. Available fresh waters; B. Surface freshwater sharing.

3. The global water cycle

The water cycle describes the existence and movement of water on, in, and above the Earth. Earth's water is always in movement and is changing states, from liquid to vapor to ice and back again (Fig.11).

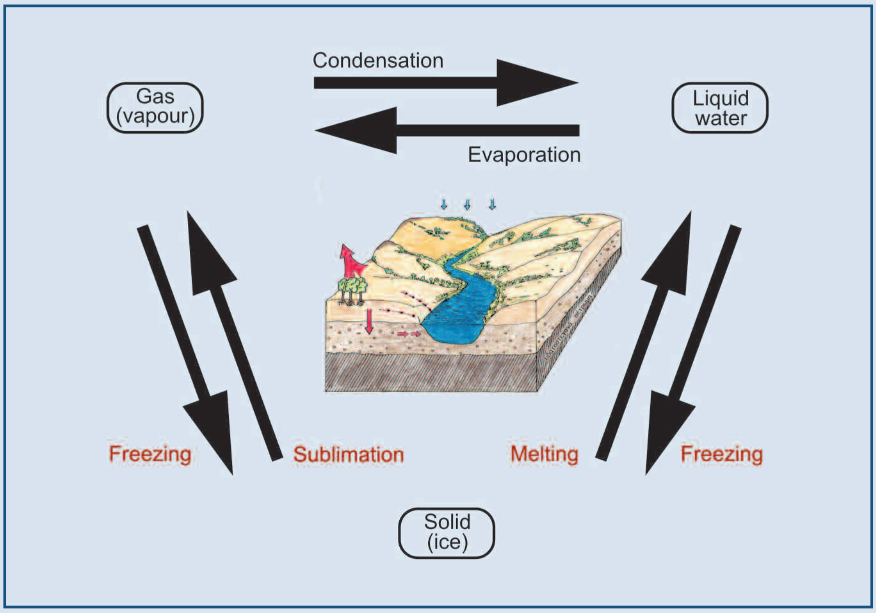


Fig. 11. The schematic outline of water cycle with including the main physical processes, contributed in the three water states forming.

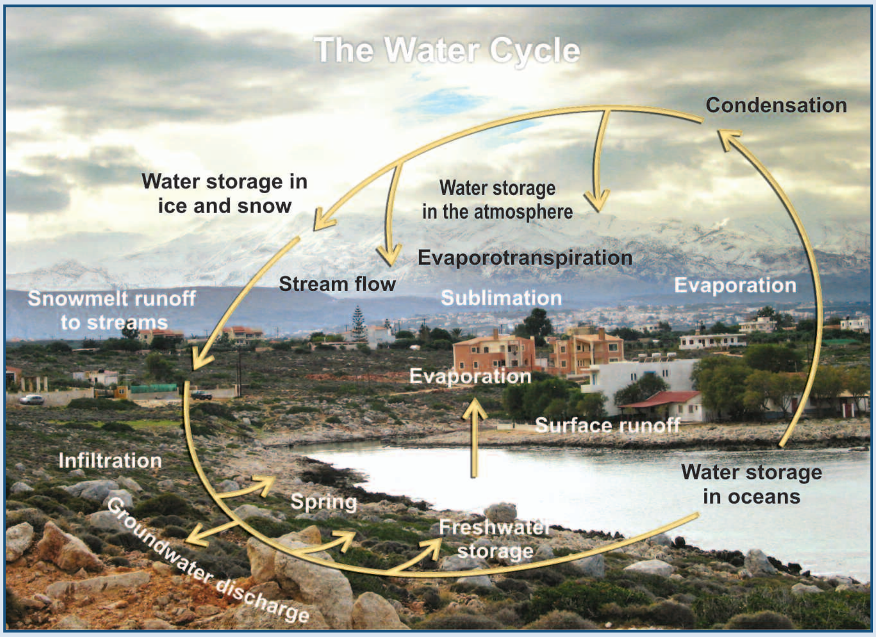


Fig. 12. The hydrologic cycle - showing the movement of water in the major water cycle processes. Photo by A. Trikali

Water, in its various forms plays a dominant role in nearly all aspects of the Earth's climate system (e.g. 86% of the global evaporation occurs from the oceans, reducing their temperature by evaporative cooling - without the cooling effect of evaporation the greenhouse effect would lead to a much higher surface temperature of 67 °C, and a warmer planet. This does not happen because water evaporates from the surface, mostly from tropical seas, cooling the surface (Fig.12).

Understanding the full cycle of evaporation, cloud formation, and precipitation is the highest priority for predicting climate change. Nations are working together, and sharing technological advances to try to prevent a global temperature rise of more 3hose 2 degrees by 2050.

The water cycle - as a continuous circulation of water within the Earth's hydrosphere is driven by solar radiation. As water moves through the cycle, it changes state between liquid, solid, and gas phases. Water begins the cycle in the oceans. The energy from the sun evaporates some of this water. Evaporation removes water molecules only, leaving the salts in the oceans. As the water vapor rises into the atmosphere it cools and condenses into clouds. The clouds are then pushed by the wind, and under the right conditions they will produce precipitation (rain, snow, sleet). This collects to form rivers and lakes, and eventually infiltrates into the ground to become groundwater. However, the cycle can be completed in different ways, for example, before reaching the ocean, water may have evaporated, condensed, precipitated, and become runoff multiple times (Fig. 11, Fig. 12, Tab. 2).

The water cycle consists of the key groups of physical processes:

(1) precipitation -is water in any of its forms that falls to earth (rain, mist, snow);
(2) infiltration and surface runoff - the process in which water is absorbed into the soil - it may also flow off the surface called surface runoff),
(3) evaporation, transpiration or evapo-transpiration - is either when water is heated and turns into water vapour or when plants use the water and give it off as water vapour;
(4) condensation - is when the water vapour cools and forms clouds.

Components of the water cycle	Definition
Water storage in oceans	Saline water existing in oceans and inland seas (96,5% of the Earth's water).
Evaporation	The process by which water is changed from a liquid to a gas or vapor.
Sublimation	The conversion between the solid and the gaseous phases of matter, with no intermediate liquid stage. Sublimation is most often used to describe the process of snow and ice changing into water vapor in the air without first melting into water.
Evapo-transpiration	The process by which water is discharged to the atmosphere as a result of evaporation from the soil and transpiration by plants (the sum of evaporation and transpiration).
Water in the atmosphere	Water stored in the atmosphere as vapor, such as clouds and humidity. Evaporation and transpiration change liquid water into vapor, which ascends into the atmosphere due to rising air currents.
Condensation	The process by which water is changed from vapor to liquid. Condensation is responsible for the formation of clouds, which may produce precipitation - the primary route for water to return to the Earth's surface. Condensation is the opposite of evaporation.
Precipitation	The discharge of water, in liquid or solid state, out of the atmosphere, generally upon a land or water surface - in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth. Most precipitation falls as rain.
Water storage in ice and snow	Freshwater stored in frozen form, generally in glaciers, icefields, and snowfields.
Snow melt run off to streams	Movement of water as surface run off from snow and ice to surface water.
Surface run off	Precipitation run off which travels over the soil surface to the nearest stream channel.

Stream flow	Movement of water in a natural channel, such as a river.
Freshwater storage	Freshwater existing on the Earth's surface. Surface freshwater includes the streams (of all sizes, from large rivers to small creeks), ponds, lakes, reservoirs and canals (man-made lakes and streams), and freshwater wetlands. The definition of freshwater is water containing less than 1,000 milligrams per liter of dissolved solids, most often salt.
Infiltration	The downward movement of water from the land surface into soil or porous rock.
Ground-water storage	Water existing for an extended period below the Earth's land surface. Most of the water in the ground comes from precipitation that infiltrates downward from the land surface.
Ground-water discharge	Movement of water out of the ground. Ground water is a major contributor to flow in many streams and rivers and has a strong influence on river and wetland habitats for plants and animals.
Springs	Place where a concentrated discharge of ground water flows ate the ground surface.

Table 2. The water cycle - the key groups of physical processes

4. Intensification of water cycle and climate changes

The Earth's climate has changed over the hundred years. Due to global warming over the past century - the water cycle has become more intense, with the rates of evaporation and precipitation is both increasing. There is new and stronger evidence that most of the warming observed in the last 50 years is attributable to human activities. Evolving computer models are predicting that, because of greenhouse gas emissions, temperatures should continue to rise over the 21st century, impacting nature and mankind both positively and negatively (Fig.13).

Glacial retreat is another example of a changing water cycle, where the supply of water to glaciers from precipitation cannot keep up with the loss of water from melting and sublimation.

Human activities that alter the water cycle include:

- agriculture
- alteration of the chemical composi tion of the atmosphere
- construction of dams
- deforestation
- removal of groundwater from wells
- water abstraction from rivers
- urbanization

The impacts should vary among regions, but they can not yet be predicted accurately, especially for small-scale areas. Therefore, although an acceptable level for greenhouse gases has not yet been determined, reducing emissions should reduce the risk of adverse effects. Many options for emission reductions are available - their costs need to be balanced with the risks left for future generations.

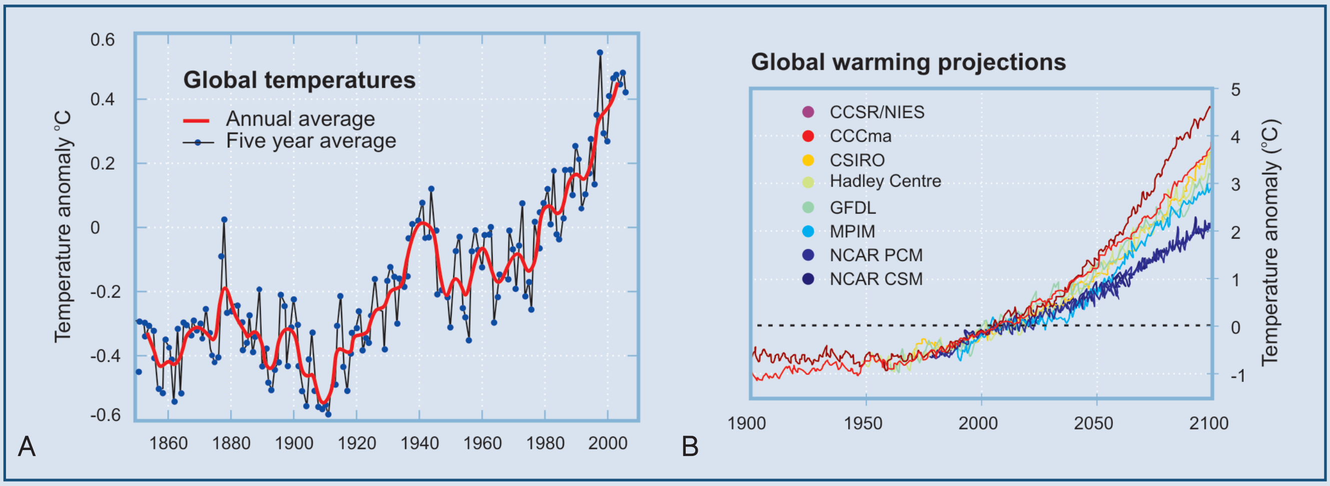


Fig. 13. A. Comparison of the average global temperature trends; B. Predictions of global warming from 8 different climate models.

4.1 Climatic and weather conditions

Climate describes the total of all weather occurring over a period of years in a given place. This includes average weather conditions, regular weather sequences (like winter, spring, summer, and autumn), and special weather events (like floods).

Weather describes whatever is happening outdoors in a given place at a given time with regards to temperature, air pressure, humidity, wind, cloudiness and precipitation (Fig. 14). The study of weather and its forecasting is called meteorology or climatology.

As a result, meteorological phenomena are observable weather events which are bound by the variables that exist in Earth's atmosphere. They are temperature, pressure, water vapor, and the gradients and interactions of each variable, and how they change in time.

A weather station is a facility with instruments and equipment to make weather observations by monitoring atmospheric conditions. Typical weather stations (Fig. 15) have the following instruments:

- Thermometer: an instrument used to measure temperature;

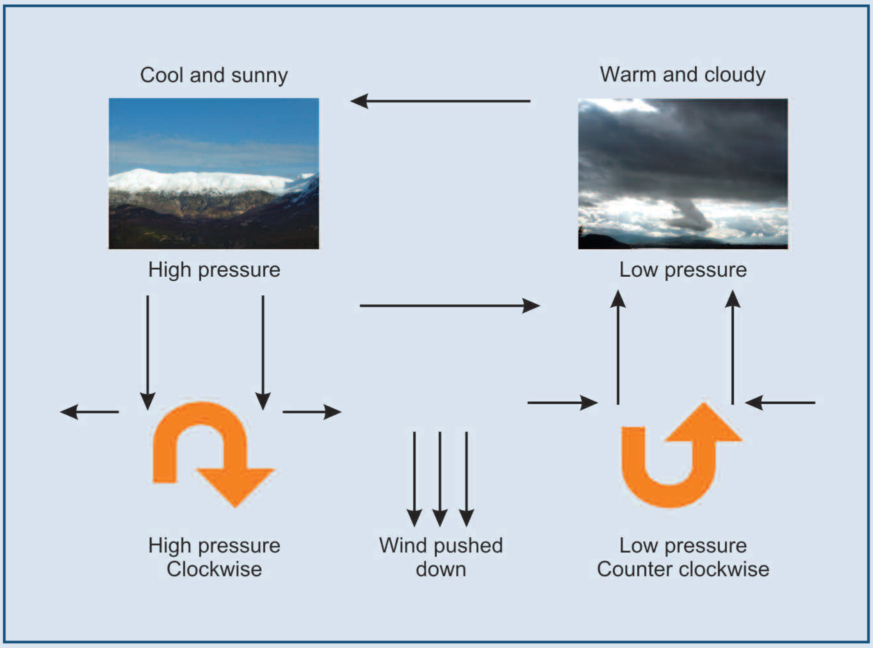


Fig. 14. The scheme to show general weather conditions: (1) high air pressure means that air is being pushed down; air travels in a high pressure system clockwise; (2) low air pressure means that air is being pushed up. The air that rises is warmer because hot air rises; air travels in a low pressure system - counter-clockwise.

- Anemometer: an instrument used to measure the strength and direction of wind, a wind gauge (Beaufort scale: Admiral F.Beaufort wrote the Beaufort scale to measure the speed of wind. His scale became the official method of ranking wind speed);
- Barometer: an instrument used to measure the weight or pressure of the

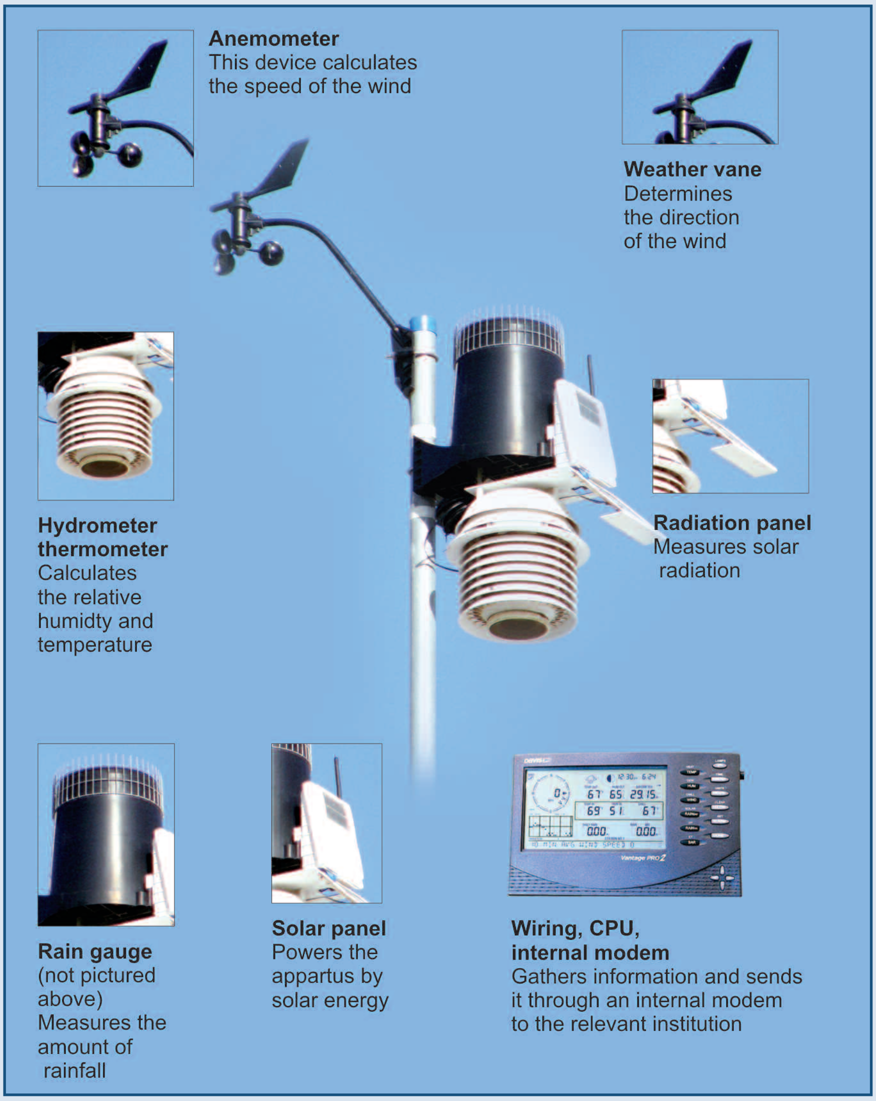


Fig. 15. Meteorological standard equipment in the weather station.
Photo by M. Dretakis

atmosphere, indicate weather change. Barometric pressure is a measurement of how air pushes down. Cool air is heavier than warm air and pushes down with more pressure: high pressure. Warm air is lighter and is related to low pressure. As air moves faster, its pressure also drops;

- Hygrometer for measuring humidity;
- Rain Gauge: An instrument used to measure a storm's precipitation.

Except for those instruments requiring direct exposure to the elements (anemometer, rain gauge), the instruments should be sheltered in a vented box (usually a Stevenson screen) to keep direct sunlight off the thermometer and wind off the hygrometer. The instrumentation (Fig. 15) may be specialized to allow for periodic recording otherwise significant manual labor is required for record keeping. Automatic transmission of data is also desirable as many weather stations' data is required for weather forecasting.

In conclusion water's unique properties make it the most biologically important substance on the planet. No other substance shares similar properties to water and in the way that one single molecule can possess such varied and essential characteristics.

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Supporting references

Other thematic pieces of literature are available at following web sources:

Water

- Water - Learning and Living - teaching and learning resources about integrated water protection: water, catchments, biodiversity and human impact: http://www.watercare.net/wll/wc-watercycle.html
- Water Words Dictionary - a compilation of technical water, water quality, environmental, and water-related terms: http://water.nv.gov/Water%20planning/dict-1/ww-index.htm
- Water Science for Schools - http://ga.water.usgs.gov/edu/index.html
- H2O - The Mystery, Art & Science of Water - webside focused on the nature, properties, place, significance, importance, and role of water in Earth's life and culture; http://witcombe.sbc.edu/water/
- The Global Water Cycle - the webside page with the most important links related to GWC: http://www.usgcrp.gov/usgcrp/links/waterlinks.htm
- Water Resources of the U.S.A. - http://water.usgs.gov/
- Water resources in Europe - http://maps.grida.no/go/graphic/world_s_water_cycle_schematic_and_residence_time
- Chemistry of Water - http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html
- UNESCO Water Portal: http://www.unesco.org/water/
- UNESCO-IHE Institute for Water Education: http://www.unesco-ihe.org/education/intro.htm
- UN Water: http://www.unwater.org/flashindex.html
- Schools resource on water rights: http://www.worldaware.org.uk/education/projects/water.html
- United Nations GEMS/Water Programme: http://www.gemswater.org/

Hydrospere and Global Water Cycle

- Hydrosphere: http://earth.rice.edu/MTPE/hydro/hydrosphere/hydrosphere_what.html
- Global Hydrology and Climate Center: http://www.ghcc.msfc.nasa.gov/ghcc_home.html
- Visible Earth: http://visibleearth.nasa.gov/view_set.php?categoryID=629
- Oceans and Water Issues WebPages: http://www.publicforuminstitute.org/issues/oceans/index.asp
- World Water Forum: http://www.worldwaterforum.org/home/home.asp
- Water in School/educational page: http://www.epa.gov/highschool/water.htm

WATER ENVIRONMENTS

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1. Europe

1.1 Location and boundaries

Europe is a continent geographically located between the 36° and the 71° of latitude. This position gives Europe great advantages as most of the region is in the temperate zone, with mild, wet climate.

Europe's boundaries are: the Arctic Ocean to the north, the Mediterranean Sea to the south, the Atlantic Ocean to the west and the crest of the Ural Mountains, together with the Ural River, to the north-eastern making its boundary with Asia. The Caspian Sea, Azerbaijan, Armenia, the Black sea, the Bosporus, the Sea of Marmara and the Dardanelles, complete the Asian boundary to the southeast.

Together with Asia, Europe forms a larger landmass, a supercontinent, known as Eurasia. Europe is close to Africa with only the Mediterranean Sea separating them. Europe, together with Africa and Asia are often referred to as "The Old World".

Europe is the third largest populated area after Asia and Africa. Its population in 2005 was estimated to be 728 million according to U.N. This is slightly more than one ninth of the world's population.

