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Subpart B—Conservation Planning

Part 610 Ecological Principles for Resource Planners

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Part 610 Ecological Principles for Resource Planners

Contents:

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Cover photos courtesy of Wendell Gilgert, Tim McCabe, Charlie Rewa, and Gary Wilson, USDA NRCS, and the Utah Division of Wildlife Resources.

610.00 Ecosystems and landscapes

An *ecosystem* is a biological community, or assemblage of living things, and its physical and chemical environment. The interactions among the biotic and abiotic components of ecosystems are intricate. Conservation of natural resources can be daunting when the social, cultural, economic, and political realities of our modern world and the complex, multidimensional nature of ecosystems are considered.

Often fish, wildlife, and plants are dependent upon several ecosystems within broader landscapes. For example, migratory birds, butterflies, and salmon use different ecosystems that traverse political boundaries (often thousands of miles apart) during phases of their life cycles. Conservation of these migratory species creates land management challenges that can only be adequately addressed at the landscape scale. *Landscape ecology* considers principles about the structure, function, and changes of interacting ecosystems in natural resource conservation and planning (Forman and Godron 1986).

Dynamic processes occurring over multiple scales of time and space determine the physical and biological characteristics of our landscapes. These include:

- Geomorphological processes, such as erosion
- Natural disturbances, such as fires, floods, and drought
- Human perturbations, such as land clearing and urban development
- Changes in the make-up of biological communities, from days to millions of years

To implement effective conservation practices that take into consideration the often-extensive migratory paths of species, think broader than the project site and longer than the project time (fig. 610–1). Even a cursory evaluation of landscape conditions and their ecological and cultural history provides a valuable context when considering fish and wildlife resource concerns. This can lead to a better understanding of how large-scale processes affect individual parcels of land and the habitats they provide, and how actions on small pieces of land can influence ecological processes and biodiversity at broader scales.

Figure 610–1 Ecological principles for land management planners (from Dale et al. 2001)

Time	Ecological processes function at many timescales, and ecosystems change through time.
Species	Individual species and assemblages of interacting species have key, broad-scale ecosystem effects.
Place	Local conditions (climate, geomorphology, soil quality, altitude) as well as biological interactions affect ecological processes and the abundance and distribution of species.
Disturbance	The type, intensity, and duration of disturbances shape the characteristics of populations, communities, and ecosystems.
Landscape	The size, shape, and spatial relationships of land cover types influence the dynamics of populations, communities, and ecosystems

