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"Strengthening the Use of Science in Achieving the Goals of the Endangered Species Act"

An Assessment by the Ecological Society of America

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STRENGTHENING THE USE OF SCIENCE IN ACHIEVING THE GOALS OF THE ENDANGERED SPECIES ACT

AN ASSESSMENT BY THE ECOLOGICAL SOCIETY OF AMERICA

EXECUTIVE SUMMARY

By enacting the Endangered Species Act of 1973, Congress established a national commitment to preserve the Nation's biological resources for the benefit of the American public. The Endangered Species Act sets out a series of steps for determining whether a species is at risk of extinction, removing the major causes of its endangerment, and returning the species to a viable state. The Act specifies all the steps, procedures, and mechanisms to accomplish its goals. Scientific information is needed for implementing each of these procedures, but the Act itself provides little guidance as to how to use science to achieve the goals of the Act.

Therefore, the Ecological Society of America undertook an analysis of how scientific information could be used more effectively to assist in the preservation of the Nation's biological resources. This report concludes that:

- The 1973 Endangered Species Act is a powerful and sensible way to protect biological diversity, and contains the procedures and mechanisms with which to achieve this goal.

- On the basis of science, the most important priorities to use in deciding which candidate species to list are: 1) number of other species that will benefit from the listing; 2) ecological role of the species; 3) the organism's recovery potential; and 4) its taxonomic distinctness.

- Formal Population Viability Analysis offers a method to identify how a species' survival potential can be maximized in the least controversial manner.

- The likelihood of restoring the viability of an endangered species is enhanced when: 1) recovery plans seek to achieve a population distributed in suitable habitats across the landscape; and 2) these plans are developed and implemented expeditiously.

- Additional programs for ecosystem-level protection that would complement existing legislation offer promise for a proactive approach that would effectively protect our Nation's biological heritage at lower long-term cost.

I. INTRODUCTION

The Endangered Species Act, as amended in 1988, has three purposes:

"...to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved.
...to provide a program for the conservation of such endangered species and threatened species."
...to take such steps as may be appropriate to achieve the purposes of the treaties and conventions..." (Endangered Species Act 1988).

By enacting the Endangered Species Act of 1973, Congress, on behalf of the American people, established a national goal and commitment to protect the Nation's biological resources. The Act establishes the form and sequence for the process of providing federal protection, from listing threatened and endangered species to the implementation of their recovery. The Act is a powerful and sensible way to protect biological diversity that specifies the procedures and mechanisms to achieve that goal. However, the original legislation and subsequent amendments to the Act do not explicitly specify how science will be used to carry out the legislative mandate. Instead, the manner in which scientific knowledge is to be used is largely left to the discretion of the implementing agencies, the United States Fish and Wildlife Service and National Marine Fisheries Service.

The goals of the Act are to identify species that are at risk of extinction, to implement a process for reducing that risk by limiting additional sources of jeopardy, and to develop and implement a recovery program. The process is flexible and can be applied to individual species or to groups of species that share an ecosystem or management area. If the valuable scientific knowledge that has accumulated over the past several decades of analytical ecological research is used to the fullest extent, the Act can become an even more powerful tool in achieving the societal goals for which it was enacted.

The Act has improved the status of some species, such as the California sea otter, peregrine falcon, American alligator, whooping crane, and bald eagle. Nevertheless, each year, many more species are added to the list of endangered species than are successfully recovered and removed from the list. Despite being protected, some species are becoming extinct. Currently 955 species in the U.S. are on the list of endangered and threatened species; only slightly more than half of them have approved recovery plans (Department of the Interior 1995).

Given this growing list of threatened and endangered species and the limited success in recovery of endangered species, the Ecological Society of America undertook an analysis of the Endangered Species Act, with the objective of assessing how the Act could be made more effective through better use of scientific information. The nation's biological diversity has great economic, aesthetic, and spiritual value. Modern society draws upon biological diversity as a source of medicines, fiber, food, as sources of genes for future incorporation into crop plants, and for uses we cannot predict. The extensive services that natural ecosystems provide, such as cleansing of air and water, control of erosion, and stabilization of climate, depend in part on the richness of species in those systems. Therefore, the Ecological Society's analysis accepts and supports the goals and objectives of preserving the biological heritage of the United States and explores how science can be used more effectively than it has in the past to enhance the achievement of those goals.