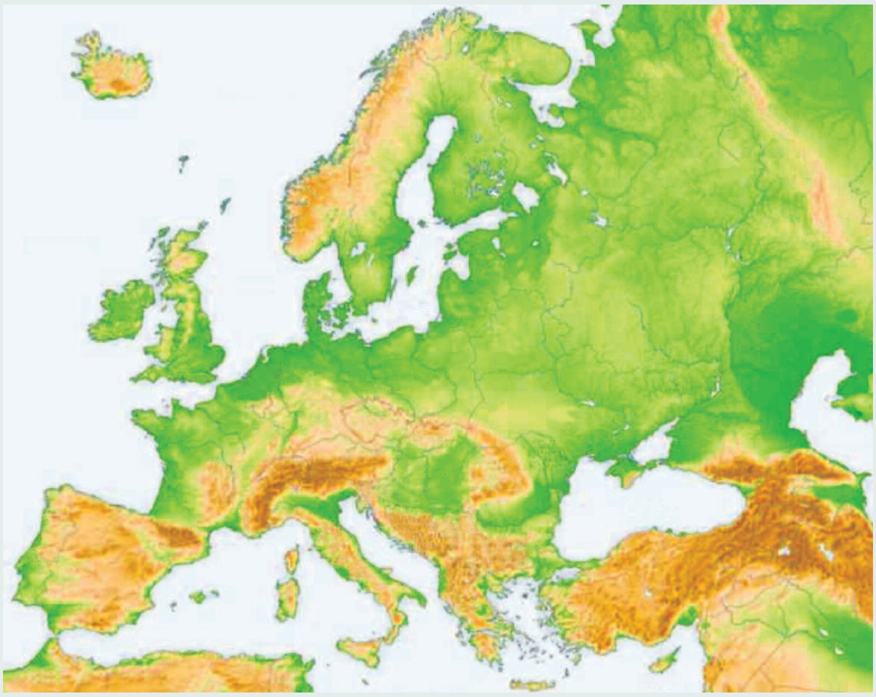

Fig. 1. Relief map of Europe.

1. 2 European countries

Europe is made up of the following countries:

Eastern Europe: Belarus, Bulgaria, Czech Republic, Hungary, Moldova, Poland, Romania, Russian Federation, Slovakia, Ukraine.

Northern Europe: Denmark, Estonia, Faroe Islands (Denmark), Finland, Greenland (Denmark), Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom, (made up of England, Northern Ireland, Scotland and Wales).

Southern Europe: Albania, Andorra, Bosnia and Herzegovina, Croatia (Hrvatska), Cyprus, Gibraltar (UK), Greece, Holy See (Vatican City State), Italy, Fyrom, Malta, Montenegro, Portugal, San Marino, Serbia, Slovenia, Spain, Turkey.

Western Europe: Austria, Belgium, France, Germany, Liechtenstein, Luxembourg, Monaco, Netherlands, Switzerland .

1. 3 Landscape

In terms of shape, Europe is a group of connected peninsulas. The two largest of these are "mainland" Europe and Scandinavia to the north, divided from each other by the Baltic Sea. Three smaller peninsulas-Iberian, Italien and the Balkans-emerge from the southern margin of the mainland into the Mediterranean Sea. Eastward, mainland Europe widens much like the mouth of a funnel, until the boundary with Asia is reached at the Ural Mountains. To the west, Europe begins to break into a series of islands, the largest of which are the UK and Iceland.

The topography of Europe shows great variation within relatively small areas, as a result of the strong geological forces that have acted in the region.

The mountains in Europe today are remnants of three different mountain forming periods, and help describe its present physical geography:

Mainland Europe is mostly lowland, although the most important European mountain ranges are found in this area, located in the central and south part of the continent:

- Pyrenees, the natural border between France and Spain
- Alps, the famous mountains known for their spectacular slopes, which extend over 4 countries, France, Italy, Switzerland and Austria.
- Carpathians, a major mountain range in Central and Southern Europe, stretching from Poland to Slovakia
- Caucasus, which, like the Ural mountains, separate also Europe and Asia

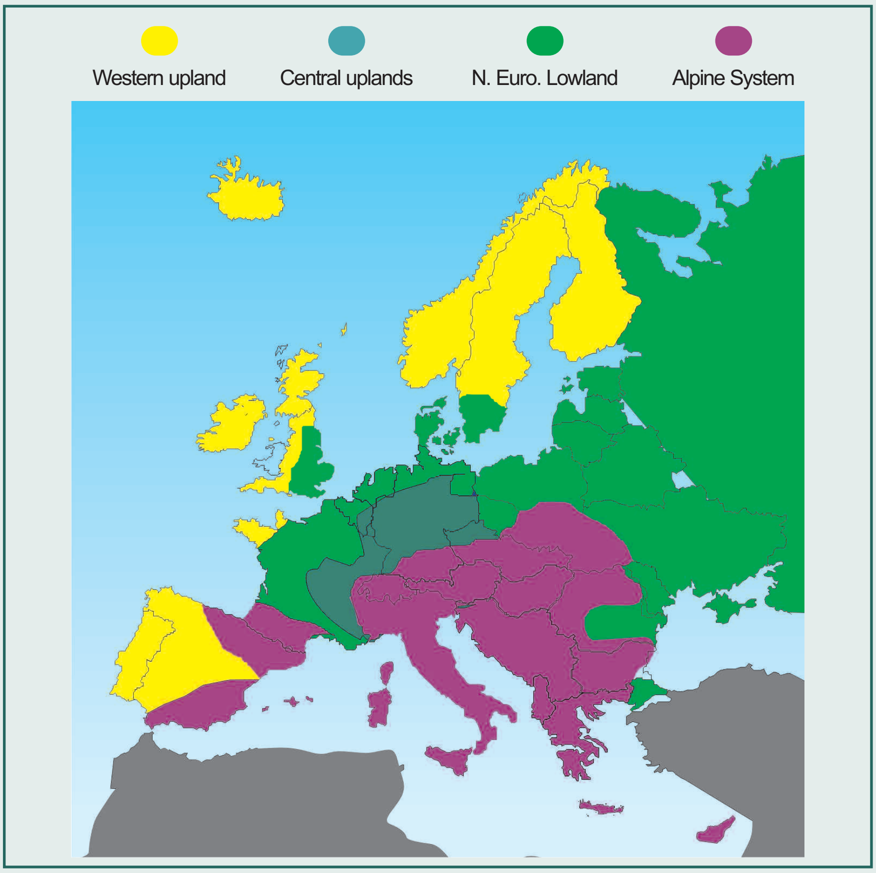

Fig.2. The main landscape regions of Europe.

In the North, a long length mountain range, the Scandinavian Alps, transverses the Scandinavian Peninsula, separating Norway from Sweden.

In the West, the Iberian Peninsula is quite mountainous, and includes the more recently formed, high mountains such as Sierra Nevada, as well as lower, older, more eroded mountains such as Sierra Morena.

In the South, the Italian and the Balkan peninsulas are very mountainous, having been formed by the more recent Alpine mountain building phase (Alpine folding). Both Italy and Greece do have mountainous "backbones" called the Apennines and Pindos, respectively.

Among these mountains are some important plains. The Po Plain, between the Alps and the Apennines, the great

Pannonian Plain of Hungary, southwest of Carpathians and the Galician Plain, northeast of Carpathians, are the greatest ones. Southern Europe tends to lack, or have small plateaux and plains due to the scattered land relief.

Europe is characterised by a great variety of natural landscapes. One can see high altitude mountains, big valleys, semi-arid lands and even areas covered with glaciers within the 10.180.000 km2 of the continent. Geographers have identified four main landscape regions (Fig. 2) that share common characteristics:

- The Northern European Lowlands
- The Western Uplands
- The Central Uplands
- The Alpine Europe

1. 4 Climate

As Europe extends approximately from the 30o to 70o latitude, it largely belongs to the temperate zone, with only a small polar zone. For this reason, its climate is mainly temperate but with some significant variations (Fig. 3). On the west coast of France, night frosts are rare, but at the same latitude, 800km to the east, in the valley of Rhone, far from the sea, night frosts are normal. This proves that the most important regulator of the European climate is the Atlantic Ocean, along with the dispersed warm seas, like the Mediterranean Sea. The further a town or city is from the ocean, the colder the winters, and the warmer the summers will be. European patterns of rainfall (precipitation) vary as well. Rainfall is more usual close to the Atlantic and reduces to the east. On the west coasts of Ireland and Norway, the annual rainfall reaches 1m in 200 days, while around Moscow it is slightly more than 40cm in 90-100 days. Europe also shows great variation in the seasons in which rain falls. In the Mediterranean, the rains fall mainly in the winter and autumn, in the Central and Western Europe it rains during autumn and spring, and in the Eastern Europe, during the summer period.

According to the above, Europe is divided in 5 geographic zones, each one including regions that share common climatic characteristics (major climatic zones), which are:

a) The Mediterranean countries, meaning the south-western Balkan Peninsula, Italy, southern France and the south-eastern Spain have the typical Mediterranean climate where the winters are mild and humid, average temperature around 5°C, and the summers are hot and dry, average temperature 25°C.

b) The Western Europe, made up of the northern coasts of the Iberian Peninsula, the greatest part of the north-western Europe and the British Isles, along with the northern and western coasts of Norway are characterized by the so-called maritime climate. This is strongly affected by the moderating influence of the Atlantic Ocean, with very mild winters and warm summers.

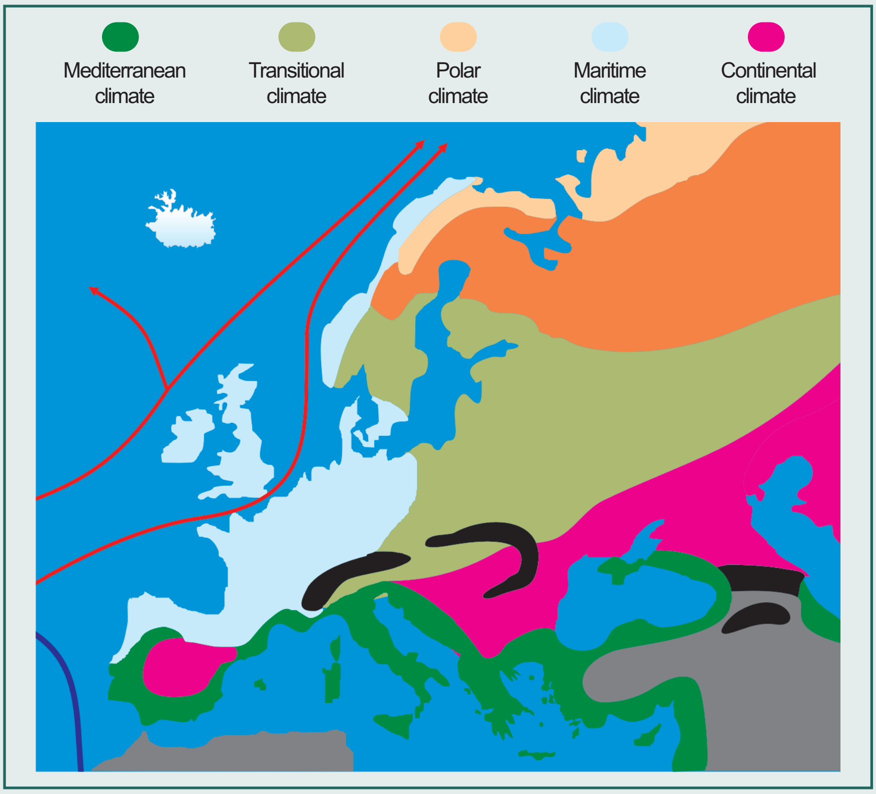

Fig.3. Climatic zones of Europe

c) The whole Central Europe, far away from the coasts, to the Russian plain, and the south part of the Scandinavian Peninsula, belong to the transitional climate. Towards the coasts, it may be temperate but as we move to the east, it becomes continental, with harsh winters and hot summers.

d) The Northern Europe, made up of the Russian plain and a large part of the Scandinavia (including the Scandinavian Alps) have a typical continental climate. The winters are cold and the summers hot and humid. Generally, conditions are extreme with soil being frozen for between three to six months of the year. When the thaw comes, flooding occurs, carrying silt and mud over the land. The summers are hot and dry, and the wind whips up clouds of dust.

e) As we move north, to the Northeastern Europe, the climate becomes colder. But above 70˚ latitude, in the northern Finland and the part of Russia the polar climate is encountered. Here there are no seasons and the average monthly temperature is stable below 10°C. Rainfall is scarce. The landscape is a "frozen desert".

a. Mediterranean climate
b. Maritime climate
c. Transitional climate
d. Continental climate
e. Polar climate

There is another also important think that we should consider that is based on altitude rather than latitude; all high mountains share a variation of the polar climate. The altitude reduces the temperature to freezing and many local conditions cause variations throughout the day.

BOX I. THE MEDITERRANEAN CLIMATE

The Mediterranean Sea is the largest inland sea of the world. It is surrounded by the south-eastern part of the Iberian Peninsula, southern France, southern Italy and central and southern Greece.

The Mediterranean climate is a transitional regime between cold, temperate and dry, tropical climates. Apart in the mountains, snow rarely falls in the Mediterranean, but periods of hard frost do occur.

The main characteristics of the Mediterranean climate are:

a) The regional and local variation in temperature and rainfall regimes

b) Unpredictability: from one year to the next, between seasons of a given year and within the course of a single day, temperature extremes, rain precipitation, winds and other climatic factors can vary dramatically.

c) The various winds, as well as many local winds and variants, but as a rule, northerly winds predominate in summer when the overheated African continent creates a southward in-draught. The opposite trend occurs in winter. Wind greatly increases evaporation, hence aggravating the effects of drought and high temperatures.

Given this unique combination of hot, dry summers and cool, humid winters, little or no surface water is available during the months when the sun is at its strongest. The main characteristics of Mediterranean freshwater ecosystems are the fluctuations in water levels and salinity, which reflect the large variation in rainfall both within and between years.

2. Freshwater ecosystems

Freshwater ecosystems are created by water that enters the terrestrial environment as precipitation and flows both above and below ground, towards the sea. These ecosystems include a wide range of habitats such as rivers and lakes, their catchment or drainage basins (see below) and the riparian zones associated with them. Their boundaries are constantly changing with the seasonality of the hydrological cycle. Their environment benefits and costs are distributed widely across time and space, through the complex interactions between climate, surface and groundwater and coastal marine areas.

Groundwater represents the largest single source of freshwater in the hydrological cycle (about 95% globally), greater in volume than all the water in rivers, lakes and wetlands combined (UNEP-GRID, 2003).

Freshwater ecosystems are unevenly distributed within Europe. The main factors that determine their distribution are the climate (solar radiation, wind and precipitation/evaporation ratio), landscape and geology (bed-rock).

2.1 Catchment or drainage basins

Catchment or drainage basin (see also chapter 5) is a natural unit of landscape, linking terrestrial and freshwater ecosystems (Fig. 4). It is an area of land that drains water, sediment and dissolved materials to a common receiving body or outlet which can be a river, lake or estuary. The catchment basin links various biotic and abiotic components of the system, terrestrial and aquatic, plants and soils, atmosphere and vegetation, soils and water, animals and water. Catchment also includes groundwater that establishes close relationships with the superficial water. The shape, size and content of a stream or a lake depends on the quality of the environments traversed.

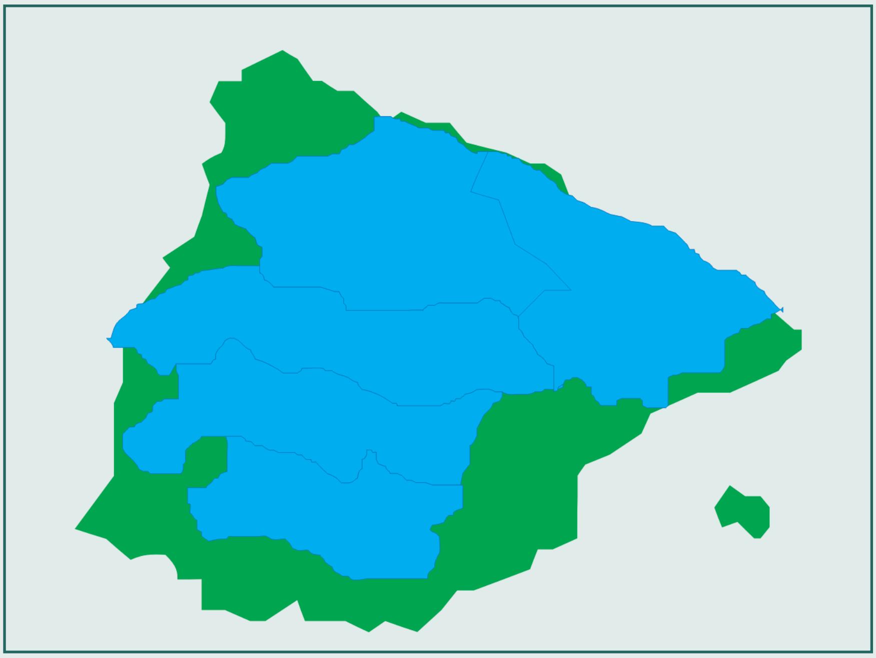

Fig. 4. Main drainage basins along Iberian Peninsula.

2.2 Lakes, Reservoirs and Ponds

Lakes cover less than 2% of Europe's surface. They are water bodies which are deep enough (greater than 2 m) to contain water for long periods of time (see also chapter 3) (Fig. 5). Some shallow water bodies, especially in the Arctic, are considered lakes simply because of their enormous surface area.

In contrast to the natural process of lake formation, reservoirs or artificial lakes are used to store water for various uses. Many of them were formed by the construction of a dam across a flowing river (Fig. 6). Reservoirs are used to generate hydroelectricity, to provide water for domestic and industrial use, fisheries, irrigation, transport, recreation or flood control. In Europe the number of reservoirs is about 3350.

The distribution of lakes along the landscape regions of Europe is the following:

" Northern European Lowlands

This landscape region includes the following ten (10) largest natural lakes of Europe.

" Western Uplands

Windermere is the largest natural lake in England. It is 17 km long, its width varies from 400 - 1500 m and its depth is about 65m. Lakes Lomond (Lough Lomond) (71 km2) and Ness (Loch Ness) (56 km2) are also big lakes in Scotland while Lake Neagh (Lough Neagh) (388 km2) is a big lake in northern Ireland.

Iceland: The biggest lake of Iceland is Thorisvatn situated at the southern highlands of the island. A number of volcanic lakes occur here. Iceland, like Azores, has a number of volcanic lakes.

Azores: The nine (9) islands of Azores (Portugal), are hotspots in the world since each island sits on volcanoes or was born by a volcanic eruption some millions of years ago. The volcanic lakes of Sao Miguel are of unique beauty.

Fig. 5. Kastoria lake in Greece. Photo by A. Trichas

Fig. 6. The reservoir of Nestos river (Greece) was formed by the construction of its dam. Photo by A. Trichas

Name	Country	Surface area (km^2)
Ladoga	Russia	17700
Onega	Russia	9610
Vanern	Sweden	5585
Greater Saimaa	Finland	4377
Peipsi	Estonia-Russia	3550
Vattern	Sweden	1912
Ilmen	Russia	1410
Vygosero	Russia	1250
Malaren	Sweden	1140
Paijanne	Finland	1081

It also includes two (2) of the ten (10) largest reservoirs of the world.

Name	Country	Surface area (km^2)
Samara	Russia	6450
Bratsk	Russia	5426

Central Uplands

The flat terrain of this landscape region is crossed by lakes and marshes (see below) mainly close to the Dutch borders with Germany and along the Frisian coast. Sandy Mecklenburg in northern Germany has many glacial formed lakes (see chapter 3) dating to the last ice age.

Alpine Europe

On the long Alp mountain chain of Alpine Europe many alpine lakes (see chapter 3) are found, such as the alpine glacial lakes in Switzerland, the Lake Constance (Geneva), the lakes of Salzburg in Austria, and Lakes Como, Garda, Lugano and Maggiore in the area of Italy.

The southern part of Europe is characterized by dry, hot, nearly rainless summers and mild rainy winters. Only few and small freshwater bodies are found there.

A pond is a small shallow body of water less than 2 m deep. They are fed by rain runoff or small springs. Ponds are vulnerable to temperature changes freezing in winter and possibly drying in summer.

Well-known ponds in Europe are the Milicz ponds (77 km2) in Poland protected by Ramsar convention (see chapter 6). They are one of the most important resting places for migratory birds and Europe's biggest fishponds.

2.3 Running waters

Running waters are natural water courses, flowing over the surface in extended hollow formations (i.e., channels), which drain discrete areas of mainland with a natural gradient. In basic terms, the existence of a river depends on three factors: the availability of surface water, a channel in the ground and an inclined surface. In this sense, the term "river" includes all kinds of water courses, from the tiniest of brooks or creeks to a massive river the size of the Amazon, flowing over 6400 Km in length and reaching over 3 Km wide in places. The term "stream" is used interchangeably with river when describing the general physical changes that occur as one goes along a water course from small streams at the upper end to a lowland river and possibly an estuary at the lower end.

