ECOLOGY AND ECOSYSTEMS 3

Wooded meadows are among the most diverse ecosystems in the Baltic Sea region. In this wooded meadow in Estonia up to 70 species of plants were found in a single 1 x 1 meter plot. The number of species of fungi depends on the diversity of vascular plants, which in turn are important as fodder or dwelling-places for insects, snails and slugs. Vascular plants and invertebrates in turn have important roles in food chains, which very often terminate with birds or mammals. (Photo: Heiki Luhamaa.)

”I saw the boundless, omniscient and almighty God from the back, as he went forward, and I felt excited! I followed his footprints over nature's domain and noticed from each one, even those that I could hardly make out, an unlimited wisdom and power, an unfathomable perfection. I saw there how all the animals are maintained by the plants, the plants by the soil, the soil by the Earth; how the Earth revolved day and night around the sun, that gave it life.”

Carl Linneaus. *Systema naturae*, 1745.

The term *ecology* is today widely used to denote any context that refers to ”environmental” or protection of the environment: We belong to ecological clubs, buy eco-labled products or read ecological magazines. This use, if nothing else, demonstrates that ecology is of key importance in the field of environmental studies, but does not explain what it is. This is, however, what we will do in this chapter.

Ecology is, strictly speaking, a field of biology. The environment and the species living in it make up the *ecosystems*, which are studied by ecologists. Ecology describes the detailed connections between the environment and the life forms and how different changes will influence the balances of the ecosystems and the life conditions for its members. It is a key science for those concerned with both natural and man-made changes in the environment. It is only by knowing how the whole system works that we are able to understand how changes in non-living, abiotic, factors, such as pollution or intrusion, will effect a community of organisms.

To give a complete coverage of all ecosystems and the biology of the Baltic region is impossible within the limited number of pages we have. We will limit ourselves to basics of ecology relevant for environmental science, and the ecosystems and biology of the Baltic region. A brief presentation of the main biological areas the of the Baltic Sea basin, the ‘biomes,’ from the northerly mountains, over the fields and forests in the south, and to the shores of the Baltic Sea will add to this picture.

The northern half of the Baltic region was covered by ice during the most recent ice age, and was colonized rather recently, only a few thousand years ago. The species and ecosystems thus did not have much time to adapt to the conditions and many species live on the fringe of their capacity. This part of the region is also rather poor in species compared to the ecosystems further south. This circumstance also makes the species living here more sensitive to additional stresses caused by environmental impact, which is very clearly illustrated by the Baltic Sea systems.

In the more densely populated southern part of the region on the other hand, landscape changes dominate large land areas. Especially earlier, these areas were very rich biotopes. Today more recent man-made ecosystems such as urban regions, and regions dominated by more or less industrialised agriculture, exclude many species that formerly were typical. Again many species live on the fringes of their capacity, now due to man-made changes.

Obviously, since man is a species and, as was described in chapter 1, man and society can be included in ecosystems – the study of which is refered to as human ecology. This will be the topic for the last chapters of the book. Here we will focus on non-human life forms, bearing in mind that the world does not only belong to us but also to our fellow living beings.

Authors of this chapter

Håkan Rydin, the sections on ecology; Urban Emanuelsson, the description of the vegetation zones in the region; Lena Kautsky, water habitats.

Ecology and ecosystems

The hierarchies of ecology

Biological change

Flows of energy and matter in ecosystems

Biology and biogeographical zones of the Baltic region

Habitats

The hierarchies of ecology

Biology and environment

Life on Earth, the inhabitants of the biosphere, are the many millions, even tens of millions of different species of animals, plants and microorganisms. In the Baltic Sea region, species diversity is not the largest, but still there are several hundred thousand species. This is what environmental protection is all about: to protect and safeguard the living conditions for all those, one of which is *Homo sapiens*, man, ourselves.

It may seem too much to make order out of this extraordinary diversity. It is, however, the task for the biological sciences. Systematic botany, zoology, entomology and so on describes, systematizes and gives scientific names to species; physiology describes how each of the organisms functions; and ecology describes how they relate to each other and to the environment. In this chapter, we will both study the most important individual environments, or biomes, and their specific and typical plants and animals, as well as the living world as a system.

Both the physical, abiotic environment and individual plants and animals are affected very differently by environmental impacts. It is important to keep track of what is going on in nature. Scientists such as botanists, zoologists, ornithologists, and entomologists observe and monitor the changes that occur. Monitoring is a basic part of environmental studies and is an important role of scientists as well as amateurs. However, data by themselves are not sufficient. The science of ecology can often provide an explanation of phenomena, such as why a species disappears or increases dramatically.

The Baltic region biology is special for several reasons. The recent – in a biological time frame – glaciation is one reason why diversity is not so large. Evolution and colonization after the retreat of the ice is still taking place. The Baltic Sea is a quite unique brackish water body, as is described in Chapter 5.

The plants and animals of the region are sensitive to environmental changes in very different ways. Many species live close to the margins of their possibilities and are especially sensitive. Species-poor ecosystems, such as the Baltic Sea, have few options for adaptation to or absorbtion of changes. It is important to understand these facts to be able to protect the living world from environmental destruction.

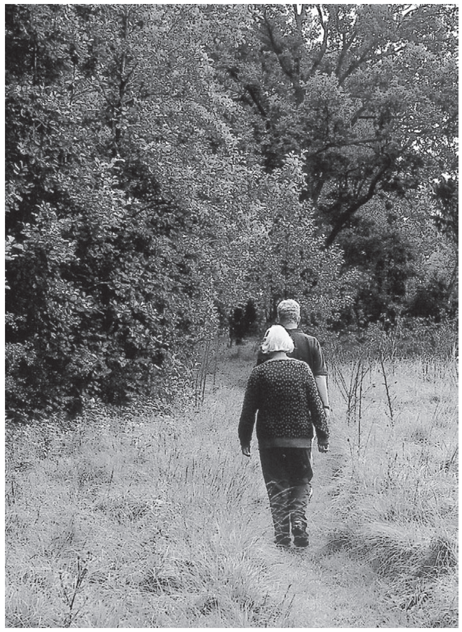


Figure 3.1. The pleasure of being in nature is even more fulfilling if we know more about how the living world works, and how plants, animals and their environment interact. This is studied in ecology, a science that is essential to environmental protection. (Photo: Lars Rydén.)

What is ecology?

What is ecology? Today the word ecology is encountered in "ecological products" and "ecological movements," but the original definition of the word stresses that ecology is a science – a branch of biology: Ecology is the study of the relationships between organisms and between organisms and their environment. The German scientist Ernst Haeckel introduced the term more than a hundred years ago.

Knowledge and understanding of ecology are fundamental aspects of environmental science. The role of ecology in understanding and solving environmental problems is to assess and predict the consequences of various human activities. However, ecology as a science will not tell us what is right or wrong. Ecologists may, for instance, predict that a certain bird species will become extinct, or try to predict what would happen if a certain genetically modified organism is released into nature. Whether or not action should be taken to prevent this extinction, or whether or not creation of this genetically modified organism should be permitted is then a political and ethical question.

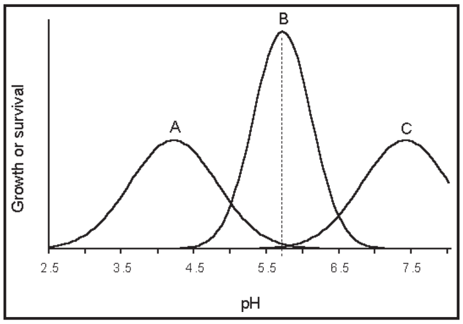


Figure 3.2. The ecological niche. The three hypothetical species differ in their tolerance to pH. Species A and C are generalist, having broad niches. Species B is more specialised, but has a higher growth rate at its optimum (dotted line, pH 5.7). Species A and B have high niche overlap, whereas A and C show niche separation. For a complete picture it is also necessary to know the requirements for or tolerance to other factors. For instance, species A and B may have different light requirements. (Drawing by Håkan Rydin.)

Where and how organisms live – habitat and niche

The environment which a particular species occupies is called its habitat. An example of a habitat for many small water-living crustacean animals is the "forest" that is formed by bladder wrack seaweed on the bottom along the Baltic coast. A typical habitat for some warbler bird species is an oak forest, whereas the magpie often has an urban habitat.

The habitat of an organism is where it lives. If we want instead to describe more exactly how, or under what environmental conditions, it lives, and how it utilises the environment, we need to describe its niche. Broadly, the niche of a species describes its function. One part of the niche is the species' exact requirements and tolerance to particular conditions, such as pH or light (Figure 3.2). Such descriptions tell us e.g. whether a species is a specialist or a generalist. This knowledge is of prime importance for understanding how vulnerable it is to environmental changes. Descriptions of niches also show how similar species are in their utilisation of resources. Species that have very similar requirements are said to have overlapping niches. This means that they are likely to use the same resources and therefore also compete with each other if these resources become limited.

The description of the requirements of various species is called *autecology*. In the early days of ecology, autecology developed as a more exact form of natural history studies. Detailed knowledge of the autecology of species is now an important basis for the Red Data Books, which for each country assess the risk of extinction for plants, fungi and animals. The Red Data Books consist of expert judgements of the risk of extinction within a certain time, if no actions are taken. The criteria used have been developed by the International Union for the Conservation of Nature (IUCN), and are the same in all countries, which allows comparison. Ecologists and amateur naturalists co-operate today to assemble the autecological data required to assess the risk for thousands of species.