II. THE IMPLEMENTATION PROCESSES OF THE ENDANGERED SPECIES ACT

The Endangered Species Act sets out a series of steps for determining whether a species is at risk of extinction, removing the major causes of its endangerment, and returning the species to a viable state. The major stages in this process are: (1) Listing a species as threatened or endangered, (2) designating the habitat that is critical for survival of the species, (3) providing immediate protection and prohibition of acts that would further jeopardize the species, (4) developing and implementing recovery plans, and (5) delisting the species once it has been restored to a viable state. Scientific information must be used at all of these stages if an accurate initial assessment and a successful recovery program are to be achieved.

The process of listing a species includes a series of steps that begins with a decision to propose a species as a candidate for protection and culminates in one of three outcomes: rejection of the claim for protection; inclusion of the species under federal protection as either an endangered or threatened species; or placing the species in an ill-defined category, known as "warranted, but precluded." Although decisions on status of species designated "warranted, but precluded" are to be made within a 12 month finding period, since 1982, 114 species have remained in this category for two or more years. Fifty-six have been in this category for at least 8 years (GAO 1992).

Once a species is listed, the Endangered Species Act requires the designation of "critical habitat." In the legislative language, "critical habitat" is defined as the minimal area that is needed to supply the species with its immediate survival needs. The Endangered Species Act also provides immediate protection to a species when it is listed as threatened or endangered. Section 7 of the Act requires all federal agencies to ensure that any actions they authorize, fund, or carry out do not jeopardize the continued existence of any listed species or adversely modify its habitat. Thus, every federal agency must examine whether any action it proposes to carry out might adversely affect a listed species and these assessments must be scrutinized and evaluated by the Fish and Wildlife Service or the National Marine Fisheries Service. Scrutiny occurs through a process known as "formal consultation" and ends with a written "biological opinion" containing the service's views. These opinions are not legally binding on the other federal agency but federal agencies are reluctant to proceed with a project in the face of a jeopardy opinion because the probability that a citizen suit will be brought against the action is very high. In such suits, jeopardy opinions are given considerable weight by the courts. Formal consultations serve other purposes in addition to making jeopardy determinations. They also search for reasonable alternatives or adjustments to the proposed action that could avoid jeopardizing a listed species.

Section 7 also deals with incidental take, which is defined as a taking of a listed species that is incidental to, and not the primary purpose of, otherwise lawful activities. The term "take" refers to many possible perturbations to the species, including "harm, harass, kill, wound, catch," etc, all of which are prohibited under the Act unless authorized by a permit, an incidental take statement, or a special rule. Incidental take has been interpreted to include harm to the habitat of a species as well as direct harm to the species itself, and this interpretation has been upheld in a 1995 Supreme Court decision. From a scientific standpoint, degradation or destruction of the habitat of a species can be at least as harmful to the survival of the species as direct injury to an individual of the species. In 1982 Congress amended the Act to provide mechanisms for regulating incidental take on non-federal land. Those procedures are now found in section 10(a)(1)(B). Persons applying for an incidental take permit under Section 10(a)(1)(B) must submit a "Habitat Conservation Plan" or HPC along with other materials attendant to their permit application.

In the case of Section 7, "harm" is defined as an action that significantly reduces both the survival and recovery of a species. Similarly, in the definition of harmful destruction of critical habitat, a jeopardy ruling requires that both the survival and recovery of a species be affected. Many actions slow a recovery process but it is difficult to show unambiguously that an action threatens the survival of a species (Rohlf 1989).

When a species is listed, the Endangered Species Act requires that a recovery plan be developed. The ultimate goal of the recovery plan is to improve the status of the species in its natural habitat to such a degree that it can be delisted. However, by the time a species becomes eligible for listing, its habitat is often destroyed or badly degraded, the population is decimated, and its genetic diversity seriously eroded. Additional delays in developing and implementing recovery plans further imperil the species. In practice, recovery plans are often not developed for years, if at all. Through 1991, 61% of the listed species had approved recovery plans but, of the more than 200 species without recovery plans, more than half had been listed for three or more years (GAO 1992). The recovery of species under these circumstances is one of the greatest challenges to the application of ecological science.

In addition to being delayed, recovery plans often have weak goals. A review of the 314 approved recovery plans for threatened and endangered species that were approved by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service as of mid 1991, found that population goals were often no higher than existing population densities at the time of listing (Tear *et al.* 1993). More than half of the vertebrates would remain in serious risk of extinction even if they met the population targets in their recovery plans. In some cases, habitat destruction was so severe that the recovery plans had little chance of success. The reviewers concluded that, "Recovery plans all too often "manage for extinction" rather than for survival" (Tear *et al.* 1993).

The ultimate goal of the Endangered Species Act is to restore populations so that they no longer are threatened with extinction. When that state is reached, the Act provides for delisting of the species.