The 20 longest rivers of Europe are:

Name	Basin area (km^2)	Length (km)
Volga	1380000	3690
Danube	817000	2860
Ural	231000	2428
Dnieper	503000	2290
Don	425600	1950
Pechora	322000	1809
Kama	522000	1805
Oka	>100000	1500
Belaya	>100000	1430
Dniester	72000	1352
Rhine	185000	1320
Elbe	148000	1165
Vistula	194000	1047
Loire	120000	1012
Sava	95719	945
Rhone	98000	810
Guadiana	66800	778
Guadalquivir		666
Po	74000	650
Garonne	57000	525

The distribution of rivers along the landscape regions of Europe is the following:

Northern European Lowlands and Central Uplands

The Northern European Lowlands is the richest landscape region of Europe in terms of big river basins. All the important European rivers, except Danube, rise in Russia and empty either in the Caspian Sea or in Black Sea. Only one, Pechora River, empties in Barents Sea of the Arctic Ocean. Volga River, which is the longest in Europe and Pechora River lie entirely within Russia. The others flow also through Kazakhstan, Belarus and Ukraine.

The main Northern European Plain hosts also the lower sections of other big rivers like Vistula, Oder, Elbe, Rhine, Seine, Loire, Garonne and Rhone. These rivers have already flown through the Central Uplands before reaching the main northern European plain.

Western Uplands

- Western Iberian Peninsula: Douro rises in the Sierra de Urbion in central Spain. Then it flows westwards across Spain and northern Portugal to the Atlantic Ocean.

Tagus is the longest river in the Iberian Peninsula. It rises in the Sierra de Albarracin of central Spain. Then it flows through Portugal where it empties in the Atlantic Ocean near Lisbon.

- United Kingdom and Republic of Ireland: Severn is the longest river in United Kingdom rising in the Cambrian Mountains. After becoming the Bristol Channel it discharges into the Atlantic Ocean (Irish Sea).

Thames in the UK is 346 Km long. It arises in the Cotswolds and flows eastwards through London eventually discharging into the North Sea.

Rivers Tay (Scotland), Bann (N. Ireland) and Towy (Wales) are also important river systems in the UK.

Alpine Europe

- The western part of Alpine Europe and the Balkan Peninsula: This part hosts the second longest river of Europe, the Danube (Fig. 8). Rising from the Alps (Black Forest, Germany) it flows through mountainous areas for the third of its length before reaching foot hills and plains. It empties into the Black sea (Fig. 9). Danube separates the Alps from the Carpathians and both of them from the Balkan Mountains.

River Sava rises in Alps and after flowing through four countries (Slovenia, Croatia, Bosnia and Herzegovina and Serbia), it joins the Danube River. It is the longest river of the Balkan Peninsula and the second longest tributary of Danube (after Tisa River).

Evros, together with Nestos (Fig. 7) and Strymonas, have their origin in the mountains of Bulgaria. Nestos and Strymonas flow south to Greece and discharge into the Aegean Sea. Evros flows to the south east. Then, its northern branch enters Turkey while its southern branch enters Greece and discharges also into the Aegean Sea.

Axios (Vardar) River rises from the Dinaric Alps and discharges also into the Aegean Sea.

- Eastern Iberian Peninsula: On the western part of the Alpine Europe, Guadalquivir and Guadiana are the main rivers. They rise from Sierra Morena Mountains and after flowing through Spain they discharge to the Atlantic Ocean.

- Italian peninsula: Po is the most important river of this area. It rises from the Alps. Its mouth is in the Mediterranean Sea (Adriatic Sea) after flowing through France, Switzerland and through its big plain (Po plain) in Italy. Arno and Tiber are also big rivers of Italy. They both flow from the north-central Apennines to the Tyrrhenian Sea.

Fig. 7. Nestos river, Greece. Photo by A. Trichas

2.4 Estuaries

An estuary is a water body formed where saltwater from the sea mixes with freshwater from rivers, streams and creeks and groundwater (see also chapter 3). Estuaries and surrounding lands are transition zones from land to sea and from freshwater to saltwater. They are influenced by tides and protected from the full force of ocean waves, winds and storms by reefs, barriers, islands or fingers of land, mud or sand.
Finally, estuaries and coastal waters are among the most productive ecosystems on earth, providing numerous ecological, economic, cultural and aesthetic benefits.

Fig. 8. Some countries crossed by Danube

Fig. 9. The extended Danube delta, covering an area of approximately 5800 km^2 .

2.5 Wetlands

Wetlands are areas where water covers the soil, or is present near the surface, during the whole year or for varying periods of time. For this reason they are transition zones between different habitats, getting the characteristics of both aquatic and terrestrial ecosystems. They vary widely due to regional and local differences, such as physical and chemical features, climate, landscape shape (topology), geology, movement and abundance of water and other factors. Wetlands are found from the tundra to the tropics and on every continent except Antarctica.

2.5.1 Bogs

Bogs (Fig. 10) are characterized by spongy peat deposits (> 40 cm), acidic waters and a floor covered by a thick carpet of sphagnum moss. There are no significant inflows or outflows of water from a bog, resulting in stagnant, unproductive environments. As a result, bogs are low in nutrients needed for plant growth, a condition that is enhanced by acid forming peat mosses.

The unique and demanding physical and chemical characteristics of bogs result in the presence of plant and animal communities, that demonstrate many special adaptations to low nutrient levels, waterlogged conditions and acidic waters, such as those found on carnivorous plants. Sphagnum moss is the dominant plant in bogs but some uncommon wildflowers, especially orchids, are also found in these environments. Few amphibians live in bogs as they cannot withstand the highly acidic conditions. Bogs are covered with a layer of floating vegetation which may look like solid ground. However, it is easy to fall through the bog surface into the pit of water below. Bogs are very common across the entire northern hemisphere in previously glaciated areas.

2.5.2 Fens

Fens (Fig. 11) are peat-forming freshwater ecosystems that receive nutrients from upslope sources through drainage from surrounding mineral soils and from groundwater movement.

Fens differ from bogs because they are less acidic and have higher nutrient levels. They are therefore able to support a much more diverse plant and animal community. These systems are often covered by grasses, sedges, rushes and wildflowers. Some fens are characterized by parallel ridges of vegetation separated by less productive hollows.

This type of freshwater ecosystems is common in arctic and sub arctic regions associated with low temperatures and short growing seasons, where ample precipitation and high humidity cause excessive moisture to accumulate.

2.5.3 Swamps

A swamp (Fig. 12) is any freshwater ecosystems dominated by woody plants. Swamps are either dominated by shrubs, such as buttonbush or smooth alder or forested swamps dominated by water-tolerant trees such as cypress (Taxodium sp.), Atlantic white cedar (Chamaecyparis thyoides), and tupelo (Nyssa aquatica). These forested wetlands develop in still or slow flowing water around lake margins, along floodplains and by oxbow lakes. Swamps are reservoirs of water which may be important in times of drought.

The largest swamp of Europe is the Pripet swamps (98400 km2) in Belarus and Ukraine. The swamps lie in the thickly forested basin of the Pripet River.

2.5.4 Marshes

Marshes (Fig. 13) are defined as freshwater ecosystems frequently or continually inundated with water, characterized by emergent herbaceous vegetation adapted to saturated soil conditions, changing water flows and mineral soils.

There are many different kinds of marshes, ranging from coastal to inland, freshwater to saltwater. All types receive most of their water from the surface but many marshes are also fed by groundwater. Nutrients are plentiful and the pH is usually neutral leading to an abundance of plant and animal life and placing them among the most productive ecosystems on earth. Marshes are subject to a gravitational water table, yet water remains within the rooting zone of plants for most of the growing season. There is relatively high oxygen saturation.

2.5.5 Shallow open waters

Shallow open waters (Fig. 14) are small bodies of standing or gently flowing water that represent a transitional stage between lakes and marshes.

They vary greatly in physical and chemical composition. Their surface is free of vegetation except for macrophytes. Unlike lakes, the water temperature in shallow open waters is uniform, lacking any stratification. They are usually free of emergent vegetation, but floating macrophytes may be present. Common vegetation in shallow open water includes milfoils (Millefolium), water hyacinth (Eichhornia crassipes), duck weed (Lemna minor) and water lily (Nymphae spp.). Amphibians, reptiles, crustaceans, mammals and fish all thrive in these habitats. Beavers and moose can often be found near shallow open waters.

Fig.10. A wet bog, Portugal.
Photo by M. Morais

Fig. 11. Fen. Rich higher plant community dominated by great tussock-sedge growing in areas with very high water-table.

Fig. 12. A forested swamp in the southeast Czech Republic. A dense tree cover is growing in completely wet soil.
Photo by B. Bis

Fig. 13. Marsh in the surroundings of ?vora (Portugal). Emergent herbaceous plants growing in a temporary pond.
Photo by M. Morais

2.5.6 Water meadows

Water meadows (Fig. 15) are seasonally flooded pastures. In dry countries water from the flood can de diverted through constructed channels to irrigate arable land.

Fig. 14. Shallow open water: an old oxbow forming a large pond.
Photo by B. Bis

Fig. 15. Water meadow in southern Portugal.
Photo by M. Morais

BOX II. FRESHWATER ECOSYSTEMS IN NORTHERN EUROPE

The southern part of Europe is characterized by dry, hot, nearly rainless summers and mild rainy winters. Only a few, small freshwater bodies are found there. Despite their sparse distribution and small size, they are very important. These small lakes, streams or estuaries, influence the local climate and are important resting places for migrating birds.

The salt lakes of Cyprus are characteristic seasonal lakes: The Larnaca salt lake fills with water during the winter and it dries up in summer. It is used to yield salt which is scraped from its dried up surface. The Akrotiri salt lake together with the extensive Phasouri reedbeds and grazing marshes, salt marshes and open coastal areas, constitute a site of high biodiversity value.

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LAKES RIVERS AND ESTUARIES

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Lakes

1. Formation of lakes

Geomorphology influences the physical and chemical characteristics of lakes, along with the local climate. While most lakes are formed by catastrophic events, others are created more gradually (Fig. 1).

1.1 Glacial lakes

Between one million and ten thousand years ago, during the Pleistocene era, our planet experienced a series of four ice ages - expansions and recessions of glacial ice over the land surface. At times of

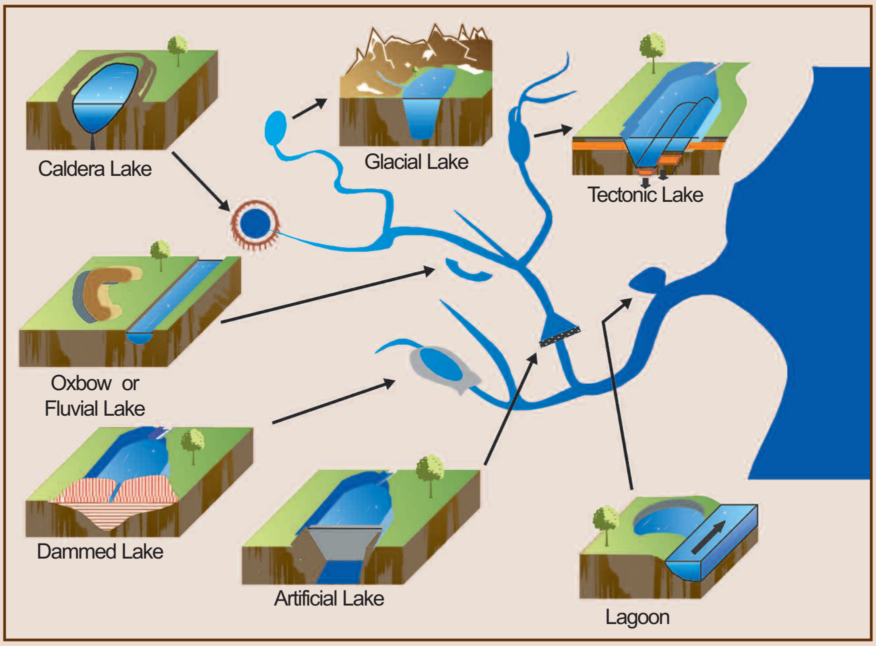

Fig. 1. Different origins of lakes.

Fig. 2. One of the three glacial lakes on the top of Pindos Mountain, Greece. These glacial lakes are the southern ones of the northern hemisphere. They are called Drakolimnes (dragon lakes) since a lot of myths with dragons and gods have been raised around these lonely mountainous lakes.
Photo by A. Trichas

maximal ice cover, 31.5% of the earth's surface was covered by glaciers. The last glaciation was responsible for shaping the landscape of northern temperate regions. Glacial ice scoured the surfaces of relatively flat, mature rock causing the formation of a vast number of small lakes. These ice scour lakes are particularly common in mountainous regions where glacial movements have removed loosened rock material. When glaciers retreat, the rock basins formed, fill with melt water. Such glacial scour lakes may be found on several places of Europe (Fig. 2).

1.2 Tectonic lakes

Tectonic basins are depressions formed by movements of the deeper portions of the earth's crust. Foremost among these is Lake Baikal, of eastern Siberia, the deepest lake in the word, which was formed in the early Tertiary period (approximately 65 million to 1.8 million years ago). Lake Baikal and many other tectonic lakes are of particular interest because they contain a large number of ancient endemic species. Movements in the earth crust causing moderate uplifting of the marine sea bed, have isolated several very large lake basins. The ancient marine basin of Eastern Europe, was lifted and divided by the formation of a Mountain ridge which isolated Caspian Sea on one side and the Sea of Aral on the other.

1.3 Naturally dammed lakes

This type of lake is formed in river valleys behind a dam created by a landslide. Large quantities of unconsolidated rock material slide down to the valley floor, damming the river and creating a lake. This type of lake is often transitory, existing only for a few weeks or months. Many disastrous floods have resulted from the rapid removal of the dam material by the force of the flowing river.

1.4 Volcanic lakes

Catastrophic events associated with volcanic activity can generate lake basins in several different ways. Basins formed by the subsidence of the roof of a partially emptied magmatic chamber are called calderas. Lagoa das Sete Cidades in Açores is the most spectacular example of such a lake (Fig. 3).

Fig. 3. A volcanic lake. Lagoa das Sete Cidades, Açores, Portugal. Photo by P.Pinto

1.5 Karstic lakes

Karstic lakes are very common in limestone regions of the world, notably the karst regions of the Adriatic, especially the Balkan Peninsula and the Alps of Central Europe. Karstic basins are usually almost circular and conically shaped sinks, called dolines, which are developed as the limestone is gradually being corroded by acid rainwater (Fig. 4). Usually, the depressions created are sufficiently deep to extend well into the groundwater table and permanently contain water.

1.6 Oxbow or fluvial lakes

Many lakes were formed along large rivers when sediments carried from the main river were deposited as layers across the mouths of tributary streams (Fig. 5). As a result, the tributary flooded its valley forming a lateral lake. Flow continued until the side valley was flooded and a lateral lake was formed. These kind of lateral lakes occur especially in the upper portion of the drainage or catchment areas.

As a river meanders along its flood plain, greater turbulence causes erosion on the concave side of the river bend, while deposition occurs on the convex side, where currents and turbulence are reduced. In time, the main course of the river cuts a new, more direct channel, leaving behind the isolated loop, referred to as an oxbow lake.

1.7 Lagoon or coastal Lakes

Marine coastal lakes commonly result from the formation of a bar of sediment across the mouths of an old estuary. River discharge and tidal currents are sufficient to prevent complete separation of the lake from the sea. So in any day the lake may contain freshwater, brackish or salt water depending on the tides.

Fig. 4. The doline of Kournas, Crete, Greece. Photo by A. Trichas

2. Physical structural components of a lake

The sun provides the energy which drives the world's wind patterns. Wind energy generates waves which lead to the vertical mixing of water in lakes. The light energy transmitted directly to the aquatic environment through solar radiation also influences the distribution of organisms and water temperature. Physical structural components of lakes include their shape and distribution of light and heat.

2.1 Lake morphology

The shape of a lake basin is largely determined by its origin. The hydraulic retention time, defined as the time required for all the water in the lake to pass through its outflow, is an important measure in assessing lake health and detecting pollution.

2.2 Light

Aquatic plants, the primary producers, can only function in the surface layers of lake water penetrated by sunlight. The productivity of the lake is dependent on this layer.

The elements of lake structure that involve light distribution are often used to describe conditions within the influence of the shore or lake bottom. Primary production in large deep lakes is entirely dependent on light transmitted through the water to enable photosynthesis.

2.3 Temperature and stratification

Water in lakes has a characteristic vertical temperature structure independent of the shape of the lake basin. The sunlight penetrates the surface waters and is absorbed, donating heat and warming the water. In summer the surface layer is much warmer and lake water becomes stratified (see chapter 1).

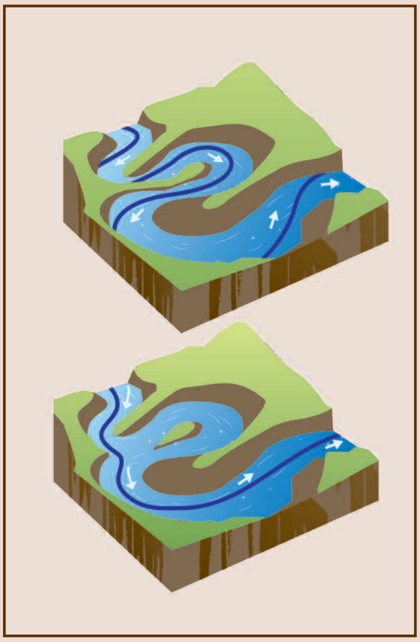

Fig. 5. Formation of an oxbow lake.

3. Chemical processes in a lake

3.1 Oxygen

Diffusion of oxygen from the atmosphere into and within water is a relatively slow process. The oxygen profile of lake waters undergoes thermal stratification in the summer and the vertical variation depends on the productivity of each lake. In low productive lakes (oligotrophic), the oxygen content of the surface layer, the epilimnion, decreases as the water temperature increases. In productive lakes (eutrophic), the organic matter is accumulated at the bottom, in the hypolimnion. This accumulation of dead material uses oxygen, for its decomposition, consequently oxygen in the hypolimnion, is reduced progressively during the period of summer stratification (see chapter 1).

3.2 Nutrients

The nutrient status of lakes is of fundamental importance in determining their living community. Primary producers such as microscopic algae and larger plants such as macrophytes, dependent on nutrients being available for them to grow. The main nutrients which these primary producers require are nitrogen and phosphorus. In general, the higher the nutrient concentrations, the higher the rate of photosynthetic activity.

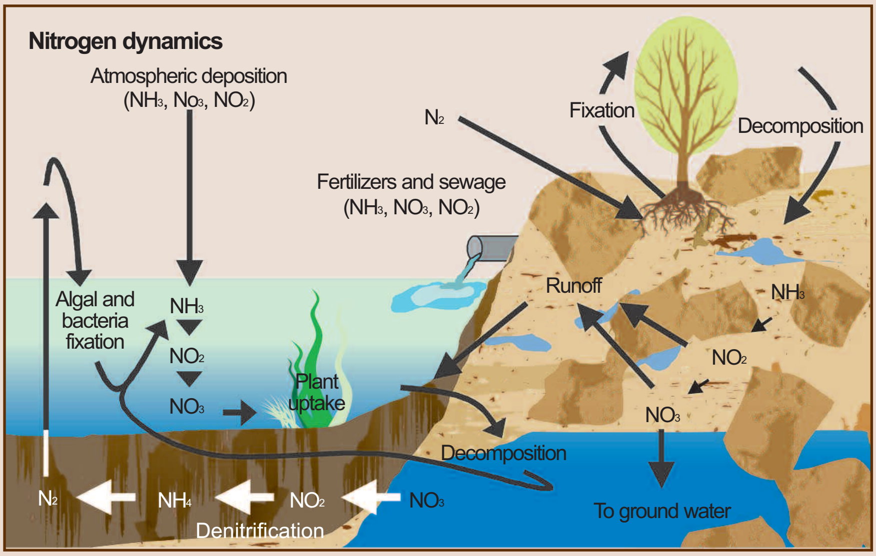

Fig. 6. The nitrogen dynamics, showing the major pathways and the different habitats involved.

3.2.1 Nitrogen

Nitrogen occurs in fresh waters in numerous forms: dissolved molecular (N2), component of large organic compounds like amino acids, ammonia (NH4), nitrite (NO2) and nitrate (NO3).
Nitrogen fixation is the process by which atmospheric nitrogen is converted to a form of nitrogen such as ammonia. In nature, most nitrogen is harvested from the atmosphere by microorganisms to form ammonia, nitrites, and nitrates that can be used by plants (Fig. 6).

In productive, eutrophic lakes, anoxia (lacking oxygen) increases levels of ammonia and nitrite, with increasing depth in the hypolimnion. In low productive oligotrophic lakes, high oxygen concentrations permit the breakdown of ammonia to nitrate, resulting in low levels of nitrite and ammonia, and high levels of nitrate in the hypolimnion.

3.2.2 Phosphorus

Phosphorus is one of the most common growth-limiting elements for all plants, although, it is only needed in small amounts. In contrast to the numerous forms of nitrogen in lake systems, the most significant form of inorganic phosphorus is orthophosphate (PO4) found in lake water (Fig. 7).
Rooted aquatic plants often obtain large quantities of phosphorus from the sediments and can release large amounts into the water. Orthophosphate is readily adsorbed into soil particles and does not move easily with groundwater. High

inflows of organic and inorganic phosphorus (total phosphorus) are due to erosion of particles from steep slopes with easily erodible soils. In spring and summer, intensive algal growth, algal bloom, usually depletes lake's orthophosphate to low levels.

Agricultural, domestic and industrial wastes are major sources of phosphorus and frequently contribute to lakes' high nutrient levels, eutrophication, and algal blooms (algae density higher than 2000 cells/ml).

3.3 Organic carbon cycling and detritus

The sources and composition of organic matter are diverse. Moreover, in most lakes much of the dissolved organic carbon comes from the breakdown of plant material brought in by the terrestrial drainage system. This can be called allochthonous carbon, produced outside the lake system. Meanwhile the lake produces its own carbon by the breakdowns of organic matter. This would be called autochthonous carbon, produced within the lake (Fig. 8).