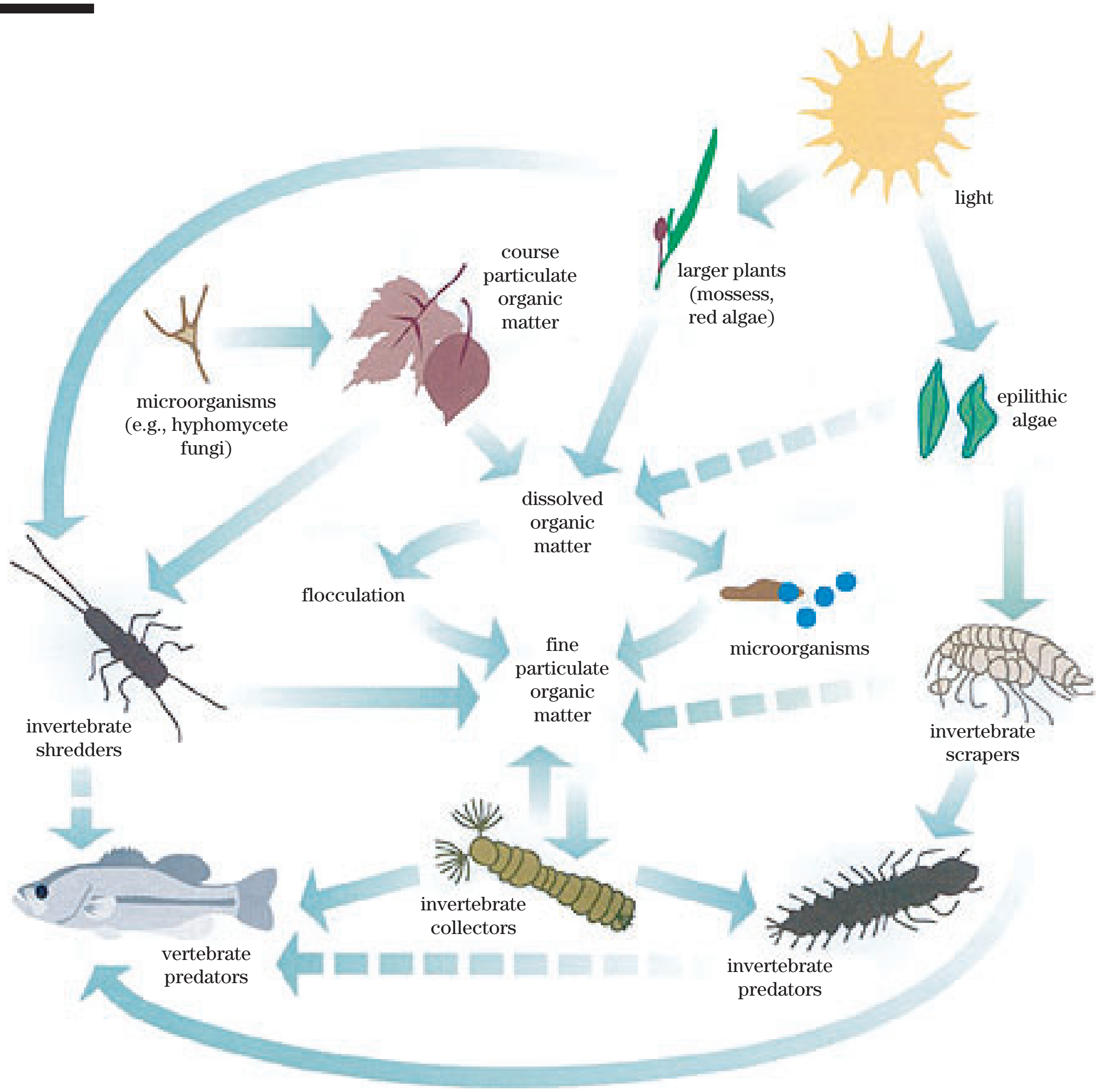
610.01 Ecosystem processes

(a) Energy flow

Energy flows through and fuels ecosystems and all living things. Virtually all energy originates from the sun. Organisms can be grouped into food chains, or more complex food webs, according to the trophic level that represents where they obtain energy from their environment as shown in figures 610–2 and 610–3. From a habitat management standpoint, the sources of available energy at each trophic level affect the mix of species in an ecosystem, their populations, and how they interact.

Green plants are *autotrophs*, or primary producers. They use solar energy for photosynthesis, combining atmospheric carbon dioxide and water into high-energy carbohydrates, such as sugars, starches, and cellulose (see section (c) Carbon cycle).

Figure 610–2 Aquatic food web (from Stream Corridor Restoration: Principles, Processes, and Practices)

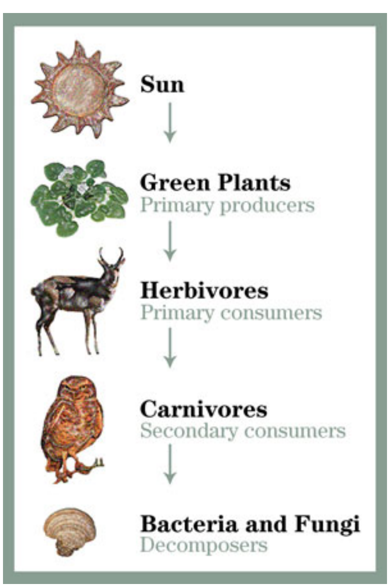


Animals are *heterotrophs;* they derive their energy from the carbohydrates stored within plants. Heterotrophs can be herbivores or carnivores. Herbivores, or primary consumers, obtain their energy by directly consuming plants. Carnivores, or secondary consumers, derive their energy by consuming herbivores and other carnivores. Animals that eat both plants and other animals are referred to as omnivores. Food chains or webs end with decomposers, usually bacteria and fungi, that recycle nutrients from dead or dying plants and animals of higher trophic levels.

The amount of energy available to organisms at different trophic levels declines as it moves through an ecosystem. Thus, more energy is available to support plants than herbivores and even less to support carnivores. As a rule of thumb, only about 10 percent of the energy that flows into a trophic level is available for use by species in the next higher level.

For example, if green plants are able to convert 10,000 units of energy from the sun, only about 1,000 units are available to support herbivores and only about 100 to support carnivores. Energy is lost primarily in the form of heat along the food chain.

Figure 610–3 Terrestrial food chain



(b) Water and nutrient cycles

Water and elements, such as carbon, nitrogen, and phosphorus, are critical to life. Unlike energy that flows through an ecosystem, these materials are cycled and reused repeatedly. In river systems, nutrients are said to spiral rather than cycle as they do on land.

Nutrient spiraling is a concept that explains the directional transport of nutrients in streams and rivers, rather than closed *nutrient cycles* associated with terrestrial ecosystems. All of these important processes provide elements that are essential to all living things, and all are powered by energy. Thus, human actions that disrupt or alter energy flow in ecosystems also affect water and nutrient dynamics in those systems.