III. THE ROLE OF SCIENCE IN THE ENDANGERED SPECIES ACT

Scientific information is needed for implementing all of the processes specified in the Endangered Species Act. The more high quality science is used, the more effectively and more efficiently the Act can achieve the important goals society has asked it to accomplish.

A. Use of Science in the Listing Process

Listing a species as threatened or endangered is the first step in conferring legal protection. It is the conclusion to a decision-making process that draws heavily on ecological science, particularly for assessing the level of risk to a species and developing priorities for listing.

Species are proposed for protection because they are thought to be in danger of extinction or at risk of becoming endangered with extinction. For species deserving protection, delaying the decision to provide protection and recovery will bring most of these vulnerable species even closer to the brink of extinction, restrict the options available for achieving recovery, and increase the eventual cost of the recovery process. Therefore, streamlining the listing process can increase the effectiveness of the Act in achieving its goals and potentially reduce the total costs of doing so.

There is no scientific reason why listing, which is an administrative decision based on the available information, should require much time or agency resources. The uncertainty that may result from sparse information is part of the risk that is evaluated during the listing process. Adding independent peer review or other administrative processes to the listing process would unnecessarily lengthen the time to make a listing decision without providing any substantial benefits. The major problem with the listing process has been its slowness, not inadequacy of the quality of the listing decisions.

1. Which Biological Units Should be Listed?

In the language of the Act, a "species" is taken to include any subspecies of fish or wildlife (including invertebrates such as insects, crustaceans, and mollusks) or plant (including fungi). For vertebrates, any distinct population segment of a species, that is one with unique morphological features or genetic traits, qualifies as a species. How distinct is distinct enough must be judged on a case-by-case basis. The meaning of "species" in the language of the Act is, therefore, somewhat imprecise, but the wording recognizes that a species is made up of an assemblage of individuals that collectively express genetic, morphological, and behavioral variation, and that this variation is the basis of evolutionary change and adaptation.

The scientific justification for extending protection to distinct population segments of species is that genetic diversity provides the raw material for adaptation of a species to changing conditions. A wide geographic range decreases the likelihood that a catastrophic event such as wildfire, disease, or alien species introduction could wipe out an entire species. The capacity to respond to environmental change through ecological and evolutionary processes is enhanced by large population size, extended geographical distribution (including spatial structure among its populations), and intraspecific genetic diversity. Therefore, because loss of specific population segments can contribute to the decline of a population and increase the probability of its extinction, protection of population segments is biologically appropriate.

The National Marine Fisheries Service has introduced the concept of an "evolutionarily significant unit" to better define and identify distinct population segments. An evolutionarily significant unit is a population that is reproductively isolated from other populations of the same species, which therefore represents an important part of the evolutionary history and future evolutionary potential of the species. For example, the species of Pacific salmon are subdivided into many distinct spawning runs that are evolutionarily significant units of central importance for the future survival and evolution of the species (Waples 1991).

New species often arise when genes from two species combine and the number of chromosomes is increased, a process called polyploidy. Polyploidy has given rise to many species of plants and some animals, including trout and salmon. Hybrid populations may play unique ecological roles and may stimulate evolutionary processes. For example, hybrid populations of plants sometimes provide opportunities for increased speciation among herbivorous insects (Bush 1975). The biological processes that produce these genetic mixtures are natural components in the larger processes of speciation and evolution. For these reasons, it is scientifically appropriate to protect species of hybrid origin.

2. Science and Listing Priorities.

Currently more than 3,000 species are "Candidates" for listing under the Endangered Species Act, including more than 2,000 vascular plants, 200 mammals, and 750 insects. This large number of candidate species greatly exceeds the capacity of the Fish and Wildlife Service and National Marine Fisheries Service to evaluate and propose species for listing as threatened or endangered. In recent years, about 100 species have been listed annually.

The scarcity of resources available for listing species requires agencies to make choices about how those resources can best be allocated to meet the objectives of the Endangered Species Act. In the 1970s and 1980s, the FWS developed several different schemes for setting priorities for listing species. These priority systems incorporated such criteria as: magnitude and imminence of threat, availability of information, taxonomic distinctness of the species, recovery potential, and population status. The current scheme, adopted in 1983, establishes priorities for listing based on three criteria: (1) Magnitude of threat, (2) immediacy of threat, and (3) taxonomic status (the greater the evolutionary distinctness of a taxon, the higher its priority). A fourth criterion--recovery potential--is included in setting priorities for the development of recovery plans.