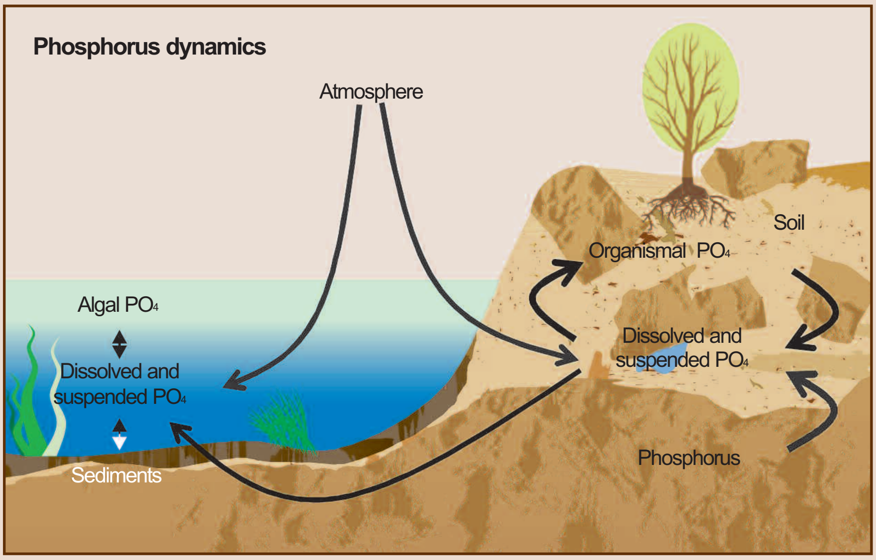

Fig. 7. The phosphorus dynamics, showing the major pathways and the allochthonous dependence.

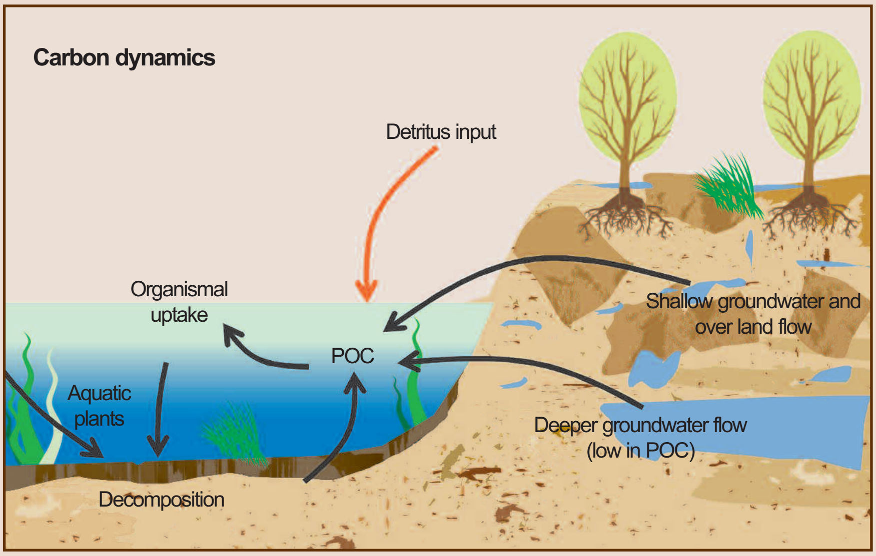

Fig. 8. Major pathways of carbon dynamic in lakes. The diagram shows the importance of allochthonous carbon coming by the drainage basin (trees and groundwater).

4. Lakes - an ecosystem concept

Lakes have a very productive area between the terrestrial drainage area and the open water. These littoral areas contain a wide variety of plants, from rooted bushes and shrubs, to semi submerged and floating species. These complex littoral areas are exceedingly important in regulating lake's metabolism. Since a majority of lakes are small and relatively shallow, their littoral components regulate their productivity. These complex interface regions are the least understood lakes' ecosystem components, and can be sub-divide into several areas known lacustrine zonation (Fig. 9).

4.1 Lacustrine zonation

a) Littoral zone extends from the shore just above the influence of waves and spray, to a depth where light is barely sufficient for algae (the periphyton) and rooted plants (macrophytes) to grow. Bottom dwelling mini beasts (macro-invertebrates) live in the sediment.

b) Photic (or "euphotic") zone is the portion that extends from the lake surface down to where the light level is 1% of that at the surface. The correspondent communities are plankton and fish.

c) Profundal zone is positioned beyond the littoral and photic zones at the bottom of the lake where light levels are too low for photosynthesis. At this level, oxygen is consumed by bacteria responsible for decomposition of organic matter.

d) Pelagic zone (or "limnetic zone") is the surface water layer in offshore areas beyond the influence of the shoreline.

Boundaries between these zones vary daily and seasonally with changing solar intensity and transparency of the water. There is a decrease in water transparency when algal blooms occur (algae density higher than 2000 cel/ml), and when sediment flows into rivers from shore erosion.

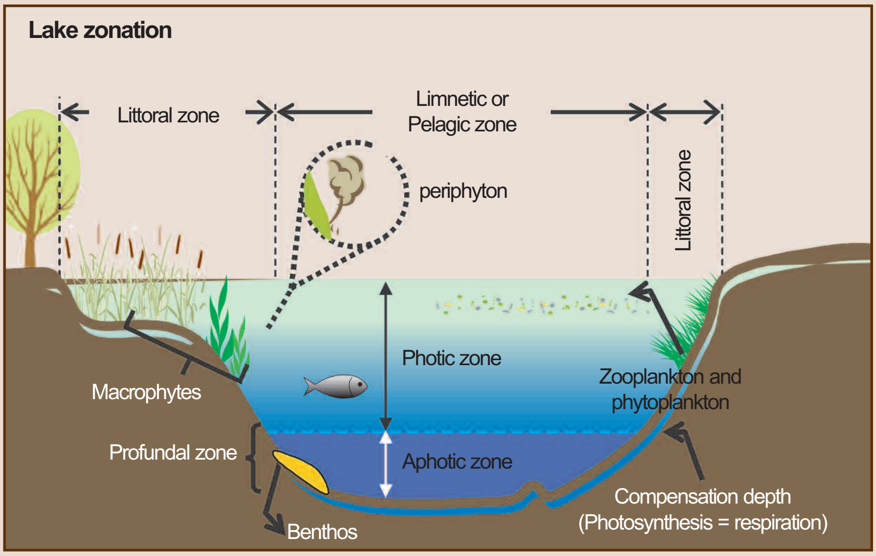

Fig. 9. The four major habitats zones in a lake and associated communities according to a lacustrine zonation concept.

4.2 Associated communities

a) Plankton community is the living fraction of material which floats in the water and is moved passively by wind or current. It is composed of microscopic plants - the phytoplankton - which are the primary producers of organic matter in aquatic habitats. The nutritionally dependent animal component constitutes the zooplankton. The phytoplankton thus stands on the base line of food webs in aquatic environments. It is in turn dependent on the activities of other microbial organisms, mainly bacteria, which convert organic material into the inorganic nutrients required by plants. Members of phytoplankton are classified as algae.

BOX I. AQUATIC PLANTS AND MAN

Aquatic macrophytes have served humans well over the centuries, providing food, medicines, and building materials. The ancient Egyptians regularly harvested water lilies (Nymphaea spp.) (Fig. 10) for human consumption. Herodatus, the Greek historian, described the practice in the fifth century BC; lilies were dried and seeds were pounded or ground into flour, which was used to make bread.

Fig. 10. Water lilies (Nymphea alba) from Kerkini lake, northern Greece. Photo by A. Trichas

b) Algae can also growth upon substrate, in the littoral zone and constitute, together with other communities like fungi and bacteria, the periphyton.

c) Macrophytes are aquatic plants. They are described as aquatic if the plant parts involved in photosynthesis are submerged or float on the water surface either permanently or at least for several months each year. The term "macrophytes" refers to all plants large enough to be visible to the naked eye - not only flowering plants but also ferns, bryophytes and algae.

d) Benthic macroinvertebrates live in the sediment at the bottom of the lake. These aquatic mini beasts are larger than a pin-head (that's about five microns). Like bacteria, these organisms are important for processing and transforming organic matter into sources of food for other aquatic life.

e) Fish communities: These are vertebrates and the best-known inhabitants in freshwater systems. Fish are the major predators in lakes. This is no doubt connected with their importance as food. Freshwater fisheries are important for domestic use and commercially worldwide.

Running waters

1. Classification of running waters

Running waters, streams and rivers, occur under widely differing conditions of vegetation, topography and geology. However they are all linked by the effect of precipitation and evaporation that affects their drainage basins. It is useful to classify running waters according to the availability of water in terms of predictability and permanence. On this basis, rivers can be arranged from the least predictable and least permanent, ephemeral and episodic systems to the most predictable, seasonal, permanent or perennial systems.

1.1 Ephemeral streams

These are only filled after unpredictable rainfall and runoff. Surface water dries within days of filling and seldom supports macroscopic aquatic life.

1.2 Episodic streams

They are dry during most of the year with rare and very irregular wet phases that may persist for months.

1.3 Intermittent streams

These are alternately wet and dry, but less frequently and less regularly than seasonal streams.

1.4 Seasonal streams

These are alternately wet and dry every year, according to season. They usually fill during the wet part of the year, and dry predictably. The surface water persists for months, long enough for some macroscopic plants and animals to complete the aquatic stages of their life cycles.

1.5 Permanent or perennial streams

These are predictably filled although water levels may vary. Most of their living communities cannot tolerate desiccation.

BOX I. DEFINING RIVER DISCHARGE AND VELOCITY

Discharge can be determined as the product of cross-sectional area (m^2) and average current velocity (V, m/s), so its units are m^3/s.
The cross-sectional area of a stream is calculated from width (W) multiplied by mean depth (D). Thus, the discharge (Q, m^3/s) is: $Q= WDV$
In practice, discharge is obtained by dividing the stream cross-section into segments, measuring velocity and area for each and summing the discharge estimates for the segments.

2. Physical processes in running waters

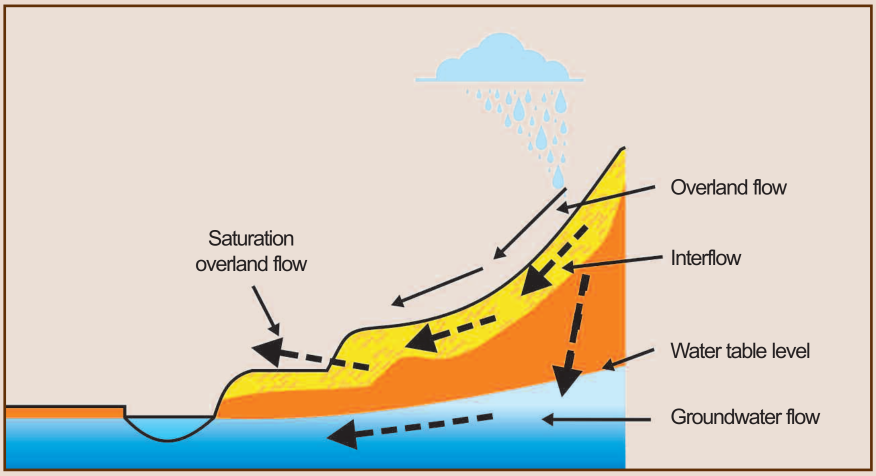

Fig. 1. Pathways of water moving downhill into a stream channel.

2.1 River flow and river channel formation

Water moves downhill by various routes (Fig.1). Climate, vegetation, topography, geology, land use and soil characteristics determine how much surface runoff occurs.

A river current is defined as the downstream movement of water. It determines the extent of erosion of the river channel, the amount of particle deposition and the nature of sediments and biological communities. The current velocity is complex since the movement of water is not homogenous throughout the whole channel. This is a result of varying degrees of friction exerted upon the water when it flows across its channel bed. Velocity can be measured using sophisticated current meters or more simply by timing the movement of a floating object over a given distance.
Discharge is the total volume of water moving past a point in a given time (BOX I).

The amount of transported sediments increases with discharge. Irregular deposition is responsible for

Fig. 2. Side point bar formed from gravel. Guadiana basin in Southern Portugal.
Photo by M. Morais

Fig. 3. Braided channel - an aerial view of a highly mobile channel with floodplain absent.
Photo by C. Voreadou

Fig. 4. Rapids. Guadiana basin in southern Portugal.
Photo by M. Morais

Fig. 5. Waterfalls. Guadiana basin in southern Portugal.
Photo by M. Morais

many structures common in rivers. Bars, for example, are extended zones of sediment accumulation (Fig. 2). Rivers carrying large amount of sediments (alluvial loads), may form braided streams where many small channels are formed, separated by elongated bars and islands (Fig. 3).

For most of the year, discharge is too low to shape channels or move much sediment. However, floods can dramatically change this process and many channels can be formed and sediments can be transported during these events. Irregularities in the profile of rivers, such as rapids (Fig. 4) and waterfalls (Fig. 5), are often due to the presence of rocks of varying hardness. Many channels in upland streams consist of sequences of fast-flowing, turbulent water, called riffles, followed by intermediate runs and deposition pools (BOX II).

2.2 Meandering rivers

Few rivers have channels that stay straight for very long. Most rivers travel at least one and a half times further than the linear distance from source to mouth, following a curving path of bends and loops called meanders. A single bend has a concave outer bank where the current is faster and erosion predominates, and a convex inner bank where the slower water deposits more alluvial sediment. Sometimes a meander will curve so much that it almost becomes a complete loop. In this case the river will often create a new channel between the beginning and end of the loop, cutting off the meander forming an oxbow lake.

BOX II. THE MAIN HYDROLOGICAL HABITATS

Riffle habitats	Habitat where the main river current deposits gravel and cobble materials. The current is fast moving, although with wide variety of current velocities. The river bed is composed by large particles (rocks and gravel). These larger particles provide a variety of living spaces with stable conditions, until they are carried off by the current. As a result of the fast current, food is carried by water flow. Due to the intensity of the current, riffle habitats are well oxygenated and with accentuated food availability. For those reasons they tend to support higher levels of biodiversity.
Run habitats	Generally are found in deeper and slower moving waters, leaving smaller particles (like sand and gravel) on the river bottom, creating a more uniform habitat. This does not provide the same diversity of living spaces and surfaces as in riffle areas: higher flows in the spring and after flood events may be capable of moving the sand and gravel, and any organism living there, downstream. Food is carried in by the current in the water column, deposited on the bottom and may also grow on the bottom, wherever the water is shallow enough so sunlight can penetrate to the river bottom. Since runs are not as stable and do not contain the variety of surfaces to hang onto, current conditions, food sources and living spaces as riffles, they contain a smaller variety of invertebrates.
Pool areas	Are deep and slow moving. This makes for a uniform bottom of smaller particle size, like sands and silts. These materials provide very limited living spaces and surfaces for invertebrates. Further, sand and silt, and the organisms living there, are easily swept downstream by runoff events which makes these habitats get periodically scoured, and then deposition fills them in again. However, they are valuable refuges for fish, since they tend to be cool near the bottom and are frequently under overhanging banks or vegetation, which provide protection from aerial predators. Food may be limited to what is deposited on the river bottom or suspended in the water column. In deeper pools, light may not penetrate to the river bottom, so plants (a food source and living surface) do not grow there. Pools support a very limited variety of organisms compared to riffles.

3. Nutrients and organic matter transportation in running waters

3.1 Nutrient spiralling

In running waters, the nutrients cycling process is affected by the longitudinal movement of the water, to produce nutrient spiralling (Fig. 6). The efficiency of this process is represented by the ratio of recycling and the distance between cycles as a measure of nutrient retention which is influenced by biological activity, nutrient concentration, and the flow of water.

3.2 Energy flow in running waters

When a dead leaf (CPOM-Course Particulate Organic Matter) falls into a stream, it may be carried along for a distance, until it sinks in a pool or is trapped by a rock. Within 1-2 days, dissolved organic matter (DOM) leaches out of the leaf and may form fine particulate organic matter (FPOM) (Fig. 7). Meanwhile, the leaf has formed a

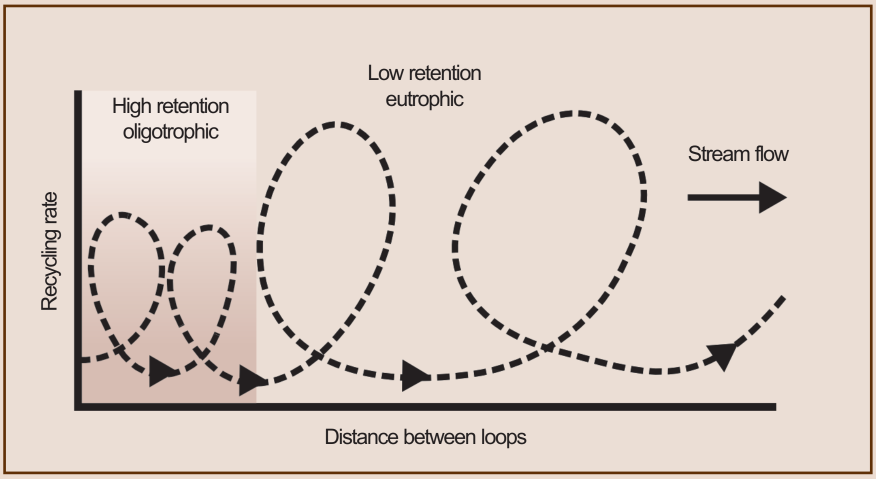

Fig. 6. Nutrient spiralling in running waters. Spirals lying together indicate high retention such in oligotrophic conditions or in upland streams with coarse substrate. Loose spirals with broader diameters represent low retention, characteristic of eutrophic systems with excess of nutrients.

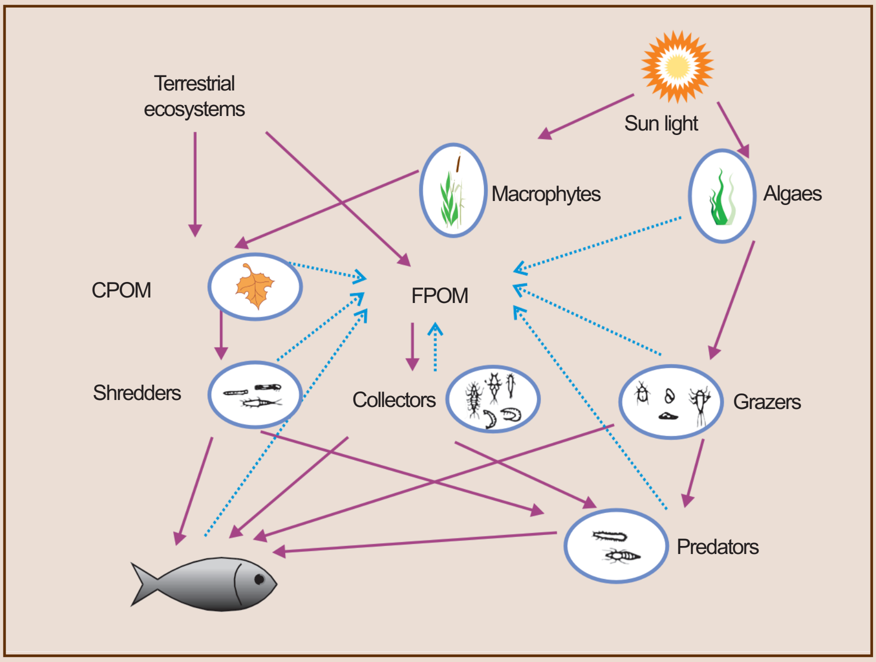

Fig. 7. Simplified model of a stream ecosystem showing the principal biological components, energy sources and material pathways. The relative importance of the pathways will differ from stream to stream and from segment to segment in the some stream according to there position along the longitudinal course. Larger blue arrows correspond to the contribution of the terrestrial environment. Blue arrows correspond to the direct flux of energy along the food web. The brown dotted lines show the different ways how FPOM is generated (CPOM partition or animal faeces).

substrate for microbes. Microbes improve leaf palatability for invertebrate decomposers by partially digesting leaf tissue.

Algae may also colonize the leaf, providing food for aquatic mini beasts such the scrapers (BOX III). The leaf begins to break down due to water currents, abrasion and the feeding activities of other aquatic mini beasts called the shredders. The shredders break up the remains of leaf which become available to the collectors, either filter feeders or gather feeders. Simultaneously, depending upon shading, season and location along the stream, in stream photosynthesis occurs. Aquatic water plants are available for the shredders and later for the collectors.

The model of energy flow identifies two main sources of energy. One from in-stream photosynthesis by water plants and algae (autochthonous) and the other from organic matter produced outside the stream (allochthonous) which arrives as leaf litter and organic matter entering the stream directly.

BOX III. FUCTIONAL FEEDING GROUPS OF INVERTEBRATES

CPOM-Course Particulate Organic Matter
FPOM-Fine Particulate Organic Matter

Feeding group	Food resource	Feeding mode	Examples
Shredder	Leaf litter (CPOM), green water plants	Chewing and mining	Caddisflies, some crustaceans
Shredder-gouger	Wood. Usually rotted	Chewing and mining	Caddisflies, some beetles, some chironomid midge larvae
Collector-filterer	Suspended FPOM	Filter-feed using specialised setae, nets or secretions	Net-spinning caddisflies, black-fly larvae, some chironomid midge larvae
Collector- gatherer	Deposited FPOM	Brushing biofilms, burrowing in soft sediments	Many mayflies, stoneflies, caddisflies, true flies, oligochaeta worms, some crustaceans
Scraper or Grazer	Algal biofilm	Scraping and browsing	Scraping and browsing Some mayflies, caddisflies, snails, beetle larvae
Predator	Animal prey	Biting and piercing	Dragonflies and damselflies, flatworms, some caddisflies, true flies, true bugs and beetles

4. River Continuum Concept: a model to explain the distribution of aquatic species

The river Continuum Concept (RCC) is a bold attempt to construct a single framework to describe the function of river ecosystems from source to mouth. Along its length, the river swells in size, gathers tributaries and drains an increasingly larger catchment area (Fig. 8).

