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# Improving Recovery Planning for Threatened and Endangered Species

## *Comparative analysis of recovery plans can contribute to more effective recovery planning*

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The Endangered Species Act (ESA) is arguably the most important legislation passed by the United States Congress to protect species and their habitats (the use of the term "species" covers species, subspecies, and even distinct populations). The ESA has three major provisions (Rohlf 1989, Schwalbe 1993, Mueller 1994, NRC 1995, Easter-Pilcher 1996). First, it stipulates a process for determining whether or not a candidate species should be listed as threatened or endangered, based solely on scientific information and specifically excluding potential economic impact. Second, it provides listed species with legal protection to reduce the threat of extinction. The principal protections are limits to "take"—that is, to the destruction of a listed species or its habitat—as well as the potential to halt development projects that might increase a listed species' risk of extinction. Third, it requires a recovery plan, a detailed program for reducing the threat of extinction of the listed species by meeting specified criteria (i.e., the downlisting criteria).

**Identifying patterns across species and environments may lead to more effective recovery plans and endangered species management**

Recovery planning is potentially the most important part of the ESA. Unlike the other provisions, it is specifically intended to promote an increase in the populations of listed species, rather than to just limit their further decline. The ESA requires an approved recovery plan for all listed species. The lead agency (US Fish and Wildlife Service [FWS] or National Marine Fisheries Service [NMFS]) appoints a team of biologists familiar with the species to construct the recovery plan, which contains an estimate of the current size and state of the population(s) of the listed species, an analysis of the conditions that caused its endangerment, and a stipulation of the activities that will be required to support population recovery. This information is used to construct the downlisting criteria, usually a specified population size, but it may include additional provisions, such as a minimum number of viable population segments or a set of habitat conditions. After review and revision, the lead agency approves and files the recovery plan; it subsequently serves as a guide to rehabilitating the species in question, until it is replaced by a revised plan.

The value of recovery planning has been undercut severely by limited data and uncertainty in the plans. Very few species seem to have recovered to the point of downlisting because of the ESA. Reffalt (1988) claimed that only five species had been recovered because of the ESA; more species have been downlisted through apparent extinction than through any form of recovery. McMillan and Wilcove (1994) estimated that seven species went extinct after listing and another 17 that were candidate species went extinct before they were finally accepted for listing. A National Research Council report (NRC 1995) found that six species were downlisted because of the discovery of additional populations or because of the banning of DDT, neither of which is evidence of effective recovery planning. Other authors have criticized the inadequacies in the structure of the recovery planning process (Cook and Dixon 1987, Culbert and Blair 1989, Dixon and Cook 1989, Tear et al. 1993, 1994, Schemske et al. 1994). Recovery planning to date does not seem to have been very successful.

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Table 1. Distribution of the 311 species whose recovery plans we analyzed.

| Taxonomic group | Species listed as of 3 June 1994 | Number of species covered by this analysis | Percentage of species covered by this analysis |
|---|---|---|---|
| Amphibians | 9 | 7 | 78 |
| Birds | 73 | 62 | 85 |
| Clams | 40 | 30 | 75 |
| Crustaceans | 4 | 4 | 100 |
| Fishes | 63 | 32 | 51 |
| Insects | 16 | 13 | 81 |
| Mammals | 37 | 29 | 78 |
| Plants | 184 | 82 | 45 |
| Reptiles | 30 | 24 | 80 |
| Snails | 28 | 28 | 100 |
| Total | 484 | 311 | 64 |

Understanding why the prospects for recovery planning seem bleak is easy (Tear et al. 1993, 1994). Recovery teams usually work under the constraints of little money, conflicting interest groups, and little time in which to produce a recovery plan. They must attempt to rehabilitate species on the brink of extinction by the time they are listed. These problems are exacerbated by the limited information available for most listed species (Schemske et al. 1994). Despite these difficulties, the effectiveness of the ESA should ultimately be measured by how many species recover to the point of delisting because of the ESA. Successful recovery planning to preserve extant species, to protect the wild areas that support these species, and to provide for the evolution of future diversity represents a major challenge for conservation biologists and ecologists in the coming decades. Even if improved recovery planning does not dramatically increase downlisting in the short term, it gives researchers an opportunity to gain data and insight into the dynamics of endangered species.

Knowing how to achieve better recovery planning is not so easy. Because it is likely that adequate data will never be available, new approaches are constrained to use what data exist effectively. Patterns emerging from comparative analysis of recovery plans seem most promising. Flather et al. (1994) analyzed regional and environmental differences in the distribution of listed species to identify the factors associated with their listing and used this information to suggest that regional differentiation in recovery planning is needed to develop and implement recovery plans more successfully. One of their principal conclusions concerns the importance of altered surface water in the Western states as a cause of threatened extinction. Similarly, Dobson et al. (1997) have shown that comparative analysis of recovery plans may reveal larger-scale patterns that may strengthen existing recovery plans and make new ones easier to develop.