This system of priority-setting has the advantage of being relatively simple. It uses information that is available for most species, and employs criteria that can be evaluated relatively objectively (Tobin 1990). However, it does not take full advantage of ecological knowledge that could better guide limited resources. From an ecological perspective, three attributes should be considered in a determination of listing priorities:

(a) Inclusive benefits. Will the habitat managed on its behalf benefit other species, especially species that are listed or are candidates for listing?

Given the limited resources available for endangered species protection, giving high priority to species that serve as protective "umbrellas" for other species makes good ecological sense. For example, the Florida Scrub Jay (*Aphelocoma coerulescens coerulescens*) is restricted to scrub oak habitats on the Florida peninsula. Many rare species of reptiles, insects, and plants inhabit, and are restricted to, those scrub habitats. Many of them benefit from the land that is managed for the protection of the jay. Similarly, many but not all species requiring old-growth temperate rain forest will benefit if sufficient spotted owl habitat is protected.

The umbrella species approach must be used carefully because every acre of land or body of water will contain large numbers of species. Thus, virtually any organism could be considered an umbrella species at some scale. Moreover, an important fact about endangered species is that they rarely have exactly the same requirements. Therefore, even when a suitable umbrella species exists, the ecological needs of other community members must also be considered. The most useful umbrella species are ones whose habitats harbor numerous endemic, rare species. Thus, umbrella species should be given priority for listing in proportion to the number of other endemic, rare species that co-occur with them.

(b) Ecological role. Does the species play an especially important role in the ecosystem in which it lives? Do other species depend on it for their survival? Will its loss substantially alter the functioning of the ecosystem?

> Keystone species--an organism whose impact on its community or ecosystem is large, and disproportionately large relative to its abundance (Power and Mills 1995)--merit special attention in the listing process. Unfortunately, determining which species are keystone and which are not is difficult because a species' importance in an ecosystem is not necessarily proportional to its size, abundance, or charisma. Tiny fig wasps and African elephants are both keystone species.

(c) Taxonomic distinctness. How evolutionarily distinct is the taxon in question?

> On scientific grounds, the more evolutionarily distinct an organism is, the higher should be its priority for protection. All things being equal, therefore, saving the sole surviving member of a genus may have a higher priority than saving an imperiled species within a large genus that contains many other species. Similarly, protecting full species would normally be given a higher priority than protecting subspecies and populations (Vane-Wright, Humphries, and Williams 1991).

Species also have important scientific, aesthetic, and social values, but, given the paucity of information about most species, priorities are difficult to assign using those values. Therefore, provisionally it seems scientifically reasonable to give high priority to species immediately threatened with extinction, to umbrella species, and to taxonomically unique species. Existing priorities for listing also could be modified by including considerations of inclusive benefits and ecological role. For example, among current high priority species (species and monotypic genera facing high magnitude imminent threats), those providing more inclusive benefits or playing more important ecological roles should be given higher priority.

B. The Use of Science to Establish Recovery Priorities

The immediate consequence of listing a species under the Endangered Species Act is to trigger a series of processes that can recover the species and enable it to be delisted. Recovery is much more complex and difficult than listing, and development of recovery plans usually requires the generation of substantial new information in addition to the evaluation of existing information.

1. Science and Critical Habitat Designation.

Once a species is listed, the Endangered Species Act requires the designation of "critical habitat." Because loss of habitat is the cause of endangerment of most species, designation and preservation of habitat is a vital part of Endangered Species Act procedures. Because recovery is a long-term, not a short-term process, and the goal of the Act is to preserve species in perpetuity, enough habitat must be preserved to allow the species to survive in the long term. But how long is long term and how much is enough?

The scientific procedure used to estimate the probability of survival of a population for a specified period of time is known as Population Viability Analysis, or PVA (Shaffer 1990). Although there is no strict definition of what is or is not included, each PVA should include an analysis of the best available information on the focal species. Most PVA analyses combine data from field studies with simulation modeling of the possible impacts of various extinction factors (Doak *et al.* 1994, Murphy *et al.* 1990; Menges 1990; Stacey and Taper 1992).

The details of a PVA analysis depend on the characteristics of the focal species (Murphy *et al.*1990). Species with low population densities and small geographic ranges (most endangered large vertebrates, for example) and small geographic ranges (many plants) require a PVA that includes analysis of the genetic and demographic factors that affect small populations. Smaller organisms, such as most threatened invertebrates, frequently are restricted to a few habitat patches, but within those patches they often have high population densities. For these species PVAs need to analyze environmental uncertainty and the probability of local catastrophic factors. PVAs for plants require different emphases than PVAs for animal species because individual plants may survive for many years even if they are not reproducing successfully (Schemske *et al.* 1994). A PVA for a migratory species may also have to incorporate explicitly how its populations are linked through migration and how its population dynamics are influenced by processes operating at a landscape scale.

