# Conservation of Ecological Processes

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## Developing Themes in Conservation

With increasing knowledge and practical experience, the conservation movement has gradually shifted its goals and the basic premises of its work. Early efforts in conservation were directed primarily toward the preservation of threatened species, especially conspicuous large vertebrates. The maintenance of viable animal populations remains the major goal of many conservation organizations and still dominates legislation in most countries. The Endangered Species Act of the United States, CITES, and the international movement to restrict or altogether stop the hunting of whales exemplify this traditional aspect of conservation.

Early in the conservation movement, however, it became clear that efforts to save species were futile without preserving suitable habitats for their populations. In general, habitat conservation, which has become a major thrust of the conservation movement, is still directed toward saving living space for wildlife, often toward setting aside reserves for particular threatened species. In the United States, for instance, the Aransas National Wildlife Refuge, within which winters the entire population of the nearly extinct Whooping Crane, is a typical example, repeated throughout the world.

Areas established for recreation or the preservation of geological formations similarly provide thousands of hectares of wildlife habitat that are relatively free from disturbance and development. In many of these cases, management programmes ignore or cannot accommodate ecological cycles and other changes, such as suppression of man-made fire cycles, which have already altered the natural vegetation in many regions.

Legislation to set aside large natural areas, for whatever reason, rarely considers the dynamics of natural processes in the way that legislation for single species often incorporates specific data on population dynamics. In some countries, movements have begun to designate representative habitats for conservation. On a worldwide basis this is exemplified by the UNESCO/MAB programme, which has established 226 Biosphere Reserves representative of the world's major biogeographic regions in 55 countries.

The conservation movement has already broadened its goals from particular species to the general habitat type in specific landscapes, and thereby to the conservation of ecological patterns. Now it becomes increasingly important that conservation and management programmes include an understanding of basic ecological processes responsible for the origin and maintenance of organisms, habitats, and landscapes. Ecological processes must themselves be conserved. This is already accepted in some densely populated regions of Europe, and especially in the Netherlands (Bakker, 1979). Other examples were presented at the International Symposium of the British Ecological Society on "Scientific Management of Animal and Plant Communities for Conservation" (Duffy and Watt, 1971).

## What Are Ecological Processes?

Ecological processes include all the physical processes and the plant and animal activities which influence the state of ecosystems and contribute to the maintenance of their integrity and genetic diversity, and thereby their evolutionary potential. The particular processes that make up the dynamics of an individual ecosystem are so numerous and their expressions so diverse that they defy simple characterization. They must be defined individually in each situation.

Ecological processes may be most easily appreciated in terms of their results, as identified by the movement of energy, materials, and nutrients; by the information which regulates these functions; and by community changes following disturbance. Other measurements of component parts of the system, such as changes in populations of certain species, may serve as adequate indices of certain ecological processes if their role in the entire system can be ascertained.

The main ecological processes may be classified in a broad sense as (1) biogeochemical cycles, especially the hydrological cycle, (2) primary and secondary production, i.e., energy flow, (3) mineralization of organic matter in the soils and sediments, (4) storage and transport of minerals and biomass, and (5) regulation of the processes in (1) through (4), often by the activities of animals.

Fig. 1. Predictable supplies of unpolluted water are required for the maintenance of many ecosystems of critical conservation value, such as this freshwater marsh in Oregon, United States. (Photo credit: US Dept. Interior.)

In both marine and terrestrial environments, the quality of water and its rate of movement determine the primary characteristics of the ecosystem (Fig. 1). In many terrestrial habitats, the quantity of water sets the overall level of primary production, its interaction with the land determines the details of the landscape and the characteristics of the soil, and it provides the major avenue of exchange of materials and energy between the various parts of the ecosystem. Therefore, the first concern of environmental management based on ecological processes must be the integrity of the water system. In many cases, the impact of environmental alteration or disturbance can be measured most meaningfully in terms of its impact on the movement and composition of water.

Whereas the hydrological cycle is often the most important physical aspect of the ecosystem and very susceptible to disturbance by man, primary production by plants provides the input of energy that drives the biological dynamics of the system. Primary production is governed by a variety of factors, such as precipitation, temperature, physical and chemical quality of the soil, and the activities of animals (i.e., defoliators, seed predators, and agents of pollination and seed dispersal).