In this article, we analyze more than 300 recovery plans, concentrating on the causes of extinction and their taxonomic, habitat, and ecological correlates. Our objectives were to detect broad-scale patterns that can increase the value of recovery planning and to evaluate the need for management intervention in species recovery.

## Analysis of recovery plans

We analyzed 64% of the recovery plans approved or available in draft form through mid-1994. We included all of the recovery plans for snails and crustaceans and at least 75% of the plans for all other groups except plants and fishes (Table 1). Each member of our group analyzed all the files in a given taxonomic group; assignments of responsibility to taxonomic groups were made according to expertise.

For each recovery plan, we concentrated on finding information in the plan bearing on all causes, past and present, that led to the species becoming threatened or endangered. Because terminology varies among authors of recovery plans, we developed a list of causes from a preliminary subset of recovery plans that would permit us to compare different plans. Table 2 contains a list of the terms we used, with examples drawn from the recovery plans. Using this information, we then identified the principal cause of endangerment; in some cases, it was necessary to designate more than one. Where information was poor, we conditioned our conclusions. All remaining causes cited in the recovery plan were designated as contributing causes.

We emphasize that decisions about principal and contributing causes of endangerment represent our individual judgments and not those of plan authors, although some plans did contain these judgments. We generally gave greater weight to contemporary than to historical causes because contemporary causes should be more important to current endangerment and more responsive to management. We also tried to determine and give precedence to ultimate rather than proximate causes when applicable. For example, if we determined that fire or logging opened vegetation gaps resulting in the invasion of exotic species, then we would designate logging or fire as the principal cause rather than the exotic species. Generally, extracting causes of endangerment from the plans and determining a principal cause was straightforward and did not require extensive independent interpretation. Assigning a particular situation to one of our general causes was occasionally difficult. For example, when livestock grazing affects an endangered plant, is the principal cause of endangerment direct population reduction, habitat reduction, or habitat modification? Our interpretation depended on the details of the particular case.

## Management categories

Our ultimate objective was to place each listed species in one of three categories of management intensity, ranging from lowest management intensity (habitat preservation), to greater effort (habitat restoration), to highest intensity (active management). These categories were also developed from a preliminary assessment of recovery plans. In brief, habitat preservation was the choice when it was deemed that a species could recover to downlisting if enough habitat were protected. Habitat restoration was indicated if a

Table 2. Definitions and examples of causes of species endangerment used in this analysis.

| Cause | Definition | Examples |
|---|---|---|
| Succession and disturbance | Ecological succession creates habitat conditions unfavorable for the listed species. We use disturbance in a restricted sense to mean a natural disturbance that maintains intermediate seral stages. | Fire-maintained plant communities in the San Bruno chaparral. These plants are hosts for the San Bruno elfin butterfly. |
| Coevolutionary relationship | A listed species has an obligate coevolutionary relationship with another species; reduction of one necessarily means reduction of the other. | The valley elderberry long-horn beetle requires the valley elderberry as habitat in riparian habitats. |
| Exotic species | Successful invasion or deliberate introduction of the exotic is responsible for the endangerment of the listed species. | The predatory snail *Euglandina rosea* has eliminated Oahu tree snails wherever the two species are sympatric. |
| Hybridization | Cross-breeding between the listed species (usually a subspecies or congener) with a more common relative threatens its identity. | A rare form of Virginia round-leaf birch is being genetically swamped by its more common congener. |
| Other biotic interactions | Competition, predation, or other interactions between native species has reduced the population of the listed species. | Roseate terns are less competitive than the gulls with which they compete for nest sites. |
| Specialized or relict habitat | The habitat required by the listed species is either highly specialized (and usually naturally rare and scattered) or a relict of a formerly more common habitat (the reduction of habitat being due to natural causes). | The desert slender salamander is limited to seepages through broken limestone slabs in a single canyon in California. |
| Habitat reduction | Habitat is reduced or destroyed because of human activity. | Drainage of many pools inhabited by desert pupfish is the root cause of endangerment. |
| Habitat modification | Habitat suitability is reduced or destroyed as a result of human activity. | Disturbance of caves occupied by listed bats, such as the Ozark big-eared bat. Although the caves are intact, visitor use can harm critical life history stages. |
| Population reduction (harvest) | The species is endangered by direct human harvest. | Hunting, nest robbing, and accidental catch has harmed sea turtles. |

species could recover to downlisting through a program of habitat preservation supplemented by habitat restoration. All species not meeting these conditions were placed in the active management group. (In this context, management refers to habitat and ecological process management, not species population management, such as captive breeding or relocation.) These criteria are explained in more detail in the definitions for each management group.