Ecophysiology is also important for environmental studies. This is the study of physiological processes in the field, or outdoors, in contrast to physiology, which is more of a laboratory science, indoors. Chemical compounds, that spread in the environment by wind, water, etc., interact with several abiotic (non-biological) factors, which moderate their properties. It is therefore necessary to investigate their effects in the ecosystem – one cannot fully predict their effects from laboratory studies. Ecophysiology is the study of mechanisms by which an organism in its natural state is affected by different kinds of pollution, such as acidification or nitrogen deposition.

Ecotoxicology is related to ecophysiology and deals with the detrimental effects of toxic pollutants, e.g. heavy metals and herbicides, on plants and animals in their environment.

The hierarchical levels in ecology – individuals, populations, communities and ecosystems

It is convenient to view nature as hierarchically organised (Table 3.1) and study patterns and processes at different scales.

The basic unit is the individual, characterised by its age, size and sex. All individuals of a species within a certain area, for instance all warblers in the oak forest, constitute the population. When studying the population we want to know how many individuals it consists of, its age and sex distribution and if the population grows or declines over time. All populations in an area together form a community. Often, plant communities and animal communities are considered separately.

The complex natural systems of which living organisms are parts are termed ecosystems. An ecosystem includes not only the organisms, the biotic

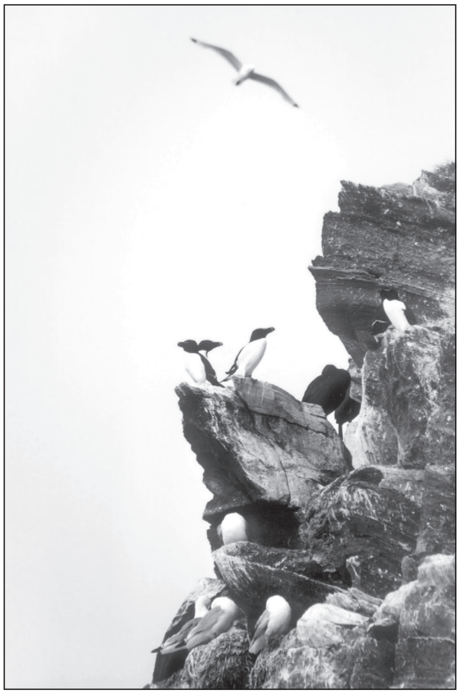
Level of organisation	Characteristics / Processes
Individual	Age, size, sex, growth, reproduction
Population – all individuals of a species in a defined area	Density (number of individuals per unit area), age and sex distribution, growth rate, mortality, intraspecific competition (competition between members of the same species)
Community – all populations in the area	Diversity (number of species), commonness and rarity of different species, interspecific competition (between different species), herbivory, predation
Ecosystem – the community and the non-living environment	Biomass, soil type, microclimate, nutrient status and other matters, flow of energy, circulation of nutrients

Table 3.1. Characteristics and processes at different levels of the hierarchical organisation in ecology.

community, but also the several non-living, abiotic, components of the environment within which the organisms are found. Most importantly, it includes all the interactions that bind the living and non-living components together into a functioning system. Ecosystems are open entities – organisms migrate between ecosystems and there is an exchange of nutrients and energy across ecosystem borders. This means that ecosystems are not concrete units that we can observe in nature. Instead, we draw rather arbitrary borders to define units that are convenient to study. An ecosystem can be a forest, a pond or a bay. The whole Baltic Sea can also be thought of as one ecosystem. The catchment area, relevant for environmental studies, is a concrete unit in terms of its hydrology, and to some extent, of its ecology.

Each level in this hierarchy has its own characteristics and there are different processes acting at each level. To explain patterns and processes at one level, such as the population, we often need detailed information on the next lower level, i.e. the individuals comprising the population. However, we also say that the units in ecology have emergent properties, which means that all characteristics of one level cannot be predicted from knowledge of the lower levels. The automobile analogy may be used to explain the concept of emergent properties: to understand how an engine works you must know how its different parts function. However, if all the springs, bolts, nuts and other parts are spread out on a table, there is no way of understanding how the engine works. You also need to know how it is assembled.

Figure 3.3. Populations and communities. The many thousand individuals of a bird species living on a bird cliff is often a clear case of a population, since they are far away from the next breeding place for the species. All the populations on the cliff constitute a community. Typical bird cliffs, otherwise only found in the large oceans, have formed in the Baltic Sea on two small islands immediately west of Gotland, the larger and smaller Karlsö. Razorbills, however, are also found on rocks along the entire Swedish and Finnish coasts. (Photo: Ewa Boklak.)



Biological change

The individual – reproduction and evolution

The genetic characteristics of the individuals in a population change over generations, as a response to a changing environment. This is the process of evolution. How does this occur? Charles Darwin developed the theory of evolution by natural selection in the middle of the 19th century. The basis for the theory is that individuals differ in morphological or physiological characteristics. At least some of these differences are genetic, and can therefore be inherited. The differences will influence how many descendants they leave. Some individuals will leave more descendants to the next generation than others, and their characteristics will become more common in the population.

The reproductive success of an individual is in evolutionary terms referred to as its fitness. This is its contribution to the number of individuals in the next

Figure 3.4. Migrating birds over the Baltic Sea. The Baltic region bird fauna has a very large share of migrating species. Migration is a mixture of learned and inherited behaviour. Over the about 10,000 years after the last glaciation many bird species have adapted to migration in the region, to make best use of the living conditions in the north and over-wintering conditions in the south. If it is connected to a genetic change in the species – changed gene frequency or changed genes – it is evolution. But many short time changes, for instance selection of migration routes and areas, have been shown to be learned behaviour. This is now used to save species that are threatened by extinction in some areas to which they migrate, in particular in southern Europe. The stork, here living on a pole at the Lithuaninan-Polish border, spend the winter in northern Africa. (Photo: Lars Rydén.)

generation, relative to the contribution of other individuals. It is important that this is expressed in relative terms – in order to have high fitness, an individual must not only raise many young, it must also raise more young than the other parents. Fitness is not simply a description of the genetics of an individual; instead it is determined by the interaction between the individual and the environment. Characteristics that give high fitness in one environment may be of little value in another environment.

A classic example of rapid evolution is the peppered moth in England. This insect species rests on birch stems and its light colour makes it difficult to detect for predators. Coal burning during the industrial revolution made the birch stems become darker by soot, and the light moths became easy targets. However, some moths happened to be darker, and since this attribute was inherited such individuals had higher fitness. We say that there was a selection for dark colour, and soon dark coloured moths were common. When coal burning ceased the advantage shifted again to the lighter form.

A more unfortunate example with environmental implications is the development of resistance to DDT and other pesticides. In an environment where DDT has been sprayed normal individuals leave no descendants at all while resistant individuals will survive. They thus have very high fitness, and resistance will spread rapidly.

Two things are important to remember. First, for any natural selection to occur some genetic variation must exist among individuals. So, in the case with the peppered moth there must have been genes present to form darker individual all the time, or they occurred as a result of a mutation, a random genetic change in some individual. In the pesticide case, mutations obviously have occurred. Secondly, the unit of evolution is the individual and its genes: evolution occurs because some individuals are more successful than others in leaving descendants.

Then why is it that pollution and toxic compounds such as DDT has almost led to the extinction of species such as the peregrine falcon? Why have they not developed resistance? To develop resistance a species needs to have a short generation time and produce many offspring, features typical for insect pests. For species with long generation time and few young (as the peregrine falcon), there is simply a very low probability that the right mutation occurs and resistance would also spread too slowly.

Evolution leads to adaptation, which means that the organism becomes suited to a particular environment. But there are limits to adaptation. When a species encounters circumstances that lie outside its capacity for evolutionary adaptation, it is forced to migrate from the area or it will become extinct. Today, pollution and other environmental disturbances add to the normal ecological factors that a species has to deal with. At present, human beings are changing the environment faster and differently than natural changes. The result is a higher extinction rate of species than during any earlier period in the history of life on earth.

The population – fluctuation in number of individuals

Population ecology deals with questions on what regulates the number of individuals in an area. For a rare, decreasing species the focal question may be why their reproduction is unsuccessful. For an expanding species, we might want to know at what population size competition among individuals will be so severe that it will balance the large reproductive capacity. This population size is referred to as the carrying capacity: if the population becomes larger, mortality increases as an effect of competition for a limiting factor, such as food. If the population becomes smaller, then reproduction will increase and the population will again approach its carrying capacity.

The pattern of population growth looks quite different in different types of organisms (Figure 3.5). Some species most of the time have a population size that fluctuates around the carrying capacity. This means that density-dependent processes, such as mortality caused by crowding, is common. Such organisms are referred to as *K* species, where *K* stands for carrying capacity. Typically, they are long-lived species that have few offspring but invest much nutrients and energy in each one of them. For plants this means that they may have large seeds, and for birds they may have few, large eggs and spend long time caring for their chicks. The peregrine falcon is a species that is an example of the *K* strategy.

Other organisms are characterised during favourable times by rapid (exponential) population growth. This is followed by a "crash" when most individuals die because of environmental stresses such as weather. These organisms are *r* species, where *r* is the parameter describing the population growth rate. Consequently, they have a rapid population growth (high *r*), which they achieve by producing many seeds or eggs. The cost of this strategy is that they can not afford to spend much resource per offspring, and they have therefore small seeds or eggs and less developed care for their young. They also characteristically have a shorter life span.