Exotic varieties of plants, sometimes greatly altered by adaptation and selective breeding, can establish themselves abundantly or may be planted extensively and achieve high levels of organic production and biomass accumulation. But with the exception of weedy species inhabiting disturbed areas, the natural maintenance of plant populations within an area depends on a variety of ecological processes that support equally well the specialized pollinators and seed dispersers necessary for plant reproduction and that prevent pests and diseases from reaching catastrophic levels. When people establish their plant and animal associations, they also must assume these supportive and regulative functions, often at considerable economic, social, and environmental cost (Pryor, 1982).

Plants assimilate minerals from their environments at a rate far exceeding that at which minerals are made available by physical processes of soil weathering and import from outside the system. For example, the flux of calcium and nitrogen in a temperate forest exceeds by a factor of ten or more the input of these elements by physical processes (Likens *et al.*, 1977), and probably by even more in tropical systems. The balance of the mineral budgets of plants is supplied by the release of elements in inorganic forms when microbes (bacteria and fungi) decompose plant detritus, animal carcasses, and excreta. Although microbes are the most ubiquitous and adaptable of all living forms, their levels of activity are strongly influenced by physical factors, including acidity and oxygen level, and by toxic chemicals and other disturbances to soil and sediments. It is generally recognized that the pollution of freshwater systems alters the activities of bacteria and blue-green algae, which may exceed the natural buffering and regulatory mechanisms and change the fundamental characteristics of the system. Even though the compensatory population processes of microbes might maintain fluxes of minerals through a system in the face of disturbance, the effect of altered conditions on microbes with specific effects, such as many plant pathogens, mycorrhizal fungi, and symbiotic nitrogen-fixing bacteria and blue-green algae may be more drastic. In particular, changes in soil properties accompanying disruption in burning regimes, including fire prevention, may have important consequences for the system mediated through the altered activities of microorganisms (Gill *et al.*, 1981).

Although animals usually comprise only a small proportion of the total biomass of the ecosystem, they can be very important as agents in the ecological process of regulation. It should be realized that plants have coevolved with animals and have become dependent upon them for pollination and seed dispersal (see Futuyma and Slatkin, 1983). Furthermore, herbivores have greatly affected both plant population dynamics and adaptations. Their important regulatory role often is revealed only when removed, either intentionally or accidentally at the hand of man. Thus, for instance, *Calvaria major,* a formerly common species of tree on Mauritius Island has not produced seedlings since its obligate seed disperser, the dodo bird, was hunted to extinction three centuries ago (Temple, 1977). This example emphasizes the close interdependence and interaction of all the physical and biotic processes in the ecosystem. In order to ensure the continuity of the processes, it is important to gain an understanding of their basic characteristics.

## Characteristics of Ecological Processes

Ecosystems have a spatial relationship to each other. The interecosystem movement of materials by organisms and by physical processes is one factor linking together the ecological processes occurring in different places and in different habitats. Furthermore, each ecosystem is a mosaic of habitat patches. The movements of organisms between these patches occur as individuals search for food, defend breeding territories, migrate between winter and summer homes, and disperse from areas of high population concentrations to less densely populated areas. These movements are critical to the regulation of local populations, determine the area required to avoid extinction, reduce inbreeding within populations, and preserve normal social organization. Therefore reducing or stopping the ecological processes of emigration and immigration inevitably leads to marked change in ecosystem structure. For instance, in the case of African ungulates and other big game, restriction of movement in and out of the parks and reserves has resulted in overpopulation, overgrazing, large-scale habitat destruction, and resulting population collapse.

The integrity of ecosystem function, particularly in aquatic habitats, depends on the transport of materials into and out of areas. This may be accomplished through the movement of individuals or by physical transport of silt by large rivers. and its deposition on flood plains, or of terrestrial plant detritus washed into streams where it forms the base of the food chain. For example, the life cycle of the salmon involves a long period at sea followed by migration into rivers to spawn. Spawning success is greatly influenced by the quality of the streams, which may be altered by agriculture, forestry, and urbanization. The fingerlings that return to sea are at the base of the food web for other species of fish, and seals and seabirds in their turn. Therefore when spawning is prevented, the effects spread widely throughout the marine and freshwater systems (Hasler, 1975) with far-reaching social and economic effects.

