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7 Preserving Nature

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To consider the broader environmental significance of protecting species at risk of extinction, we must first consider the roles or functions that species fulfill in nature. Although "nature" has many definitions, here we define it to mean the end product of ecological and evolutionary processes. That is, within a habitat, region, or biosphere, the condition of the soil, water, air, and biota reflects the outcome of physical, chemical, ecological, and evolutionary processes. We refer to this combination of abiotic and biotic conditions as "nature" and to the ecological and evolutionary processes that create it as "natural processes."

Using these definitions, we propose three approaches in which environmental actions can protect or conserve nature. The first approach is to preserve natural processes by directly managing them or providing suitable substitutions. For example, we can directly manage a polluted watershed to restore its water quality, or we can build expensive water treatment facilities to treat the water (Chichilnisky and Heal 1998). The second approach is to protect nature itself, assuming that with adequate protection nature and its natural processes will persist. For example, we can designate marine protected areas that exclude human activities. The third approach is to protect the biotic components of nature that govern the environment. This approach encompasses the intent of the Endangered Species Act (ESA): to protect nature by protecting species.

In this chapter, we examine the broader environmental significance of the Endangered Species Act by reviewing the roles species play in natural processes and by examining how natural processes govern our environment, how human activities modify nature, and how the Endangered Species Act can ameliorate the impacts of human activities.

Ecological and Evolutionary Processes

At any scale, from microsite to the biosphere, natural environments consist of matter cycling between organic and inorganic material. These cycles are driven by a diversity of organisms that consume energy. The simplest is the "green-slime perspective" in which photosynthetic biomass consumes solar energy and inorganic nutrients and produces biomass. This autotrophic biomass is consumed by heterotrophic organisms that convert the organic biomass they consume back to inorganic matter through mineralization and respiration. Many computer-based ecosystem and climate models use this approach.

In fact, at the level of the biosphere, biomass consists of tens to hundreds of millions of species each composed of highly dynamic populations constantly evolving and adapting to ever-changing environmental conditions. The role a species plays in ecological and evolutionary processes is determined by where it resides in the complex structure of earth's biota. Important features of this structure concern what species eat (trophic structure, or linkages), how species interact with it in other ways (community structure, or biotic linkages), where species are found (distribution and abundance), how matter is cycled between inorganic and organic forms by the biota (biogeochemistry, or ecosystem processes), and the evolutionary relationships among species and populations (evolutionary processes). If natural processes were largely random and nature merely the epiphenomenon of such randomness, we could do little to understand or manage it, and there would be little motivation to study it. Nature, however, is not the random end-product of biomass (e.g., green slime) exhibiting metabolic processes. Rather, it is a patterned distribution of interacting species whose dynamics cycle matter between organic and inorganic forms. Through competitive, facilitative, and trophic interactions a web of interconnectedness regulates the dynamics and stability of natural processes. This diversity is generated by evolutionary and coevolutionary processes in which the origin and extinction of species constantly yields a biota that adapts to Earth's changing conditions. The evolutionary trajectories species take are governed by the number of populations, their connectivity, and the impacts of ecosystem change on all populations, both central and peripheral.

A Summary of Human Impacts on Nature

In the previous section, we described a world in which species play key roles in structuring and regulating the magnitudes and dynamics of the ecological and evolutionary processes that govern our environment. The modern world, however, is increasingly one in which humans are the dominant species, governing the environment. In this section we examine major human impacts that have altered nature.

Most prominent among these impacts are human influences on rates of biological invasion, extinction, biogeochemical processes, climate change, and habitat modification. These changes also occur naturally, but humans have invariably increased their rate and frequency.

Biological invasions The distribution of a species is often constrained by physiological barriers (e.g., tropical plants lacking frost tolerance) or physical barriers (e.g., inability of most species to cross oceans). Deliberate or inadvertent human transport of biota has removed many of these limits to movement, leading to a vast degree of biotic homogenization (Drake et al. 1989; Lodge 1993; Mack et al. 2000). In addition, invaders also intensify local rates of extinction of native species (Wilcove et al. 1998).