**Habitat preservation.** In this category of management, a sufficient area of habitat is set aside for the species in question, relying on natural processes to facilitate population recovery. This strategy assumes that it is possible to protect sufficient habitat for the species, that the species presently exists in at least part of the habitat, and that the species is effectively protected in that habitat. Any unoccupied habitat would be colonized by natural dispersal or, in some cases, by active relocation. If these assumptions are fulfilled for a given species, then no other management should be required to recover the species, beyond monitoring both the species and its habitat to ensure that the approach is working.

Most of the species that we classified as likely to benefit from habitat preservation were threatened by a singular and easily identified threat. For example, the Rocky Mountain gray wolf (*Canis lupus irremotus*) has sufficient prey and habitat. This subspecies has recently been reintroduced in parts of its historic range. As long as direct killing of wolves is prevented, the subspecies should recover without direct manipulation of the habitat, prey species, or other ecological processes. Similarly, the listed species of the Eureka Valley dunes ecosystem of Nevada and California require little more than protection from off-road vehicles; adequate protection should lead to spontaneous recovery of species such as evening primrose (*Oenothera avita eurekensis*) and Eureka Valley dune grass (*Swallenia alexandrae*). These species fall into the habitat preservation category in that none requires more than adequate habitat and adequate protection.

**Habitat restoration.** When sufficient potential habitat for a species exists but the habitat quality is insufficient to support the species' recovery, the habitat restoration category of management is called for. Initial habitat restoration is required to return habitat areas to suitable quality. Once restoration is completed, the habitat preservation strategy should effect species recovery.

Restoration of appropriate water conditions is a typical action needed for species falling within this category. For example, the California clapper rail (*Rallus longirostris obsoletus*) requires more areas of mature tidal marshlands around the periphery of the San Francisco Estuary than are currently available. Restoration of diked wetlands to tidal flow would provide the necessary

Table 3. Associations between four system characteristics (exotics, island taxa, fire, and aquatic dependence) and management strategy chosen. Exotics include only those species for which exotics were a listed cause of endangement; the number of cases in which exotics were a principal cause is in parentheses. Island taxa refers to the number of listed taxa occurring on islands, fire refers to the natural occurrence of fire in the ecosystem containing the listed species, and aquatic dependence includes all species living in water or using aquatic trophic resources.

| Management strategy | Exotics | Island taxa | Fire | Aquatic dependence |
|---|---|---|---|---|
| Habitat preservation | 18 (1) | 15 | 1 | 32 |
| Habitat restoration | 13 (2) | 2 | 0 | 50 |
| Active management | 82 (45) | 44 | 30 | 43 |
| Total | 113 | 65[a] | 31 | 125 |

[a]Management categories for four of the island taxa could not be determined.

quantity and quality of habitat to support the clapper rail's recovery. Similarly, restoration of water levels in Mojave Desert pools would increase habitat for the pupfish (*Cyprinodon* spp.). Restoration of suitable hydrologic regimes would also benefit such plant species as Ruth's golden aster (*Pityopis ruthii*), Kral's water plantain (*Sagittaira secondifolia*), Solano grass (*Tuctoria mucronata*), and Furbish's lousewort (*Pedicularis furbishiae*). Habitat restoration will be most effective when habitat requirements for a listed species are clear and habitat restoration to meet those requirements is feasible.

**Active management.** The category of active management applies to those species for which there is evidence that neither of the other two strategies would arrest their continued decline and eventual extinction. Instead, continuing human intervention is required for the foreseeable future. For some species that require active management, endangerment results from a permanent alteration of the system, such as an exotic competitor or predator. For other species, management of a functional aspect of the ecosystem that has been altered by human activity, such as a natural fire regime, is necessary.

Many species require some level of active management. The Delmarva Peninsula fox squirrel (*Sciurus niger cinereus*) is a good example. The forest environment is largely natural, but human influences have changed the forest from a mature canopy with a minimal understory to a younger, more open forest with thicker undergrowth. The present forest does not favor the fox squirrel. The fox squirrel also is threatened by competition with the native gray squirrel (*Sciurus carolinensis*). Management of the forest structure and possibly reduction of the gray squirrel would be needed to recover the fox squirrel. The Florida scrub ecosystem, home of nine listed plant species, requires a very patchy regime of fire occurring at a variety of frequencies and intensities to meet the needs of the suite of fire-adapted plants. Fire is increasingly difficult to use as a management tool in this system because of nearby human habitation; the situation is complicated further by the invasion of an exotic fire-adapted species (Burma reed, *Neyraudia reynaudiana*), which thrives at the high fire frequencies occurring with altered hydrology and increasing urbanization. For species in this category, continuing management is needed to mitigate the impact of the changed dynamics.