Ecological processes undergo regular temporal cycles. Production and accumulation of organic material and detritus are seasonal. Animals have seasonal cycles of activity, migration, and dormancy. Just as seasonal patterns in life cycles determine the optimum time for hunting seasons, they may also determine the times of least impact on ecological processes of disturbance or management programmes. Most ecological systems undergo cycles of disturbance and recovery which occur on characteristic scales of space and time. Natural recovery of the system may depend upon recolonization from outside the area or the availability of refuges for local populations. Disturbance may be necessary to maintain local ecological processes. Thus regular occurrence of fire in shrub and prairie habitats prevents the incursion of some plant species while favoring others resistant to, or depending upon, fire; it also furthers the cycling of minerals, and generally ensures the continuity and inherent diversity of these vegetation types.

The scale of disturbance varies; smaller ones often occur more frequently than larger ones. In river systems, small floods occur on nearly an annual basis, whereas larger floods causing more change come much less frequently. In forests, small disturbances include treefalls, small landslides in hilly terrain, blowdowns involving several trees, and localized epidemics of pests and diseases. Larger disturbances include meander erosion at the edge of rivers, hurricanes, earthquakes, volcanism, and drought and frost, which may affect whole regions. Similar disturbances on coral reefs may come from storms and hurricanes, or from explosions of populations of predators such as the Crown-of-Thorns Starfish (*Acanthaster*). The time scale of such disturbances varies from a few years to centuries or millenia.

As a result of disturbance, one of the most important aspects of conservation is the preservation of the capacity of recovery from disturbance. At the same time, some disturbances themselves might be vital for the maintenance of the integrity and diversity of the ecosystem. Without such disturbances, the system may tend towards geographical and temporal uniformity, with a resulting reduction in the variety of life forms and important plant and animal species. This has been shown in the Mediterranean shrub ecosystem where the prevention of grazing, fire, and cutting has resulted in a 75% reduction in plant diversity and also animal abundance and diversity (Naveh and Whittaker, 1979). Mediterranean forests and shrublands have evolved and are maintained since Middle Pleistocene under "disturbances" of natural and human-set wildfires, wild and domesticated herbivore grazing as well as cutting pressures. Therefore, the complete and prolonged cessation of all these perturbations in nature reserves is creating an unnatural situation, leading to dense, monotonous, unpenetrable, and highly flammable *maqui* thickets, as shown in Fig. 2.

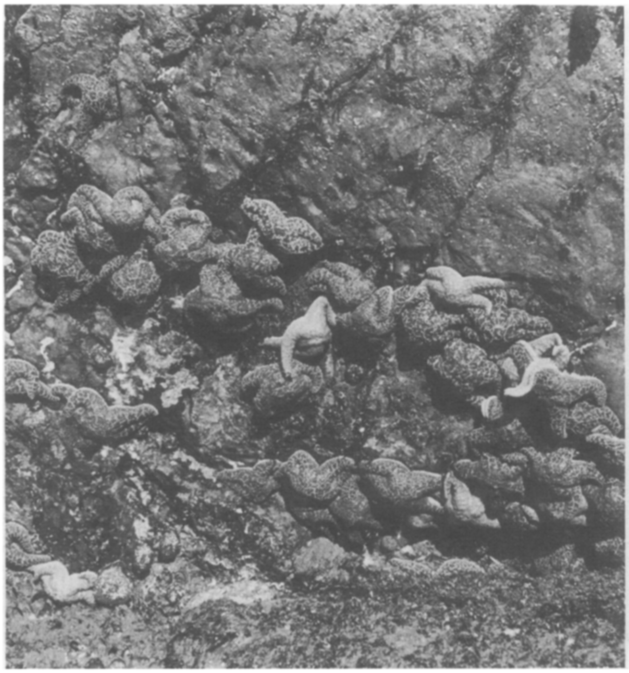
Fig. 2. Um Rechan Forest Reservation in Samarian mountains in Israel, protected for 60 years and dominated almost exclusively by *Quercus calliprinos* (40–50% cover) and *Phyllirea media* (20–30% cover). In the rear: outside the reservation, different grazing and cutting pressures have created typical mosaic-like open shrublands with many more species of plants. However, in the center, all shrubs have been uprooted for patch-cultivation. (Photo credit: Z. Naveh.)

Population processes within ecosystems are such that when one population changes in size, others may respond in a manner that tends to preserve the overall function of the system. Populations interact through various pathways, one of which is competition for shared resources. When the population of one species decreases, those of competitors may increase owing to the added resources available to them. This principle has been invoked to explain spectacular recent increases in antarctic seal and penguin populations following reduction of southern whale stocks, all of which feed upon krill (*Euphausia superba*). Similarly, predators may switch their feeding to new prey when the population of a preferred prey is reduced. Such compensations occur continually, but when population levels change drastically, they may not be sufficient and overall ecosystem function may be altered.