Extinction Although difficult to quantify precisely, there is little question that extinction rates due to human activities are orders of magnitude higher than rates of extinction due to natural processes (Wilson 1988a; Soulé 1991; Jenkins 1992; Lawton and May 1994; Heywood 1995; May et al. 1995). The most dramatic declines are due to local extinctions—the loss of diversity on a per-unit area basis—rather than to global extinctions. Such declines in local diversity occur through habitat modification or habitat degradation in which managed or degraded systems steadily replace natural or wild systems (Wilcove et al. 1998; Balmford et al. 2002). Harvest can also be a significant factor, especially in marine systems (Myers and Worm 2003).

Biogeochemical processes Humans dominate a number of biogeochemical processes. For example, humans have doubled atmospheric carbon dioxide (CO_2), consume nearly 50 percent of net primary productivity, and have doubled nitrogen (N) deposition in terrestrial ecosystems (Vitousek et al. 1997b).

Climate change Earth's biota and ecosystems are experiencing unprecedented levels of climate change. Climate change has been and continues to be a common feature of nature, but anthropogenic acceleration of the process has raised a number of concerns about the ability of populations and natural systems to adapt to such change (Peters and Lovejoy 1994; Huntley 1995; Parmesan and Yohe 2003). Recently, increasing attention has focused on abrupt climate changes—such as the melting of polar ice caps or reorganization of the oceans' circulation patterns—and how anthropogenic climate change may trigger such events (Broecker 1997; Alley et al. 2003). Thus, not only are the rates of climate change likely to be higher than experienced in the past, but the frequency of abrupt changes may be on the rise as well.

Habitat modification Balmford et al. (2002) noted that the majority of Earth's wildlands have continued to decline in spite of the Earth Summit in 1992 in Rio de Janeiro and 2002 in Johannesburg, suggesting that the summit has had little effect in halting the continued transformation of natural or wild habitat to managed or degraded habitats. According to one estimate, twenty-seven ecosystems have declined in area by 98 percent, and what is protected is often dominated by poor-quality habitat not suitable for cultivation (Shaffer et al. 2002). On top of such change, habitat fragmentation, also an increasingly common feature of landscapes, alters food webs (Terborgh et al. 2001), biomass (Laurance et al. 1997), species interactions (Fagan et al. 1999), and the survivorship and persistence of populations and species (Bascompte and Solé 1996; Lens et al. 2002).

Summary The distribution and abundance of species is determined by many factors, some of the most important being invasion, extinction, biogeochemistry, climate change, and habitat loss. Although natural processes affect all of these factors, today they are dominated by human activities. Collectively, these activities are resulting in ecosystems that are more homogeneous in their species composition, increasingly species poor, and changing chemically and physically at untypically high rates—with the possible exception of such extreme events as asteroid impacts.

The Role of Species in the Modern World

Human influences have altered the world to a degree that ecological and evolutionary processes are increasingly less relevant to environmental processes. Earlier, we described how species collectively regulate the environment and also how biodiversity is declining rapidly, both taxonomically and ecologically. In this section we consider the significance of this decline.

Biodiversity and ecosystem functioning Ecosystem processes are regulated by their biota, and changes in local biodiversity can affect the magnitude and stability of such processes, although there is debate over the specific mechanisms and magnitudes involved (Loreau et al. 2001). This ecological perspective is a novel way to consider the importance of biodiversity since it ascribes an active role for diversity in regulating the environment rather than assuming that biodiversity is a passive epiphenomenon of abiotic processes such as climate (Schulze and Mooney 1993; Loreau et al. 2002; Naeem 2002b).

For our purposes, the most important idea from this work is its suggestion that loss of biodiversity will decrease the magnitude of (Naeem et al. 1994; Naeem et al. 2000a; Tilman et al. 2001a) and stability (Tilman and Downing 1994; Naeem and Li 1997; Pfisterer and Schmid 2002) of ecosystem functioning.