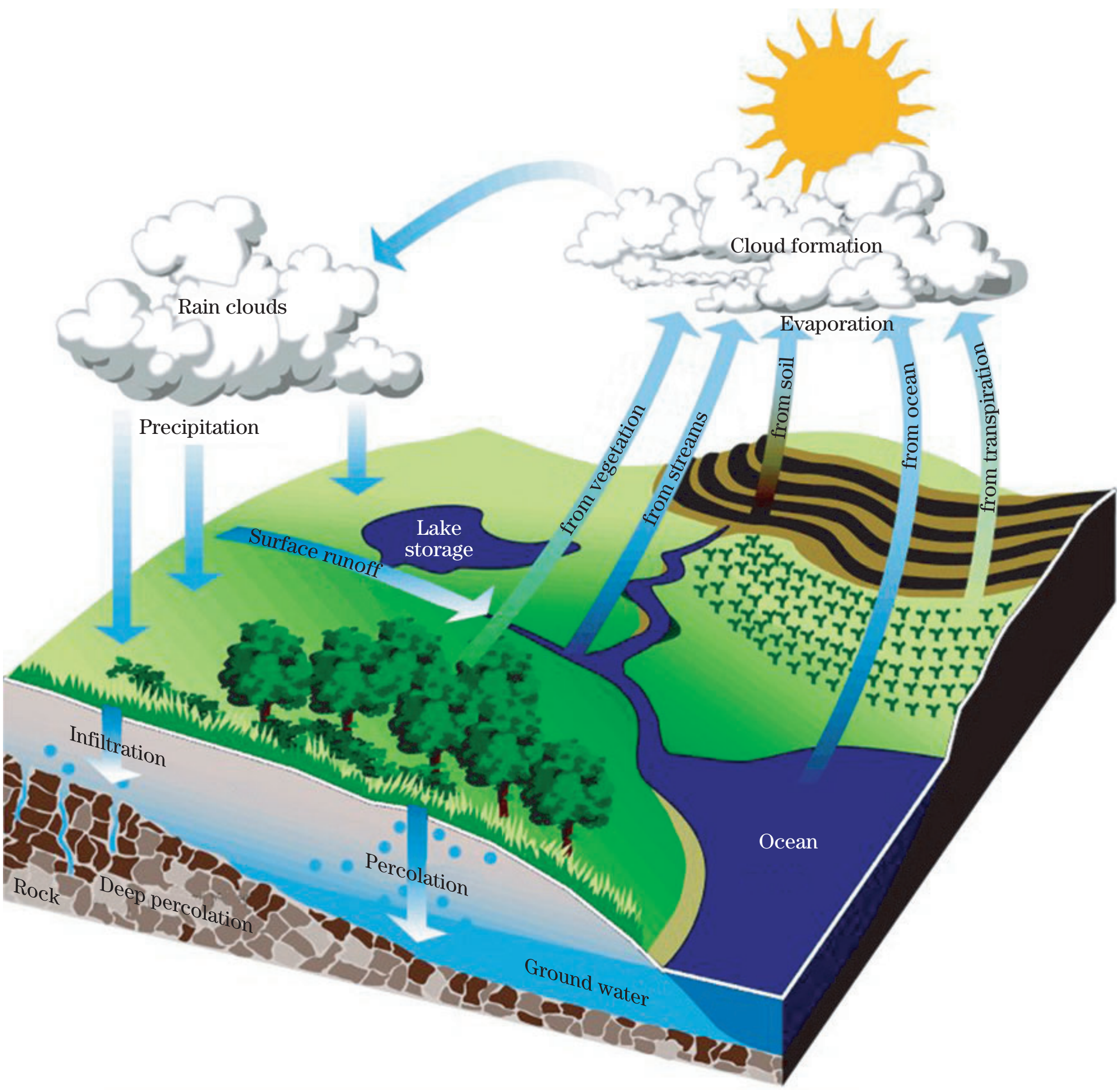
The water, or hydrologic cycle (fig. 610–4), has two phases: the uphill phase driven by solar energy, and the downhill phase, which supports ecosystems.

Most rainfall comes from water evaporated from the sea by solar energy (uphill phase). In fact, about a third of the solar energy reaching the Earth's surface is dissipated in driving the hydrologic cycle.

Approximately 80 percent of rainfall recharges surface and groundwater reservoirs and only 20 percent returns directly to the sea. As water moves through ecosystems (downhill phase), it shapes the physical structure of the landscape through erosion and deposition. It also affects the distribution and abundance of living things as it regulates availability of nutrients in soil that must be dissolved by water to be utilized by plants. Soil is thus an essential component in the water cycle.

The water cycle links the land to aquatic ecosystems where the flow rate and nutrient levels determine the make-up of their biological communities. Carbon dioxide (CO_2) in the Earth's atmosphere, and that which is dissolved in water, serves as the reservoir of inorganic carbon from which most carbon compounds used by living things are derived. During photosynthesis, plants use CO_2 to manufacture carbon compounds such as glucose and lignin, thus beginning the *carbon cycle*.