The principle of compensation suggests particular species are not necessarily crucial to ecosystem function, and a reduction in diversity need not lead to a collapse of the overall integrity of ecological processes. But because each species is different and because species are mutually coevolved, the effects of a loss or serious decline of a species can never be perfectly predicted. Certain species exert unusual control over ecosystems and their removal can have serious consequences. Such species often are difficult to identify without experimental study because the control they exert is a part of the natural system. Recent experiments on the rocky intertidal zones of western North America have shown the crucial role of predatory starfish in maintaining species diversity (Paine, 1974). After experimental removal of starfish, or in habitats where the surf is too great for the starfish, mussels quickly replace other sessile organisms and spread throughout the zone. As a result, the diversity of the system, formerly maintained by the starfish, declines rapidly (Fig. 3).

The role of predators and herbivores in community structure often depends on the environmental conditions. In many simple communities with efficient predators, predation is so efficient as to reduce the total biomass and the diversity of prey. Overgrazing by domestic and feral animals has resulted in the elimination of native plant species in many parts of the world, especially where the flora has not been exposed to such grazing over evolutionary time. Many other such examples in a variety of systems have been cited (Elton, 1958).

Consideration of the evolution of species with respect to each other over long periods of evolutionary time is fundamental to understanding ecological processes. Pollination, seed dispersal, and parasite–host interactions are cases in which particular species can have large effects on a system because of their specialized adaptations. Such species have figured importantly in many cases of introducing exotics while leaving behind highly evolved and specialized control species.



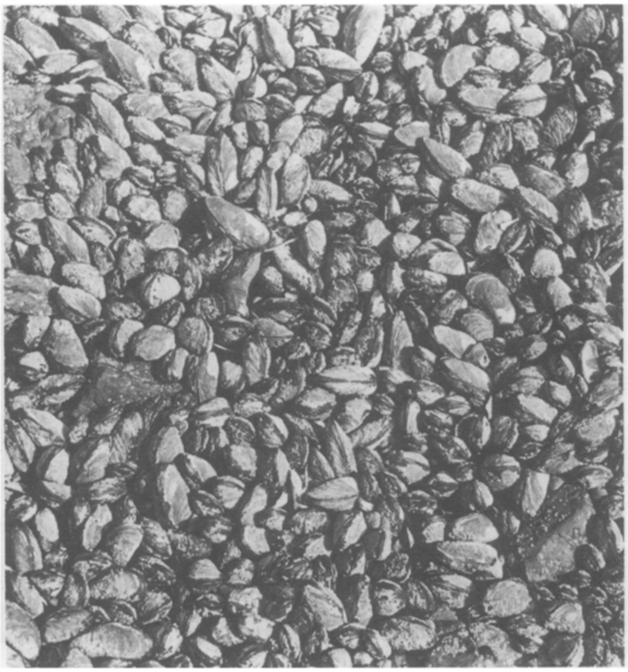


Fig. 3. On the rocky shores of the Pacific coast of North America, where the predatory starfish *Pisaster* (left) is absent or removed experimentally, the mussel *Mytilus* (right) crowds out sessile invertebrates and algae, and dominates the ecosystem. (Photo credit: R. E. Ricklefs.)

The success of many introduced 'pest' species stresses the need for preserving the complex web of functional and evolutionary interrelationships within every system. Thus, for example, euglossine bees, which are solely responsible for the pollination of certain species of orchids in mature New World tropical forests, depend on plants in early successional stages to obtain food for their larvae. Hence patches of vegetation maintained through disturbance cycles have been a part of the evolutionary history of the system and are necessary for its maintenance (Feinsinger, 1983).

## Fluctuations and Dynamic Flow Equilibrium

Natural systems are in a constant state of flux resulting from physical processes, and by energy and nutrient flow through them as individuals die and are replaced by their descendents or other kinds of organisms. But the general structure of natural systems can remain in a closely regulated steady state for a long period. This does not preclude the cybernetic capacity of the system to respond to large-scale perturbations. These processes may occur on time scales that are long relative to the human lifespan and probably the practical lifetimes of any programmes that we initiate today. Therefore ecological processes may encompass mosaics of local disturbance and regeneration that allow us to perceive this dynamic steady state only on vast scales of time and space, and not in a short-term view of a local climax. More and more ecologists realize that this steady state should be regarded as a dynamic flow equilibrium, incorporating and to a large degree maintained by fluctuations in processes and changes in patterns. This view is supported by recent findings in the field of non-equilibrium thermodynamics by Prigogine (1976), and further elaborated by other papers in the important book edited by Jantsch and Waddington (1976). Through these fluctuations, both structure and function are integrated and maintained in the face of perturbations of physical properties of the environment and dynamic characteristics of populations.