## Management category and system characteristics

Of the 311 species whose recovery plans we analyzed, 305 could be assigned to one of the three management categories. We classified 37% as "habitat preservation" species, 21% as "habitat restoration" species, and 42% as "active management" species. It has traditionally been assumed that an endangered species will recover if sufficient habitat is available. Our analysis points out, however, just how unwarranted this assumption is. Fully 63% of the species analyzed would require some form of management, either by initial restoration or in continuing intervention, to recover to the point of downlisting.

Different causes of endangerment and characteristics of the systems are associated with the management categories (Table 3). In the vast majority of cases in which exotic species or fire are important in the system, active management is required (112 of 144 species combined, 78%). The majority of island species whose recovery plans were analyzed require active management as well (68%). These factors often occur together. For example, the problem of ecosystem disruption due to exotics on islands is well known: 39 of 65 island species (60%) have exotics as a principal threat, and 16 more have exotics as a contributing cause (our unpublished data). Although aquatic species are represented in all three categories, they are most strongly associated with the habitat restoration category of management.

## Identification of principal causes of endangerment

We analyzed the data on causes of endangerment to determine which causes were most prevalent, how these causes were related to our management categories, and how they were related to the different taxonomic groups. We determined principal and contributing causes for 292 of the 311 species whose recovery plans we reviewed.

Figure 1 shows the frequency for each category of causation (i.e., the percentage of species for which a given cause was cited in the recovery plan). Habitat reduction was the most frequently cited principal cause (34%), followed by habitat modification (23%), exotics (16%), population reduction (8%), specialized and relict habitats (5%), and succession and disturbance (4%). Biotic interactions, hybridization, and coevolution were each the principal cause of endangerment for less than 2% of the species.

All of the most common principal causes were frequently cited as contributing causes, whereas others were mostly cited as contributing causes. The six most frequent contributing causes all were cited in 17% or more of the recovery plans. We calculated ratios of principal to contributing cause to estimate differences in frequency of citation of a cause as princi-

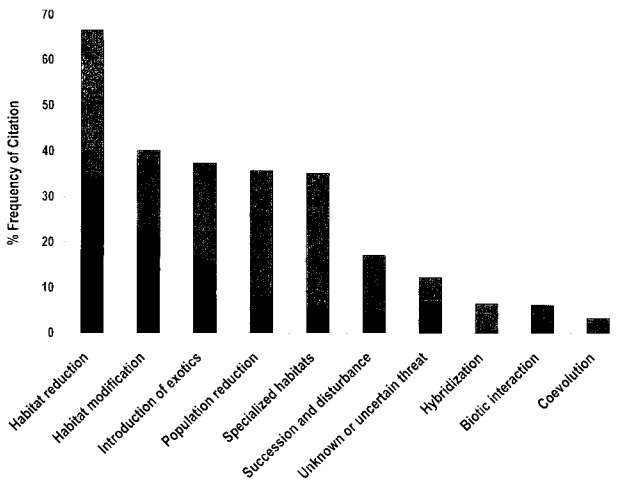


**Figure 1.** Relative importance of each of the endangerment causes listed in Table 2. The black portion of each bar represents the percentage of species for which the cause was the principal threat; the gray portion represents the percentage of species for which the cause was a contributing threat.

pal or contributing. Habitat reduction, habitat modification, and exotic species were the three most frequently invoked causes of endangerment, with equal occurrence as principal and contributing cause (i.e., with ratios approaching 1.0). Specialized and relict habitats and population reduction were infrequently cited as principal causes but were cited relatively frequently as contributing causes (15% and 23%, respectively). They are examples of important causes that are likely to be underestimated when only principal causes are examined.

## Management category and principal cause

Figure 2 shows the disposition of principal cause by management strategy, with all taxonomic categories aggregated. Four principal causes accounted for 93% of the cases in which habitat preservation was the designated strategy: habitat reduction (40% of cases), habitat modification (21%), population reduction (18%), and specialized or relict habitats (14%; Figure 2a). Two principal causes accounted for 86% of the cases in which habitat restoration was the appropriate recovery strategy: habitat modification (54%) and habitat reduction (32%; Figure 2b). When active management was indicated, exotic species was the most important principal cause of endangerment (36%; Figure 2c), although habitat reduction still accounted for 32% of the species placed in active management.

Habitat reduction and habitat modification are the most frequently cited principal causes when all three management strategies are considered together. Habitat reduction strongly affects species from all three management categories, and it is clearly the principal cause that produced threatened and endangered species in the first place. Consequently, stopping or reversing habitat loss will likely be a factor in almost all recovery plans. Direct population reduction and specialized or relict habitats were cited more frequently as principal causes of endangerment for species that fall in the habitat preservation category (83% of the cases in which they were cited as principal causes) than for species in the other two management categories, whereas 92% of the species whose principal threats were exotics or succession and disturbance fell into the active management category.

