Seeking a Rational Approach to Setting Conservation Priorities for Marine Mammals

LEAH GERBER

The U.S. Endangered Species Act establishes categories for endangered and threatened species but provides no criteria for deciding when a species should be listed, delisted, or downlisted. As a result, listing and recovery actions for marine mammals are widely inconsistent. In most cases, Endangered Species Act listing and recovery actions have been done without the benefit of high-quality population assessments and have been based on arbitrary, nonquantitative criteria. A new approach to determining classification criteria for marine mammals is presented, with the North Pacific humpback whale as a test case. The key idea underlying this approach is an attempt to incorporate biological uncertainty explicitly in the definition of threatened and endangered. I sketch the essential ingredients of this new approach and its motivation and use this discussion to illuminate the challenges we face in pursuing conservation in an uncertain and data-poor world.

KEY WORDS: Endangered Species Act listing criteria, marine mammals

Marine mammals have captured the public's imagination as symbols of conservation—often appearing on the front pages of newspapers or even on national television broadcasts. Since thousands of species from the lowly tartar to the grizzly bear are threatened with the risk of extinction, it is interesting to consider why the 17 endangered marine mammals elicit so much passion and emotion. One reason may be that the causes of their endangerment often include overharvesting, pollution, kills incidental to commercial fisheries, and entanglement in marine debris, all of which seem unnecessary and tragic. Certainly another appeal of marine mammals is simply how unique they are. To a biologist, all species are unique, but to the public there is no denying that some species possess a special charisma, and marine mammals seem to epitomize this quality.

When scientific controversy and sentimentality meet, conservation biologists typically face their greatest challenge. In this paper I consider Endangered Species Act (ESA) listing decisions regarding marine mammals as a prism with which to view a central conundrum of conservation—what types of data are needed and how those data should be used to decide when a species warrants listing as endangered. Before delving into this question, it is useful to review the history of marine mammal extinctions and their current conservation status.

EXTINCTION HISTORY OF MARINE MAMMALS AND CURRENT STATUS

The exploitation of marine mammals dates from the earliest occupancy of North America. Marine mammals provided a source of food and oil to early immigrants. Thousands of whales, dolphins, porpoises, sirenians, seals, sea lions, and sea otters have been killed annually since aboriginal people learned to hunt large vertebrates successfully. However, it was not until the onset of European technology that species and populations of marine mammals were actually extirpated in the Northern Hemisphere.

Ironically, although we have been harvesting marine mammals for the last 350 years, we are still surprisingly ignorant about their distribution and abundance prior to the onset of exploitation.

We do know that to date, four marine mammal populations have disappeared forever: the Steller’s sea cow, the Atlantic gray whale, the Caribbean monk seal, and the Japanese sea lion. The Steller’s sea cow, a member of the order Sirenia (manatees and dugongs), was exterminated by Russian sealers in 1767, only 27 years after its discovery. Unlike other sirenians, sea cows occupied a cold environment, subsisted on kelp, and reached a length of 25 feet, nearly twice that of their tropical counterparts. These subarctic sea cows had thick, barklike skin and were completely toothless, with only horny pads at the front of their jaws to mash kelp (Fig. 1). Among the marine vertebrates, sea cows were unique in having no phalanges on their short flippers and in seldom submerging themselves but habitually floating with their backs out of the water. Sadly, there are only four species remaining from this order, which historically included as...
many as seven species. All four extant species are currently threatened with extinction (the Amazon manatee, the West Indian manatee, the West African manatee, and the dugong). The extinction of an entire order would be dire, and conservation efforts have been vigorously directed at conserving manatees and dugongs.

The now extinct Atlantic gray whale was a mysticete, the family of cetaceans that includes the largest animals ever to inhabit the earth. The mysticetes, or baleen whales, are distantly related to the hoofed mammals, and have adapted over the last tens of millions of years to feeding on small fish and zooplankton, and have evolved plates of baleen in place of teeth to filter minute organisms of the sea. Little is known about Atlantic gray whales, but whaling records and subfossil specimens indicate that the species was present up to the 17th century. Although the species is categorized as extinct, it is possible that some living specimens exist on remote islands in the Sea of Japan or off the coast of Russia.