Ecological processes have two overriding characteristics which present a formidable challenge to management programmes. First, the particular interactions between organisms and their physical environments and among organisms have evolved over long histories of association. Just as the organism is adapted to the particular conditions of its environment, the dynamic local system is composed of particular populations whose properties have evolved in response to each other as well as to their physical environment. Second, the regulatory processes of natural systems may extend over great geographical distances and across ecological formations, and they may exhibit seasonal change and cycles of disturbance over time followed by compensatory response. The practical implications of these properties have made themselves felt in particular management and conservation problems, but the more general attitude of directing conservation efforts at ecological processes themselves is still embryonic in the minds of most conservationists.

## Rationale for the Conservation of Ecological Processes

As the pace of exploitation and development of the natural world quickens, the scope of the conservation movement must grow to meet new challenges, as outlined in the World Conservation Strategy (IUCN, 1980). Unless programmes can be devised to preserve the basic integrity of natural and semi-natural systems on scales matching the scope of their regulatory processes, efforts with narrower goals will quickly prove futile.

The rationale for incorporating the principles of ecosystem dynamics into conservation planning and management at all levels can be summarized as follows:

(1) The conservation of ecological processes is crucial to the preservation of individual species because each is inseparable from the system in which it lives.

(2) The conservation of ecological processes is crucial to the preservation of natural habitats because such habitats, though seemingly static as we usually envision them, are expressions of the underlying dynamics of ecosystems.

(3) In general, it is more prudent for conservation purposes to rely on the powerful self-regulatory and self-stabilizing processes of intact or nearly intact bio-ecosystems than to rely on continuous intervention.

(4) Where intensive management clearly is required, as in agriculture, fishing, and forest use, understanding of ecological processes may prevent management mistakes that can intensify the damage of development.

In 'natural' ecosystems (very few remain) all these processes and patterns are induced solely by natural environmental and biotic forces. In semi-natural ecosystems, including most of the present natural reserves and protected areas, to some extent people have affected patterns and processes as an integral part of the system and their role must be maintained in order to ensure

Fig. 4. One of the few, remaining old *Quercus ilex* forests near Orgosolo, Sardinia, with wooden huts of traditional shepherds. The forest has maintained and renewed itself during hundreds of years of continuous grazing pressures of swine (consuming about 50% of acorns) and cattle. (Photo credit: Z. Naveh.)

continuity (Fig. 4). In systems intensively managed for economic purposes, such as agroecosystems, people have greatly simplified these patterns and processes, and eliminated most of the natural regulatory feedbacks.

In natural ecosystems, the main object of conservation management should be to ensure the continuity of processes and to avoid their disruption, as has been done in the cases where natural fire cycles, predation, and other natural perturbations have been modified. But in all other ecosystems, we must recognize vital people-induced ecological processes, such as hunting, gathering plants for food and fuel, grazing, burning, and cutting. These have become major forces of change and inevitably will continue. Of course, practical experience with management and conservation problems instills a deep appreciation for the ecological processes of particular situations. What is required now is to set the general principles of ecological processes and their implications for dynamic conservation practice.

## Conservation and Development

As stated clearly in the World Conservation Strategy, the goals of conservation must be more and more closely tied to the problems of regional development. It can be envisaged that the area of more or less intact ecosystems will decline and these areas will increasingly have common boundaries with developed areas. The idea of basing conservation on the fate of particular species or even on the maintenance of a natural diversity of species will become even less tenable as the number of threatened species increases and their refuges disappear. Natural areas will have to be designed in conjunction with the goals of regional development and justified on the basis of ecological processes operating within the entire developed region and not just within natural areas.

As in the case of population dynamics, the most serious implication of basing conservation and management on the principles of ecological processes is that these processes can extend spatially across political boundaries, both local and international, and they extend in time beyond the duration of most administrations. Conservation efforts and supporting legislation must eventually be regional and international; management programmes must mimic natural systems in accommodating natural disturbances. The recognition of the need for the conservation of ecological processes can provide a solid framework on which to build the programmes of the future.