Figure 610–4 Hydrologic cycle (from Stream Corridor Restoration—Principles, Processes, and Practices)



During plant respiration, some CO_2 is released back into the atmosphere, but much is stored, or sequestered, in both live and dead plant tissues (fig. 610–5). The majority of climate researchers believe that human activities, including the burning of fossil fuels and clearing of forests, have increased the amount of CO_2 in the atmosphere (Houghton et al. 2001). A greenhouse effect results as CO_2 increases the amount of heat trapped in the atmosphere.

One of the most biologically important elements for living things is nitrogen, which constitutes about 78 percent of Earth's atmosphere as nitrogen gas (N_2). Although important, nitrogen gas is virtually unusable by all but a few living things.

The *nitrogen cycle* (fig. 610–6) is dependent on bacteria and algae in soil and water capable of using atmospheric nitrogen to synthesize or fix nitrogen. The resulting nitrogen-containing compounds can then be used by higher plants and animals. Some legumes and other plants fix nitrogen through bacteria that live in specialized nodules on their roots. Nitrogen stored in plants is available to plant-eating heterotrophs. As animals die or are consumed by other organisms, the nitrogen eventually enters the soil where denitrification returns it to the atmosphere (fig. 610–7).

Figure 610–6 Nitrogen cycle

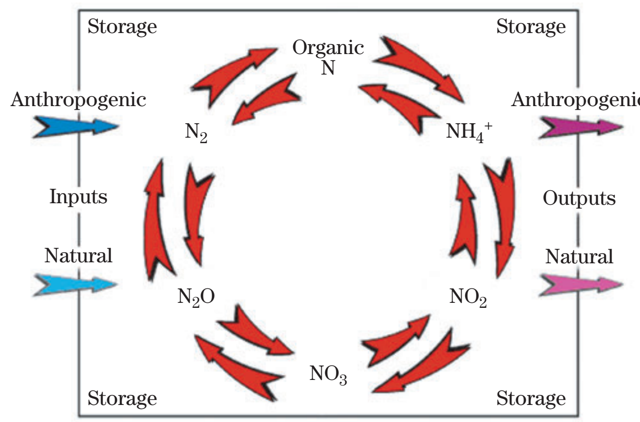
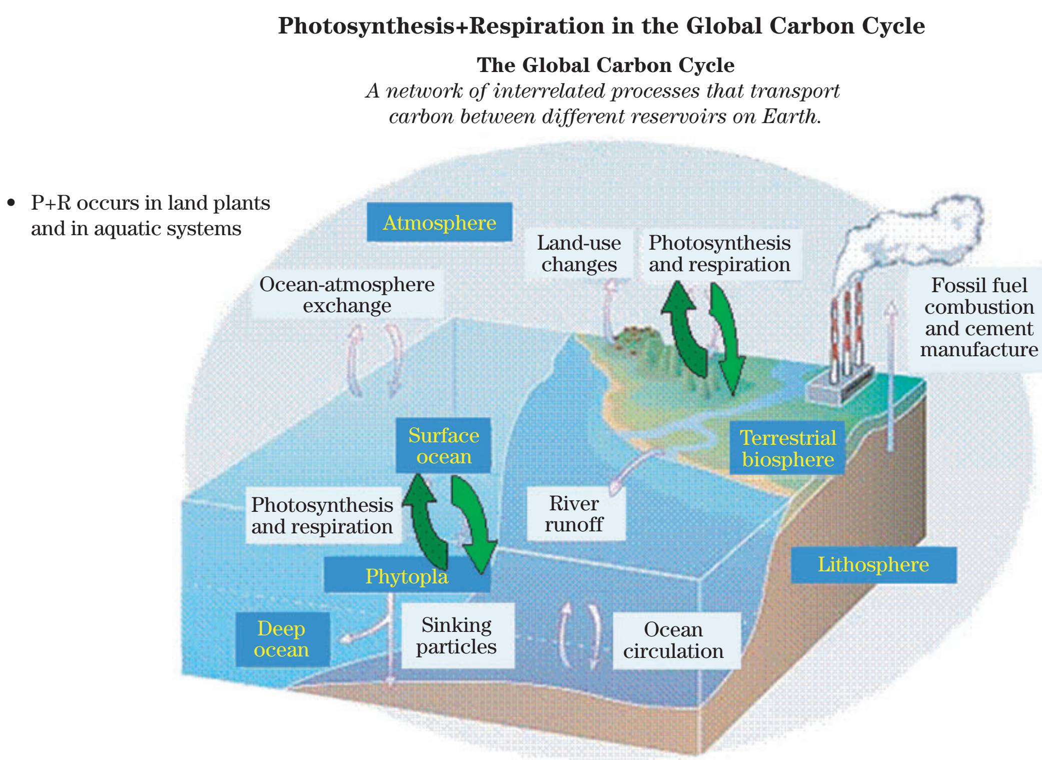
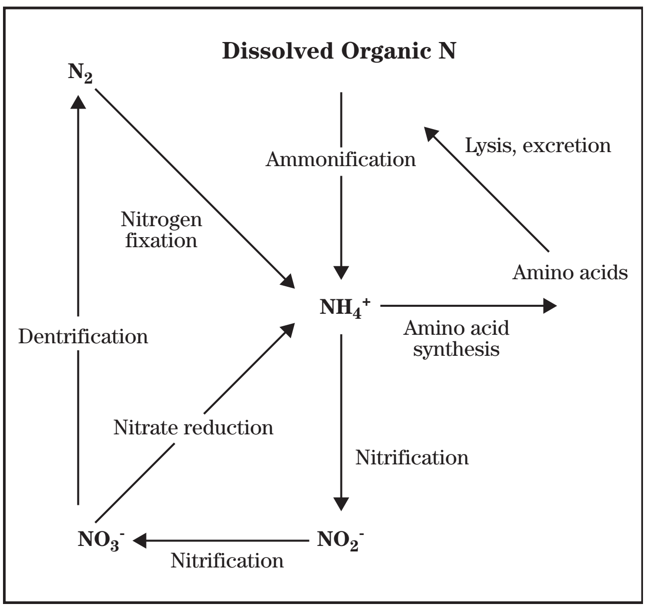