These findings point to an emerging conservation strategy. Habitat loss is so pervasive that it is a concern independent of the chosen management strategy. When a species is threatened predominately by direct harvest or collection or by living in a very specialized habitat, effectively protecting the habitat and the species within it should provide long-term protection. When habitat modification is an important threat, then, if the deleterious effects have not been too profound and long term, simply protecting the habitat and the species may be sufficient for recovery. More severe habitat modification may require significant restoration followed by habitat protection. When significant biological dynamics, such as the presence of an invasive exotic species or altered succession and disturbance dynamics, do not favor re-

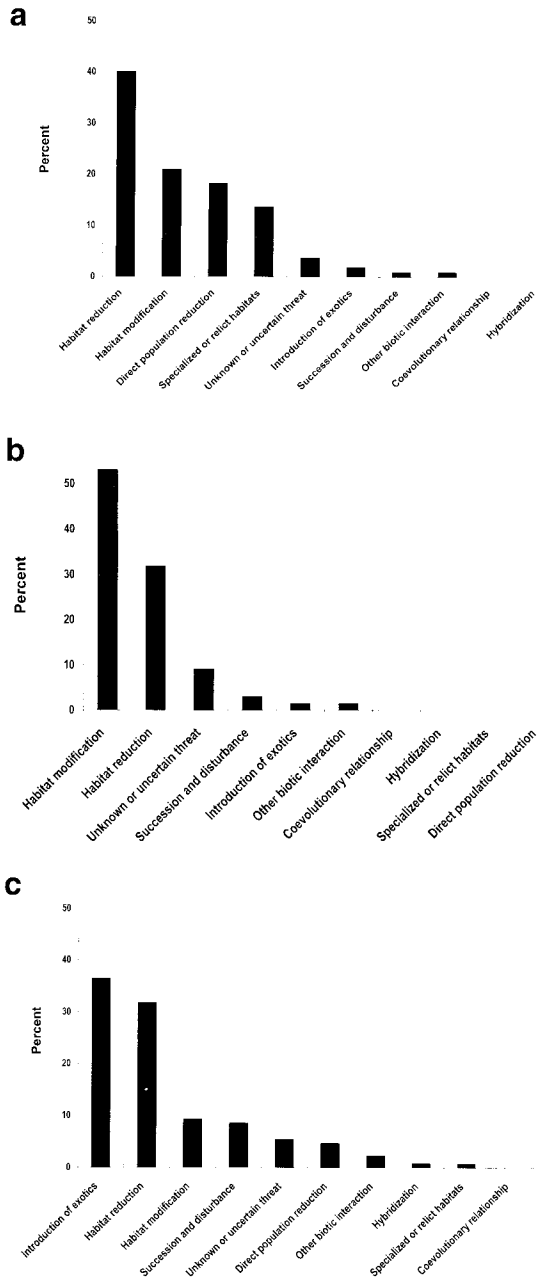


**Figure 2.** For each management category, the percentage of species that are threatened by each endangerment cause. The x-axis for each plot shows the causes in descending order of importance. (**a**) Habitat preservation. (**b**) Habitat restoration. (**c**) Active management.