Fig. 5. An area of slash and burn in the wet forests of Gabon, Africa. (Photo credit: WWF/S. Zalewski.)

## Threats to Ecological Processes

The potential threats of disturbance, management, and development to ecological processes are as varied as the processes themselves. Several kinds of threats may be present in any situation, but the magnitude of their impact on particular systems always will depend on the nature of the system itself. The following categories of threats are meant primarily as a checklist against which individuals interested in regional conservation problems can assess their local situation.

*(1) Alteration of major mineral or organic components* of a system can lead to the depletion of soils and a reduction in the fertility of the land, e.g., by inappropriate, overly intensive slash and burn agriculture (Fig. 5).

Many kinds of pre-technology agriculture create mosaic patches of disturbance. If the natural fertility of the land is to be maintained, it is important that disturbance does not slow natural recovery. Otherwise, considerable, expensive restoration may be required to maintain local ecological processes.

Disturbance also may occur through additions to certain compartments in the ecosystem. Overgrazing may follow the artificial maintenance of herbivore populations far above levels which the environment can support (Fig. 6). The consequences of intense herbivore pressure may occur through severe depletion of plant biomass or through altering the species composition of vegetation, both having potentially widespread effects through the ecosystem.

Another common addition to ecosystems is through sewage and runoff from fertilized agricultural lands. The increase in nutrients may increase production in some cases, but the disturbance may also upset ecological controls and seriously modify the quality of the system. Organic wastes promote increase of bacterial populations and increase demand for oxygen. One result of such pollution in freshwater systems is anaerobic conditions intolerable to much of the natural fauna. Inorganic nutrients more frequently lead to increased algae populations, but unnatural ratios of such elements as nitrogen, phosphorous, and manganese may favor blue-green algae over green algae. Because the blue-greens are resistant to grazing, their presence may depress the herbivore-based community, ultimately leading to a reduction in fish populations. Artificial inputs of nutrients rarely match the seasonal ability of the system to handle them. Sewage is produced year round, but streams in temperate climates can degrade organic material and assimilate inorganic nutrients best in the summer. The diluting effect of stream flow on pollutants