Biological changes along the length of the river are many. This was initially conceived to describe what happens in a temperate woodland stream. Near the source the stream is narrow and generally well-shaded by trees. Thus, insufficient light reaches the stream bed to promote algal growth and the current is too fast and the substrate is often unsuitable. Nutrients are too low to promote growth of macrophytes. The tree cover and small surface area of the stream result in a lot of woody debris enters the stream. So the shredders reduce this organic matter, making it available to the collectors that are more abundant downstream. Grazers are essentially absent because of the lack of algae.

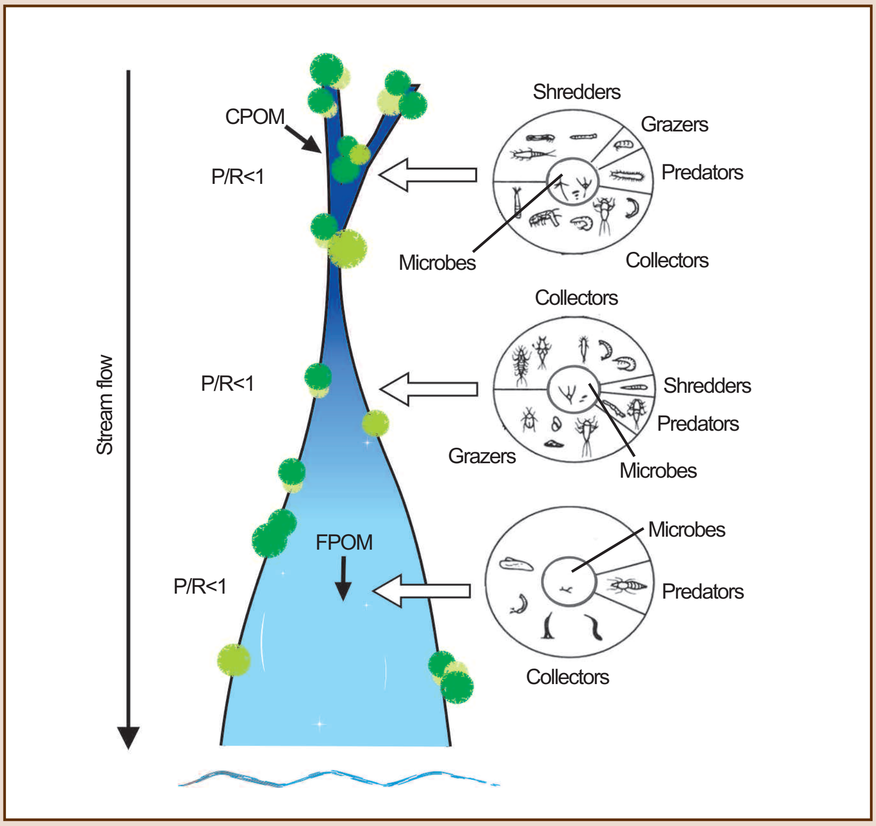

Fig. 8. Relationship between stream size (order), energy sources and ecosystem function predicted under the River Continuum Concept (from Vannote et al., 1980).

As the stream increases in size, the influence of the surrounding woodland decreases, shading and organic matter inputs will be minimal, and ample sunlight should reach the river bottom. This will support significant algae production. The collectors are as numerous as they were upstream, although they are typically different species. The major change is in the reversal of the shredders and grazers. Organic matter is low and algae plentiful, so shredders are rare and grazers are as numerous as the collectors. Larger aquatic plants, macrophytes, become more abundant with increasing river size, particularly in lowland rivers where reduced gradient and finer sediments form suitable conditions for them to grow.

Even further down the river, terrestrial input of organic matter is insignificant. The water column contains large amounts of suspended organic matter from the excess production of the mid reaches of the river. This material limits light penetration.

The benthic community is largely made up of collectors, both filterers and gatherers. Shredders and grazers are absent. Along the continuum, the proportion of predators, namely fish, remains relatively consistent.

This model of the river continuum demonstrates the natural sequence of events. However, disturbances such as logging and damming interrupt these pristine conditions and can have far reaching consequences.

5. Fish zonation

The physical habitat characteristics of a stream also influence the fish community. Fish species have adapted to specific river habitats. For example, stiff pectoral fins and flat profiles allow some fishes to survive well in the fast flowing rivers with riffle features. Others evolved specialized mouths to take advantage of the food sources in the soft sediments of pools and runs. These adaptations seen in fishes have lead to their use in zoning rivers. The zones are not precise but give an indication of the different habitats along the course of the river. In most European large rivers, 'trout', 'grayling', 'barbel' and 'bream' zones are recognised and can be characterized as follows:

Trout zone - This zone has a characteristic steep gradient, fast flowing water and cool temperature. The fast flow rate causes turbulence which keeps the water well oxygenated. Fish species found in this zone usually lay adhesive eggs that can stick to the substrate and this helps prevent eggs being carried down stream by the water flow. Characteristic fish species are: Brown trout (*Salmo trutta*); Atlantic salmon (*Salmo salar*); Bullhead (*Coltus gobio*); Stone Loach (*Barbatula barbatula*).

Grayling zone - Similar in physical characteristics to the Trout zone, although the temperature is usually slightly higher. Fish species in this zone also lay adhesive eggs. Characteristic fish species include all of the former species, with the addition of: Grayling (*Thymallus thymallus*); Minnow (*Phoxinus phoxinus*); Chub (*Leuciscus cephalus*); Dace (*Leuciscus leuciscus*).

Barbel zone - This zone is essentially lowland, but retains some characteristics of upland rivers. It has a gentle gradient with a moderate water flow and temperature. It also has good oxygen content and a mixed substrate of silt and gravel in which plants can take root. Most of the fish species found in this zone lay their eggs in the vegetation on the river bed; this provides them with good protection and allows the eggs a good supply of oxygen given from plants. Characteristic fish species include all of the species from the previous zones with addition of: Barbel (*Barbus barbus*); Roach (*Rutilus rutilus*); Rudd (*Scardinius erythrophthalmus*); European perch (*IPerca fluviatilis*); Pike (*Esox lucius*); Eel (*Anguilla anguilla*).

Bream zone - The true lowland zone; has a very gentle gradient and slow flowing water, the temperature is much more variable than in the other zones. This zone has a fine substrate and is often turbid. Fish species found in this zone lay adhesive eggs in the weeds. Most upland fish species can not survive in this zone. Characteristic fish species include only a few species from the Barble zone (*Roach, Rudd, Perch* and *Pike*), with the addition of: Bream (*Abramis brama*); Tench (*Tinca tinca*); Carp (*Cyprinis carpio*).

Estuaries

1. Classification of estuaries

Estuaries are divided into four types, depending on how they were formed (Fig. 1).

1.1 Coastal plain estuaries

These are formed when the sea level rises and fills an existing river valley.

1.2 Tectonic estuaries

These are formed by the folding or faulting of land surfaces.

1.3 Bar-built estuaries

These are formed when a shallow lagoon or bay is protected from the ocean by a sand bar or barrier island.

1.4 Fjords

These are a very special type of estuaries formed by flooding a U-shaped glacial valley. Fjords are found in areas with long histories of glacier activity, like northern Europe, Alaska and Canada.

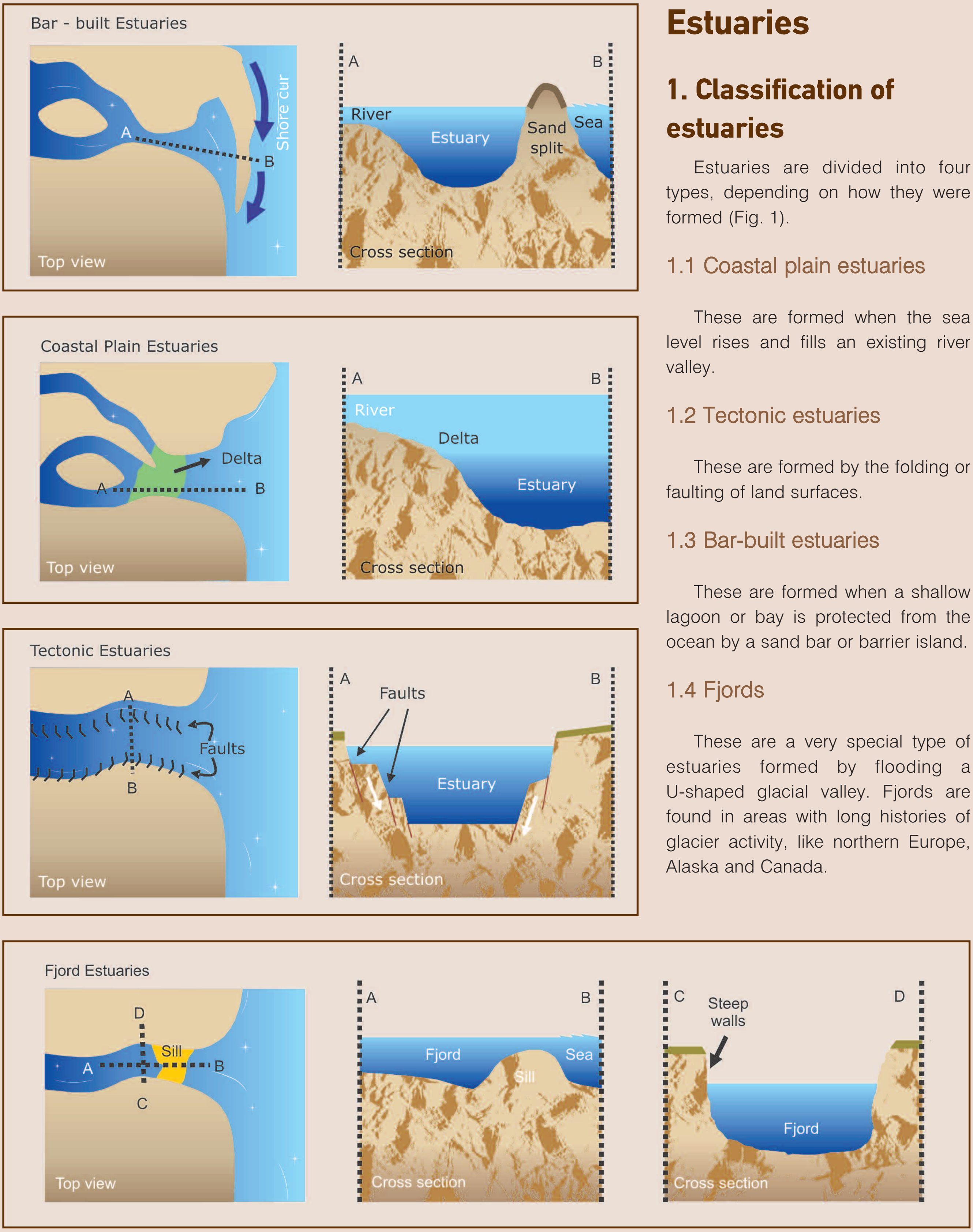

Fig. 1. Different estuary types according to its formation.

2. Inter-tidal habitats

Inter-tidal habitats are wetlands located between the low and high tide lines in estuaries or in coastal zones. Species living in these habitats are adapted to fluctuating environmental conditions such as variation in salinity. Some of these inter-tidal wetlands are very productive, representing important wildlife habitats. Mudflats, salt-marshes, and mangroves swamps are important inter-tidal habitats.

2.1 Mudflats

Mudflats are very characteristic habitat of most estuaries. They are formed by the deposition of sediments from upstream and from the sea. Mudflats are very productive habitats, exhibiting a complete food web.

2.2 Salt marshes

Salt marshes occur in shallow quiet water, where suspended particles are able to settle and accumulate (Fig 2). Salt marsh are relatively flat, grass covered coastal area occurring within the estuarine ecosystem. They are partially flooded by the sea each tide. These marshes are some of the most productive lands in the world and produce so much organic matter that their influence can be seen far out into the coastal ocean waters.

Salt marshes appear to be grass covered, but mats of algae grow in the upper layer of soil. Crabs, snails, insects, birds, reptiles and mammals are common inhabitants. Salt marshes are important seasonal stopping places for migrating birds. Every autumn and spring, thousands of ducks and geese find temporary refuge there during their travels.

Fig. 2. Saltmarsh, during the low tide, at Mira river estuary, Portugal. Dense herbaceous vegetation traversed by small meandering canals is observed growing on the mud
Photo by P.Pinto

2.3 Mangrove swamps

Mangroves take over from salt marshes in tropical latitudes, filling many of the same functions, although they are not quite as productive (Fig. 3). The dense and spreading roots of the mangrove trees provide sanctuary for fish, reptiles and insects. Thick foliage gives birds plenty of places to nest or perch while searching the shallow waters below for food. Mangroves help protect the shorelines from erosion.

Fig. 3. Mangrove, during the low tide, at Gambia river estuary (Gambia, Western Africa). Big shrubs are observed growing on the mud. Small orange spots observed on the mud are crabs that typically inhabit mangroves.
Photo by P.Pinto

3. Main features of an estuary

3.1 Delta formation

The physics of estuarine mixing are complex and are affected by several features such as geology, topography and fresh water discharge. For instance, deltas occur in estuaries where the sediment load carried by the river is so large that accumulations of sediment near the river mouth grow towards the sea. Deltaic sediments tend to include smaller particles, such as clays and silts, rather than sands. The shores of the complex channels that are formed in deltas provide extensive protected shallow habitats that invariably support dense vegetation of vascular plants.

3.2 Circulation of water

Circulation of water in the near shore is complex and is affected by differences in density between freshwater and saltwater, differences in temperature of waters, differences in tidal forces, wind-driven circulation and the effects of the earth's gravitational field.

Less dense or warmer water tends to remain in the surface layers, denser, colder water remains in a layer below, and the water column is therefore stratified. Winds and tides, however, may mix the water column, causing a vertical exchange between surface and deeper layers (Fig. 4).

The flow of some large rivers is so immense that a wedge-shaped bottom layer of salt water, called a salt wedge, is pushed up the estuary along the river bottom by the force of the outgoing fresh water above it. This wedge of salt water can penetrate several kilometres from the river's mouth.

Estuaries and coastal waters often contain various mixtures of fresh and salty water that create physiologically and ecologically special conditions for organisms.

3.3 Biological components

Estuaries are among the most biologically productive ecosystems on the planet. Tens of thousands of birds, mammals, fish, and other wildlife depend on estuarine habitats as places to live, feed, and reproduce. Estuaries provide ideal spots for migratory birds to rest and refuel during their journeys, and many species of fish and shellfish rely on the sheltered waters of estuaries as protected places to spawn.

3.3.1 Plants

Only certain types of plants can tolerate the physical conditions peculiar to estuaries, and each of these plants occupying a particular niche. Some plants can tolerate high levels of salt concentrations, excreting the salt they take up through special salt pores on their leaf surfaces such as cord-grass (Spartina) and salt-grass (Distichlis), while others tolerate only fresh water further in land.

A second factor influencing the growth of plants in an estuary is the flooding intensity. The longer and deeper an area is flooded, the less oxygen is available in the soil. So, plants that grow in these areas are adapted to shortage of oxygen. Sea-grass form extensive beds or meadows in many estuaries. In temperate climates, eelgrass (Zostera marina) dominate, stabilizing coastal sediments. Sea-grasses can also be collected to be used to fertilize sandy

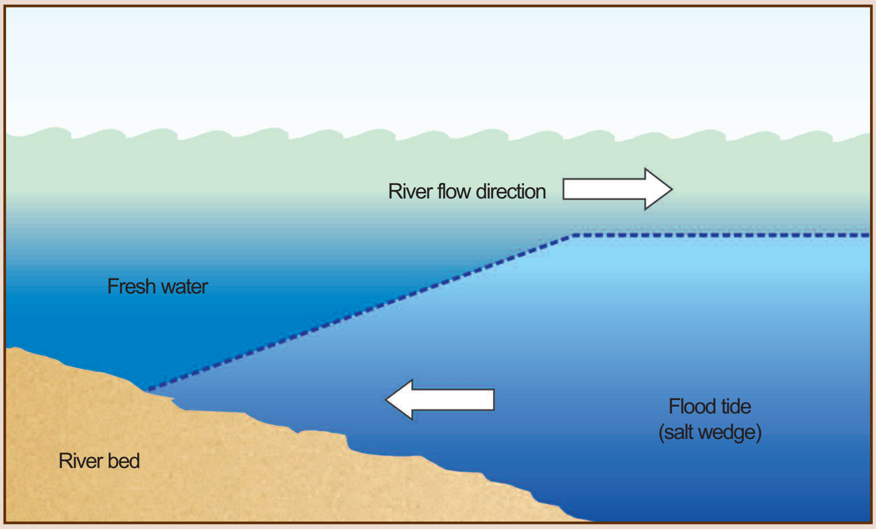

Fig. 4. Water mixing in an estuary. Fresh water and salt water mixing inside an estuary. Density stratification is observed. Sat water, being denser tend to penetrate inside the estuary near de bottom. Fresh water, that is less dense, tend to stay in the upper layers of the water column.

soil. This was an important activity in the Ria de Aveiro, Portugal.

3.3.2 Animals

Estuaries are critical habitat for certain animals at particular stages of their lives. Only a few animals can live in this environment all their life. They have adapted to constant variation in salinity, oxygen levels and temperature. However, most animals are only temporary residents and visiting to feed or breed. In turn, the survival of predators depends on populations of fish and birds that use these coastal ecosystems at key times in their life cycles.

A variety of invertebrates, including mussels, clams, snails, amphipods, or small shelled creatures, segmented worms, and lugworms, feast on detritus and each other in the mudflats and fall prey to a multitude of fish and birds. Mudflats, despite their desolate appearance, teem with invertebrates that burrow into the mud for protection from predators and the elements.

We can find in estuaries species of birds like Dunlin (*Calidris alpina*), Avocet (*Recurvirostra avosetta*), Grey Plover (*Pluvialis squatarola*), Ringed plover (*Charadrius hiaticula*), Kentish plover (*Charadrius alexandrinus*) and Black-winged Stilt (*Himantopus himantopus*). One can also find playful dolphins, herons, white swans, flamingos, river birds, ducks, and birds of prey along with the European otter, which just show the diversity of life in the estuary.

4. Nutrients flow in estuaries

Nearer shore, nutrients are supplied to marine ecosystem principally from nearby land. Erosion and decay on land provide organic matter, nutrients and minerals to freshwater and then to the sea.

5. Estuaries and their importance

Besides serving as important habitat for wildlife, the intertribal habitats that fringe many estuaries also perform other valuable functions. Water draining from the uplands carries sediments, nutrients, and other pollutants. As the water flows through fresh and salt marshes, much of the sediments and pollutants are filtered out. This filtration process creates cleaner and clearer water, which benefits both people and marine life. Wetland plants and soils also act as a natural buffer between the land and ocean, absorbing flood waters and dissipating storm surges. This protects upland organisms as well as valuable land from storm and flood damage. Salt-marsh grasses and other estuarine plants also help prevent erosion and stabilize the shoreline.

As transition zones between land and water, estuaries are invaluable laboratories for scientists and students, providing countless lessons in biology, geology, chemistry, physics, history, and social issues. They also provide a venue for boating, fishing and bird watching.

Finally, the tangible and direct economic benefits of estuaries should not be overlooked. Tourism, fisheries and other commercial activities thrive on the wealth of natural resources estuaries supply. The protected coastal waters of estuaries also support important public infrastructure, serving as harbours and ports vital for shipping, transportation and industry.

CHAPTER 4

ASSESSING THE ECOLOGICAL STATUS OF FRESHWATERS

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1. The new European water policy under the Water Framework Directive (WFD)

The critical decline of biological diversity and water quality at the global scale was sobering evidence that valid water management requires effective tools and commanding methodology to control excess pollutants, nutrients, organic materials and specific substances being transferred from modified landscapes into freshwater ecosystems.

A new regulation for the European Community action in the field of water policy the Water Framework Directive (WFD) (2000/60/EC) was agreed by the European Parliament and Council in September 2000, and came into force on 22nd December 2000 as part of a general re-structuring of the European Union water policy.

Nowadays, the WFD is the most influential legal instrument on the EU level in water protection and management (e.g. Jungwirth et. al. 2000; Butterworth et al., 2001; Statzner et al., 2001; Bis, 2002; Bis & Usseglio-Polatera, 2004; Furse et al., 2006).

However, the Water Framework Directive implementation at a consistent, Paneuropean scale - poses an immense challenge to water management sector in Europe (Fig. 1, 2).

First of all, environmental policies are increasingly executed across large biogeographical areas (ecoregions or river basins).

As a result, one of the main aims of the WFD is to establish a framework for the protection of all european water types: inland surface waters, transitional waters, coastal waters and groundwaters.

Secondly, the recent scientific debates about sustainable water management induced reorientations of considerable environmental targets to enhance and protect biological diversity, and ecological integrity of aquatic ecosystems in Europe.