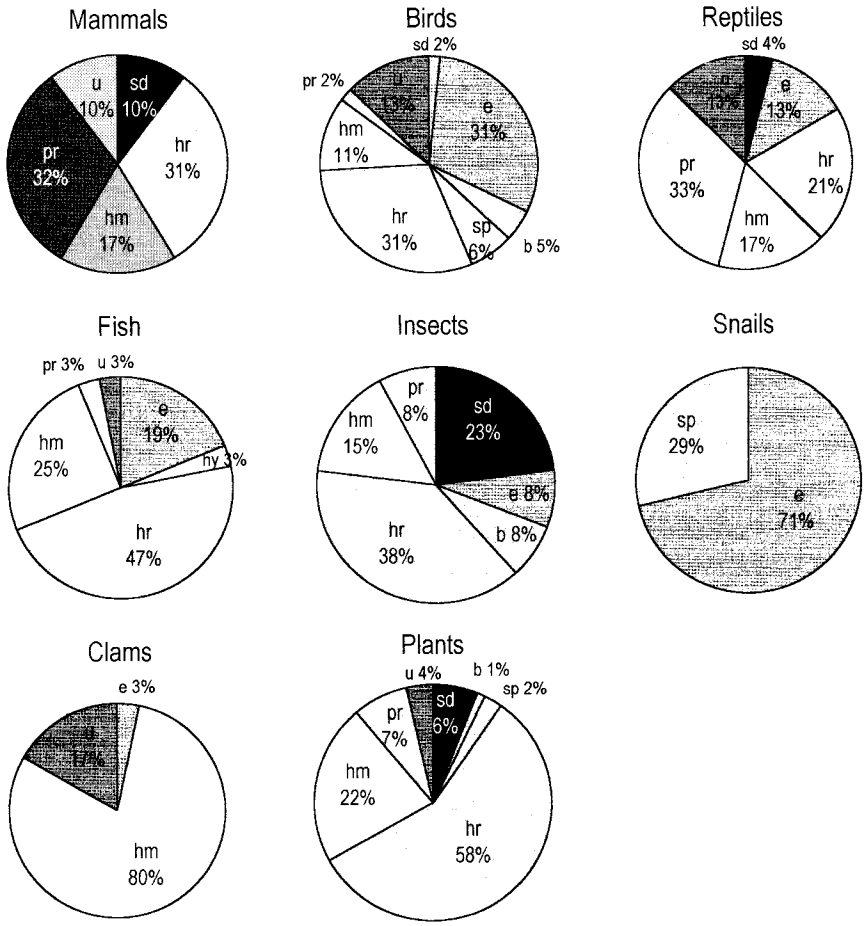


**Figure 3.** Relative importance of principal causes of endangerment for all taxonomic groups covered in this article, except amphibians and crustaceans. Each sector is labeled with the cause of endangerment and the percentage of species for which that threat is the principal cause of endangerment. sd, succession and disturbance; e, exotics; h, hybridization; b, biotic interaction; sp, specialized or relict habitats; hr, habitat reduction; hm, habitat modification; u, unknown or uncertain threat.

covery of a species, then lengthy and intensive management will be needed. In many of these cases, it is unclear that even such management will be effective.

## Lessons from higher taxonomic groups

The different taxonomic groups show clear patterns of placement in the three management strategies (Table 4). All of the crustaceans and 88% of the mammal species covered in the 305 recovery plans for which we could determine a management strategy were classified as recoverable through the habitat preservation strategy. Less than half of the amphibians and plants were estimated to be recoverable with habitat preservation. The two groups that would benefit most from the habitat restoration strategy are the clams (80%) and fishes (43%), both of which require the restoration of adequate stream flow. For birds, reptiles, snails, and insects, more species require active management than habitat preservation or restoration, although for reptiles habitat preservation is a close second. A substantial minority of the plants would also require active management.

Figure 3 shows the principal causes of endangerment cross-tabulated by taxonomic category. The source of endangerment varies across taxonomic groups. For mammals, the most important factors are habitat reduction and direct harvest; for birds, habitat reduction and exotic species; for reptiles, direct harvest; for fishes and plants, habitat reduction; for insects, habitat reduction and succession and disturbance. Snails are threatened largely by exotic species, whereas clams are endangered by habitat modification. (Amphibians and crustaceans are not shown because their sample sizes are too small.)

One factor contributing to differences in principal causes among the species is biological distinctiveness. Biological differences also relate to the taxonomic patterns in management category placement noted above. For example, many mammals have been heavily hunted, thus leading to direct population reduction as an important principal cause of endangerment and to habitat preservation (with population protection and natural recovery) as the management category of choice. Large mammals are especially vulnerable to habitat loss because their range requirements are so extensive; habitat reduction is thus a major cause of listing, and habitat preservation the appropriate management strategy. A second example comes from reptiles, many of which have been harvested for food

**Table 4.** Classification of species into the three management categories.

| Taxonomic group | Habitat preservation | Habitat restoration | Active management |
|---|---|---|---|
| Amphibians | 3 | 2 | 2 |
| Birds | 15 | 11 | 36 |
| Clams | 3 | 24 | 3 |
| Crustaceans | 4 | 0 | 0 |
| Fishes | 5 | 13 | 14 |
| Insects[a] | 4 | 2 | 7 |
| Mammals[a] | 21 | 0 | 5 |
| Plants | 39 | 11 | 32 |
| Reptiles[a] | 9 | 2 | 10 |
| Snails | 8 | 0 | 20 |
| Total | 111 | 65 | 129 |

[a]Two mammals, three reptiles, and one butterfly could not be placed in a single category and were therefore omitted.

and products and by collectors; this fact explains the importance of direct reduction as a threat and of habitat preservation as the appropriate management strategy. That habitat reduction is the dominant threat to plants and fishes is, perhaps, not surprising because these two groups often have low vagility in the face of habitat loss and degradation. Snails and birds are heavily threatened by exotics, thus explaining the prevalence of active management for these groups.

## Recognizing the need for active management

Our findings have several implications for recovery planning. Probably the most striking result of our recovery plan analysis is that 63% of the plans were classified as calling for habitat restoration or active management—that is, simply preserving habitat will not be sufficient to recover these species. Moreover, our estimates of the intensity of management required for threatened and endangered species are probably conservative. Species that we classified as in need of habitat preservation may prove to need more management in the future. For example, areas of habitat thought to be usable may become degraded and require significant restoration, or the spread of a new exotic or the discovery of a complex but important ecological dynamic may require active management, particularly in aquatic systems.