A good PVA addresses the issue of how long is long enough by attempting to answer the following questions: Is the population viable in both the short term and the long term? What factors are currently putting it at risk? How can these risks be reduced or eliminated so that the population can both survive and recover? There are no clear criteria for determining how long is long enough, but in practice a minimum viable population (MVP) is typically defined as one that has a 90% probability of persisting for 200 years.

A PVA was performed on the Acorn Woodpecker (*Melanerpes formicivorus*), a non-endangered bird that lives in small, isolated populations in the oak woodlands of western United States and Mexico (Stacey and Taper 1992). A simulation model showed that most of these populations would become extinct within 20 years if they were totally isolated from one another. However, with a small amount of migration among populations, the model indicated that most of the populations would last more than 1,000 years. Historical records indicate that local populations of these woodpeckers have survived more than 70 years, suggesting that migration must be important in maintaining them.

Population viability can seldom be assessed by focusing on a single patch of suitable habitat and the organisms living in it. Most organisms live in islands of suitable habitat, among which there is an exchange of individuals, embedded in a larger landscape. Because the populations in the various patches are linked by the movement of dispersing individuals, the fate of the populations is interconnected. Studies of population viability of many organisms will therefore need to consider the importance of factors that link subpopulations. The whole set of populations of a species that are linked through migration in a habitat mosaic is known as a "metapopulation."

The long-term survival of metapopulations can be strongly affected by the spatial and temporal distribution of suitable and unsuitable habitat patches. Populations living in high quality habitats (referred to as "source" habitats) have birth rates greater than death rates; the excess individuals may migrate into lower quality habitats ("sink" habitats) where birth rates are less than death rates. The viability of metapopulations depends on the existence of sufficient high quality habitats, but a large fraction of the individuals may live in the sub-optimal habitats (Pulliam 1994). To determine the critical habitat needs of such species requires identification of source and sink habitats, which may be difficult.

Not every rare and endangered species is patchily distributed in a spatially structured habitat mosaic. Some live in just a few continuous or in completely isolated habitats. Some have a "core-satellite" structure in which one very large population (the core) determines the population dynamics in the small (satellite) populations. Nonetheless, because many species do depend on source and sink habitats, every protection and recovery plan for species should investigate the need to include (1) spatially distributed populations that are linked through migration, and (2) special protection of the most stable, high quality habitats.

For some species, the designated critical habitat may need to include more than habitat actually occupied by the species. This is especially true in cases where the quality of critical habitat is dependent on land use in the surrounding area (e.g., Noss 1983, Turner *et al.* 1994). Although this is a general concern, the need for a larger scale of focus in the designation of critical habitat is most apparent for aquatic species. If the watershed that supplies river and lake ecosystems is degraded, the critical habitat needed by the endangered species may also be destroyed.

The data available for most candidate species will not allow a precise determination of MVP or critical habitat. From a scientific standpoint, the resolution to this problem is to designate interim critical habitat at the time a species is listed and to designate long-term critical habitat as part of the recovery plan. A monitoring and research program that generates information about the requirements of the species needs to be established. Procedures should allow for revisions of critical habitat designations if suggested by additional information.

The Endangered Species Act, although it focuses on species as the objects of concern, clearly recognizes that preservation of the ecosystems upon which endangered and threatened species depend is a necessary component of the recovery process. This feature was written into the Act because loss of habitat is by far the most important cause of endangerment of species in the United States. A particular habitat type may be lost by destruction or conversion to other habitat types unsuitable for the species that live in it. A habitat may also be degraded by pollutants without being otherwise altered. The fact that habitat preservation is the most important element of most recovery plans creates several possibilities for using scientific information in more comprehensive ways.

Because many species that depend upon a habitat that has been greatly reduced in area or otherwise degraded are similarly affected by losses of that habitat, a number of listed or candidate species are likely to live in the same habitat. In a recent out-of-court settlement, the United States Fish and Wildlife Service formalized a commitment to emphasize multiple species listings and proposals that address entire ecosystems (Jaffe 1993), a result that demonstrates the appropriateness and legality of multispecies processes under the existing Act. Managing for multiple species within a single management area focuses efforts on recovery of threatened species while simultaneously directing attention to broader issues of habitat quality and quantity.