In addition to the above extinctions, several pinniped species have come perilously close to extermination. Six species of otariids (fur seals and sea lions), including the Guadalupe, Juan Fernandez, Antarctic, Subantarctic, New Zealand, and South African fur seals, were driven to populations in the low hundreds during the 1800s and early 1900s as a result of over-harvesting. Among the phocids (true seals), the Mediterranean monk seal is currently on the brink of extinction as a result of mortality due to commercial fisheries, poaching, and pollution. Fortunately, pinnipeds have shown the potential to rebound from low populations if the pressures that drove them toward extinction are removed. This is well illustrated by the northern elephant seal, which was harvested so severely in the 1800s that by 1890 the species was estimated to include fewer than 100 animals and may have dropped as low as only 20 animals. Once the species was protected from harvesting in 1922, it began to reoccupy its original range, so that by 1991 there were an estimated 127,000 animals. Of course, dramatic recoveries from population bottlenecks carry with them (at least in theory) their own hazards. In particular, the thousands of elephant seals alive today are all direct descendants of a small group of animals that managed to survive the period of extreme overexploitation.

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The final victims in this tale of marine mammal extinction are the pinnipeds, some of which have been exterminated by fishing activities and by direct harvest. The Caribbean monk seal was nearly extinct in the 17th century but managed to persist for another two centuries. Ironically, this species was finally driven to extinction during the 1950s by fishermen who viewed the last handful of animals as competitors. This notion of pinnipeds as competitors to ourselves persists today, and many species are still routinely killed for this reason. The apparently extinct Japanese sea lion (a subspecies of the California sea lion) had long been hunted for meat and oil and was harvested to the point of extremely low numbers by the early 1900s. The species was considered to be virtually extinct until one sea lion was sighted in 1952. Although the species is categorized as extinct, it is possible that some living specimens exist on remote islands in the Sea of Japan or off the coast of Russia.

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Overall, 20 marine mammal species are currently listed under the Endangered Species Act's List of Endangered and Threatened Wildlife (the List) (Table 1). Due to concern about overutilization and inadequate protective regulations, 8 of the 11 species of large cetaceans—blue, fin, sei, humpback, right, bowhead, gray, and sperm whales—were listed as threatened with extinction under the Endangered Species Conservation Act (ESCA) of 1969 and subsequently as endangered under the ESA in 1973 (which replaced the ESCA). The remaining 12 species in Table 1 were listed on an individual basis in response to either declining or low abundance, or to specific risks of extinction. Population size for marine mammals listed as endangered ranges from 43,000
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*Species for which a Recovery Plan has been finalized.

(for Steller sea lions) to less than 600 (for Northern right whales) (Fig. 2).

Despite the real threats to marine mammals, in the broad scheme of species conservation, these and other "charismatic megafauna" seem to have received special preference over other species. For example, 70% of the mammals that are listed under the ESA are afforded protection as subspecies or populations; in contrast, the average percentage of protection at the subspecific or population level for all other taxa is less than 15%. Plants are probably the least protected of all species, as evidenced by the fact...
TABLE 1. Summary of marine mammal species on the List of Endangered and Threatened Wildlife and primary threats

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that whereas they represent 50% of the listed species they have received only 8% of the recovery funds. Setting conservation priorities based on the public definition of which species are most lovable is clearly not ideal, and the job of scientists should be to push more rational approaches to the forefront. We certainly should not invoke conservation actions more vigorously and with less data just because the species of concern is particularly photogenic.

Perhaps as a result of their popularity, marine mammals have been afforded a tier of protection in addition to that provided by the ESA. The Marine Mammal Protection Act of 1972 as amended (MMPA) provides an overarching framework for protecting all marine mammals, while the ESA applies only to those species that are designated as threatened or endangered. The central objective of the MMPA is to maintain populations at their optimum sustainable population level (OSP). This level is defined as the number of animals that will result in the maximum productivity of the population, consistent with the optimum carrying capacity of the habitat and the health of the ecosystem. Clearly, OSP constitutes a population level significantly larger than a population defined as being at risk of extinction. Thus marine mammals have a legislative advantage over those less charismatic species that must decline to extremely low sizes to be afforded protection. In fact, the OSP criterion means that marine mammals can be protected under the MMPA with population sizes as large as 1,000,000 (e.g., Northern fur seals), whereas the median population size of species when listed under the ESA is about 1,000 for vertebrates and 100 for plants.