Moreover, even for those endangered species that appear to fall in the habitat preservation category, recovery will not necessarily be cheap or easy. Habitat that is available and suitable may not be protected, dictating an expensive and often complex process of land acquisition. Even if habitat is protected on paper, enforcing protection, both of the habitat and the species, may be difficult and costly. Finally, even if habitat is protected effectively, the species may need to be relocated there, or it may need to be bred to obtain requisite numbers before reintroduction. Nevertheless, the message is clear: some form of active management, costly in both time and money, will be necessary to recover most threatened and endangered species. A recent report from the Ecological Society of America (Carroll et al. 1996) confirms this conclusion. Realistically recognizing and evaluating what is needed to recover a particular species is a crucial step toward recovery. Patterns seen in recovery plans for similar species, for ecologically similar areas, or with similar obstacles to recovery should help those who manage endangered species streamline and improve recovery planning.

## Focusing on species that can recover with help

Biologists have a natural aversion to the idea of triage. But as several biologists have stated (e.g., Reffalt 1989, Flather et al. 1994), the disparity between the number of species being proposed for listing and the cost of preparing recovery plans has exceeded the ability of the FWS and NMFS to meet the requirements of the ESA, much less devote serious effort to recovery. If inaction means the continuing loss of species, then a better, more practical way for allocating funds for recovery must be found (Norton 1988).

Our results suggest that even with the limited and often imperfect data available for most listed taxa (Mattson and Craighead 1994), scientists should be able to determine which species have a good chance of recovery with limited human intervention and to estimate what level of intervention will be required for the others (Britten et al. 1994). Currently, a combination of the uniqueness of the species, the degree of endangerment, and the chance of recovery are used to determine which recovery plans have the highest priority for funding. This system suffers from being overridden by political considerations favoring certain species and from a general lack of funding. Considering the management requirements of each species (as well as other relevant information) could be useful for setting priorities for recovery funding.

At one end of the management gradient, some species (invertebrates in particular) have been listed because they were rare, had a limited distribution, and were potentially in danger of extinction, but now they face little threat. For these species, protection of current habitat is probably adequate. Some of these species may even be protected adequately with present resources or even no conscious effort at all. Other species extend the gradient from "recoverable at moderate cost" to "unrecoverable under any practical circumstances." The resources required for recovery, the critical data needed to select among management options, the size and availability of the critical habitat needed, and the degree of protection required could be estimated, at least roughly, and used to develop an improved system for allocating recovery funds. Effort and money could be funneled toward species with a good chance of recovery and, perhaps more important, toward tasks and projects that would lead most directly to recovery. We do not propose that species that require extensive and long-term management—our "active management" species—should be abandoned or relegated to last priority. Realistic management will plan for the tasks required for different species and will focus on available resources on those tasks that will lead eventually to recovery—not simply those that are the least expensive or the most convenient. For those species whose recovery does not seem feasible, a captive breeding strategy might be a last-ditch alternative for some future time when changing human attitudes or greater resources might make restoration of wild populations possible.

## Promoting real recovery

We strongly advocate a continuing effort in comparative analysis to identify patterns of extinction and recovery, such as we have begun here. Further work emphasizing patterns shared by species and environments may provide shortcuts to developing management strategies for newly listed species and their recovery plans. Ultimately, this research should indicate paths that could benefit more than single species and in that way contribute to an effective theory of ecosystem management.

We recommend two changes in the recovery planning process. First, we advocate that all recovery plans be required to choose an appropriate management strategy, with the choice defended by comparative analysis of

similar species (taxonomically and/or ecologically) as well as by the particulars of the species. For all listed species, it is necessary to make a realistic appraisal of the requirements that must be met if further decline is to be halted and the process of recovery begun. Although conservation biologists must strive to learn more about the ecology and natural history of threatened and endangered species through further research, it is usually not possible to wait for better data before taking action. Considering the relative strengths and weaknesses of each management option, therefore, seems justified.

Second, we recommend that the principles of "adaptive management" (Holling 1978, Walters 1986, Gunderson et al. 1995) be incorporated into the evaluation and implementation of recovery plans. As part of adaptive management, all recovery plans should be reexamined periodically, the results of any previous work on the plan reported and critically analyzed, and, if needed, a revised plan developed. Periodic reevaluation could help to focus attention on the management actions needed for the recovery of a species. Although current policy calls for revision of recovery plans whenever significant information becomes available, the pressure to keep up with new listings has made such revisions practically impossible. Consequently, recovery teams should be given the authority to make revisions to improve the effectiveness of recovery of the species the team is managing. The process of adaptive resource management has been proposed as a guiding principle for the Biological Resources Division of the US Geological Survey (Sarewitz et al. 1996), and it is now attracting increasing attention from ecologists (Christensen et al. 1996, Ringold et al. 1996, Weinstein et al. 1997).