Figure 610–5 Carbon cycle and its effect on the Earth's atmosphere



In the *phosphorus cycle*, plants and bacteria take up phosphorus from soil. Phosphorus is required for energy transformations within the cells of organisms. Animals obtain it from plants and other animals. Phosphorus returns to an ecosystem's reservoir through excretion and decomposing organic tissue of both plants and animals.

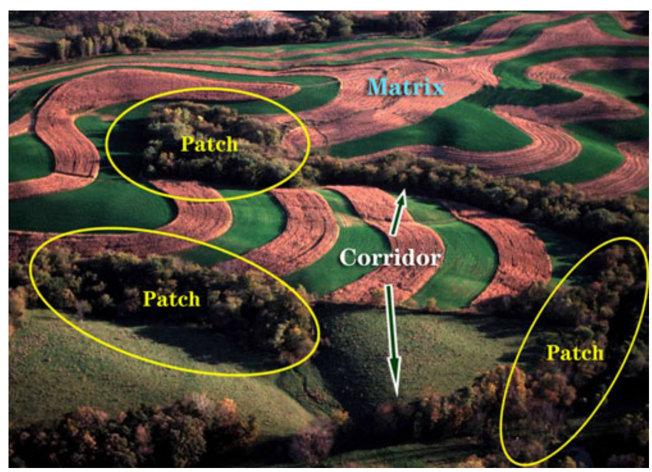
Figure 610–7 Nitrogen pathways on working lands



610.02 Ecosystem structure and its relation to ecosystem function

The physical structure of ecosystems varies according to climatic patterns, soil types, soil qualities, disturbance patterns, geologic events, biological interactions, and human perturbations. Individual ecosystems of a landscape can be thought of as patches or corridors within a matrix where flow of energy, materials, and species occurs (fig. 610–8). The components of ecosystems, such as animals, plants, biomass, heat energy, water, and mineral nutrients, are heterogeneously distributed among patches or corridors that vary in size, shape, number, type, and configuration.

Figure 610–8 Landscape elements: patch, matrix, and corridor (photo courtesy Iowa NRCS)



610.03 Ecosystem changes and disturbance

(a) Stability in ecosystems

Many of the familiar ecosystems have changed dramatically over the last 10,000 years. For example, following the last glacial period, North America became more arid and deserts now occupy areas that were once coniferous forests. Ecosystems and their processes may appear static because the frame-of-reference is typically limited to the perspective of a human life span.

In reality, ecosystems are in a constant state of flux. The stability and health of ecosystems are human concerns. This stability is measured by the resilience to natural disturbances or human perturbations. Natural disturbances, although temporarily disruptive, are important for maintaining many ecosystem processes and thus biological communities. They can also wreak havoc on infrastructure and human economies. On the other hand, human-induced perturbations that cause a departure from normal ecosystem processes may disrupt ecosystem sustainability and the associated production of goods and services.

Natural disturbances, such as fire, floods, hurricanes, and tornadoes, all affect and change ecosystems. They may significantly alter the existing community of plants and animals, making conditions favorable to other species, including alien invasive species. The community progresses through a series of overlapping, successive steps that provide habitat for different species. Over time, succession may lead back to an ecosystem similar to the original. However, if there have been climatic changes or new species have moved into the area, the biological community may be significantly different. Fire is one of the most important natural disturbances because of its high frequency and the extent of area it affects. Where fire is frequent, plants and animals have adapted to it. In fact, the seeds of many plant species lie dormant in the soil waiting for a fire event to release nutrients and provide sunlight that was once blocked by the previous canopy of vegetation. Fire and other natural disturbances create a diversity of habitats within the landscape.