The *K* and *r* species represent end points in a continuum and all sorts of compromises between them are found in the flora and fauna. However, arable weeds and pests, as in the DDT resistance example above, are typical examples of *r* species. For them, mortality caused by crowding is not so important. Detailed knowledge of the population ecology of weeds and pests is crucial to be able to minimise the use of pesticides. At the right time of their population growth a small dose of pesticide might prevent their expansion and avoid the need for much larger doses later.

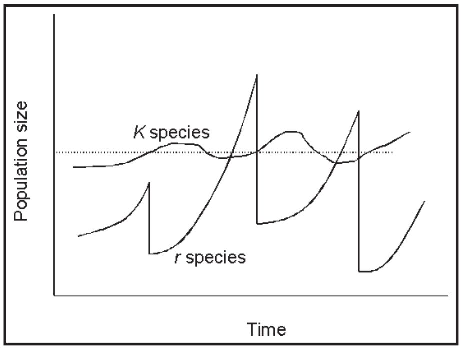


Figure 3.5. Population dynamics. Change in population size over time in two hypothetical species. The *K* type species shows rather small fluctuations around its carrying capacity (dotted line), while the *r* species (for instance an arable pest insect) has periods with rapid population growth interrupted by environmentally caused crashes. (Drawing by Håkan Rydin.)

The community – diversity and interactions

Community ecology focuses on species diversity and interactions among species. Theories why some communities are rich in species and others are species-poor are essential for efficient nature conservation practices.

An example of differences in species diversity is that the brackish Baltic Sea is less species rich than the saltwater Atlantic. Over evolutionary time, large brackish water bodies have not existed for long periods or over large areas. Therefore, there has been far less time for the evolution of brackish water species than for saltwater species. Most species in the Baltic are therefore either saltwater species or freshwater species, both living at the outermost part of their niches. There are very few true brackish water species.

Not all species capable of living in a certain community are actually found there. A common reason is that competition between species with high niche overlap may lead to competitive exclusion of some of them. So if species exploit different niches, they are more likely to avoid competition and may thereby coexist in the community.

The traditional grazed pastures in the Baltic region are examples of species-rich plant communities. Today we see great losses of diversity in such communities. With the cessation of grazing, tall grasses, which were earlier kept in check by the grazing cattle or sheep, grow up and out-shade the rich flora of low-grown plants. The trampling of the cattle also creates soil disturbances in which the seeds of annual species establish. We can say that the disturbances (grazing and trampling) caused by the cattle help the weak competitors to survive. Of course, with too high grazing pressure, the most palatable species may become extinct and overgrazing may even lead to soil erosion. It seems that an intermediate level of grazing tends to give the highest species diversity. In fact, this appears to be valid also for intermediate levels of other types of disturbances such as wave action or predation. These can also prevent a strong competitor to achieve total dominance. Consequently, this explanation for high diversity is called the intermediate disturbance hypothesis.

If a species goes extinct in the community, it can of course appear again after immigration. The balance between local extinction and colonisation, or immigration, of new species in fact determines the diversity in many communities. These processes are most easily illustrated by island communities. On a small island, there are often rather few individuals of each species. Such small populations are vulnerable, and a single unfortunate event might kill the whole population. But the species can of course re-colonize the island and the chances for it to do so will depend on how far from the mainland the island is located. In general terms, a community will be species rich if it covers a large area, and species poor if it is isolated by a long distance from other similar communities. This leads to important implications for nature conservation. Nature reserves with, for instance, old-growth forests can be viewed as islands in a sea of a more species-poor commercial forest. To have high diversity, the reserves must be large, and for long-term maintenance of diversity, they must not be too far away from other areas with virgin forests.

Flows of energy and matter in ecosystems

Ecosystem ecology

Ecosystem ecology, sometimes referred to as systems ecology, is concerned with the flow of energy and circulation of matter in a whole ecosystem, that is how the whole system functions. The intimate couplings between the environment and the species living there will influence the balance of the ecosystem and the living conditions for its members. It is only by knowing how the whole system works that we are able to understand how changes affect a community of organisms.

Energy and biomass in an ecosystem – flow of energy and circulation of matter

Organisms can use energy in several forms. Depending on the form of 'food' they use, the systems contain several categories of plants and animals.

The majority of plants obtain their energy directly from sunlight using green chlorophyll and sometimes additional pigments (like the brown and red algae). Plants are the primary producers of the ecosystem. In their photosynthesis, they convert the energy in sunlight into energy stored in carbohydrates (sugar, starch, cellulose, etc.) and other organic compounds. They build biomass in the form of roots, stems and leaves. In addition to sunlight they need water, carbon dioxide from the air and nutrients such as nitrogen, potassium and phosphorus from the ground.

Animals living on plant biomass are called grazers or herbivores. They fill the role of consumers, or primary consumers, in the ecosystem.

Those animals that live by catching other living animals are predators, or carnivores, also called secondary consumers.

Finally, bacteria, and other organisms living on dead organic matter, detritus, are called decomposers. Soil animals, such as earthworms make up the first stage in the decomposition of detritus, while fungi and bacteria take care of the final decomposition. By decomposing the organic matter they return the nutrients

Systems or ***ecosystem ecology*** is concerned with the flow of energy and circulation of matter in a whole ecosystem, that is how the whole system functions. The intimate couplings between the environment and the species living there will influence the balance of the ecosystem and the living conditions for its members. It is only by knowing how the whole system works that we are able to understand how changes`affect a community of organisms.

to mineral form and the organically bound carbon to carbon dioxide. The roots of plants can then again capture the mineral nutrients, and the circulation of chemical matter has made a full cycle. The decomposers are in many ways the most important organisms in the ecosystem. Plant growth is in most terrestrial ecosystems limited by the lack of nitrogen and in aquatic ecosystem often by lack of phosphorus. If the decomposers did not effectively re-circulate these nutrients, primary production would soon cease. Re-circulation of nutrients and other substances is thus essential to all ecosystems.

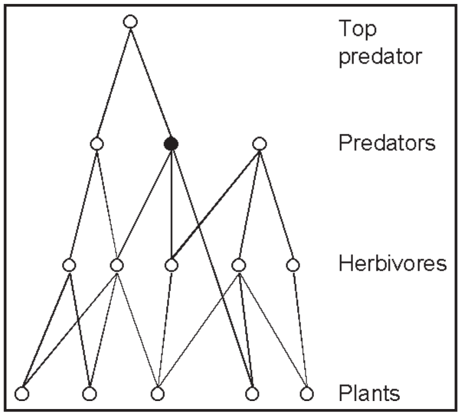


Figure 3.6. A food web. Each symbol represent one species. The lines connect predators and herbivores with the animals and plants they eat. The filled in circle at the predator level represents an omnivore species. (Drawing by Håkan Rydin.)

Food chains and food webs

A feeding relationship in an ecosystem is called a food chain, while the totality of the chains constitutes a food web (Figure 3.6). Food webs are often quite complex with many different feeding relationships. In addition to primary producers, herbivores and carnivores, omnivores are common in some ecosystems. Many bird species, such as finches and sparrows are examples of omnivores. In autumn they feed on seeds and are herbivores, but in summer they feed their offspring on insects and are then predators. However, it is often possible to differentiate between the levels described. These are called trophic levels. In an ecosystem there are normally four trophic levels but there might be more or less.

The biomass in an ecosystem is very unevenly distributed between the trophic levels. This is so because not all of the biomass consumed is converted to the body mass on the next level; it is used as an energy source for running, flying, swimming, maintaining body temperature, etc. Thus, no more than 1-10 % of the mass of a lower level becomes biomass on the next level. This explains why an ecosystem normally does not support more than three or four trophic levels. In the transfer between trophic levels, most energy is lost as heat (much like the engine in an automobile – much petrol is wasted as the engine becomes hot).

From this description we can see the distinct difference between the transfer of energy and nutrients in the ecosystem. Energy enters the ecosystem through photosynthesis and is gradually lost as heat through the trophic levels (including the decomposing level, Figure 3.7). Nutrients circulate from plants to consumers and decomposers and back to plants. An important environmental issue is how closed this circulation is. With excessive addition of fertilisers to arable land and by nitrogen added as an air-borne pollutant, the plants may be unable to take up all nutrients, and excess nutrients leak into soil water. This water leads to eutrophication in downstream rivers and lakes and, finally, of the Baltic Sea.

Human use of ecosystem resources, for instance by agriculture, forestry or fishing has had dramatic effects on energy flow, nutrient circulation and biological diversity, locally as well as globally. Sustainability has been suggested as an overall aim for environmental protection work. This implies that our use of ecosystems should not jeopardise central ecosystem functions in the short or long run (Box 3.1). The role of ecologists is to try to establish levels of resource use, e.g. fishing quotas, that lead to sustainable use of ecosystems.

To really know if human use of ecosystems is sustainable we need environmental monitoring. This means that we carefully measure long-term changes in species diversity, nutrient levels and vital ecosystem functions (Box 3.2).

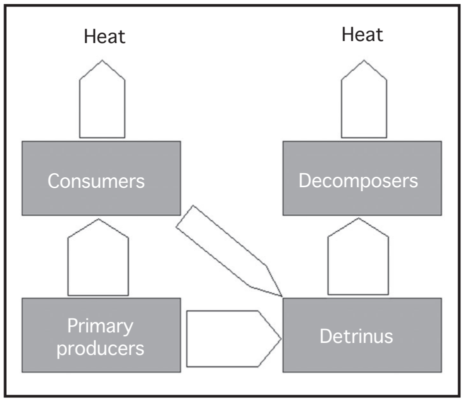


Figure 3.7. Energy flow though an aquatic ecosystem dominated by plankon (see further Chapter 6). The size of the boxes illustrates the amount of biomass – which is a measure of stored energy – in each trophic level, and the width of the arrows indicates the rate of flow between the trophic levels. In a terrestrial ecosystem the amount of biomass contained in plant roots and stems is much larger than the biomass of consumers. (Redrawn from Begon et al., 1996.)