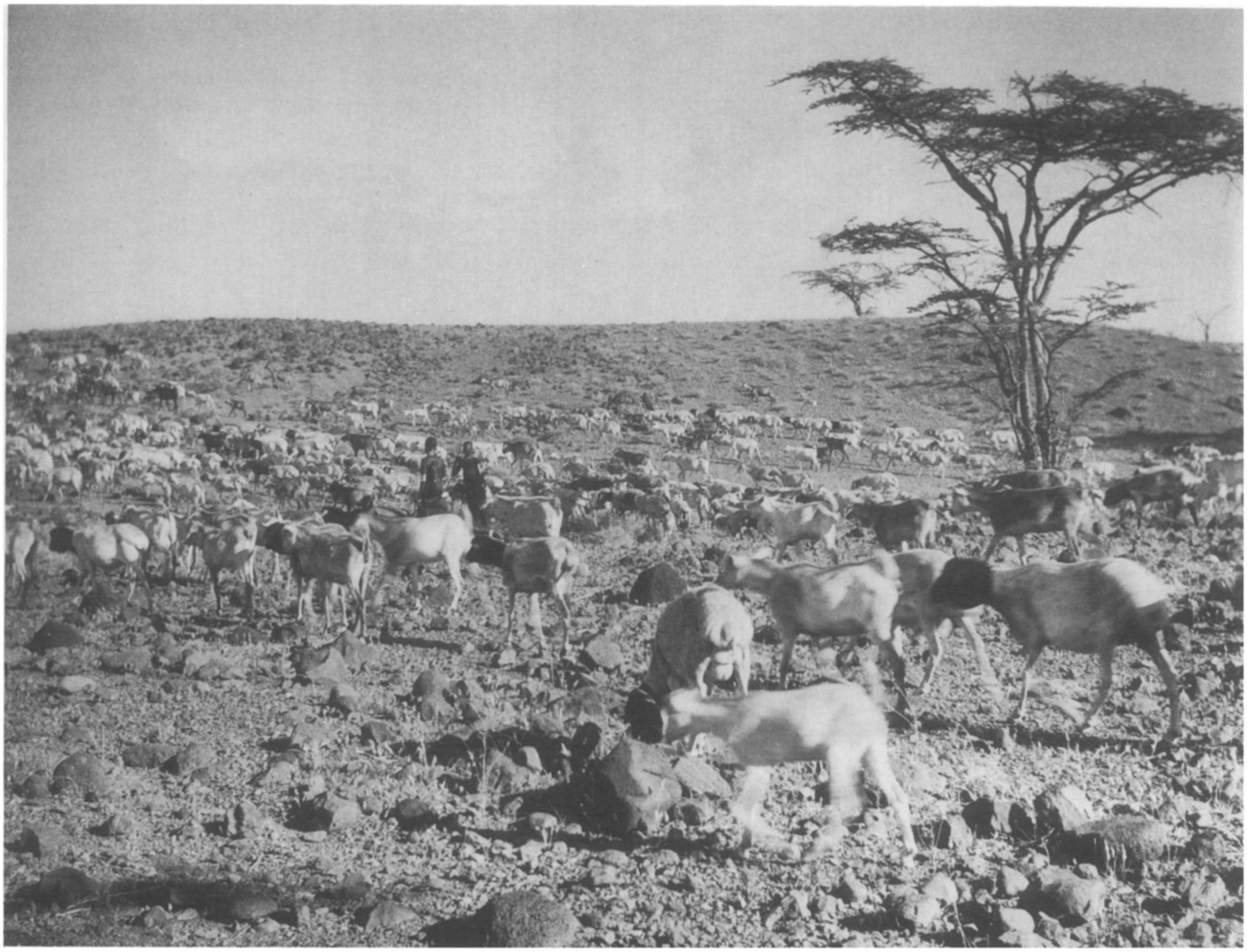


Fig. 6. Perennial supplies of water in an area of northern Kenya enables flocks of sheep to destroy the herbage before it has had the time to seed. (Photo credit: WWF/IUCN.)

usually is greatest in the spring in temperate and Mediterranean climate regions and during the rainy season in the tropics.

*(2) Physical disturbance to landforms,* especially when related to the hydrological cycle, may have important effects. Damming and channelization of streams not only reduce the diversity of aquatic habitats, but cause upstream and downstream adjustments of channel morphology affecting vegetation and flood regimes. Development can greatly alter patterns of water runoff and recharge into groundwater aquifers. Wetland habitats may act as natural reservoirs for water, evening out the effects of variations in precipitation on stream flow.

*(3) Removal of vegetation* either directly by forest clearcutting, urban and road development, and clearing for agricultural development, or indirectly through overgrazing and the introduction of plant diseases and pests, can seriously affect the fertility of the soil, the hydrological cycle, animal habitats, and the overall integrity of the system. Experimental studies of forested watersheds such as the Hubbard Brook Experimental Forest in the US (Likens *et al.*, 1977) have shown that clearcutting may increase streamflow by 100% or more and that some nutrients are lost from the soils of the watershed at tremendous rates. Nitrate, which is a negatively charged ion, is not bound closely to soil particles. When intact plant roots are not present to take up nitrate as it is released by microbial action, the nutrient is washed out of the soil. The effect of vegetation removal may be more pronounced in the tropics where the nutrients are retained primarily in the plants themselves, rather than in accumulated organic detritus in the soil.

*(4) The application of toxic compounds,* e.g., herbicides, pesticides, heavy metals, and air pollutants, can have far-reaching and prolonged effects on ecological processes. Thus insecticides often kill beneficial predatory species as well as the target pest organism. Some of the more persistent pesticides, such as DDT, spread through

the food chain, threatening the existence of sensitive species of birds and other animals several feeding steps or even habitat steps away from the intended targets. Evidence is accumulating that acidic precipitation caused by air pollution is sterilizing oligotrophic lakes in eastern North America and in Scandinavia. Air pollutants, such as ozone and nitrogen oxides, are also stunting forest growth and by weakening conifers are making them susceptible to catastrophic secondary pest infections.

*(5) The destruction or inhibition of certain key species,* such as top predators and migratory species of herbivores, or the *introduction of pest species,* such as rats and goats, may pose very serious potential threats to ecological processes. Introductions of exotics usually are more successful in depauperate or disturbed areas lacking highly coevolved regulatory mechanisms than in intact systems. Often introduced weeds are confined mainly to disturbed sites and rarely invade intact or undisturbed habitats. Island ecosystems, which tend to have few species of native plants and animals, appear particularly vulnerable to invasion.