Conservation cannot be effective if ecology cannot react quickly and wisely to the rapid population decline of many listed species. Hundreds of species are listed as threatened and endangered under the ESA in the United States, more are being listed and need consideration, and woefully little information is available about many of these species. Continuing inaction means continuing decline. Conservation biologists need to make the acquisition of better data a higher priority, learning as much from the patterns and histories of other species as possible. This information must be used to determine the best management strategy for each listed species and to revise such strategies whenever necessary. If recovery plans are effective, they can bring the rarest plants and animals away from the brink of extinction.

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## References cited

Britten HB, Brussard PF, Murphy DD. 1994. The pending extinction of the uncompahgre fritillary butterfly. Conservation Biology 8: 86–94.

Carroll C, Auspurger C, Dobson A, Franklin J, Orians G, Reid W, Tracy R, Wilcove D, Wilson J, Lubchenco J. 1996. Strengthening the use of science in achieving the goals of the Endangered Species Act. Ecological Applications 6: 1–11.

Christensen NL, et al. 1996. Comments on the scientific basis for ecosystem management. Ecological Applications 6: 665–691.

Cook RE, Dixon PM. 1987. A review of recovery plans for threatened and endangered plant species. Washington (DC): World Wildlife Fund.

Culbert R, Blair RB. 1989. Recovery planning and endangered species. Endangered Species Update 5(10): 2–8.

Dixon PM, Cook RE. 1989. Science, planning, and the recovery of endangered plants. Endangered Species Update 6(10): 9–14.

Dobson AP, Rodriguez JP, Roberts WM, Wilcove DS. 1997. Geographic distribution of endangered species. Science 275: 550–553.

Easter-Pilcher A. 1996. Implementing the Endangered Species Act. BioScience 46: 355–363.

Flather CH, Joyce LA, Bloomgarden CA. 1994. Species endangerment patterns in the United States. Washington (DC): USDA Forest Service, Rocky Mountain Forest and Range Experimental Station. General Technical Report no. RM-241.

Gunderson LH, Holling CS, Light SS, eds. 1995. Barriers and bridges to the renewal of ecosystems and institutions. New York: Columbia University Press.

Holling CS. 1978. Adaptive environmental management. New York: Academic Press.

Mattson DJ, Craighead JJ. 1994. The Yellowstone grizzly bear recovery program: Uncertain information, uncertain policy. Pages 101–129 in Clark TW, Reading RP, Clarke AL, eds. Endangered Species Recovery. Washington (DC): Island Press.

McMillan M, Wilcove D. 1994. Gone but not forgotten: Why have species protected by the Endangered Species Act become extinct? Endangered Species Update 11: 5–6.

Mueller TL. 1994. Guide to the federal and California endangered species laws. Sacramento (CA): Planning and Conservation League Foundation.

[NRC] National Research Council. 1995. Committee on Scientific Issues in the Endangered Species Act. Science and the Endangered Species Act. Washington (DC): National Academy Press.

Norton BR. 1988. Avoiding the triage question. Endangered Species Update 5(8/9): 1–4.

Reffalt WC. 1988. United States listing for endangered species: Chronicles of extinction? Endangered Species Update 5(10): 10–13.

Ringold PL, Algeria J, Czaplewski RL, Mulder BS, Tolle T, Burnett K. 1996. Adaptive monitoring design for ecosystem management. Ecological Applications 6: 745–747.

Rohlf DJ. 1989. The Endangered Species Act: A Guide to Its Protections and Implementation. Stanford (CA): Stanford Environmental Law Society.

Sarewitz D, Barber M, Huyler J Jr., DeMorgan P. 1996. Interdisciplinary scientific opportunities at the new consolidated US Geological Survey and National Biological Service. GSA Today, October 1996: 10–11.

Schemske DW, Hubbard BC, Ruckelshaus MH, Goodwillie C, Parker IM, Bishop JG. 1994. Evaluating approaches to the conservation of rare and endangered plants. Ecology 75: 584–606.

Schwalbe R. 1993. The Endangered Species Act at twenty: An analytical survey of Federal endangered species protection. Natural Resources Journal 33: 1027–1075.

Tear TH, Scott JM, Hayward PH, Griffith B. 1993. Status and prospects for success of the Endangered Species Act: A look at recovery plans. Science 262: 976–977.

_____. 1994. Recovery plans and the Endangered Species Act: Are criticisms supported by the data? Conservation Biology 9: 182–195.

Walters CJ. 1986. Adaptive management of renewable resources. New York: MacMillan.

Weinstein MP, Balletto JH, Teal JM, Ludwig DF. 1997. Success criteria and adaptive management for a large-scale wetland restoration project. Wetlands Ecology and Management 4: 111–127.