Interactions in ecosystems – competition and co-operation

In addition to "eating or being eaten," there are many other types of interactions and connections between species.

A species may function as a vehicle for spreading diseases, but can also carry spores, pollen or eggs or may be used as protection by other species. Mutualism is a beneficial interdependence between two species. The most important example is the mycorrhiza, which is a link between a vascular plant and a fungus. Here the fungus acts as an enlarged root system helping the plant

Review
Box 3.1

Ecological principles of sustainability

The study of ecology gives us an understanding of the basic principles man has to observe in order to create a society that is in harmony with the environment in the long term. Man lives in the environment just like other species and violation of the basic principles will lead to pollution, over-exploitation and, in the end, degradation of the environment and damage of the resources nourishing our society.

Following are four ecological principles for sustainability that can be used as guidelines for environmental protection work (Based on Nebel and Wright, 1996, p. 104.).

1. **For sustainability, ecosystems dispose of wastes and replenish nutrients by recycling all elements.** This rule is today violated by the extensive use of artifical fertilizers as well as all other linear waste flows in society that leads to growing waste dumps on land, in water and in the atmosphere.
2. **For sustainability, ecosystems use sunlight as their source of energy.** In ecosystems, sunlight is used by the primary producers to synthesize carbohydrates, used by the rest of the ecosystems. Today, human society uses a large amount of fossile fuel, which leads to massive environmental impact.
3. **For sustainability, the size of consumer populations are maintained so that overgrazing or over-use does not occur.** Today, the size of the human population is increasing rapidly and overexploitation of natural resources, such as fishing, occurs. At some point, population increase will have to halt, and overexploitation of natural resources end.
4. **For sustainability, biodiversity is maintained.** Today, the rate of species extinction is very large and biodiversity is decreasing at a high rate. This is loss of a future resources and damaging to the environment.

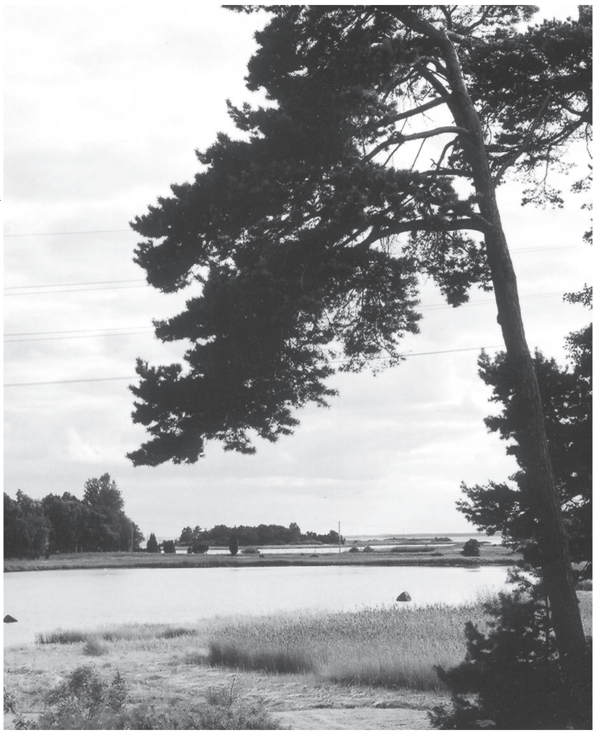


Figure 3.8. Succession on the Baltic coastline outside Kalmar, Sweden. Fifty years ago the shore was covered with short grass, grazed by cows and horses, up to the clear water and sandy bottom. Since then, removal of animals, decreased water circulation and eutrophication has led to muddy bottoms, intense growth along the shores, and a diminishing water surface. Plant communities follow each other in a succession that will in the long term lead to disappearance of the small bay. At present *Scirpus lacustris* dominate the vegetation belt. (Photo: Margareta Grauers Rydén.)

to obtain for instance phosphorus, whereas the fungus will obtain carbohydrates as a source of energy from the plant. As many as 80% of the plant species in a terrestrial ecosystem might depend on mycorrhiza for their nutrition, and mycorrizha is absolutely vital for forest tree growth. Another common mutualism is the lichen, which consists of a fungal and an algal component. A third example is the *Rhizobium* bacteria growing in mutualism with clover and related plant species. The bacteria have the ability to take up nitrogen from the air. Soil nitrogen is a limited resource in most terrestrial ecosystems, and the clover plant will use the bacterially fixed nitrogen. In exchange, the bacteria will take carbohydrates from the plant.

Another interaction is the host-parasite relationship. A parasite is an organism, which feeds on another organism without killing it (in contrast to a predator) (see further Chapter 8).

The fungi are a group of organisms with many types of relationships in the ecosystem. Fungi are not plants – they do not have chlorophyll and can therefore not obtain energy from photosynthesis, and thus need carbohydrates. As we have seen some species of fungi are mutualists and get carbohydrates from the plant in mychorrhiza or lichen. Others are decomposers living on, for instance, dead wood. Others again are parasites, taking their carbohydrates directly from living trees.

How ecosystems develop – succession

The popular notion of balance in nature is somewhat of a myth. Even without human influence, nature is highly dynamic. We have already discussed that populations fluctuate. Population size is affected by competition for food and other resources, as well as predators and parasites.

Ecosystems develop through succession. A good example in the northern part of the Baltic Sea is the creation of new land as an effect of the continuous land uplift (ca. 50 cm per century outside Stockholm, and even more further north). Small plants invade the newly emerging shores, later alder trees colonize and finally a forest develops. A similar development took place after the last ice age as the ice sheet retreated and left bare soils open for colonization. These processes are examples of primary succession, in which an ecosystem develops on previously unoccupied ground.

Methods

Box 3.2

Environmental monitoring

What is monitoring

Environmental monitoring is the general term for systematic observations of what is going on in the environment. It may most often consist of observing changes in plant and animal communities. Formally these observations are the responsibility of authorities and researchers, which establish field stations and monitoring stations to carry out the observations. These may be quite simple, just inspections, but often advanced equipment is used to follow chemical parameters, such as acidity, nutrient levels, and specific chemical compounds etc. Typically Environmental Protection Agencies, national EPAs, have a major task in setting up and carrying out such monitoring.

The role of amateurs

However, an extremely valuable observation work is also carried out by amateur biologists, such as bird watchers, in a country. Since it is in practice impossible for the authorities to keep track of all the various biotopes, environments and areas in a country, these in-official observations are important. Interested individuals might regularly and over a long time visit a limited area and can then notice over the years what changes occur. Such observations may give a warning for new environmental impacts.

For example oil damage along the shores of the Baltic Sea are most often discovered by the persons living on the shores, but also more difficult-to-discover changes are noted by e.g. hunters, or farmers. Amateurs in the same way have an important role in research. Long-term changes in species composition in an area, such as appearance of a new species, disappearance of another, or exchange of one variety of a species for another are often detected and reported by amateur botanists, ornithologists etc. Associations of amateur biologists have contributed in important ways to such monitoring. For instance birds in all Europe are counted by the members of birds watchers associations one day in October every year.

The role of long-term environmental monitoring – Baltic co-operation

Very long term and systematic monitoring of a particular area is a key component in ecological research. The description of the ecology and biology of the Baltic Sea reported in this book (Chapters 5 and 6) are based on the result of many years of research of many institutions in the countries surrounding the Baltic. Some of these activities are organized in a regional cooperation for environmental monitoring to collect data in a long term frame. Such monitoring programs are needed to follow changes in the environment, to spot serious changes at early stages, and be able to plan proper measures to protect the environment. Most importantly they will be needed to trace the sources of environmental impact, understand its consequences on ecosystems, and constructively address the causes of pollution.

The co-operation of laboratories in the region constitutes the base both for environmental research and for environmental protection measures. The design and execution of emerging monitoring programs needs relevant competence both as to environmental science and chemical and biological analysis.

Secondary succession is the process in which an already existing ecosystem recovers after a major disturbance, either natural, such as a forest fire, or man-made. Today, major disturbances are more often than not man-made. After a clear-cut in a forest, secondary succession starts with the establishment of short-lived plants with good dispersal ability (largely *r* species). Later on, shrubs and trees (such as birch) replace these and grow rapidly, and finally the slow-growing but strongly competitive conifer trees re-attain their dominance. Succession is a directional process, and the final result is, predictably, a new forest.

Abandoned arable fields provide an interesting case of secondary succession. After ploughing, succession starts with short-lived (mostly annual) weeds. These are eventually out-competed by grasses and other long-lived plants. Later on, shrubs enter and the final stage will in most parts of Europe be some kind of woodland. Agriculture is a human struggle against such a natural succession. Most crop plants are annual species developed through plant breeding efforts over thousands of years. They have poor competitive ability and can only survive in an ecosystem kept at the early succession stage by ploughing each year, and still, mechanical and chemical warfare against weeds seems necessary.

A second hazard to agriculture is that a large area covered by a single crop species, a mono-culture, offers unlimited resources for expansion of herbivores or parasites specialised in this very crop species. In order to maintain mono-culture, man uses biocides, which have often turned into nightmare situations because the chemical killed other components in the same or other ecosystems.