Multispecies planning differs from ecosystem management because its focus is still on species. Nonetheless, a multispecies approach to preservation plans inevitably directs attention to habitats and ecosystems. Habitat-based packages that combine the listing efforts for many species have the potential to eliminate unnecessary duplication of efforts and to prevent species from becoming threatened in the first place. Thus, a likely consequence of more extensive use of a habitat approach is that the need to invoke the Endangered Species Act will arise less frequently than it does now.

2. Use of Science in Protection and Prohibition against Jeopardy

Section 7 of the Endangered Species Act provides immediate protection to a species when it is listed as threatened or endangered. The analyses leading to no jeopardy or jeopardy opinions, together with the search for nonjeopardizing alternatives, offer considerable scope for the use of ecological knowledge. Jeopardy opinions, as well as non-jeopardy opinions, may become irrelevant unless they are regularly updated to reflect changed circumstances and new information. Ideally, recovery plans should provide tangible standards or yardsticks for judging whether particular federal actions satisfy Section 7. Recovery teams could play a useful role in this regard, by advising the Fish and Wildlife Service and National Marine Fisheries Service with respect to particular consultations.

The likelihood that a species will become extinct does not increase uniformly as its population declines. Rather, thresholds at which the probability of extinction rises rapidly are the rule. The importance of thresholds needs to be taken into consideration during evaluations of "incidental take." A determination of the consequences of incidental take should be based on the effect it would have on the process of restoring the species to its safe minimum population density. Thus, if the damage from incidental take was estimated to cause a 5% loss in the population size of a listed species, the consequences of that additional mortality on the likelihood of extinction could be shown explicitly through a population viability analysis. Furthermore, because PVAs emphasize the principal causes of a species' vulnerability to extinction, alternatives to the proposed action, such as mitigation, could be considered and evaluated.

In the broadest sense, the implementation of the Endangered Species Act is a process of risk assessment and risk management. Assessing risk of extinction, which is the function of the listing process, is a purely biological procedure. Any associated economic consequences that might arise from designating an imperiled species as endangered or threatened are not, and should not be, part of the risk assessment equation. However, in the "risk management" phase which follows the listing of a species, the Act appropriately permits the consideration of possible economic costs and infringement of personal property rights in the designation of critical habitat, in the determination of allowable harm to the species (takings and jeopardy), and in the development and implementation of recovery plans.

Formal population viability analyses could assist this process because a given level of probability of survival for a specified time period might well be achieved in many different ways, some of which would impose more restrictions on private land owners than others. PVAs could identify those options that would achieve maximum protection while reducing costs and lowering political controversy.

Science can play a valuable role in stimulating the consideration and evaluation of a wide range of actions at the time a federal action is contemplated. All too often formal consultations are limited to a consideration of a small number of options that are proposed as ways of avoiding harm to some listed species. Impacts of the options on other species often are not considered, and options that might be better than those being evaluated are rarely discussed. Broadening the range of options being considered increases the up-front costs, but if superior options are identified and eventually implemented, long-term costs may be reduced substantially.

Biologists in the agencies responsible for implementing the Endangered Species Act generally try to use the best scientific information and methods available. Failure to use the best available information and methods is generally due to inadequate budgets and overworked staff. Incorporating greater scientific rigor into the recovery process will result in initially higher costs because better methods for identifying species at risk, formal population viability analysis, and adequate habitat restoration and recovery programs all require greater investment. However, if the best available science is used consistently, common patterns will emerge and species protection and recovery will become more cost-effective. In other words, as experience is gained, each new case can build upon the results of previous cases. Rather than treating each new species to be protected as a totally novel situation, more powerful general rules can be applied and the process thereby simplified. The rapidly growing field of Conservation Biology, with its own professional, scientific Society of Conservation Biology, is already providing some of the needed information.

Furthermore, the development of general rules that are well-grounded in both experience and theory, can be useful in predicting which kinds of species and circumstances are likely to be sensitive to disturbance from human activities and in evaluating acceptable alternatives to the proposed actions.

In many regions of the United States, particularly the West Coast and the Southeast, threatened and endangered species occur on private land, and the concurrence of landowners will be required to protect the habitat of the species and to implement species recovery plans. This situation generates a need for interdisciplinary studies by resource economists and ecologists. The objectives of these studies should be the development of models and field approaches for determining least-cost solutions to habitat protection.

Furthermore, the pathways to these solutions should be "user-friendly" so that landowners can identify with the process. As an example of this approach, Liu (1992) developed a model for pine plantation management that shows the effects of different tree harvesting patterns and rotation lengths on the population size of Bachman's sparrow. This model shows how the real opportunity costs of forgoing the most profitable management plan are related to the probability of survival of Bachman's sparrow.