An additional piece of legislation, the International Convention on the Regulation of Whaling, has dramatically changed management practices of marine mammals since large whales were listed under the ESA in 1969. In 1985 and 1986 the International Whaling Commission (IWC) imposed a moratorium on commercial harvesting of large whales. Since the early 1970s, many large whale populations have increased in abundance. However, while several large whale populations have apparently started to recover, several dolphin, porpoise, and pinniped populations have declined. This suggests that large whales may be receiving undue protection or attention in comparison with small cetaceans and pinnipeds. Indeed, several prominent whale biologists have recognized that some large whale populations may no longer need such "coddling" and have gone so far as to propose that certain populations be considered for removal from the List. One such population, the eastern North Pacific population of gray whales, was removed from the List in June 1994. Ironically, this means that the only marine mammal species to be delisted is a species for which no recovery plan was ever written; in contrast, the six species for which recovery plans exist remain unrecovered! We discuss below the role of recovery plans in ESA conservation and implementation.

Figure 2. Despite its "charisma," the Western population of Steller sea lions has declined by 65% since the 1960s and is currently listed as endangered under the ESA.
cies have recovery plans, and within those that do, listing and recovery criteria for species are widely inconsistent. At first glance, the fact that only a small fraction of listed species have recovery plans may seem reprehensible. However, because these documents have no legislative "teeth" (i.e., no mandate to implement recovery actions outlined in the plan), the absence of plans may be irrelevant to actual recovery. Moreover, recovery plans are not legally required in all cases; instead the U.S. Fish and Wildlife Service (FWS) (for all terrestrial species and a few marine species) or the National Marine Fisheries Service (NMFS) (for most marine species) are required to develop a recovery plan only if these agencies determine that a plan will promote the recovery of a listed species.

Although recovery plans lack the legal clout to implement their recommendations, they do have one important regulatory attribute—only in recovery plans is it specified what criteria would suffice to remove a species from the List. Thus, for those listed species lacking recovery plans, there is no formal document in which delisting criteria may be defined. For those species that do have recovery plans, there is still no guarantee that criteria for delisting are rational. In fact, previous analyses of existing recovery plans have led some biologists to conclude that most plans do not include biologically defensible guidelines in terms of population size and trends.14

Ironically, 28% of threatened and endangered species for which population size data were available had recovery goals set at or below the existing population size.15 While there may be good reasons for this, it raises some suspicion about whether biology or political pragmatism determines recovery goals.

Since the late 1970s, only six species have recovered enough to be removed from the List. An additional 14 species were removed after they either became extinct or new information was uncovered indicating they never should have been on the list in the first place. Recently, a proposal to delist 29 plant and animal species was announced by the Department of Interior. This proposal, unveiled by Interior Secretary Bruce Babbitt in May 1998, marks the first time in the law's 25-year history that such a large number of species would be earmarked for removal from the list. Over a two year period, some of the species would be down listed to threatened and others for removal from the law's protection altogether, although states could still regulate them. This proposal is remarkable in light of the inconsistency or absence of delisting criteria for each of these 29 species. As environmentalists scrutinize the merits of each species that is delisted, it will be interesting to see how the scientific rationale underlying these decisions will stand up under fire, and to ask whether alternative approaches might produce a less vituperative debate. Certainly, this landmark announcement by Babbitt highlights the fact that the development of delisting criteria will be increasingly in the limelight of conservation biology.