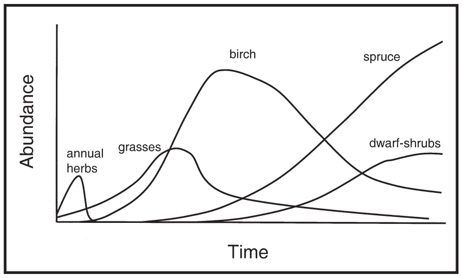


Figure 3.9. Succession. Schematic description of a forest succession over ca 100 years following a clear-cut. Short-lived herbs (e.g. *Senecio* species) dominate initially and shortly thereafter grasses (e.g. *Deschampsia flexuosa*). Birches grow quickly, but are later outshaded by spruce. Understorey dwarf-shrubs (e.g. *Vaccinium myrtilius*) recover slowly after the disturbance. (Drawing by Håkan Rydin.)

Biology and biogeographical zones of the Baltic region

Biology of the Baltic region

The biology of the Baltic region, which comprises some 15% of Europe, can not be described in a few pages. It consists of many thousands of species of fungi, plants, animals, micro-organisms, etc. Instead we will give a short characterisation of each of the major life zones (also called biomes or vegetation zones) in the region, and mention some of the most characteristic species in each of them. Each of these might be seen as an, often very extensive, ecosystem.

Biomes are of interest for several reasons. Each of them are influenced differently by environmental impacts and are sensitive to impacts in different ways. The biomes concept is especially important in the context of nature conservation. In this context, each of the biomes should be considered separately, and since we would like to protect all of them, they can not be exchanged for each other. The biomes, or types of nature in the region, may also be approached with some awe. They make up a beautiful region, from the high mountains to the sea shores.

Life in the Baltic Sea itself is not treated here, as it is the topic of Chapter 6.

Vegetation zonation

The climate in the Baltic region varies from north to south, from oceanic to continental and from lowland to high altitudes. This variation of course affects the vegetation. The Baltic area can be arranged in vegetation zones according to latitude and altitude (Figure 3.10), and major ecosystems refered to as biomes.

Roughly speaking, Denmark, southernmost Sweden and the area south of the Baltic Sea proper belongs to the temperate zone in which the natural vegetation is dominated by deciduous forests. The term 'temperate,' stresses that the climate is a basis for the zonation. The more or less synonymous term 'nemoral zone' is used for the originally spruce-free zone in Scandinavia.

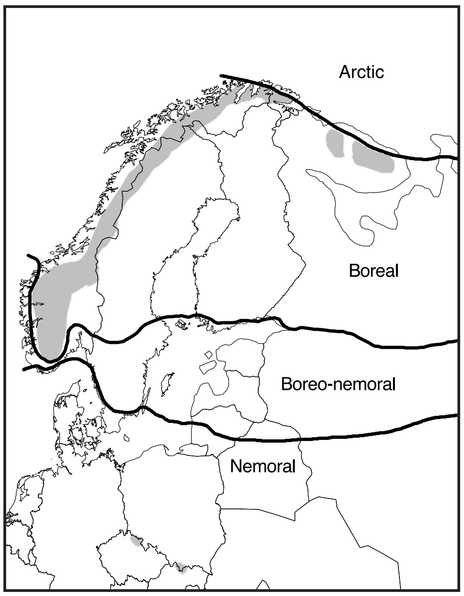
Travelling northwards, the boreo-nemoral zone, in traditional Swedish terminology, or hemi-boreal zone, in Finnish terminology, is the mixed coniferous and broad-leaved forests at the latitudes of southern Sweden and Estonia, Latvia and Lithuania.

Further north, most deciduous trees disappear one by one, and the border towards the boreal zone is set at the northern distribution limit of several southern deciduous tree species, notably the pedunculate oak (*Quercus robur*). The boreal zone is dominated by coniferous forests, in which species of birch (*Betula* spp.), aspen (*Populus tremula*) and willows (*Salix* spp.) are among the few deciduous trees.

Where tree-growth is precluded by harsh climate, at high latitude or high altitude, we find the tree-less tundra of the arctic and alpine zones, respectively.

"Swedish Plant Geography" (Rydin et al., 1999) gives a modern treatment on the zonation and vegetation types (including marine and brackish waters), with descriptions relevant also to neighbouring countries (see also Dierssen, 1996).

Figure 3.10. The vegetation zones in the Baltic region, with the four typical vegetation belts. Shaded areas are alpine zone, and subalpine and subarctic birch forest. (Adapted from Sjörs, in Rydin et al., 1999.)



Arctic-alpine areas – the Scandinavian *fjell* (mountains) and Tatra-Carpatian mountains

In the Baltic region, there are in principle two large areas where trees can not occur due to climatic conditions on high altitudes, the Scandinavian mountains also called the *fjell* (mountains) in the north, and the Carpatian mountains in the south.

The plants and animals in the Scandinavian mountains belong largely to a group of arctic species found around the polar area, but some species are more closely connected to the fauna and flora in the central European mountains. The treeline is as low as around 600 meters above sea level in Northern Sweden and even very close to sea level in the northernmost parts of Norway, where some areas quite similar to the true tundra of northernmost Russia. In central Norway, the treeline is at 1,000 meters above sea level. In southern Poland, the treeline is nearly 1,800 meters above sea level.

In all the mountains, both low-productive dwarf-shrub heaths and higher productive grass/herb areas can be found. More to the north or at higher elevation, lichens play a very significant role. Reindeer, the dominating herbivore of the Scandinavian mountains, eats lichens found in the coniferous northern forest during winter, and regularly migrates between arctic/alpine areas in the summer to coniferous lichen-rich forests in the winter. Most reindeer found in the Baltic region are semi-domesticated animals. However, in southern Norway there is quite a large wild reindeer population, especially in the Hardangervidda area, and a very small population of forest roaming reindeer in Central-Eastern Finland.

In the Carpatian mountains, the camois, marmout and ibex were long the dominant herbivores. The ibex is extinct since historical times, but the other species have survived.

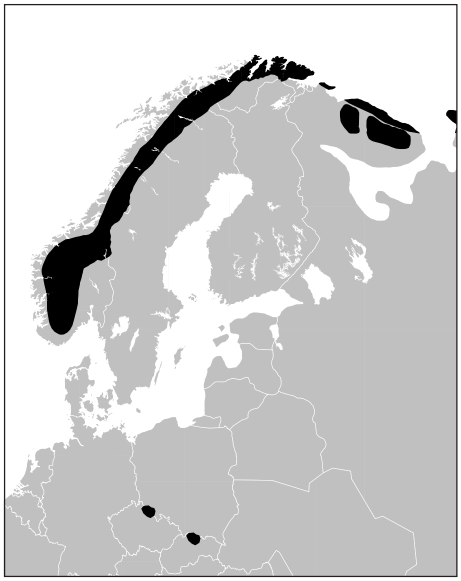
Other important herbivores in the Scandinavian mountains are voles and lemmings. Their populations fluctuate greatly between years. In the Carpatian mountains and in the southern parts of the Scandinavian mountains, domesticated sheep have also played an important role as grazers. Today, sheep still play a role only in the southern part of the Scandinavian mountains and in some places in the Carpatian mountains.

A big difference between the Scandinavian mountains and the Carpatian mountains is the much larger amount of wetlands and lakes in the northern region. This richness of wetlands gives rise to very abundant wetland bird-fauna. These birds are migrants and some are found in the southern part of the Baltic Sea region during winter. Thus, the long-tailed duck winters in large numbers south of Gotland, other species winter in the West European mudflats, while some migrate to Africa.

Figure 3.11. The Arctic tern (*Sterna paradisaea*). This beautifully slender tern migrates the longest distance of any bird species in the world, and is one of the most impressive travellers in the animal kingdom. The Arctic tern nests in the entire Baltic Sea region all the way up to the north, and migrates yearly between the Arctic and Antarctic regions. (Photo: Tero Niemi.)

Figure 3.12. View of the arctic zone in summer. A landscape in the Swedish *fjell* (mountain) close to Kebnekaise, the highest peak in Sweden (2123 m) characterized by no trees or few low growing birches at lower heights, year around snow at higher altitudes, and much water. (Photo: Lars Rydén.)

Figure 3.13. The alpine and arctic vegetation zone, marked in darker colour.



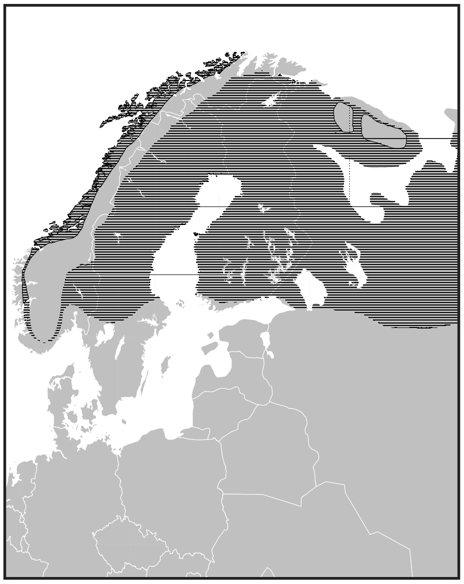


Figure 3.14. The boreal forest and taiga vegetation zone, marked in darker colour.

Figure 3.15. The boreal forest zone, the taiga, covers large areas in the northern Baltic region, and is characterized by spruce, often dramatic water courses, and large wetlands, such as the mire seen in the distance. (Photo: Christian Andersson.)