Biodiversity and invasion Although Charles Elton proposed that biodiversity was an important element in determining the susceptibility of an ecosystem to biological invasion (Elton 1958; Levine and D'Antonio 1999), only recently has empirical investigation of this possibility intensified (Palmer and Maurer 1997; Tilman 1997; Naeem et al. 2000b; Kennedy et al. 2002; Levine et al. 2002). As in the case of ecosystem functioning, it is difficult to tease apart extrinsic factors that regulate invasion from that of biodiversity since the two are correlated (Stohlgren et al. 1999; Levine 2000; Rejmánek 2003; Stohlgren et al. 2003).

Biodiversity and phylogenetic information A region's biota is its repository of phylogenetic information. Anthropogenically enhanced rates of extinction are producing extinction rates higher than origination rates thereby driving down biodiversity not only in regions but also across landscapes and in the biosphere itself. Such change threatens phylogenetic information—a primary motivation for identifying and concentrating efforts on biodiversity hotspots that contain particularly high levels of phylogenetic information (Myers et al. 2000; Sechrest et al. 2002).

Some analyses suggest that considerable levels of extinction are required before phylogenetic information is lost (Nee and May 1997) but this applies only if extinction is random. Extinction, however, is seldom random, more often exhibiting a pattern in which related species share similar fates. For example, with respect to carnivores and primates, 50 percent of the variance in the World Conservation Union's threat status is explained by high trophic level, low population density, slow life history, and small geographic range; the rest is attributed to anthropogenic factors such as hunting or habitat modification (Purvis et al. 2000b). Under such circumstances, the loss of phylogenetic information is more severe than one might expect from random extinction (Purvis et al. 2000a).

There are ecological consequences of such nonrandom extinction. For example, carnivores and top predators often face higher extinction rates for a variety of reasons (Purvis et al. 2000b; Gittleman and Gompper 2001), which means that changes in community structure or possibly predator regulation of lower trophic-level densities are likely to occur in the face of higher extinction rates. These could lead to cascades of extinction if such top predator species are keystone species.

Finally, loss of biodiversity through its impacts on biocomplexity can affect the sustainability and resilience of communities and ecosystems. For example, Hilborn et al. (2003) demonstrate that stock and life history differences among Alaskan sockeye salmon (*Oncorhynchus nerka*) stocks contributed to high levels of productivity over a fifty-year period.

Summary The modern world is increasingly depauperate, with habitats that are increasingly species poor and increasingly homogeneous. Contemporary studies suggest that biodiversity loss is changing the way ecosystems function and the way our biota serves as repositories of phylogenetic content necessary for its evolution in the face of changing environments. This depauperate world may be less stable, lower in its rates of ecosystem functioning, and less capable of adapting to environmental change.

Species Preservation

The significance of the Endangered Species Act in slowing biodiversity loss is demonstrated by an imaginary game based on contemporary patterns of extinction. Imagine a grid in which each square carries a multitude of colored pieces. Each square is different. Some, like the tropical regions, carry many differently colored pieces (species) but few of each color; others, like the tundra, carry many pieces but only a few colors. We now set a game in motion in which we throw a die once for each square. This is the extinction die. It has as many faces as there are colors of pieces, and when the die is thrown, each square loses whatever piece shows on the top of the die. If the die comes up a color that is not on the square, then no species pieces are removed from the square. The other rule specifies that if the colored piece is the last of that color on the board, the Endangered Species Act is invoked and the persistence of that color (i.e., species) is guaranteed somewhere on the board. The end result would be a board with one piece of each color someplace on the board. This game demonstrates how, under these rules, a species is listed only when on the brink of extinction. By manipulating species independent of their population, community, and ecosystem roles, we ensure the preservation of phylogenetic information. But in the absence of multiple populations, community structure, and ecosystem function, ecological or evolutionary processes are generally lost.