It implicates the reorganisation of all national water monitoring systems in EU states - in terms of moving away from pollution focused monitoring to assessing the health of the aquatic environment overall and to integrating factors such as quality, quantity and physical structure with ecological indicators.

The health of animals and plants that live in waters will now be among the main indicators of the quality state of water bodies.

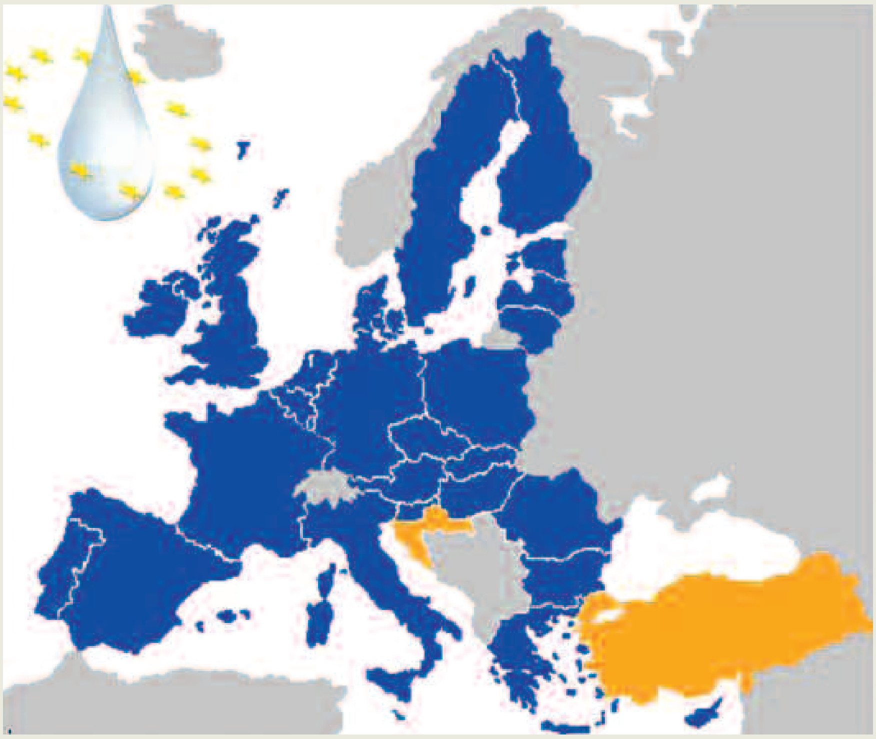


Fig. 1. The water policy scene of the European Union (on the upper left - a logo of the EU-WFD implementation in the EU states; the 27 EU countries highlighted by blue background).

Consequently, the major objective of the Water Framework Directive aims at:

- preventing any deterioration in the existing status of water bodies,
- maintaining 'high status' (reference conditions) of all water types where it exists, and
- achieving at least "good status" in relation to all European water types by 2015.

The added objectives of the WFD are:

- to enhance protection of aquatic ecosystems, and terrestrial ecosystems and wetlands - directly dependent on aquatic ecosystems;
- to promote long-term protection of available water resources based on sustainable water use;
- to establish a register of 'protected areas' - areas designated for protection of habitats and/or species;
- to provide for enhanced protection and improvement of the aquatic environment by reducing emissions and losses of priority (hazardous) substances;
- to provide for sufficient supply of good quality surface water and groundwater as need for sustainable, balanced and equitable water use.

This EU-WFD approach is currently a basic philosophy both for developing the recommendations for environmental policy, and for defining all supportive - political, socio-economical and ecological targets for water sector enhancement.

2. Identification of water bodies under the Water Framework Directive

All water bodies in Europe, including

- inland waters: surface and groundwaters,
- transitional and costal waters

should be now attributed to the basic management units - to the river basin districts (WFD CIS 2, 2003; WFD CIS 10, 2003) (Fig. 2).

Therefore, any management goals undertaken by regional water authorities have to consider the River Basin's scale of potential impact, particularly in the case of the transboundary river systems (encompassing some administrative borders and flowing by different countries).

3. Categories of surface waters

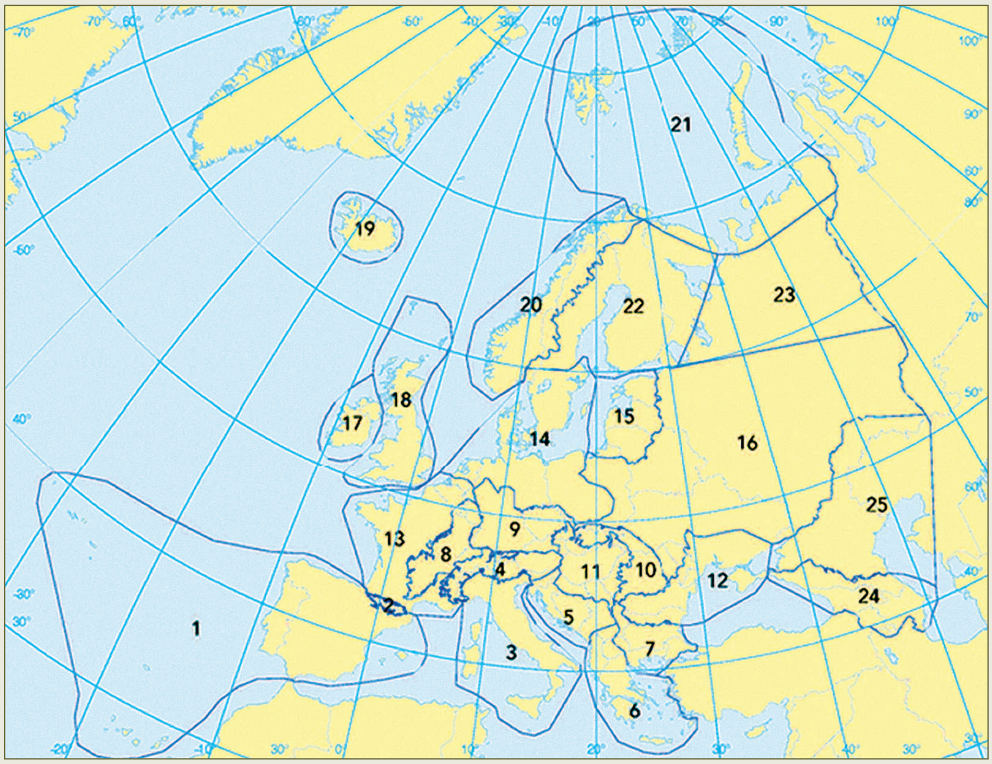
The WFD established three main categories of surface water bodies:

- Natural surface water bodies:
  - ✔ rivers
  - ✔ lakes
  - ✔ transitional waters
  - ✔ coastal waters
- Heavily modified surface water bodies (with heavily physical alterations by human activity);
- artificial surface water bodies.

The divisions of surface water bodies with a separation of heavily modified and artificial waters - is connected with the proper water management procedures (the quality of these waters should be effectively improved).

For these purposes, there is also important to recognize the dominated stressor type and its intensity (e.g. organic pollution, canalization), different planned water uses (e.g. drinking water) and local protected areas (e.g. Natura 2000 sites).

Fig 2. Surface waters in Europe
Photo by R. Jaskula



Ecoregions for rivers and lakes:

1. Ibero - Macaronesian region
2. Pyrenees
3. Italy, Corsica and Malta
4. Alps
5. Dinaric western Balkan
6. Hellenic western Balkan
7. East ern Balkan
8. Western highlands
9. Central highlands
10. The Carpathiens
11. Hungarian lowlands
12. Pontic province
13. Western plains
14. Central plains
15. Baltic province
16. Eastern plains
17. Ireland and Northern Ireland
18. Great Britain
19. Iceland
20. Borealic uplands
21. Tundra
22. Fenno - scandian shield
23. Taiga
24. The Caucasus
25. Caspic depression

Fig. 3. Ecoregions are based on fauna communities living in European inland surface waters (the data was published as a map in Annex XI, Water Framework Directive, in Official Journal of the European Communities).

4. Typology of surface water bodies: river basins and ecoregions

As was stated, accordingly to the WFD objectives - all the European river basins are water management units - and are grouping within BIOGEOGRAPHICAL ECOREGION (Fig. 3). Ecoregions correspond to the typical environmental variability of European aquatic ecosystems, based on type-specific biocenosis, and also geological settings, and hydrological regime.

The EU-member states for the key characteristics of all river basins will use selected obligatory parameters:

- ecoregions, which covering the studied river basin (Fig.3);
- geographic location of the river system: latitude and longitude (for the studied river section),
- altitude - as defined by the elevation of the source, or the elevation of the river section being assessed (mountain rivers >800m above see level; upland rivers 200-800m a.s.l.; lowland rivers <200m a.s.l.),
- river basin size - as defined by catchment area,
- geology of the river basin (calcareous, siliceous, organic).

However, the EU-member states can apply other complementary criteria that identify as important for defining the regional characteristics of river systems.

5. Reference conditions and high ecological status

The identification of reference conditions - defined as the best conditions of a given stream-type (e.g. lowland or mountain streams) with a minimal degree of modification - is a rigid requirement for assessing the ecological quality of European waters (Fig 4).

To establish the main WFD goals, directed to the ecological status improvement - an understanding of a water body's reference conditions, in unimpacted state - is strictly needed. When reference conditions are established (as a control/benchmark system), they can be used to assess environmental impacts, conservation status, or biodiversity modifications at any water type.

EU-Member States were expected to develop a reference network for each water body type - containing a sufficient number of sites of high ecological status to provide a sufficient level of confidence about the values for the reference condition.

BOX I. REFERENCE CONDITIONS UNDER THE WFD

Reference conditions (RC) - do not equate necessarily to totally undisturbed, pristine conditions. They include very minor disturbance which means that human pressure is allowed as long as there are no or only very minor ecological effects; as results

- RC are equal "the high ecological status" (no or only very minor evidence of disturbance for each of the general physico-chemical, hydromorphological and mostly biological quality elements);
- RC shall be established for each water body type, and for each quality elements and should be revised every 5 years;
- There are two primary approaches for selecting reference conditions (having no or minimal impact) at surveyed sites:

Selection of reference sites based on a definition of reference site criteria - is used when a sufficient number of pristine or unimpacted rivers and/or reaches exist;

- Determination of reference conditions based only on the best conditions, which can be actually found in the given water type range -is used when few reference sites exist or are not suitably defined.

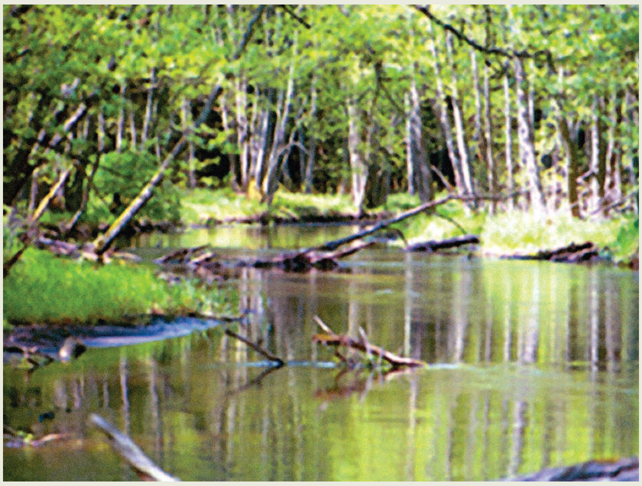


Fig.4. An example of reference conditions for different water types: small-sized mountain streams, and middle-sized lowland rivers. Photo by B. Bis

6. Ecological status assessment

The WFD specify that the ecological status of the surface water is defined as "an expression of the quality of the structure and functioning of aquatic ecosystems associated with water-type" (WFD, 2000; Furse, at al., 2006).

Consequently, the ecological status assessment should evaluate how the biological structure and ecosystem functioning are altered in response to different anthropogenic pressures (e.g. nutrient loading, acidification, toxic and hazardous substances, physical habitat alterations, etc.).

All the WFD requirements are a novel approach in the European water policy, which in the past has was based on the evaluation of emission values - but now is focused on the strict control of the allowed impacts on the recipient ecosystems. this conceptual approach is directly connected with EU nature conservation legislation such as the 'Birds Directive' (79/409/EEC) and the 'Habitats Directive' (92/43/EEC) - which have established a legislative framework for protecting and conserving Europe's wildlife and habitats (creation of a coherent ecological network of protected areas across the EU - NATURA 2000).

According to the WFD, there are three basic QUALITY ELEMENTS applicable to assessing ecological status (Fig. 5, Fig. 6):

1. Biological quality elements;
2. Physico-chemical quality ele ments; and
3. Hydromorphological quality elements (river channel and its val ley conditions).

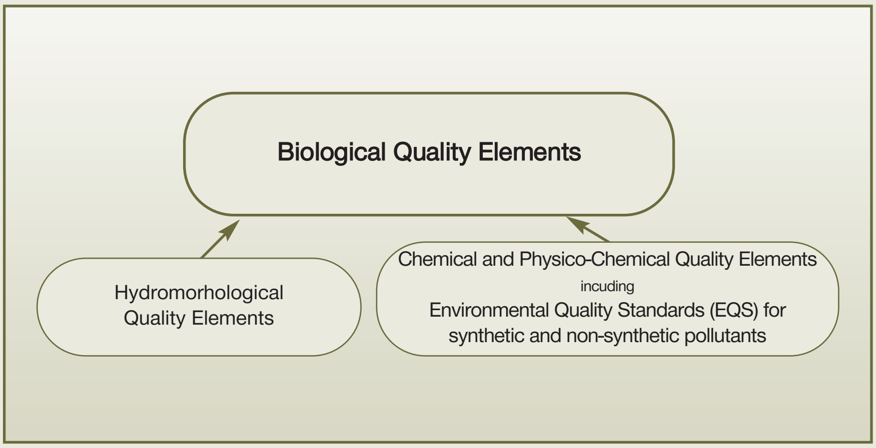


Fig. 5. The three basic quality elements of the ecological status assessment.

Biological Quality Elements

Phytoplakton
(only in large rivers and lakes)
Phytobenthos
Macrophytes
Benthic macroinvertebrates
Fish fauna

Hydrochemical Quality Elements

Oxygenation conditions
Nutrient concentration
Salinity
Termal conditions
Acidification status
pH
Hazardous substances

Hydromorphological Quality Elements

Morphological conditions
Hydrological regime
River continuity

Fig. 6. The quality elements of the ecological status assessment: (1) biological quality elements (algae, phytoplankton, macrophytes, macroinvertebrates, fishes); (2) hydromorphological assessment of river channel and its valley; (3) physico-chemical quality elements - with quality standards for hazardous substances.
Photo by B. Bis

It is very important to note that now under the WFD the hydromorphological and the general physico-chemical conditions are ONLY supporting elements for the biological elements assessment. In addition, for development of the ecological status classification scheme, all the EU Member States - needs to establish the most optimal methods and tools for assessing ecological status in their biogeographical conditons.

BOX II. THE WFD CONSEQENCES FOR WATER MANAGEMENT

The ecological status of natural waters:

- ◆ needs to be determined using primarily biological quality elements (BQE: phytobenthos/phytoplankton; macrophytes; macrozoobenthos; fish)
- ◆ biological assessment is the basis for the water body classification;
- ◆ ecological classification sets the principal water managements goals for the river basins.

7. Harmonized class boundaries in Europe

Each EU country should define and establish the five water quality classes (Fig. 7) related to the human impact - for all biological quality components (BQC) in different water types (e.g. WFD CIS 10, 2003; UKTAG, 2005; Urkiaga et al., 2006).

The WFD gives definitions of the different quality class as follows:

- High status: reflect undisturbed conditions and no or only very minor evidence of alteration;
- Good status: Low level of human-impacted alterations and only slight deviation from undisturbed conditions;
- Poor status: High level of deviation and alteration.

The boundary between good and moderate status is especially important in the context of the WFD objectives (in the near future, all waters should reach a good quality status) - actually, it will set the targets for restoration and improvement plans of water bodies which are in risk to fail the environmental objectives (Fig.7).

This central concept is the most innovative for the EU-WFD environmental principles. In the past - each standard monitoring system was based on the hydrochemical quality assessment and the class boundaries were easy to determined.

Nowdays, the class boundaries for all groups of the indicative organisms (diatoms, macrophytes, benthic invertebrates, fishes) and their responses on the stressor type must be established to give a final and integrated ecological status assessment of freshwaters. It is much more difficult for determining, but it can be directly connected with the aquatic ecosystems conservation and future ecologically-sound management.

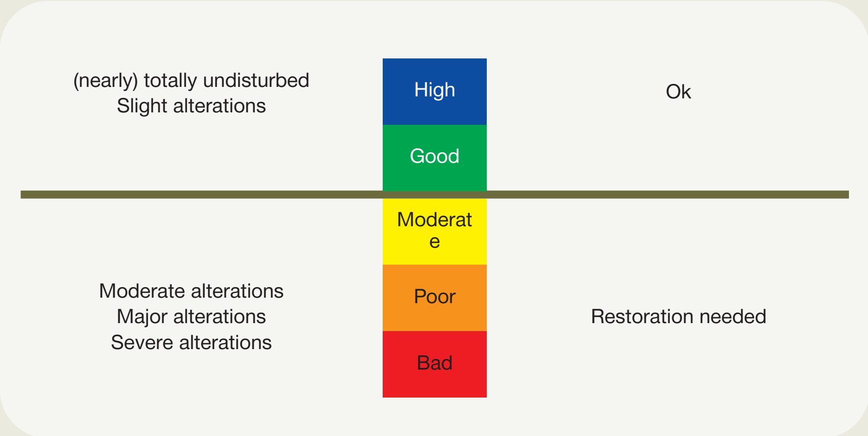


Fig. 7. Diagram of the five quality classes - under the WFD - based on the ecological status assessment (biological, hydrochemical and hydromorphological quality elements) - with the indication of responsibility for the river restoration tasks.

8. Why are biological quality elements (BQEs) the basis for ecological assessment?

Ecological indicators can be used to assess the condition of the environment, to provide an early warning signal of changes in the environment, or to diagnose the cause of an environmental problem. Ideally the suite of indicators should represent key information about structure, function, and composition of the ecological system (Markert et al., 2003).

Ecological indicators need to capture the complexities of the ecosystem yet remain simple enough to be easily and routinely monitored. As a result, ecological indicators should meet the following criteria: be easily measured, be sensitive to stresses on the system, respond to stress in a predictable manner, be anticipatory, predict changes that can be averted by management actions, be integrative, have a known response to disturbances, anthropogenic stresses, and changes over time.

Algae as biological indicators

As primary producers - algae and aquatic plants (macrophytes) are considered as early-warning system groups, that distinctly react on hydrochemical disturbances (e.g. eutrophication = nutrient richness of any type of stagnant waters - mainly lakes and lagoons). Periphyton are benthic (attached) algae that grow attached to surfaces such as rocks or larger plants.

The periphyton, mostly diatom assemblages - serves as a good biological indicator due to: (1) a naturally high number of species; (2) a rapid response-time to both disturbance and ecosystem recovery; (3) ease of sampling, requiring few people; (4) tolerance or sensitivity to specific changes in environmental condition are known for many species. By using algal communities in association with macroinvertebrate and fish data, the significance of biological assessments is optimized.

Aquatic and terrestrial plants as biological indicators

Macrophytes are aquatic plants, growing in or near water that are either emergent, submergent, or floating. Macrophytes - as a primary producers (organisms in an ecosystem that produce biomass from inorganic compounds; autotrophs) - are excellent indicators of water body status because they: (1) respond to nutrients, light, toxic contaminants, metals, herbicides, turbidity, water level change, and salt; (2) are integrators of environmental conditions (e.g. nutrients, soil composition; ground waters).

Macroinvertebrates as biological indicators

Aquatic invertebrates, involved in bioassessment, live in the bottom parts of our waters. They are also called benthic macroinvertebrates, or benthos (benthic = bottom, macro = large, invertebrate = animal without a backbone) and are indicators of water quality because they: (1) live in the water for all or most of their life; (2) stay in areas suitable for their survival and their occurrence is not limited by seasonal changes (macrophytes, algae); (3) are easy to collect; (4) differ in their tolerance to amount and types of pollution; (5) are easy to identify in a laboratory; (6) often live for more than one year; (7) have limited mobility; (8) are the best biological integrators of environmental conditions.