In river and stream ecosystems, recurring floods are critical to sustained production of fisheries, flood plain forests, wetlands, and riparian habitat. Rivers and streams derive most of their biomass from within the flood plain and their biological communities are dependent on lateral exchanges of water, sediment, and nutrients among the flood plain, the riparian area, and river channel (fig. 610–9).

Aquatic species move into the flood plain at rising and high water levels because of feeding and spawning opportunities; terrestrial animals along the rivers then exploit the available food sources that result from receding water. Dams, dikes, and extensive revetments along rivers have significantly reduced the function of flooding in sustaining ecosystem processes in large rivers (fig. 610–10).

Figure 610–9 Flood pulse concept

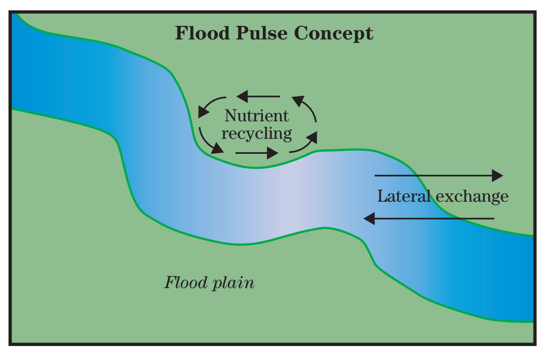


Figure 610–10 Rock and timber revetment on the Willamette River, Oregon (photo courtesy Kathryn Boyer, USDA NRCS)

Ecosystems are dynamic, and change is the normal course of events. Change in vegetation structure often creates a more diverse or heterogeneous array of habitats for terrestrial wildlife. Many past management decisions, such as fire suppression and flood prevention, have been undertaken to minimize the dynamic nature of some ecosystem processes to protect and promote human interests. From a fish and wildlife standpoint, this has tended to simplify habitats, disconnect the flow of nutrients, and isolate populations.

610.04 Biological diversity

(a) Hierarchy of diversity

Biological diversity or *biodiversity* is the variety and variability among living organisms and the ecological complexes in which they occur.

Biodiversity is organized hierarchically, beginning with the genetic diversity of individual organisms and ending with the diversity of ecosystems available in landscapes (Noss 1990) (table 610–1). It includes the full range of species, from viruses to plants and animals, the genetic diversity within a species, and the diversity of ecosystems in which a community of species exists. Land management goals that include conservation of biodiversity require that decisions be made over spatial scales that are much larger than individual parcels of land.

A *species* is a group of individuals that are morphologically, physiologically, or biochemically distinct. In addition, they have the potential to breed among themselves and do not normally breed with individuals of other groups. Species that range over wide geographical areas often are divided into *subspecies* if their morphological characteristics vary enough to make them distinctive.

A *population* is a group of individuals of the same species that share a common gene pool. This means they are in close enough proximity to each other to potentially interbreed, although they often do not. Populations of many species have wide distributions and to a greater or lesser extent are geographically isolated from each other by physical barriers or distance. A population of frogs in a small pond is isolated from a population of frogs in another pond many miles away. The probability that the two populations will interbreed is low.

A *metapopulation* is the collective group of discrete populations of a species across a landscape upon which the species' continued existence depends. For example, a natural disturbance, such as fire, may cause local extermination of an amphibian species population. The existence of other populations in a

Table 610–1 Indicators of biodiversity at four levels of organization (Noss 1990)

Organizational level	Compositional factors	Structural indicators	Functional indicators
Regional landscape	Identity, distribution, richness, and proportions of patch (habitat) types, collective patterns of species distributions (richness, endemism)	Heterogeneity, connectivity, spatial linkage, patchiness, porosity, degree of fragmentation, juxtaposition, perimeter-area ratio, pattern of habitat layer distribution	Disturbance processes, nutrient cycling rates, energy flow rates, patch persistence and turnover rates, rates of erosion and deposition, human land-use trends
Community ecosystem	Identity, relative abundance, frequency, richness, evenness, and diversity of species and guilds; proportions of endemic, exotic, threatened, and endangered species	Substrate and soil variables, slope and aspect, vegetation biomass and physiognomy, foliage density and layering, horizontal patchiness, canopy openness and gap proportions, abundance, density, and distribution of key physical features, water and resource availability	Biomass and resource productivity, herbivory, parasitism, predation rates, colonization and local extinction rates, patch dynamics (fine-scale disturbance processes), nutrient cycling rates, human intrusion rates and intensities
Population species	Absolute or relative abundance, frequency, importance or cover value, biomass, density	Dispersion, population structure (sex ratio, age ratio), habitat variables (see community-eco-system structure, above)	Demographic processes (fecundity, recruitment rate, survivorship, mortality), metapopulation dynamics, population genetics (see below), population fluctuations, physiology, life history, growth rate (of individuals), adaptation
Genetic	Allelic diversity, presence of particular rare alleles, deleterious recessives, or karyotypic variants	Effective population size, heterozygosity, chromosomal or phenotypic polymorphism, generation overlap, heritability	Inbreeding depression, outbreeding rate, rate of genetic drift, gene flow, mutation rate, selection intensity

landscape that allows their dispersal increases the chances that the species will eventually recolonize the burned area as it recovers.