Coniferous forest, boreal forest – taiga

The boreal forest is found in northern and central Sweden and Finland and the neighbouring parts of Russia. Spruce (*Picea abies*) and Scotch Pine (*Pinus silvestris*) are the dominating trees. The pine is found in dryer conditions and in very wet conditions. The spruce does best in more fertile soils. Fires have always played a significant role in the dynamics of the coniferous forest. In areas with drier climate and in places with more frequent fires, the pines have been favoured. The number of vascular plant species in such forests is often low. An important role is played by dwarf-shrubs such as blueberry (*Vaccinium myrtillus*), lingonberry (*Vaccinium vitis-idea*), crowberry (*Empetrum nigrum*) and heather (*Calluna vulgaris*). The moss and lichen flora are often quite dominant, and there is often a significant diversity of species in these groups.

Few larger mammals are specialised to live in the boreal forest. Those found there today have been pushed out of other biomes by human activity. Those therefore regarded as typical for such areas are brown bear, wolf, and lynx. Moose is more confined to the coniferous forests. Some birds are, however, very typical for these forests. Examples are the ural owl, Tengmalm's owl, Siberian tit, and Siberian jay.

Even if the northern coniferous forests of Sweden, Finland and neighbouring parts of Russia are much influenced by forestry and other types of traditional human use, parts of them can be regarded as Europe's most natural forests.

Mixed coniferous – broad-leafed forests, boreo-nemoral forests

This type of forest covers large parts of south central Sweden, the southern part of Finland, the Baltic republics, and parts of neighbouring Poland, Russia and Belarus. This is a transitional zone where the coniferous trees in principle are found on infertile soils and deciduous trees on better soil. Almost since the late stone-age, coniferous trees have expanded into areas once dominated by broad-leaved trees. Only just 500 years ago, the broad-leaved deciduous trees played a much larger role than today. Acidification in combination with hard grazing pressure has favoured the coniferous trees. Also in this zone, agriculture has for a long time been an important activity, which has changed large forest areas

Figure 3.16. The boreo-nemoral, mixed coniferous-broad-leafed forest typical for the middle part of the Baltic region. This forest is economically important for pulp and paper and timber production. It is grows much faster than the forests further north. (Photo: Courtesy of Stora Enso.)

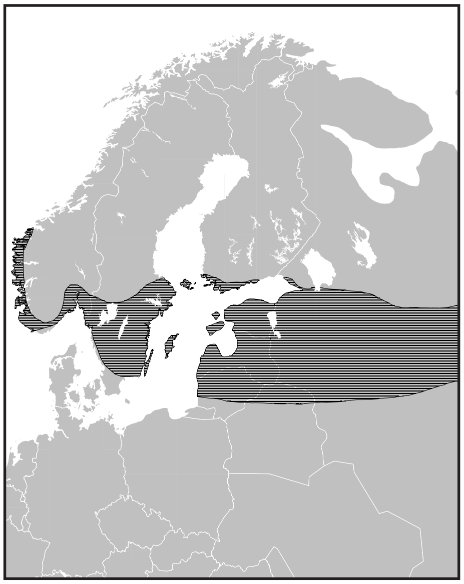


Figure 3.17. The boreo-nemoral forest vegetation zone, marked in darker colour.

into open grazing areas or arable land. During recent decades, the forest has largely returned in less fertile arable land and grazing areas.

This zone has much the same tree species as the northern coniferous zone but also in addition has a number of other deciduous trees species. The oaks (*Quercus robur* and *Q. petrea*) are very important trees here. From a biodiversity point of view, the occurrence of old oaks is very important. Such trees can be the home for a large number of insect species, lichens, mosses and fungi. Also a number of birds and even bats depend on oaks. Other important deciduous trees of the zone are lime (*Tilia cordata*), ash (*Fraxinus excelsior*), elm (*Ulmus glabra*) and maple (*Acer pseudoplatanus*). Mixed forests can be quite rich in bird species and mammals. Typical for this zone is the roe deer. In some areas, red deer and wild boar also play important roles.

Broad-leaved forests, nemoral forests

In the southern parts of the region, broad-leaved forest is the natural vegetation type except in very wet areas. In addition to the broad-leaved tree species mentioned, the broad-leaved forests contain beech (*Fagus silvatica*) in the southwest, and hornbeam (*Carpinus betulus*) and maple (*Acer campestre*) in the most southern parts. Especially the beech together with the oak are economically valuable trees that in some cases dominate these forests. Among all the bushes in this zone, the hazel (*Corulus avellana*) is especially visually impressive.

Traditionally large parts of the broad-leaved forests have been used as coppices, meaning that sections of the forests have been cut in regular intervals of 5 to 30 years. The trees have had an ability to grow new shoots from the stumps resulting in multi-stemmed trees. Many of those forests have also existed for a long time in the form of different types of very open, grazed broad-leaved woodland, and wooded meadows. During the 20th century, many of the areas have been either agricultural land or transformed into forest stands with high trees suitable for timber production. As well, many of today's broad-leaved forests are the result of quite recent spontaneous succession into forest from old abandoned fields and open grazing land. Today, as a result of plantations, coniferous trees are common

Figure 3.18. The nemoral forest, with broad-leaved deciduous trees, once covered all of the European continent. It is still characteristic of some areas in the southern Baltic region. Here, a view from the Belovezhskaya Pushcha forest in Belarus. (Photo: Lars Rydén.)

Figure 3.19. The nemoral broad-leafed forest vegetation zone, marked in darker colour.

and even dominant in many parts of this zone. Especially spruce (*Picea abies*) are used for this purpose.

Typical of nemoral forests are colourful spring flowers, including a number of *Anemone* and *Corydalis* species. During summer, it is quite dark in these forests, and few plants are in flower, especially in the beech forests. As more light penetrates into oak forests, there is a greater diversity of species on the forest floor, and oak forests are more interesting to visit in the summer.

Old broad-leaved forests with long continuity, and large and old trees can be the habitat for a very large number of insects, birds, fungi and lichens. Such areas are very rare and quite scattered. Among mammals, the wild boar (*Sus scrofa*) is an important species. It was extinct for a long time in Denmark and Sweden but has been reintroduced. However, it was not made extinct in the three Baltic republics, Poland and Germany. Hundreds of years ago, the European bison was probably an important species in these forests. The bison survived into historical time as did the aurox (wild ancestor to modern cattle) by royal protection of Polish-Lithuanian kings. While the aurox went extinct in the 17th century, the bison has survived into modern time.

Habitats

Semi-natural grasslands

One of the most species-rich groups of biotopes in northern Europe are the semi-natural grasslands. Their vegetation is composed of indigenous northern European species, as well as species that only occur naturally further south or east. These types of vegetation have successively developed during the last 6,000 years, mostly due to long periods of grazing by domesticated cattle, sheep, goats, and horses. During the last 2,000 years, cutting for winter fodder created habitats, called meadows, that are similar to the semi-natural grazing areas. Collectively, semi-natural grazing areas and meadows are called semi-natural grasslands.

During the last 150 years, most semi-natural grasslands in northern Europe have disappeared. There is probably just a few percent of the area left that existed in 1850. The regression has occurred at different times over the region. In northern Sweden and Finland as well as in Germany and Denmark, the retreat was early. In Poland, the Baltic states, Norway and southern Sweden many areas survived into the 1960s. Since 1989, the regression has been tremendously fast in the Baltic states. Today, south-eastern Sweden is probably the best stronghold for semi-natural grasslands in northern Europe. The Great Alvar on the island of Öland is the largest continuous area of semi-natural grassland in northern Europe.

Recently, much work has been done to save and even restore semi-natural grasslands. For instance in Sweden, Great Britain and Denmark semi-natural grasslands are promoted using EU environmental subsidies to the agricultural sector. Similar conservation work is being carried out in Finland and Estonia.

There are many types of semi-natural grasslands, some totally open without trees and shrubs, and others with trees and shrubs as a prominent part. Many of these types of vegetation are extremely rich in species, and very attractive for recreation.

Arable land

Around 1930, the area of arable fields in the Baltic region reached its maximum. Since then, many arable fields have been planted with trees or have been spontaneously colonised with forest, especially in the north where this

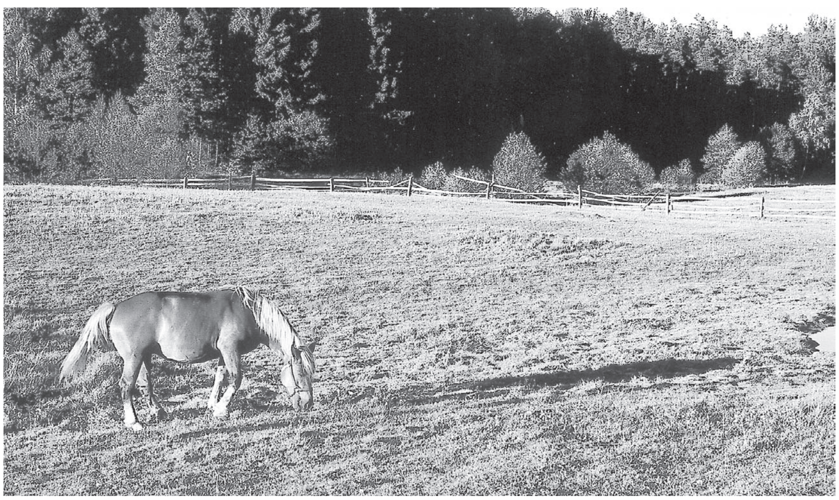


Figure 3.20. Grassland habitat. The habitats formed by interaction between society and nature are crucial for biodiversity. They include the semi-natural grasslands, pictured here from western Belarus, where a horse is enjoying the grassland pasture. (Photo: Lars Rydén.)