The role of macroinvertebrate assemblages in aquatic food web (fig. 8) as primary consumers of producers (i.e. periphyton) and decomposers (i.e. heterotrophic bacteria and fungi), as prey for secondary and tertiary consumers (i.e. fish) make this group of organisms important for the holistic assessment of streams: the community's total integrity of the system, and

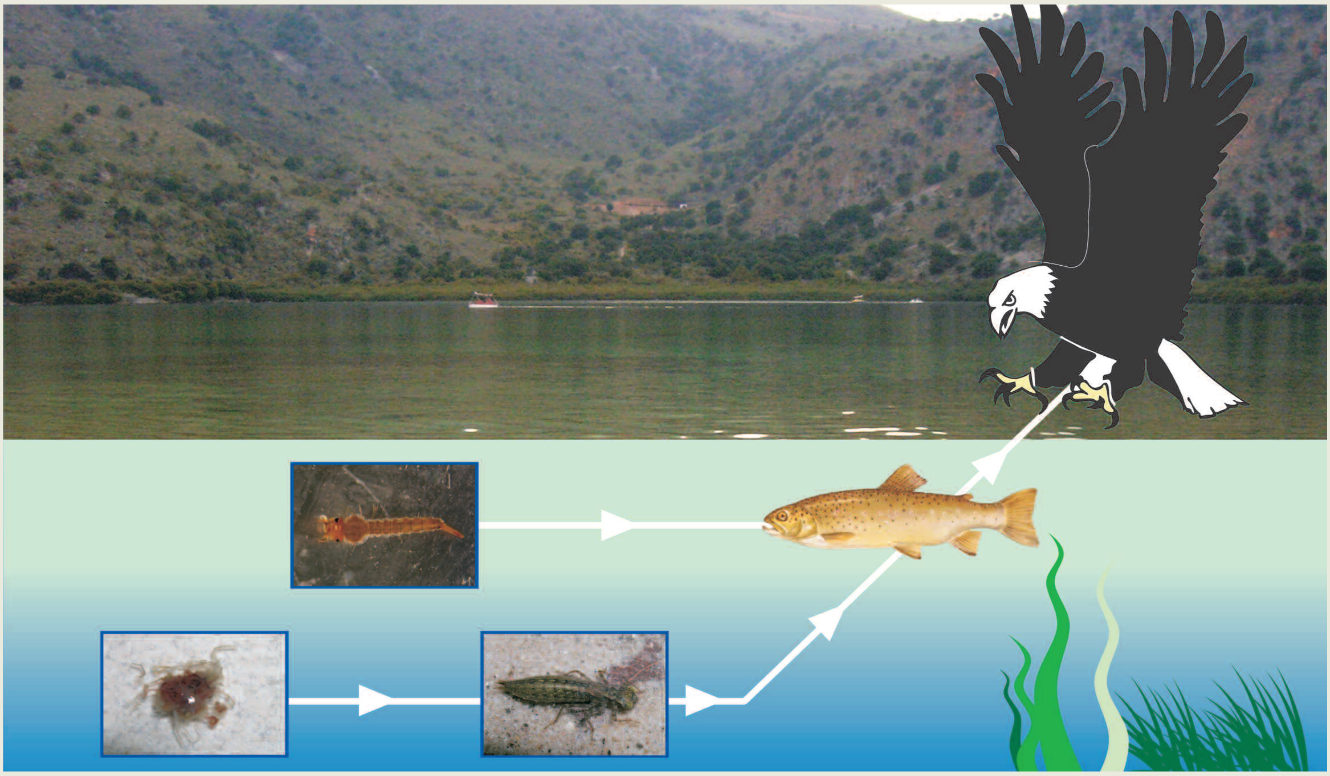


Fig. 8. The role of macroinvertebrates in the aquatic food chain, showing structural and functional importance of this group in the aquatic system (marked by yellow frames).
Photo by A. Trichas

multiple-stress indication (all stressor types and its intensity: chemical contaminations, organic pollution, acidification, morphological and biotic degradation).

The utility of macroinvertebrates assemblage structure for describing the integrity of aquatic ecosystems and diagnosis of the anthropogenic stress has been widely recognized. More than one hundred different bioassessment methods exist in Europe, two thirds of which are based on macroinvertebrates (Fig. 9) (e.g. Rosenberg and Resh 1993, Verdonschot 1990, 2000).

Photo by R. Jaskula

Non-polluted waters - very sensitive bioindicators


Larva of Plecoptera


Larva of Ephemeroptera


Hydropsyhe sp.

Moderate water quality - sensitive bioindicators


Gammarus sp. (Amphipoda)


Larva of Sialis sp.

Poor water quality - tolerant bioindicators


Asellus aquaticus (Isopoda)


Anodonta anatina


Hirudo medicilanis

Bed water quality - very tolerant bioindicators


Tubifex tubifex


Larva of Chironomus sp. (Chironomidae)


Stratiomys sp. (Stratiomyidae)

Fig. 9. Freshwater bioindicators (benthic macroinvertebrates) of freshwater ecosystems.
Photo by R. Jaskula

Fish as biological indicators

Fish are excellent indicators of watershed health because they: (1) live in the water all of their life; (2) differ in their tolerance to amount and types of pollution; (3) are easy to collect with the right equipment; (4) live for several years; (5) are easy to identify in the field.

Generally, fish are very good bioindicators of river assessment at basin-scale, particularly morphological properties of river systems (habitat structure, refugia), and also very good bioindicators for marine and costal monitoring system. Hydrochemical conditions are secondary/additional determinants of their distribution in river systems - therefore this group of biota is mainly used to ecotoxicological studies.

In conclusion, the ecological integrity approach, based on the WFD philosophy (2000), and the investigations of potential human impact at all levels of biological organization in different geographic scales are of importance for biodiversity protection and potential ecological risk assessment (e.g. Lanz & Scheuer, 2001).

BOX III. WHY IS MAINTAINING BIODIVERSITY SO IMPORTANT?

Biodiversity is the variety of all living things. All organisms rely on other life forms for their existence. Organisms that use oxygen for respiration rely on plants for oxygen production. Their food comes from plants, animals and fungi. Any change in the numbers of one species will affect other species, and ecosystem functioning.

The term biodiversity is also often used to describe the diversity of organisms within a particular area. The 'local' biodiversity is of concern when human activity encroaches on habitats. This often pushes one or more species out of the area, and in some cases, it may also cause local or the complete extinction of a species.

Worldwide, more than 10,000 species become extinct every year and while precise calculation is difficult, it is certain that this rate has increased alarmingly in recent years. The central cause of species extinction is the destruction of natural habitats by human beings.

Biodiversity is priceless.

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Supporting references

Other thematic pieces of literature are available at following web sources:

Water Framework Directive

- The EU Water Framework Directive - integrated river basin management for Europe: http://ec.europa.eu/environment/water/water-framework/index_en.html
- Implementation of the EU-WFD: http://ec.europa.eu/environment/water/water-framework/implementation.html
- Common Implementation Strategy for the Water Framework Directive: http://www.eeb.org/activities/water/Common%20EU%20Strategy%20for%20WFD%20Implementation.pdf
- WFD page at EMWIS website: http://www.emwis.org/WFD/WFD.htm
- Environmental Agency - the WFD: http://www.environmentagency.gov.uk/aboutus/512398/289428/655695/
- CIRCA Forum Implementing the WFD: http://forum.europa.eu.int/Public/irc/env/wfd/home
- Join Research Centre - Institute for Environment and Sustainability http://www.jrc.cec.eu.int/default.asp@sidsz=our_organisation&sidstsz=ies.htm

Freshwater Protection and Sustainable Management

- European Rivers Network: http://www.rivernet.org/
- WaterWeb: http://www.waterweb.org/resources.php
- Freshwater Life: http://freshwaterlife.info/index.jsp
- WWF - Freshwater Work: http://www.panda.org/about_wwf/what_we_do/freshwater/index.cfm
- Euro-Mediterranean Information System on the Know-how in the Water Sector - EMWIS: http://www.emwis.org/
- US Environmental Protection Agency - http://www.epa.gov/
- International Year of Freshwater 2003: http://www.wateryear2003.org/en/ev.php-URL_ID=1456&URL_DO=DO_TOPIC&URL_SECTION=201.html;
- European Environmantal Bureau Hanbook: http://www.eeb.org/publication/chapter-4_5.pdf

Freshwater Protection, Biological Indicators and Biomonitoring in Educationn

- CEH's School Net - is the educational section of CEH Web, and is intended to be used as a resource by teachers of primary and GCSE-aged school children: http://schools.ceh.ac.uk/
- EEK! Environmental Education for Kids: http://www.dnr.state.wi.us/org/caer/ce/eek/teacher/index.htm
- Educational Materials: http://www.ucar.edu/learn/1_1_2_1t.htm
- Stream Biomonitoring Unit - Key to Aquatic Macroinvertebrates: http://www.dec.state.ny.us/website/dow/stream/index.htm
- Digital Key to Aquatic Insects - North Dacota: http://www.xerces.org/CD ROM%20for%20web/id/index.htm
- Freshwater Macroinvertebrates - Oregon http://www.nwnature.net/macros/
- EPA - Biological Indicators of Watershed Health: http://www.epa.gov/bioindicators/html/invertebrate.html
- Stream Biomonitoring http://www.yni.org/yi/monitoring/stream_biomonitoring.html
- ACD Technical Assistance - Stream Monitoring http://www.anokaswcd.org/tech_assist/monitoring/biomonitoring.htm
- Drinking Water and Groundwater Kids Stuff http://www.epa.gov/safewater/kids/kids_9-12.html
- NSW Water Bug Survey - Bugasaurus Explorus!: http://www.bugsurvey.nsw.gov.au/

DISTURBANCES

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1. Disturbances

Disturbance is regarded as an event of intense environmental stress occurring over a relatively short period of time and causing large changes in the affected ecosystem. Disturbance can result from natural causes (natural disturbance) such as fires, floods, droughts, volcanic eruptions, hurricanes, tornadoes, soil erosion, earthquakes and over geological time, glacial advance and retreat. It can also result from human activities (man made or anthropogenic disturbance) which include logging, deforestation and drainage of wetlands, clearing for cultivation, elevated water withdrawals for irrigation, water pollution or the introduction of foreign species, sometimes referred to as alien or invasive species.

Disturbance can occur over varying time scales. The most extensive disturbances involve landscape scale events, such as glaciations, which can affect entire continents. Some disturbances, however, are much more local in their effects for example flooding and landslides.

Whenever an ecosystem is affected by a substantial disturbance event, individuals and even entire species may be weakened or killed. Other ecological damage may occur, such as changes to a water course and hydrologic processes or soil contamination. However, once the actual disturbance event has finished, a process known as

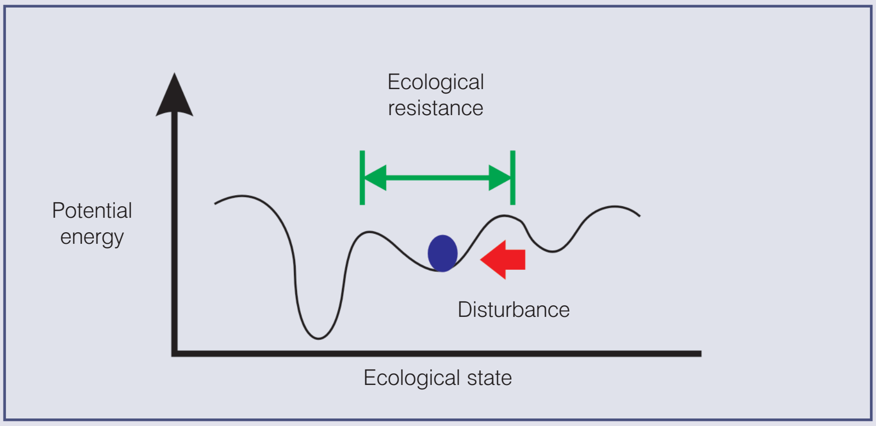

Fig. 1. Resilience of an ecosystem in relation with disturbance.

succession begins, which may eventually produce a similar ecosystem to the one that existed prior to the disturbance. Biological diversity depends on natural disturbance. Usually the success of a wide range of species, from all taxonomic groups, is closely tied to natural disturbance events such as fire, flooding and windstorm.

The Intermediate Disturbance Hypothesis is an ecological hypothesis which proposes that biodiversity is highest when disturbance is neither too rare nor too frequent. Resistance is the ability of an ecosystem to resist disturbances and resilience is the ability of an ecosystem to recover after a disturbance and return to its steady state (Fig. 1).

2. Natural disturbances

Unpredictable (episodic or sudden) droughts and floods are the most common natural disturbances for freshwater ecosystems. Droughts are caused by insufficient rain fall, precipitation, over an extended period of time and should be considered relative to some long-term average condition of balance between precipitation and evapotranspiration (evaporation + transpiration) in a particular area. Other climatic factors such as high temperature, high wind and low relative humidity are often associated with drought. With the onset of a drought there is a sequential decline in precipitation, run off, superficial stream flow, soil moisture and groundwater levels. In severe droughts whole sections of streams may loose any trace of surface water (Fig. 2). Streams and rivers loose their connection with each other and the ground water flow. Stream channels may become fragmented to a series of pools which can be either permanent and keep water during the whole drought period, or temporary and dry up. With reduced flow from inflowing rivers, estuaries can become disconnected from the sea and form lagoons, with low water quality which can deplete populations of estuarine organisms.

Sudden droughts are unpredictable in timing and duration and thus are more difficult for organisms to deal with. Organisms tend to be killed by these extreme events rather than being able to adapt to them over time, evolving coping strategies. Aquatic communities are characterised by adaptations to their watery environments. Since droughts are followed by falling water levels, the amount of habitats available for most aquatic species, are reduced. High densities of freshwater animals can be trapped in pools where factors such as high water temperatures, low oxygen and low availability of food, can be lethal for them.

Nowadays human action such as extended withdrawal of water together with climatic change, have resulted in long term droughts, which are common events in several places on earth today. Occasional or episodic floods also cause severe changes in the freshwater animal communities. A flood is a high flow or overflow of water from a stream, river or similar body of water. Flash or episodic floods are quick-rising floods that usually occur as the result of heavy rains over a short period of time, few hours or less. Several factors contribute to flooding. The two key elements are rainfall intensity and duration. Intensity is the rate of rainfall and duration as in how long the rain continued. Topography, soil conditions and ground cover, play an important role in predicting where flooding may occur. Floods can be devastating for aquatic communities as was seen when two

Fig. 2. Dry channel of Bramianos stream and of Koronia lake.
Photos by C. Voreadou, R. Jaskula

streams in Spain, La Rambla del Moro stream, belonging to Segura river, and Matarranya stream, belonging to the Ebro river catchment, flooded. In each case the population of aquatic macro-invertebrates was reduced by 97 -99 % and the number of taxa, plant and animal groups, was reduced to 32-40% of what had been present before.

Human action has worsened the consequences of excessive rainfall. Urbanisation, tarmac and paved surfaces along with general building sprawl, is one of the main aggravating factors of present day flooding. Many homes have been built on flood plains and rain no longer has access to the soil and can not sink into ground water.

Fig. 3. Flooding after fire in summer 2006, Halkidiki, Greece.
Photo by S. Mousterakis

Town and country planning regulations, and the urgent need for more homes, has often leaded to the use of flood plains for construction. Forty years ago such sites would never have been used and many countries have experienced dramatic flooding in such developments in recent years. Deforestation, clearing land for cultivation and fires, have also worsened the consequences of excessive rainfall. Over the coming years we may see more erratic weather patterns and more flooding as the effects of climate change become known (Fig. 3).

BOX I. THE MEDITERRANEAN AREA

In the area around the Mediterranean Sea, there are periodic seasonal droughts and floods (Fig. 4). Most of the streams there are also seasonal (see also chapter 3) with a drought period during summer time and flood period during autumn, winter or spring. These seasonal droughts and floods are not counted as disturbances because freshwater animals and plants can survive either phases due to physiological, morphological, behavioral or life-cycle adaptations. These cyclical droughts and floods are very important for Mediterranean streams. Just as in the case of permanent streams which can suffer the sudden episodic drought, some members of a seasonal stream fauna may be killed if stream fails to go dry one year or if the duration or sequence of the dry period is somehow altered substantially.

Fig. 4. Seasonal drought (with accumulation of leaf litter) and flood in a Mediterranean stream, Crete, Greece.
Photo by C. Voreadou

3. Man made disturbances

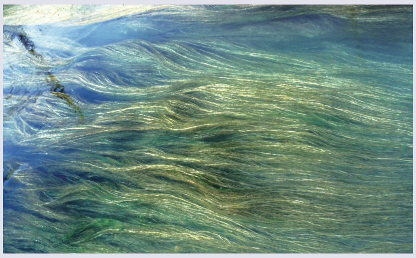

Fig. 5. Eutrofication in lake Kournas, Crete, Greece.
Photo by A. Trichas

Human activities cause a large set of effects such as the "greenhouse effect", the acid rain or the disposal of different organic and toxic pollutants to the water. In parallel the elevated water withdrawals for domestic, industrial and irrigation purposes together with the construction of dams or reservoirs can cause severe disturbances to freshwater ecosystems.

Fresh waters naturally contain chemicals dissolved from the soils and rocks over which they flow. The major inorganic elements include calcium, magnesium, sodium, potassium, carbon, chlorine, and sulphur as well as plant nutrients, such as nitrogen, silicon, and phosphorus. Organic compounds derived from decaying biological materials may also be present. Chemicals resulting from human activities that increase the concentration of specific compounds above natural levels may cause water pollution problems and are called pollutants. Pollutants can be taken up by plants and animals through contact with contaminated sediments, or directly from the water.

Modern agriculture depends on chemical fertilizers, pesticides, and irrigation to produce high-quality crops for animal and human consumption. To maximize the crop yield, nitrogen-based fertilizers are spread on the land. In addition, phosphorus and other essential minerals also may be applied where they are lacking or have been depleted in the soil. To

Fig. 6. Eutrofication in Aposelemis intermittent stream, Crete, Greece.
Photo by C. Voreadou

improve production, herbicides (to kill weeds) and insecticides (to kill insects) are frequently applied to crop lands. Not all of the fertilizers and pesticides stay where they are applied; consequently, some are released to the atmosphere, seep into groundwater, or are carried to lakes and streams as runoff, causing pollution problems. Pesticides, herbicides, and insecticides can cause toxicity, while fertilizers, which contain large amounts of nutrients (nitrogen and phosphorus) compounds, can result in eutrophication (Fig. 5, 6), the excessive growth of aquatic plants and algae. When these die and decay, breakdown of their bodies uses all the oxygen dissolved in the water, reducing the amount of oxygen available to fish and other aquatic life.

Industry is mainly responsible for the build-up of carbon dioxide and other gases in the atmosphere which is known as the "greenhouse effect" and which results in climatic change (Fig. 7). The accumulation of these gases is believed to have altered the earth's protective cover, resulting in more of the sun's heat

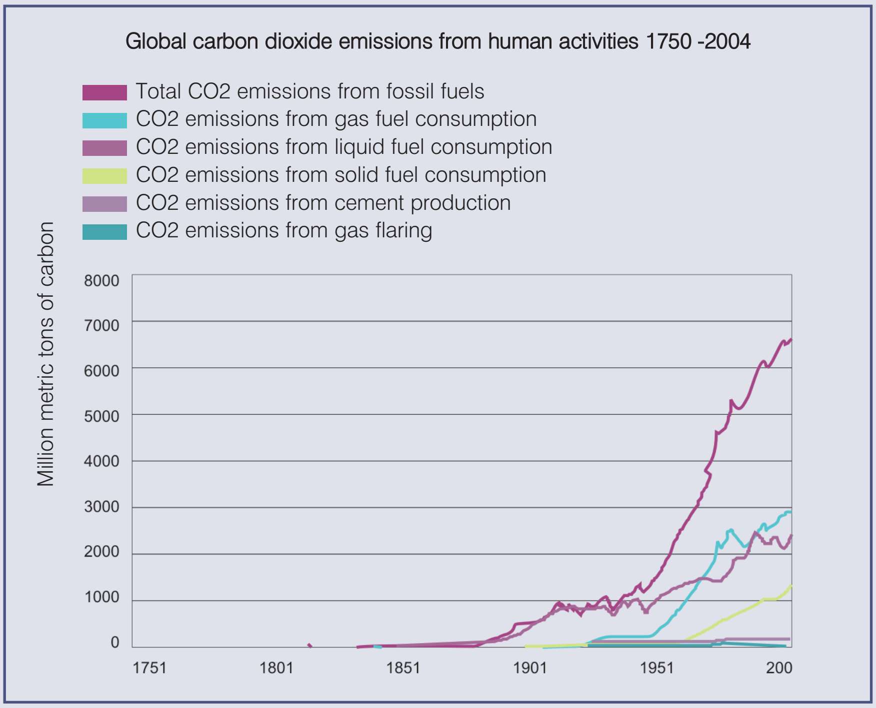

Fig. 7. Global CO2 emissions from human activities from 1750 till 2004.

being absorbed and trapped inside the earth's atmosphere, producing global warming. The higher temperatures and other factors, such as melting polar ice, will raise sea level. The sea is a tremendously important resource for us and some of the world's largest cities are on the coast. A change in sea level will affect these cities and coastal ecosystems like river deltas, wetlands, swamps, and low-lying forests, which play an important role in providing services for mankind, in addition to housing biological diversity.

Water pollution covers a large set of adverse effects upon water bodies such as lakes, rivers, oceans, and groundwater caused by human activities. Water pollution has many causes and characteristics. Sewage disposal causes also pollution problems to freshwater bodies since it also contains nutrients and toxic elements.

Industries discharge a variety of pollutants in their waste water including heavy metals, organic toxins, oils, nutrients and solids, resulting in water toxicity. Industry is also mainly responsible for acid rain or more accurately acid precipitation which is commonly used to mean the deposition of acidic components in rain, snow, dew, or dry particles. Acid rain occurs when sulphur dioxide and nitrogen oxides are emitted into the atmosphere, undergo chemical transformations, and are absorbed by water droplets in clouds. The droplets then fall to earth as rain, snow, mist, dry dust, hail, or sleet. This increases the acidity of the soil, and affects the chemical balance of lakes and streams. Acid rain causes a cascade of effects that harm, reduce or kill individual species and populations.

Another big issue for freshwater ecosystems are the elevated water withdrawals by humans for commercial, domestic, industrial and irrigation purposes. Irrigation is the largest category of water use worldwide. The excessive demand for water fuels the need to build dams, dig wells, and make withdrawals from our natural water bodies. New technologies in the industrial sector that require less water, improved, more efficient, industrials processes , increased water recycling, higher energy prices, and changes in laws and regulations, will all result in decreased water use. The enhanced awareness, by the general public, of water resources and active conservation programs in many countries both contributed to reduced water demands.