3. Use of Science in Development and Implementation of Recovery Plans.

When a species is listed, the Endangered Species Act requires that a recovery plan be developed. The ultimate goal of the recovery plan is to recover the species in its natural habitat to such a degree that it can be delisted. However, by the time a species becomes eligible for listing, its habitat is often destroyed or badly degraded, the population is decimated, and its genetic diversity seriously eroded. Therefore, scientific information is especially needed for setting population goals, captive breeding and release, and habitat protection and restoration.

(a) Setting Goals for Recovery. The first goal of a recovery plan is to stop the population decline before the species is on the brink of extinction. If listing as an endangered species was warranted, a recovery plan usually must aim for a population size significantly greater than the size at the time of listing. A good recovery plan for an endangered species typically has three goals for achieving viable populations. First, it calls for the establishment of multiple populations, distributed so that migration among them is possible, so that a single catastrophic event cannot wipe out the whole species. Second, it moves to stop known threats that guarantee the continued decline and eventual extinction of the population. Third, it plans for achieving annual population growth rates greater than zero, which will increase the size of populations to levels where demographic and normal environmental uncertainties are less threatening. Doing so requires careful analysis of the habitat requirements of the species and the distribution of suitable habitats in the landscape.

Analyses to determine long-term recovery goals and programs for attaining them are a vital component of recovery plans. However, because their development may require considerable time, short-term interim goals may be needed to prevent the species from becoming extinct while long-term plans are being developed. Interim population goals should be biologically attainable during the first years of the recovery process. One exception to setting larger recovery goals is if a species were naturally restricted to a very small area. In such a case, it might be listed as endangered, but recovery might require only removal of the threat it faces, in the restricted area.

General tentative guidelines for establishing viable population sizes are available (e.g., Gilpin and Soulé 1987) but these target population goals are no more than rough estimates and should not be viewed as substitutes for a more thorough analysis. Interim populations goals need to be flexible and readily adjustable. For example, an appropriate goal over a three-year period for a rapidly reproducing species might be the establishment of three semi-isolated populations with a combined population size greater than three times the original population size at the time of listing. For species with low reproductive rates, an increase in the size of the population of that magnitude within a few years may not be possible. Although interim goals are necessary, population viability analyses should begin immediately so that long-term population goals can be established and the most important factors threatening the species can be identified in a timely manner.

It is always tempting to set as a recovery goal a population of a specific size and spatial distribution. For many species, however, a goal of a relatively constant population is biologically unrealistic and probably intrinsically undesirable. Many species live in unstable, fluctuating environments, and their populations have historically fluctuated together with the states of their environments. For example, many species depend upon habitats that are maintained by periodic fires, droughts, or floods. Populations of such species inevitably fluctuate greatly in space and time. Realistic management goals must reflect this biological reality.

For example, the 1986 recovery plan for the Snail Kite (*Rostrhamus sociabilis*) in the Florida Everglades sets an interim population goal for reclassification from endangered to threatened of an "annual average of 650 birds for a ten-year period with annual population declines of less than 10% of the average." However, kite numbers vary, and have probably always varied, considerably according to surface water conditions, which change dramatically along with drought cycles in southern Florida. Achieving a population having the stability outlined in the interim population goal is probably unattainable. Also, attempting to achieve great population stability might well lead to management interventions that in the long term reduce the quality of kite habitat and, hence, the long-term viability of the population. However, it is generally useful to establish critical minimum population sizes below which extinction probabilities become unacceptably high even if they are sustained for only short time periods.

(b) Captive-breeding and Translocation. Reintroduction of captive-bred individuals and translocation of individuals between populations are often components of recovery plans. However, captive breeding programs are expensive, can save only one species at a time, and can be used only rarely because available facilities are limited. Also, because unexpected undesirable consequences may arise, captive propagation programs are risky. Deleterious genes may arise in captivity, or individuals released in areas other than the ones from which they or their parents were taken may not be adapted to the environments in which they are released. Diseases may be carried by the reintroduced individuals. Behavioral traits may develop in captivity that prevent individuals from functioning appropriately in nature. For these reasons, careful attention must be given to the sources of individuals for release to the wild and their treatment in captivity. Similar considerations apply to introductions of plants propagated in botanical gardens and other artificial environments.