Waterscape habitats

Wetlands

Wetlands is a broad term for vegetation types with the water table close to the surface, such as mires, shores and swamp forests. There is a large variation of wetland types in the Baltic region. There have been tremendous drainage campaigns in the southern parts of the region, contrasting to the large untouched peat wetlands of the north, in particular in northern Sweden. Especially in Finland, peat is used as a fossil fuel, and in 1994 the peatland area used for extraction was 52,000 ha, from which 25 million m^3 was extracted (Vasander, 1996).

Peat is made up of plant remains, which accumulate where the water table in a wetland is stagnant and therefore anaerobic. Such wetlands with peat formation are called *mires*. The most important peatformers are the peat mosses (*Sphagnum*). With their capacity to retain water (up to 20 times their dry mass) they turn the habitat into an anaerobic sponge.

Many wetlands have earlier been open ponds or lakes, which successively were filled up with lake sediments and later with peat as wetland plants encroached. There are two types of mires, *fens* and *bogs*. The water in a fen has passed through the mineral soil of the surrounding terrain, and for this reason fens are referred to as minerotrophic mires. A fen may have a pH of 6-8 if the terrain is calcareous. Although all mires are nutrient poor (in terms of nitrogen, phosphorus and potassium), such fens are called *rich fens*, indicating that they are rich in calcium and often very species rich. Numerous sedge species and "brown mosses" (a group of bryophytes mainly from the Amblystegiaceae family) dominate, and there are many herb species and attractive orchids. When the surrounding soil is acidic, pH in the fen will typically be 4.5-5.5. These fens are *poor fens* and are dominated by *Sphagnum*.

The *Sphagnum* plants act as an ion exchanger: they exchange hydrogen ions, which enables them to bind other cations (e.g. potassium) from the mire water. As they grow upwards, the anaerobic, acid sponge of peat will finally be isolated from the surrounding ground water. At this stage, the fen has turned into a bog, and the only nutrient source is rain and snow. A bog is an ombrotrophic mire (*ombro* = rain). The pH is often 3.5-4.0 and not many species thrive. Apart from *Sphagnum*, there are vascular plants with very low nutrient demands, such as *Eriophorum vaginatum* and *Calluna vulgaris*.

There are also wetlands dominated by trees and shrubs. Alder dominated *swamp forests* and *Salix* dominated wetlands along lake and river shores can for examples still be found in large regions of Eastern Poland and Belarus. The impressive black storch is found in this biotope.

Wetlands can sometimes be very productive areas attracting a large number of birds, although some wetlands, for example raised peat bogs, may have a very low biomass production. Sandpipers and ducks are found in most types of wetland. The crane is a species typical for larger low-productive wetlands.

Figure 3.21. Wetland in Belarus. Belarus, where the drainage basins of the Baltic, Black and Caspian Seas meet, is flat, rich in wetlands. It has one of the classical routes for the vikings going to the Black Sea. (Photo: Lars Rydén.)

Rivers and lakes

The majority of lakes in Finland and Sweden are small and have a low nutrient level, i.e. are oligotrophic. Usually mires, heath and coniferous forests dominate the catchment area of an oligotrophic lake. Eutrophic lakes and rivers are found in the southern part of the Baltic drainage area and are generally situated in the more fertile lowland areas, which are densely populated. In forest and peatland areas many of the lakes are not only low in nutrient content but also have a brown-water which is due to humic substances leaching from the surrounding area. These lakes are called dystrophic.

Since many planktonic algae have a cosmopolitan distribution, the number of species in a lake is more related to types of water than to the area. Thus, due to the large variety of water bodies in the northern parts of the Baltic drainage area, the species diversity of algae is very large, especially in the oligotrophic lakes. Phytoplankton is also easily dispersed, e.g. by water flow, wind, or animals.

Small flagellates dominate in nutrient poor lakes in the mountains in the north and in acidified lakes (pH<5). The majority of forest water bodies are oligotrophic and brown coloured and may be subjected to acidification. This is usually the case if the surrounding bedrock and soils have a low buffering capacity. One area that has been negatively affected by acidification is the south-western part of Sweden, due to the low buffering capacity of the soils and bedrock and a high deposition of acid rain. This has affected the food webs in many lakes, destroyed fish recruitment and fresh water crayfish populations.

Plants in lakes are mostly flowering plants but some ferns, mosses and benthic algae are also found. Macrophytes are divided into three different life forms, depending on depth of growth. Emergent macrophytes are growing close to the shore and have a well-developed root system which can survive in oxygen poor muddy sediments. Free-floating macrophytes may cover the whole surface of smaller lakes or ponds especially if eutrophied, since they take up their nutrients directly from the water. The third group are submerged, rooted macrophytes, which can take up nutrients both from sediment and water. In calcareous regions, e.g. Öland and Gotland, many of the lakes have high alkalinity and low levels of phosphorous, and are often dominated by charophytes. Most of the 32 known species of charophytes in the Baltic region are very rare and many are threatened by human activities.

Common macrophytes in oligotrophic lakes are rosette plants such as *Lobelia dortmanna* and the common quillwort *Isoëtes lacustris*. Both have roots and leaves that are rich in air-filled spaces, which improves the transport of carbon dioxide from the roots to the leaves. In agricultural areas the nutrient concentrations are higher and the lakes are usually fringed with stands of the common reeds *Phragmites australis*, *Schoenoplectus lacustris* and *Typha angustifolia*. Cattle may drastically reduce the reed belt around a lake since common reeds are very susceptible to grazing and trampling and will be replaced by sedges.

The number of oligotrophic nutrient poor lakes has declined during the last 50-100 years due to changes in land use. Thus, the efforts to gain arable land in the late 19th and early 20th century led to

Figure 3.22. The freshwater courses in the entire Baltic region constitute biotopes often of large richness and of crucial importance to the environment. Emån in south-eastern Sweden is still a habitat for the rare otter and almost extinct sheat fish, and offers good salmon fishing for people. (Photo: Lars Rydén.)

lowering of the water table of many lakes. This has speeded up the eutrophication process in many lakes and rivers. These changes have affected the species composition where small evergreen rosette species are replaced by fast-growing submerged annual macrophytes. In lakes with even higher nutrient load, the macrophyte vegetation is replaced by phytoplankton, restricting the macrophyte vegetation to the shallowest parts of the lake. Nutrient rich, eutrophic lakes are dominated by filamentous and large-cell colonies, and the pH will rise above 7 in summer during intense primary production and algal blooms. Diatoms dominate these lakes in spring and autumn, green algae in early summer and cyanobacteria (blue-green algae) produce algal blooms in summer and autumn. Another factor that may alter the structure of the lake ecosystem is the introduction of alien species. One such example is the submerged macrophyte, *Elodea canadensis* that produces dense stands in many lakes, hindering boating and fishing.

The Baltic Sea coasts

The coastal areas around the Baltic Sea are different compared to other coastal areas in northern Europe because of the lack of tidal zones. But even without larger tidal movements the brackish water of the Baltic Sea influences the shore meadow vegetation, since there is considerable water level fluctuations over the year. The fluctuation is less than 1.5 m in the main part of the Baltic Sea but may reach more than 3 m in the northern most part of the Gulf of Bothnia. As a result, the shore meadows will become more or less saline, and plants and animals living in seashore habitats will have to cope with a comparatively wide salinity range. The shore meadows are the habitat for a number of plant species not found in other environments. To be able to grow and survive on soils with high salt content, the shore species have adapted several strategies, such as excreting salt through hairs or glands, or collection of salt in shoots that dry out and fall off.

Some coastal areas have extensive shore meadows, important for a number of wetland birds. Shore meadows are found in the Baltic states – especially in western Estonia where the Matsalu bay is famous – in parts of southern Sweden as well as in parts of Germany and Denmark. Among the birds on flat shore meadows, sandpipers are important. During the last centuries, two species of geese have expanded tremendously on the shore meadows, the graylag goose earlier nearly brought to the rim of extinction in this region, and the barnacle goose. The barnacle goose, earlier being an entirely arctic species, has expanded its breeding grounds and becomes a colony breeder on for example the shore meadows of the island of Gotland.

The Baltic Sea is well known for its large archipelagos, along coasts in Sweden, Finland and Estonia. The Stockholm archipelago is one of the largest in the world, with more than 50,000 islands. The archipelagos often have a very rich bird life. The vegetation here is also special, with a forest zonation resembling the zonation found in mountainous region in Scandinavia. In the larger archipelagos, the forest is dense and tall close to the mainland. Further out, species such as spruce and pine are gone and birch dominates. The outermost parts lack trees and many of the islands are very barren. These islands are often the best bird islands.

A typical feature of the shores of the northern part of the Baltic Sea is the land uplift, which is at most almost one meter per century in the North. This phenomenon continuously creates new land to be colonized. The fresh soil coming up from the sea is rich in nutrients but lacks nitrogen, and this favours species with mutualistic nitrogen-fixing microorganisms. Especially the bush *Hippophae ramnoides* should be mentioned. It has beautiful orange, extremely vitamin-C rich berries in autumn.

In the southern part of the Baltic, long sandy coasts dominate. These are nutrient poor and mostly vegetation free. The rhizomes of large perennial grasses such as *Leymus arenarius* and *Elytrigia juncea* may, however, stabilise the sand and also trap drift material. The sand dune closest to the shore, i.e. the white stable dunes, are more nutrient rich as a result of a continuous transport of nutrient rich material from the sea, compared to older, grey dunes further inland. If these grey dunes are left undisturbed by trampling a crust of lichens and mosses may develop mixed with creeping woody plant species, e.g. *Empetrum nigrum* and *Salix repens*. Grazing by cattle may open the sand to wind erosion and create wandering dunes.