BOX II. POLLUTION AND MEDITERRANEAN AREA

The area around Mediterranean Sea is quite dry and rainfall over much of the land is highly variable, with extended drought periods during summertime. Surface fresh water bodies which are quite scarce, have a limited volume and quite often a temporal flow. Both surface and groundwater, although in many cases directly interlinked, have been severely degraded by human use. Pollutants from agricultural (Fig. 8), urban and industrial sources such as nutrients, chemicals, fertilizers and pesticides, have altered ecosystems' balance and have resulted in algal blooms with toxic effects and acute or chronic toxicity. Unfortunately, pollutants are not diluted in the Mediterranean area, as rainfall is minimal, so they have a more pronounced effect on fresh water ecosystem than would be the case in countries with more rain fall. For these reasons an intergraded management plan in accordance with the initiatives of the Water Framework Directive 60/2000 is essential for the Mediterranean.

Fig. 8. Olive oil mill wastes in a Mediterranean stream, Crete, Greece. Photo by A. Trichas

CHAPTER 6

PROTECTION AND SUSTAINABILITY OF FRESHWATER ECOSYSTEMS

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Freshwater ecosystems are the most endangered of all ecosystems. For centuries, river valleys and their associated floodplains have been occupied by human civilizations. But only recently we begun to understand the importance of freshwater ecosystems and how they function naturally, improving water, providing flood protection and erosion control.

Freshwater ecosystems are important elements of the drainage or catchment basins because they serve as a link between land and water resources. The functions of a freshwater ecosystem and the values of these functions to human society depend on a complex set of relationships between this ecosystem and the others into the catchment basin. Freshwater ecosystems store carbon within their soil and plant communities instead of releasing it to the atmosphere as carbon dioxide. Thus freshwater ecosystems help to moderate global climate conditions.

Freshwater ecosystems play an integral role in the ecology of the catchment basins. The combination of shallow water, high levels of nutrients and plants, is ideal for the development of organisms that form the basis of the food web. Many species of birds and mammals rely on wetlands for food, water and shelter, especially during migration and breeding.

Freshwater floodplains can provide water and fertile soils which in turn are used for agriculture in many areas of the world (e.g. rice is grown in rich fertile floodplain soils). Freshwater ecosystems are also used for wood production, fishing, hunting, boating, bird watching and other outdoor recreation.

Freshwater ecosystems are very rich in habitats and species and can include many species unique to a particular location (endemic species) (Fig. 1, 2). This is especially true in river systems which, in geological terms, are ancient habitats. Many species are endemic to specific freshwater ecosystems or to a region, and many are rare. Threatened freshwater ecosystems have lost more of their biodiversity, than ecosystems on land or in the oceans, and are in greater danger of further losses. Worldwide around 50% of freshwater ecosystems are estimated to have disappeared since 1900. During the first half of the 20th century, this mostly occurred in the northern temperate zones, however since the 1950s, tropical and sub-tropical freshwater ecosystems have also disappeared rapidly.

Freshwater ecosystems are very vulnerable because they depend on a constant re-supply of fresh water (rain) to sustain them. In many areas, such as the Mediterranean, water is becoming a scarcer and much coveted commodity.

Artificial drainage, the excessive extraction of groundwater, the construction of dams, is some of the threats that freshwater ecosystems face. Others include settlements and urbanization, pollution (including nutrient enrichment) and the invasion of foreign species often referred to as alien species. Over exploitation of underground water resources is widespread in some Mediterranean areas. This lowers the water-table to the degree that springs and seepages disappear - and with them the plants and animals dependent on these habitats. Other impacts, of an economic nature mainly, can of course be dramatic, as sea water intrudes into aquifers.

Plants and animals that inhabit wetlands are often dependent on a particular water regime, and may be affected by changes that upset well established ecological equilibriums. Even salt lakes need fresh water to function and maintain the delicate salinity cycles needed for the reproduction of the aquatic species that form the basis of the food chain. The Brine shrimp (Artemia salina), for example, needs water with low salinity at the beginning of the winter season, low enough to ensure that its cysts (eggs) hatch and restart the life cycle. If the salinity remains high, the Brine shrimp cysts do not hatch and the whole food chain is disturbed. Ultimately this would mean that the flamingos, which normally feed on the brine shrimp, will have no food and they will need to move on elsewhere - if they can. So if sufficient freshwater does not reach the salt lakes, the flamingos would have no food.

Freshwater ecosystems are the recipients of pollution, not only from point sources (factories etc) but also from diffuse sources, such as agriculture, with pesticides and fertilizers, running off the catchment basins to the lowest points - the rivers and lakes. Agricultural fertilizers can cause enrichment of water bodies, leading to the excessive growth of algae, known as eutrophication (Fig. 3), which can result in oxygen depletion, anoxic con-

Fig. 1. Campanula pelviformis, an endemic species in Crete, growing close to rivers.
Photo by M. Avramakis

Fig. 2. Pelophylax cretensis, endemic to Crete.
Photo by A. Trichas

Fig. 3. Excessive growth of algae in a stream.
Photo by C. Voreadou

Fig. 4. Procambarus clarkii. An alien species which has invaded many water bodies in Cyprus.
Photo by A. Demetropoulos

ditions and, eventually, habitat and biodiversity losses.

The rehabilitation of degraded or destroyed freshwater ecosystems to their original status may well prove impossible, especially of course when endemic species have been lost.

The introduction of foreign species, (alien species), to a particular freshwater ecosystem can cause havoc, as has been seen many times. Some alien species are invasive, i.e. they can spread very quickly in a new ecosystem which has no natural predators to hold them in check. Some of the worlds' worst invasive species are aquatic (the Mosquito fish, the Red-eared slider terrapin, the Bull frog, the Louisiana crayfish and some aquatic snails). What makes such invasions worse is that in aquatic ecosystems such invasions are practically impossible to control; eradication is not a feasible option. In other words once an alien species invades a new water ecosystem it is there to stay. This has been proven in many cases in both freshwater and marine ecosystems (Fig. 4).

There are well known examples such as the water hyacinth and the Nile perch in Lake Victoria in Africa, and of two algae, Caulerpa taxifolia and Caulerpa racemosa, in the Mediterranean. The Nile perch is a large freshwater fish which can grow to 200 kg and two metres in length. It was introduced to Lake Victoria in 1954 where it has contributed to the extinction of more than 200 endemic fish species through predation and competition for food. The Louisiana crayfish (Procambarus clarkii) is now a pest in many water bodies in Europe. This occurs especially in the warmer southern countries where its introduction is causing dramatic changes in native plant and animal communities. The Louisiana crayfish has taken over from local species but has no natural predator to control its numbers. It is a particular pest in rice cultivations causing economic losses to that industry.

Bearing in mind the examples above and understanding the various threats to freshwater ecosystems it is obvious that the threats vary from country to country and from region to region. However there is a common realisation that freshwater ecosystems are the most endangered and that they are being lost so rapid that governments have to cooperate in order to set up a series of actions. On a global level an international agreement or treaty - now known as the Ramsar Convention - has spearheaded the conservation of freshwater ecosystems (referred as "wetlands" in the Convention). The official name of this treaty - The Convention on Wetlands of International Importance especially as Waterfowl Habitat - reflects its original emphasis on the conservation and wise use of freshwater ecosystems, primarily to provide habitat for water birds. Over the years, however, the Convention has broadened its scope to cover all aspects of freshwater ecosystem's conservation and wise use, recognizing freshwater as ecosystems that are extremely important for biodiversity conservation in general and also for the well-being of human communities. For this reason, the treaty is more popularly known as the "Convention on Wetlands'.

The Convention was adopted in 1971 in the Iranian city of Ramsar and came into force in 1975. As of 1st May 2003 it had 136 Contracting Parties. More than 1280 freshwater ecosystems have been designated for inclusion in the List of Wetlands of International Importance, covering some 108.7 million hectares (1.87 million km2), more than the surface area of France, Germany, and Switzerland combined (BOX I).

Concerned by wetland losses in the Mediterranean, organisations and countries have set up the MedWet Initiative. This operates under the Ramsar Convention, and is a long term, collaborative effort towards the conservation and wise use of Mediterranean freshwater ecosystems (referred also as "wetlands" in the Initiative). MedWet brings together all governments of the region, the Palestinian Authority, UNDP, the European Commission, the Barcelona, Bern and Ramsar Conventions, NGOs (Non Governmental Organizations) and Freshwater Centres. The goal of the Mediterranean Wetland Strategy is "to stop and reverse the loss and degradation of Mediterranean wetlands as a contribution to the conservation of biodiversity and to sustainable development in the region".

The protection of water ecosystems and their wise use, aimed at by these agreements, are of course not simple issues. Current policies for example in the use of freshwater reflect political priorities and realities, with economic and social concerns in the forefront of political thinking. Water pricing policies often reflect this. Water for the conservation of biodiversity has only become an issue in the last few decades, so is a new comer to political agendas. The major issues in freshwater availability and demand in the Mediterranean region are well known. They can hardly be overlooked. Water is a

BOX I. RAMSAR SITES IN CYPRUS

Two Ramsar sites have been declared in Cyprus: The Larnaca Salt Lake and the Akrotiri (Limassol) Salt Lake. Both are seasonal lakes which usually host thousands of flamingos (Fig. 5, 6) as well as other waterfowl.

Fig. 5. Larnaca Salt Lake was the first Ramsar site in Cyprus.
Photo by A. Demetropoulos

Fig. 6. Brine shrimp cysts (eggs) on the shores on Larnaca Salt Lake. When they hatch they provide food for the flamingos and other birds.
Photo by A. Demetropoulos

Table 1

scarce and precious commodity which is becoming scarcer as demand increases with population growth and associated higher standards of living, agricultural needs and tourism.

The reduction of nutrients entering freshwater ecosystems is no simple matter. It requires water discharge "upstream" to be cleaned up and agricultural run off to be reduced. Sewage outputs and other effluents must be returned to the environment as clean water. In recent years 'the polluter pays' has become a standard phrase emphasising that it is industries' responsibility to return water in the same clean state as they extracted it.

Education, public awareness and public participation will help and can influence political thinking and decision making. There are many stakeholders. Some of the mistakes made in the past were obviously the result of lack of knowledge and in many cases different priorities. The eradication of malaria in some areas in the Mediterranean, for example, was understandably a priority in the 1950s. The drainage of "swamps" and the use of insecticides, such as DDT, helped - but created a set of different problems, diagnosed decades later. Greater knowledge, newer technology and better understanding of processes have led to more effective alternatives to deal with such issues. Many harmless species are now backing from the brink of extinction as a result of these more modern approaches. More effective water pollution control has lead to healthier aquatic ecosystems (Fig. 7).

Fig. 7. Hyla savigny - a tree climbing frog which, like the other frogs on the island, have largely recovered from the use of DDT. It is now a fairly common species in some parts of Cyprus, though it is still vulnerable.
Photo by A. Demetropoulos

Greater knowledge, newer technology and better understanding of processes have led to more effective alternatives to deal with such issues. Many harmless species are now backing from the brink of extinction as a result of these more modern approaches. More effective water pollution control has lead to healthier aquatic ecosystems. A great deal is being done now, in Europe and in the Mediterranean basin, not only to safeguard freshwater (and marine) bodies from further deterioration but also to reverse the process. Appropriate national legislation in the EU countries is mandatory. All EU countries must comply with EU Directives and norms - and implementation of new standards is progression. Education and improved public awareness (Fig. 8) are inevitably raising the benchmark - but of course much more is needed.

Fig. 8. Education plays an essential role in the protection of freshwater ecosystems.

The "wise use" of freshwater ecosystems motto of the Ramsar Convention implies that these ecosystems can be used - but used wisely. The Ramsar Convention definition of "wise use" is: "The wise use of wetlands is their sustainable utilization for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem." This definition was considered to be synonymous with "sustainable use".

The 'Wise Use Guidelines' call upon Contracting Parties to the Ramsar Convention to:

▪ adopt national freshwater policies, involving a review of their existing legislation and institutional arrangements to deal with freshwater matters (either as separate policy instruments or as part of national environmental action plans, national biodiversity strategies, or other national strategic planning);

▪ develop programmes of freshwater inventory, monitoring, research, training, education, public awareness and

▪ take action at freshwater sites, involving the development of integrated management plans covering every aspect of the freshwater ecosystems and their relationships with their catchments.

Fig. 8. Education plays an essential role in the protection of freshwater ecosystems.
Photo by C. Voreadou

ART AS AN INSTRUMENT FOR CHANGE

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In this chapter a methodological proposal is presented to apply drama techniques in the environmental education as a part of the process which will lead to an attitude change regarding the domestic management of water supply.

This proposal is included in a teaching pattern called environmental education through the art, which is the basis of the teacher training courses within the Regional Programme of Environmental Education through the Art of the Algarve Regional Education Directorate, Portugal.
The activities mentioned below are practical procedures that use games and simulations only with pedagogical goals. These activities give the opportunity to use one's own personality skills in order to represent and express oneself, creating material that will be later used within the group; these activities imply the use of one's imagination, memory and the capacity of bringing to the present old experiences or to plan future actions.

There are many drama techniques for the environmental education in connection with art. However we have considered these which are related to environment topics, namely games and dramatization:

games: imply body movement, voice, creativity and emotion which help the group to unblock its inhibition, lead to funny situations and create an appropriate atmosphere throughout the session; the aim of the games in the teaching process is to make students understand more easily what we want them to present.

dramatization: to dramatize is to give a dramatic structure to something that, a priori, hasn't got one; it is an action which takes place at a certain time / in a certain space with some characters. We can perform a play / dramatize a text, a story told by someone using sounds, objects, characters and so on.

The methodology we are presenting uses a sequence of drama techniques in order the students to be able to face their own attitudes regarding certain environmental aspects. In this way, the proposed methodology contributes to a possible change of their thinking and behaviour towards these environmental aspects. This would be possible by creating a product and presenting the result in an artistic way.

The different stages of this process are related to certain activities and have specific aims:

Stage 1: sensitization / approach to the topic

To motivate and to help students become aware of the topic to be handled in the session;

Stage 2: create characters

To confront the students with their personal opinions and the others' opinions and find out their reference board. Come up with ideas that lead them to make up contexts.

Stage 3: create art expression products with a specific message

First: to create proposals of a drama structure based on imagined characters. Second: the group decides which art expression product(s) they want to present based on the already created drama structure: rap song, hip - hop or another one, choreography, happening, tale, radio programme, radio theatre, cartoon, comic strips, setting, film script and so on.

Stage 4: intervention proposal / public presentation and evaluation

First: the group decides the best way for each person to put into practice the behaviour they think is best; second: the group decides how the public presentation of their work would have more impact; third: the group decides the best way to present it to the community and to evaluate it.

Stage 5: presentation / work discussion

Everyone will be invited to show their work; the discussion will take place after the presentation. The viewers make their statements before the people in the group so that it is possible to see up to which point the message was made clear.

Stage 6: conclusion

The students tell the group how they felt during the session, what they thought of the creative process, their points of view regarding the topic and the importance and possibility of putting the results of their work into practice. It is intended that they get a critical attitude, synthesizing capacity and become conscious of their own position when it comes to the environmental topic.

1. Activities

Now we will present proposals of activities to be accomplished during these stages, in a working session dedicated to the topic of domestic management of water supply:

Stage 1: sensitization/approach to the topic

In the beginning of the session, the coordinator asks participants to enumerate daily behaviours in our homes that would take to a waste of potable water, to set the group subject to the context of the expected objectives. With these examples it's easier to be in the atmosphere of the thematic and thus granted with immediate material to be used on the next activities.

Examples of:

- to fix the leaking taps
- to turn off the tap while you brush your teeth or soap your hands
- to have a shower instead of taking a bath
- to use the washing machines only when they are totally loaded
- to put a litre and a half bottle of water into the toilet flush
- to water the gardens either in the morning or in the afternoon, in order to

avoid evaporation in between 12 pm to 3 pm

- to cover the swimming pool to avoid evaporation
- to wash the car with a bucket, not with the hose

- Alice in the Water land

All participants form a circle and each one is asked to introduce himself / herself using a composition in rhyme using is name and a word related with water like "Alice in the Water land". When he/she says his/her rhyme, he/she should step forward and gesture, then should step backwards and take his/her place in the circle. Afterwards all participants should imitate him/her. The exercise can be repeated just with choreographic movements and music.

- The chairs game

In the centre of the room you put less number of chairs than the number of participants. The coordinator asks everyone to walk around the chairs using the body to express his proposals, e.g., walk as if you were rain drops touching dry land. When the coordinator claps, it means "sit down". Participant(s) that didn't manage to sit on a chair, will not play again, and this will be repeated successively until two chairs remain in the room and thus you decide who the winner is. Suggestions for the "walk" between the chairs: Persons could be:

- water drops falling down rapidly from a not properly turned off tap
- showering and while soaping themselves the tap is turned off
- water drops being evaporated at noon
- water drops "travelling" through conducts that unify a dam to the tap of the science lab of the school
- high pressured water drops sprayed from a break in a distribution conduct

Stage 2: to create a character

- Brain storming

The "brain storming" is applied to the creation of characters that caricature specific behaviours. The coordinator asks each student to record on a piece of paper one of the behaviours that were defined on the first stage as contribution towards a better domestic management of the water, for instance, to fix taps that leak.

Afterwards he asks to record individually the first ideas that come to their minds about a character that is obsessed by this behaviour or by an opposite behaviour, for instance, by the idea of fixing taps that leak or by placing leaking taps. The coordinator will slowly communicate the following list, in order to originate and write down ideas: name, nickname, age, religion, physical and psychic characteristics, why is the character worldwide known, which was the childhood trauma that has determined his / her "obsession", the name of his / her worst enemy, where he/she is now and doing what.

There is no problem if some of the participants cannot answer all the parameters: the goal of this technique is to originate ideas to build up a character and his/her enemy. Ideas originate others, they're all good and the more different they are, the better. The first character to be created, the "enemy" or the "guardian", the "good" or the "bad", is determined by its author that introduces him / her to the class. The second character can be deeply characterized when the story is being brought up. Making up a character can be done through analogy: to select a famous duo hero / villain, to characterize it according to the parameters mentioned above, and at the same time, to create a strong and coherent new duo related to the message you want to work on.

When everybody is done, the coordinator will give some free time so each participant can put up a character from the information given in the paper. Finally, he asks each character to be introduced to the class by his author.

For instance, Walter Flush is a big and fat flushing who has fun flushing water down, and therefore he spends his whole day pushing his own button... He feels very proud to know that he is responsible for the biggest waste of potable water in the house! He is the only one to face Captain Litre and a Half that with his bottle shaped body throws himself inside Walter Flush to make him save one and a half litre in every flushing down.

- creative language games

To find creative names for the characters:

In a rain of ideas ask students to write down words that are related to the place associated to the image to be transmitted. For instance, if it's about "fixing leaking taps", one has to do a rain of ideas with places where there are taps, such as the bathroom. E.G: wash basin, bidet, water flush, brush, shampoo, shower, soap, light, toilet brush, towel, and so on. Then a selection and association of the words could be done, e.g. Miss Little Tap; it is also possible to divide them and put different parts together, e.g. Don Show Shower.

Stage 3 - to create products of artistic expression with a message

Participants are organized into groups according to the topic affinities of their characters. In each group there is:

1. a clear and determined message;
2. characters;
3. conflict;
4. space/time;
5. script;
6. means of expression.

Example:

1. clear and determined message: to reduce the waste of water by putting a bottle of one litre and a half inside the flushing.
2. characters: Captain One Litre and a Half and Walter Flush
3. the conflict: Captain One Litre and a Half with his bottle shaped body throws himself inside Walter Flush, forcing him to save one litre and a half in each discharge of water
4. space and time: in our own house
5. the script: action sequence, from the time that Captain One Litre and a Half arrives home, goes to the bathroom and manages to open the upper cover of the Walter Flush without him noticing it...
6. means of expression: radio theatre and cartoon

- To tell a tale in group

After the definition of the above mentioned parameters each group has a story to tell collectively. The different parts of the tale are attributed to each participant and they tell it in group, forming a circle, randomly distributed between the presents in the session.

Stage 4: suggestion for intervention/ public presentation and evaluation

The group defines behaviours for each of the elements and the way it will be disseminated to obtain results.

In this example, the participants commit themselves to put a bottle of water in their flushing and to create a leaflet and mail it to all the houses of their town. In this leaflet is suggested the use of the bottle and subsequent record of the number of discharges of water during one week. It is requested that the filled in leaflet would be sent to the school for a calculation of the volume of saved water.

Stages 5 and 6: presentation/ work discussion/ conclusion

The work is presented, discussed and selected according to a strategy of local intervention defined by the group. For instance, a session of tales is presented to the community, where the created tales and their results obtained from concrete actions regarding the savings of the water are presented.

2. Conclusion

The mentioned methodology helps, firstly, to raise the awareness, that means, the students and the teachers discover the students' reference boards facing up a determined environmental topic. Playing brings up emotions that are not subjected to the webs of the critic.

Secondly, there is the discussion of what path to follow and suggest it to ourselves and the others as a way of changing. That is the message being handled creatively and the artistic product that comes out is presented to the community.

Finally, the evaluation is done and the results disseminated.

When the student presents an art project that is part of him, he feels part of a group, with an identity, with a place, with value. By performing and suggesting an action towards sustainability, the student becomes a social protagonist.