There is also a danger that wild populations may be depleted to obtain individuals for captive breeding programs, although in special instances, such as occurred in the case of the California Condor in the 1980s, capture of all remaining individuals in the wild population may be warranted. Captive breeding programs may draw attention away from the need to protect and restore habitats for the focal species. Successful species recovery plans ultimately depend on adequate amounts of protected habitat. Captive-release or translocation programs of native populations, although important, cannot substitute for the failure to protect or restore natural habitat (Povilitis 1990). The danger is illustrated by the Gila topminnow, which was reclassified from endangered to threatened because artificial habitats were successfully restocked with captive-bred fish. However, the natural habitat continued to degrade from the effects of alien mosquitofish and agricultural water withdrawals (Simons *et al.* 1989). The continuing loss of the fish's natural habitat makes its survival in artificial pools increasingly improbable.

(c) Habitat Protection and Restoration. Often the best approach for restoring habitat is to control the source of the degradation and let nature take its course. Unfortunately, habitats are often very badly degraded or too small to contain adequate heterogeneity and natural disturbance regimes. In those situations, active management is needed to restore and maintain the habitat. Habitat restoration and ecological management are critically important to the species recovery process. Methods to restore and manage habitats are not yet well-developed, but the field of

Restoration Ecology is growing rapidly (Jordan, Gilpin, and Aber 1987; MacMahon and Jordan 1994). Its practitioners increasingly should be able to provide insights and guidance for restoration efforts in a variety of habitats.

Critical components in the development of a recovery plan for a listed species are determination of the current extent of its suitable habitat, assessment of the quality of the remaining habitat, and establishment of priorities for the areas to be targeted for restoration efforts. Restoration efforts can also be designed to test hypotheses about how the ecological community in question functions and the roles of the various species that might be reintroduced as part of the restoration project. Ideally, several different restoration projects should be initiated in different patches of a given habitat so that more than one hypothesis about the functioning of the community can be tested. Such a procedure would increase the probability that the results of specific restoration projects are generalizable to other habitats, while increasing the speed of restoration of the habitat in question by identifying more promising restoration techniques.

C. Delisting, the Ultimate Goal of the Endangered Species Act

Delisting is the ultimate objective of the Act. Measures of progress toward this goal include prevention of extinction and slowing the rate of population decline. The criteria for delisting should be established early in the recovery process, and they should be based on sound biological information. As discussed previously, delisting criteria should be consistent with natural fluctuations in the habitats supporting a species.

However, results obtained as recovery was underway may require modifications in the original criteria as better information about habitat requirements and population dynamics of the species become available.

IV. CONCLUSIONS

Protection is not afforded to species and their habitats under the Endangered Species Act until species are already threatened with extinction. By that time, both the range of a species and its total population size are likely to have been seriously reduced. Reccvery under these circumstances is likely to require major habitat restoration efforts and, possibly, captive propagation. These activities are more expensive and are less likely to be successful, the later in the decline of the population they are initiated. Therefore, the goals of the Endangered Species Act are more likely to be achieved, and to be realized at lower total cost, if preservation of biological diversity were approached in a more proactive manner.

The most important elements of a proactive approach would be to identify habitats and biological communities that are being seriously reduced in area or are being otherwise degraded and then to establish policies that prevent further losses of those habitats and restore degraded parts of them. Such an approach could not replace a species-by-species analysis because not all species are threatened by habitat loss and threatened species require different habitat types. Nonetheless, a habitat-based, proactive approach should greatly reduce the number of species that would need to be considered for listing. In addition, a proactive approach, by identifying habitats experiencing or likely to experience serious losses would allow federal agencies to initiate preservation plans while more options are available than will be present at such time when particular species would become candidates for listing. Habitat- and ecosystem-level planning can be accomplished under the existing Endangered Species Act, particularly through the use of critical habitat designations for already listed 'umbrella species." For both scientific and economic reasons, such proactive planning needs to be greatly increased. The establishment of the National Biological Service is an important step in developing the data needed for proactive, habitat and ecosystem level planning.

However, if the protection of habitats and ecosystems is to become an important means for conserving biological diversity, some important questions need to be addressed. Ecosystems are not closed systems; they are dependent on outside conditions. Ecosystems and habitats can be recognized at many scales. Aquatic ecosystems may range in size and complexity from small ponds to the Great Lakes. Determining the most appropriate scales for protecting them will require considerable information and complex biological judgments. New legislation for ecosystem-level protection, designed to complement and strengthen current legislation, could greatly assist protecting the nation's renewable natural resources, including its rich biological diversity. An ecosystem approach could help to reverse the slide towards extinction by preventing habitat degradation. The Endangered Species Act would then function as the safety net for those species whose survival cannot be guaranteed within the protected ecosystems.

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