Lena Kautsky

Figure 3.23. The Baltic Sea coasts has many characteristic plants such as the beautifully slender *Valeriana sambucifolia* with white-pinkish flowers, the intensely red-flowered *Lythrum salicaria* and the tall and impressive grass *Legmus arenarius*, all three often more than a meter tall, here pictured together on the rocky Swedish coast of the Bothnian Sea at Hälsingland. (Photo: Inga-May Lehman Nådin.)

Figure 3.24. Urban habitats are increasingly important. Parks and vegetation along paved areas, buildings, railroads, and particularly watercourses, offer habitats for many species. (Photo: Inga-May Lehman Nådin.)

development has been very pronounced. In areas where agriculture has continued, the individual arable fields have grown in size considerably, and much efforts were made to take away ponds, small fens, trees and stone fences. A much more simplified arable landscape has been created, especially pronounced in for example Lithuania, Scania in southern Sweden and on the Danish islands.

The fauna and flora earlier found in arable dominated landscapes are today threatened by forest takeover or by large-scale industrialised agriculture that leaves little room for wild species. There has been a number of plant species adapted to live in arable fields that were rare outside this biotope. Their seeds were often not possible to separate when threshing for example rye or wheat. These well adapted weeds of arable fields are now becoming more and more rare due to increasingly efficient methods of threshing. Examples of such rare weeds, often classical in the farming society and with beautiful flowers, are *Centaurea cyanus*, *Melampyrum arvense* and *Agrostemma githago*.

Birds living in the arable landscape are among the most threatened birds in Europe today. The great gustard (*Otis tarda*) once lived in the Baltic. Now there is only a tiny population outside Berlin. A less imposing species, but still a very nice bird is the corn bunting (*Emberiza calandra*). Around 1950, this bird was still very typical in the southern part of the Baltic Sea region, but it is disappearing rapidly.

In forested areas, fields can be important complements for many species that also live in forest and mire biotopes.

Urban areas

The urban areas have increased tremendously in the Baltic region during the last century. Today, in addition to traditional densely built-up areas, there are also very large suburban areas. In the city centres, the 'stone cities,' much of the biodiversity is gone, but still there are organisms that have adapted to this environment. Notable are a number of bird species, that seem to regard the 'stone-city' as a natural cliff-landscape. First, the feral dove should be mentioned. Its wild ancestor is the rock dove, today still found in Britain and earlier also in Norway. The domesticated rock dove has increased enormously and now inhabits all larger 'stone-cities' in the Baltic region. Other original 'cliff-birds' that are now found in the cities are the house martin, swift, house sparrow and black redstart.

Specialised plant species are also found in the 'stone-city'. A famous example is the calcareous loving cliff living fern *Asplenium ruta-muraria*. Old industrial areas, harbours and other marginal areas in the urban landscape can be habitats for many plant species that are easily outcompeted in more natural habitats. Many rare plants are especially found in connection with harbours, and were probably 'imported' unintentionally by man. Some of these become invaders, or invasive species, but most of them remain in limited sites where soil is dug up, for example by building activity.

In the sub-urban areas, there could be a high degree of biodiversity, especially when the natural landscape has prevented all land from being used for buildings and roads. This is typical in the outskirts of Stockholm, while cities on plains are often much poorer in biodiversity.

One interesting feature of many sub-urban areas is their richness in old trees. In many regions, modern forestry and agriculture have eradicated almost all older trees in the landscape. In such situations, the sub-urban areas are the only remaining places where older trees have survived. For example, Djurgården in central Stockholm still has many large, old oaks, which are homes for many rare beetles and fungi.

Review questions

1. Explain the concepts of ecology, population ecology, community ecology and systems ecology.
2. Define the concepts of habitat, niche, species, population, community, ecosystem and biome.
3. Give examples of why the composition of an ecosystem may change, using the concepts of adaptation fitness and evolution and intermediate disturbance hypothesis.
4. Describe the various patterns of how the number of individuals in populations change in an area using the concepts of carrying capacity, *K* species and *r* species.
5. Describe the flow of matter and energy in an ecosystem using the concepts of food chains and food web, and the trophic levels producers, primary, secondary and tertiary consumers.
6. Describe an ecosystem using the concepts herbivores, carnivores, predators, omnivores and decomposers.
7. Describe two relationships between species in an ecosystem other than eating and being eaten.
8. Explain a succession in an area, especially primary succession and secondary succession, and exemplify with the development of a lake.
9. Describe the main vegetation zones of the Baltic region by their location and character using the concepts of nemoral zone, boreo-nemoral zone and boreal zone.
10. Select at least three biomes of the region and describe their typical landscape features and characteristic plant and animal species.

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Internet resources

Biozone
http://www.biozone.com.au/

Environmental Organizations Web Directory
http://www.webdirectory.com/

IUCN Red List of threatened species
http://www.redlist.org/

Organisation for Economic Co-operation and Development, OECD
http://www.oecd.org/

The Regional Environmental Center for Central and Eastern Europe (REC)
http://www.rec.org/

The Virtual Library: Biosciences
http://vlib.org/biosciences.html

The World Conservation Union, IUCN
http://www.iucn.org/

UC Berkley Library: Checklist of online vegetation and plant distribution maps
http://www.lib.berkeley.edu/EART/vegmaps.html

United Nations Environment Programme, UNEP
http://www.unep.org/

World Resources Institute, WRI
http://www.igc.org/wri/

World Wildlife Fund for Nature, WWF
http://www.wwf.org/

Glossary

adaptation
the fact that the organism becomes suited to a particular environment

autecology
the description of the requirements of various species. In the early days of ecology, autecology developed as a more exact form of natural history.

biome
major life zone, vegetation zone

boreal zone
the zone dominated by coniferous forests, in which species of birch, aspen and willows are among the few deciduous trees, north of the distribution limit of several southern deciduous tree species, notably the pedunculate oak

boreo-nemoral zone
the mixed coniferous and broad-leaved forests at the latitudes of southern Sweden and Estonia, Latvia and Lithuania

carnivores
animals that eat other animals

carrying capacity
the population size, where competition between individuals balance their reproductive capacity

community
all populations in an area taken together. Often the plant community and animal community are considered separately.

community ecology
focuses on species diversity and interactions among species, investigating why some communities are species rich and others are species poor, questions essential for efficient nature conservation practices

decomposers
bacteria, fungi and other organisms living on dead organic matter, detritus

detritus
dead organic matter

ecology
the science of relationships between organisms, and between organisms and their environment

ecophysiology
the study of physiological processes in the field, or outdoors, in contrast to physiology, which is more of a laboratory science, indoors.

ecosystem or systems ecology
is concerned with the flow of energy and circulation of matter in a whole ecosystem; how a whole system functions

evolution
the change over generations of the genetic characteristics of the individuals in a population as a response to a changing environment

extinction
disappearance of a population or a species from a locality or from its entire distribution area

fitness
the reproductive success of an individual in evolutionary terms, measured by its contribution to the number of individuals in the next generation, relative to the contribution of other individuals

food chain
a feeding relationship in an ecosystem

food web
the totality of the food chains in an ecosystem

habitat
the environment which a particular species occupies

herbivores
animals that live on plants; grazers; primary consumers

intermediate disturbance hypothesis
the hypothesis that intermediate levels of various disturbances such as wave action, grazing or predation tends to give the highest species diversity

***K* species**
species which have a population size fluctuating around the carrying capacity; *K* stands for carrying capacity. Larger animals are typical *K* species.

mutualism
a beneficial interdependence between two species, such as *mycorrhiza*, which is a link between a vascular plant and a fungus

nemoral zone
the originally spruce-free zone in Scandinavia, characterised by temperate climate

niche
how, or under what environmental conditions, a species lives, and how it utilises the environment; the niche of a species describes its function

omnivores
animals that feed both on plants and animals, at the same time or intermittently, such as many bird species, which feed on seeds in the autumn but feed their offspring on insects in summer

parasite
an organism that feeds on another organism, the host, without killing it (in contrast to a predator)

population
all individuals of a species within a certain area, for instance all warblers in an oak forest

population ecology
deals with questions on what regulates the number of individuals in an area

predators
animals that live by catching and eating other animals

primary consumers
animals which obtain their energy from plant biomass, e.g. primary consumers of an ecosystem

primary succession
when an ecosystem develops on previously unoccupied ground

producers
plants that obtain their energy directly from sunlight using green chlorophyll and sometimes additional pigments (like brown and red algae) are the primary producers of an ecosystem

Glossary

***r* species**
species which have a population size fluctuating between rapid (exponential) population growth during favourable times followed by a ‘crash’ when most individuals die because of environmental stresses; *r* indicates the rapid population growth. Arable pests are typical *r* species.

secondary consumers
animals that live on herbivores, or primary consumers

secondary succession
the process in which an already existing ecosystem recovers after a major disturbance, such as a forest fire or, more often, an environmental disturbance caused by man

succession
when, in a specific area, species replace each other in a directed way, for instance the re-establishment of a forest after clear-cutting

tertiary consumers
animals that live on herbivores, or secondary consumers

trophic levels
the levels in a food chain in an ecosystem from producer to the highest consumer level

vegetation zone
a region on a defined latitude and altitude with a typical vegetation type; major life zone; biome