Reality adds some subtle complexities to the game. Because the ESA allows for subspecies and races to be preserved (closely colored pieces treated as different), some retention of population structure and of heritable variability may occur. Also, because some states list species endangered in their state, we may have more individuals of a color if a square actually represents two or more states that both list the same species. Further, most species management plans do not save just one individual but aim to maintain a population of individuals that would ensure persistence of the species. So a colored piece actually represents a minimally viable population.

In an alternative game, the rules might require that each square must retain at least one piece of each color (species) it originally had—it does not matter if the color is on the board elsewhere—it is not allowed to go extinct on its square. Thus, each square (e.g., county) must conserve whatever species is endangered in its habitat, even if it is not endangered elsewhere on the board (the United States). In this variation of the game, our board shows the same color patterns observed at the outset, but by the end of the game the pattern is thinner, because only one individual of each color is present in a square where previously many were found. Biologically, the result is a landscape more likely to ensure phylogenetic content, some degree of population structure, and some ecosystem functioning, but it would consist of species-rich squares each low in density and thereby consisting of readily invaded habitats, expressing low levels of functioning, and exhibiting little resilience. This landscape would lack biological complexity.

The point that emerges from our game playing is that divesting a species of (or disassociating it from) its function or role in evolutionary or ecological processes is the environmental equivalent of extinction. Yet the language of the Endangered Species Act suggests that it recognizes that species must be preserved in the wild, for it is in the context of natural environments their true value emerges. The ESA does not espouse housing remaining individuals of a threatened species in zoos or pickling them for museums; but ranching or relocating threatened species to a protected park is little different from placing them in a zoo or pickling them. Such actions divest species of their roles in ecological and evolutionary processes. The role of a nitrogen fixer is retained only if it continues to fix nitrogen in that ecosystem at the same rate. If the species is a pollinator, its community role is only retained if it continues to pollinate its native plants. If a species is to persist through the vagaries of environmental change, effective protection needs to ensure genetic robustness such that the species contains sufficient genetic variability to accommodate local or even global environmental change. If a species is to be the source of newly adapted subpopulations, subspecies, or even new species, effective protection needs to ensure its ability to serve in those roles.

Shoring Up the Disentangled Bank

Our consideration of the role of species in natural processes fits the entangled bank metaphor of Darwin's famous closing passage in *The Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life* (Darwin 1859, chap. 14). Darwin envisioned nature as an entangled bank, "clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth" (459). Clearly, nature is diverse and interconnected, and, most important, these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us. In this chapter we have rephrased this entangled-bank description of nature, describing it instead as the collection of interacting species whose diversity is governed by evolutionary processes and whose distribution and abundance is governed by ecological processes. We have further shown that the environment is derived from the biogeochemical processes governed by these species.

The metaphor for the modern world is that of a *disentangled* bank. Habitat modification and degradation and biological invasion yield simpler, species-poor, ordered communities. Prairie grasslands, for example, that once contained hundreds of species have been replaced by managed grasslands such as corn, wheat, soybean crops, and rangelands. Complex forests have been replaced by monoculture plantations. Natural stocks of Pacific salmon in northwestern North America have declined while sea-ranching hatcheries and salmon farming of large pens of Atlantic salmon have grown to take their place. As discussed above, such depauperate systems provide needed ecosystem goods and services but with lower levels of ecosystem functioning, less resiliency, and lower adaptability to changing conditions. While the methods used to assess the costs of the loss of natural ecosystem services are controversial, preliminary estimates suggest that these costs are likely to be enormous (Costanza et al. 1997; Balmford et al. 2002).

The scientific basis for biodiversity as a critical factor in governing Earth's environment is not without controversy, but its central premise has been recognized by the majority of the world's countries. In 1992, the Earth Summit in Rio de Janeiro established a strategy for sustainable development, allowing extraction of natural resources necessary for sustaining human populations while ensuring the same privileges for future generations. The Convention on Biological Diversity arose from this meeting and was signed by the majority of the world's governments. Its premise: maintaining biodiversity is the equivalent of maintaining the world's ecological underpinnings; but it also allows participants to continue economic development.