Genetic diversity among individuals of a population allows for greater flexibility of a species to adapt to changing environmental conditions. For example, genes of one population may offer resistance to a disease that members of another population do not have. If the disease eliminated the other population(s), the resistant group serves as a source for reestablishment of populations in other areas.

Some populations may go extinct on a local scale, and new populations may become established on nearby suitable sites. The close proximity of another population of the same species allows colonization of a disturbed site following natural disturbance or human perturbation. For example, draining and converting a wetland basin to agriculture results in loss of wetland-associated species from the site. However, where wetlands are restored, dispersal of plant seeds and emigration of animals from nearby wetlands provide a ready means of recolonization.

A *biological community* is an assemblage of populations of many species. Within the biological community each species uses resources that constitute its niche. For example, a niche for a bird includes where it nests, what it feeds on, how it obtains water, where it migrates, and even its daily time of activity.

When managing for a single species, it is important to understand its role in the biological community and how it interacts with the assemblage of other species that are part of its ecosystem. Community composition is often affected by predator-prey interactions and competition among species. Predators can dramatically reduce the numbers of herbivore species. This alters the trophic structure of the entire community. Reduction in one herbivore species lessens consumption of specific plants within the community and may allow another species to use the resource and increase its population size.

Predators can also increase the biological diversity and individual species numbers of an area. For example, coyotes control mid-size predators, such as foxes and cats that prey on songbird populations. A reduction in foxes and cats allows songbird numbers and diversity to increase.

(b) Species interactions

Within biological communities, thousands of organism species interact. Some species may be considered more valuable because their presence is critical to the ability of other species to persist in the community.

Keystone species are those that have an ecological function on which other species and components of the ecosystem depend. The black-tailed prairie dog (fig. 610–11) is an example of an organism considered by many to be a keystone species of the shortgrass prairie ecosystem.

Indicator species are species whose presence indicates a particular state or condition of an ecosystem. For example, stream conditions are often assessed by monitoring the presence of aquatic insects, such as mayflies, stoneflies, and caddisflies. In stream ecosystems these species serve as indicators of water quality and good coldwater habitat.

Figure 610–11 Black-tailed prairie dog (photo courtesy US FWS)

610.05 Applying ecological principles to habitat conservation, restoration, and management

The loss and fragmentation of natural habitats have reduced biological diversity and resulted in considerable loss of fish and wildlife resources important to society. Land use changes are not the only culprit, however. Another factor affecting the loss of biological diversity and decline of species important to ecosystems is the introduction or invasion of alien species.

Nearly half of the imperiled species in the United States may be threatened directly or indirectly by alien species (Wilcove et al. 1998). Considering these threats, the following topics are important issues when working with fish and wildlife habitat and should be considered during planning activities.

(a) Area of management actions

The number of individuals and species an area can support is related to its size and the life histories and dynamics of the biotic community it supports. In some ecosystems, such as grasslands, areas smaller than 250 acres may not be able to withstand significant perturbations without the loss of many species of vertebrate animals and plants (Crooks and Soule 1999).

Small areas of habitat are usually insufficient to support larger species. Therefore, conservation and restoration efforts should consider project size and connectivity potential to the extent possible. In addition, efforts should be made to work with adjacent landowners to build contiguous blocks of habitat and link isolated patches of both terrestrial and aquatic habitats.

(b) Edge effects

The ratio of edge to habitat interior increases geometrically as fragment size decreases. Edge occurs when habitat meets a road, crop field, land use change, or other feature, such as a stream. Wildlife management has historically focused on creating edge habitat for the benefit of specific species. However, increased edge can adversely affect many species. These adverse effects are:

- Greater rates of habitat desiccation and loss of native vegetation
- Greater frequency and increased severity of fire
- Greater rates of predation by native and exotic predators (e.g., house cats, foxes, crows, blue jays)
- Higher probability of nest parasitism
- Greater windfall damage
- Greater intensities of browsing, grazing, and other forms of disturbance that favor the growth and spread of weedy and alien invasive species, both plants and animals (Wilcove et al. 1986, Noss and Cooperrider 1994)

Roads are the most frequent source of new edge and may facilitate the movement of weeds and pests. They also cause erosion, stream sedimentation, pollution, and increases in mortality rates of wildlife from collisions (Noss 1992). Especially in situations where area-sensitive species needs are considered, habitat conservation, restoration, and management efforts should reduce edge and minimize roads to the greatest extent possible.