*(6) Prevention of natural disturbance cycles* may allow development to proceed to a monotonous community, and thereby alter the natural vegetation or fauna, and reduce the diversity of local habitats.

## Conservation and Management Applications

*The need for identification of conservation goals*

It is important to identify major goals before designing a conservation, management, or development programme. These goals in turn will dictate the limits within which one may apply the principles of conserving ecological processes. The most frequent goals are the preservation of populations of particular species, the maintenance of the natural diversity of a locality, and the preservation of particular habitat types either as refuges for animal populations or in their own right. It is critical to recognize the importance of conserving ecological processes not only in support of these goals but in order to maintain the productivity and stability of systems altered and maintained by human activity. In each case it is important to identify key populations or habitat structures and to understand how they are related to other components of the intact system. Management of altered systems and development of regions for agriculture and urbanization also are reasonable conservation goals; hence for each one must consider potential alterations of ecological processes and the overall impact of such changes on the maintenance of a steady state.

Conservation should be approached at the level of large natural units, such as major watersheds and coastal areas, perhaps even local biogeographical provinces, which circumscribe the movement of materials and populations in the areas in question. All programmes of conservation and management within such areas are inevitably linked and cannot be considered apart from one another. In addition, the costs and benefits of conservation and management programmes are realistically assessed only on the scale of the natural ecological region. Otherwise, costs may be transported from one part of the system to another and not properly weighed in decision-making processes focussed on small areas. The MAB Biosphere Reserve Network is implementing programmes which take these factors into consideration.

*Identification of major conservation problems*

In the design of any programme of conservation and management, answers are needed to the following questions in order to put the programme into a proper context of ecological processes.

(1) What are the major pathways of flow of materials through the system?

(2) Are there major inputs from outside, either by rivers or ocean currents? Can the sources be included in the management area? If not, will basic ecological processes be threatened by outside disturbances?

(3) Are there important migratory species? On land these might be grazers and other herbivores, including migratory insects. Although many birds and bats are generalists and their functions may be easily compensated by ecological processes, some specialists may be important as pollinators or seed dispersers. In addition, large-scale habitat destruction, hunting, and use of pesticides elsewhere may drastically reduce the numbers of all migratory species taken together, with potentially large ecosystem consequences.

(4) What kinds of disturbance cycles occur in the area and on what scale and frequency: fire, flood, hurricane, infestation, drought, and other perturbations initiate natural cycles of change and recovery that may contribute to the natural diversity of the region. How does the system recover following each of these disturbances? Do natural reserves occur within dispersal distance of the conservation area? What species would be lost due to lack of reserves or buffer areas outside the area in the event of disturbance? Can disturbances be managed, especially in the case of fire and flood, to reduce the probability of catastro-

phies? For example, a programme of controlled burning may prevent large-scale fires that could destroy an entire conservation area.

(5) What are the key regulator species in the system? Herbivore populations may be sensitive to disturbances particularly if their populations are controlled by predators. Is the region large enough to maintain natural predator control? If small conservation areas are to include the natural herbivores, their populations may have to be culled periodically.

*Working with nature*

A primary principle of the conservation of ecological processes is that management should work within the framework of natural patterns and cycles, rather than change them. This requires the identification of appropriate use for various regions and habitats on a sustained level with minimal management, i.e., that which leaves the maximum number of natural regulatory mechanisms intact. The importance of natural mechanisms in development and management programmes argues strongly for the preservation of large representative tracts of intact ecosystems so that their natural self-regulatory mechanisms may be comprehended through research and experimentation and applied to specific management problems within the same biogeographic region. This will be particularly important when attempting restoration of areas suffering from chronic damage. In general, management should mimic natural processes. Thus, for instance, seasonal cycles of agricultural activities should be matched to local natural cycles in order to reduce impact on natural processes, especially on the hydrological cycle or seasonal use of an area by migratory animals.

The conservation of ecological processes should be recognized as a further and most vital step in the conservation movement, going beyond species and habitat preservation. This cannot be achieved without a comprehensive understanding of the operation of ecosystems as dynamic entities. Presently, our knowledge of particular ecosystems is inadequate for the detailed conservation management of ecological patterns and processes. In view of the exponentially increasing threats to natural and semi-natural ecosystems, it is imperative to ensure long-term, systematic monitoring and experimental manipulation of ecological processes, and to integrate dynamic process-oriented thinking as part of any conservation, management or development programme. These are the major challenges facing both ecologists and conservationists.

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