The Convention on Biological Diversity and the Endangered Species Act are similar in structure. The convention's emphasis on conservation and sustainability does not preserve interconnectivity among species and ecosystem resilience necessary for biodiversity to persist in the face of environmental change and variability (Knapp 2003). Likewise, the ESA aims to conserve species by rescuing them from extinction, but it has little investment in notions of ecosystem resilience (though delisting requires demonstration of long-term persistence of a population) and no investment in interconnectivity among species.

For thirty years, the Endangered Species Act has been shoring up the entangled bank by preserving its components. The act's emphasis on species independent of their roles in ecological and evolutionary processes is the best strategy available in the absence of knowledge about the specific roles a species may play; it allows at least core species richness to be maintained.

The wording of the act clearly recognizes the importance of species as agents of natural processes. Its execution, however, has focused on the preservation of the species to the exclusion of their ecological and evolutionary role. When a species has declined to the point that it is considered threatened under the ESA, its role in ecological or evolutionary processes is usually severely diminished; but it can return to this role with sufficient shepherding. Over the long term, continued rescuing of our nation's species can provide not only natural services but also the stability that comes with diverse habitats.

Conclusion

The Endangered Species Act, like many environmental statutes, follows a command-control format. Standards, such as allowable concentrations of sulfur in smokestack emissions, permissible arsenic concentrations in drinking water, or minimal viable population sizes, are key elements of such statutes. They are the bases for regulations (commands) that control activities to ensure standards are met. By themselves, command-control approaches lead to complex rules and regulations; the federal Environmental Protection Agency has become an organization that manages and enforces an enormous array of regulations of almost incomprehensible complexity (Dietz and Stern 2002).

Command-control works best for point-source problems, but when the problem is diffuse, other approaches are necessary (Dietz and Stern 2002). Over the past thirty years, the ESA has treated the problem of biodiversity loss as a point-source problem. For example, establishing minimal viable populations is an attempt to establish the equivalent standards, but such activities have never had the same degree of precision or ready application as other environmental standards—a standard of 10 parts per million of arsenic, no matter how contentious, is easy to understand and implement. Protecting fifty individuals within a species, however, is not easily applied to all species. The command-control approach has been a good start, but it requires modification when applied to natural processes and nature.

The suggestion that emerges is to reconfigure the game rules governing allowable changes in our biota. Under such a scenario, the landscape would consist of ecoregions based on the ecological and evolutionary roles species play within these regions. That way, when the roll of the die names a species, the rules for removing or conserving a piece would be based not only on the presence or absence of that species, but also on the extent to which the loss of that species in that habitat affects the ecological and evolutionary role the species plays in the landscape. Proposing changes to the Endangered Species Act requires a more rigorous, quantitative approach—assessing its existing ability to ensure species' roles and determining how it could better safeguard not only the persistence of species but also their ecological and evolutionary roles.

This proposition—to modify the Endangered Species Act to allow it to regulate the ecological and evolutionary roles species play—has complex implications for policy, property rights, jobs, and management. On the surface, it could be misconstrued as a vehicle by which we replace our increasingly anthropic environment with wild nature. Presented in this light, such a proposition would not sit well with Americans who support the ESA's role in preventing extinction but are generally in favor of regulating nature through fire suppression, flood regulation, pest control, and genetic engineering. Currently, the ESA confronts property rights, jobs, and management issues when a species is directly threatened by such activities, and such confrontations will likely escalate. It is one thing to challenge property rights when an owner's land use jeopardizes the persistence of a species; it is quite another to challenge them because an owner's land use jeopardizes a species' role in an ecological or evolutionary process.

For now, the Endangered Species Act at least preserves the many colored pieces on the board so that if we decide to change the rules and look more to nature and natural services, our game board will contain more than just a handful of playing pieces.