(c) Disturbance effects

Natural disturbances, such as fire, storms, floods, and disease outbreaks, can increase the mosaic of habitat and increase biological diversity within a large habitat area. They can also overwhelm small habitat patches. Small areas are more likely to burn completely, resulting in loss or degradation of the community. These factors require careful management and control of disturbance in smaller habitat patches.

(d) Isolation and distance effects

Fragmentation is the alteration of natural patterns of landscapes or ecosystems, creating smaller patches or disrupting the continuity or connectivity of corridors and networks. As habitat patches become isolated and the distance between patches increases, it is harder for many species to disperse and migrate between them. Life cycles of the organisms that make up a biological community are dependent upon the ability of the organism to safely disperse or migrate. Lower dispersal and migration rates increase the likelihood a species will be extirpated from the area, and possibly become threatened or endangered in the long term.

Habitat conservation should focus on maintaining habitat connectivity and linking isolated patches. Maintaining connections on land and in streams and rivers is critical to the long-term survival of fish, wildlife, and all of the ecological components on which they depend.

(e) Habitat heterogeneity

Heterogeneity is the complexity or variation in physical structure of habitats. For example, in streams, water depth, velocity, substrate, wood, and pool/riffle complexes add to the heterogeneity of the habitat. Increased heterogeneity creates a variation in habitats for terrestrial and aquatic organisms and supports a greater diversity of species. It also provides more flexibility for species as they seek different types of habitats during different stages of their life cycles.

The complexity of interactions within and among species in ecosystems often defies our capacity to understand how to effectively manage natural resources. Actions and practices that maintain habitat and nutrient linkages, allow dispersal and migration, and sustain the processes that support the biological community as a whole are likely to be more effective at enhancing habitat for all dependent species, including those featured in specific management objectives.

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610.07 Glossary

Anthropogenic—Caused by humans.

Autotrophs—Primary producers, such as green plants, that use solar energy for photosynthesis, combining atmospheric carbon dioxide and water into high-energy carbohydrates, such as sugars, starches, and cellulose.

Biological diversity (biodiversity)—Variety and variability among living organisms and the communities, ecosystems, and landscapes in which they occur.

Community—An assemblage of populations of many species living and interacting in close proximity to each other.

Decomposers—Organisms, such as bacteria and fungi, that are found at the bottom of the food chain. They recycle nutrients from dead or dying plants and animals of higher trophic levels.

Ecosystem—A conceptual unit of living organisms and all the environmental factors that affect them; a biological community or assemblage of living things, and its physical and chemical environment.

Genetic diversity—Array of different genes available in a population's gene pool. Genetic diversity is needed among individuals of a population to allow for greater flexibility of a species to adapt to changing environmental conditions.

Heterogeneity—Complexity or variation in physical structure of a habitat.

Heterogeneous habitat—Diverse or consisting of many different structural components, substrates, types of vegetation, climates, etc.

Heterotrophs—Animals that derive their energy from the carbohydrates stored within plants. Heteroptrophs can be herbivores or carnivores.

Indicator species—Those species whose presence indicate a particular state or condition of an ecosystem.

Keystone species—Species that have an ecological function on which other species and components of an ecosystem depend.

Landscape—(1) An area of land consisting of a number of ecosystems; (2) A heterogeneous land area consisting of three fundamental elements: patches, corridors, and a matrix. A *patch* is generally a plant and animal community that is surrounded by areas with different community structure. A *corridor* is a linear patch that differs from its surroundings. A *matrix* is the background within which patches and corridors exist and which defines the flow of energy, matter, and organisms.

Landscape ecology—Study of the spatial and temporal relationships of interacting ecosystems, especially their structure, function, and ecological processes.

Natural disturbance—Any relatively discrete event in nature that disrupts ecosystem, community, or population structure and changes resources, habitat availability, or the physical environment. Natural disturbances include floods, wildfire, earthquakes, volcanic eruptions, tornadoes, hurricanes, and tidal waves.

Metapopulations—Collective group of discrete populations of a species across a landscape upon which the species' continued existence depends.

Niche—All of an organism's interactions with its environment.

Nutrient spiraling—Directional transport of nutrients in streams and rivers, rather than closed nutrient cycles associated with terrestrial ecosystems.

Omnivores—Animals that eat both plants and other animals.

Perturbations—A departure from the normal state, behavior, or trajectory of an ecosystem; alteration of ecosystem processes as a result of human actions, such as land use. Examples of perturbations include disruption of natural flow regimes with dam construction or changes in groundwater hydrology caused by poor livestock management or wetland drainage.

Population—A group of individuals of the same species that share a common gene pool. They are close enough to each other to potentially interbreed, although they often do not.

Primary consumers—Organisms that eat green plants, or herbivores.

Secondary consumers—Organisms that eat herbivores, or carnivores.

Species—A group of individuals that are morphologically, physiologically, or biochemically distinct.

Subspecies—Division of species into subcategories that best describe the relationships of their morphological characteristics.

Trophic level—An organism's position in a food chain or food web.