### Marine mammal recovery planning and listing decisions create a demand for sharper science.

In addition to these regulatory subtleties involving recovery plans, the issue of recovery takes on a special challenge with regard to marine mammals. For many terrestrial species, habitat destruction is the primary source of endangerment, and recovery can often be directly linked to habitat protection and restoration.15 In contrast, for marine mammals, there is generally no straightforward solution that can be identified as the key to recovery. For example, biologists may know that northern right whales have failed to recover due to a low population growth rate, yet even if there were political will and unlimited resources, it would not be possible to adopt any single action that would immediately increase the growth rate of the northern right whale. Taken together, the conflation of regulatory and biological ambiguities surrounding marine mammal recovery planning and listing decisions creates a demand for sharper science. Clearly, science alone cannot solve conflicts among economic and political interests and the well-being of certain species. However, science can help to define when species should be listed as endangered or threatened, and when species should be heralded as recovered. Towards this end, modern conservation biology has yielded new tools for evaluating species viability, determining appropriate strategies for protecting threatened species, designing nature reserves, and initiating captive breeding programs. These practical approaches may help fulfill the ESA requirement that recovery plans include "objective, measurable criteria which, when met, would result in a determination that the species be removed from the List."16 Here I explore the possibility of applying conservation biology theory to practice—the pragmatic question I seek to answer is how we establish listing and recovery priorities for marine mammals. To do this I examine the listing criteria for a particular species—the North Pacific humpback whale—and suggest an approach to developing quantitative, biologically based criteria that are applicable to species with similar life histories.

### A CASE STUDY EXAMINING BIOLOGICAL UNCERTAINTY IN DECIDING WHETHER A SPECIES IS ENDANGERED: NORTH PACIFIC HUMPBACK WHALES

The IUCN, or World Conservation Union, has been one of the first major public institutions to embrace some of the modern theoretical ideas from conservation biology. In particular, in an effort to increase the scientific rigor of listing decisions, the IUCN has recommended new quantitative criteria for classification of species on the Red List of Threatened and Endangered Wildlife.17 These criteria, which emphasize factors such as extent of occurrence or degree of fragmentation, are primarily oriented toward terrestrial species and are difficult to apply to wide-ranging marine species. For large whales, the IUCN criteria are not easily applied because habitat fragmentation...
is not relevant and even the seemingly simple idea of extent of occurrence is quantifiable only with great difficulty in the marine realm, particularly for highly migratory species such as humpback whales. Furthermore, the IUCN criteria for the most part do not allow for incorporation of uncertainty in available data.

We need to develop classification criteria for listing species as endangered or threatened even when data on population size and trend are poor. The key is that the criteria should be based on data that either exist or are attainable in the foreseeable future. I show how available information for humpback whales can be used under a new classification scheme and how increasing the precision of parameter estimates regarding demographic rates affects our ability to make classification decisions.

Humpback whales are one of the two large whale species for which a recovery plan exists. The Humpback Whale Recovery Plan of 1991 describes three types of recovery-related goals. The first is a biological goal of building and maintaining populations large enough to endure changes in oceanographic conditions, epizootics, anthropogenic stress, environmental catastrophes, or inbreeding depression. The second is a numerical goal to establish desirable population sizes consonant with the biological goal and with continuing human use of the oceans. Specifically, this goal aims to increase humpback whale populations to at least 60% of either the number existing before commercial exploitation began (i.e., historical carrying capacity) or the current carrying capacity of the environment. Because accurate estimates of historical or current carrying capacity are not available, an interim goal in the Recovery Plan is to double existing population size within the next 20 years. The third goal is to develop objective criteria to classify stocks of humpback whales as either endangered or threatened. Unfortunately, the seemingly precise goal of a doubled population within 20 years really has no solid scientific basis. To redress this problematic situation, I have developed with my colleague Doug DeMaster a new approach for consideration. The approach is based on the recommendations of several prominent whale, population, and conservation biologists during an "expert opinion" workshop in January 1997. Here I sketch the essential ingredients of this new approach and its motivation as a means of offering insight into the challenges we face in pursuing conservation in a world of biological uncertainty and limited data.

The key idea is that endangerment depends on two critical aspects of a population: population size and trends in population size due to intrinsic variability in population growth rates. The way to combine these features is to attempt to identify a population size and range of population growth rates above which there is a negligible probability that the population would fall below a level from which extinction is inevitable.

The method of implementing this approach will vary among species depending on the type and amount of data available. For humpback whales, the data on population size, trends, degree of subdivision, and demographic rates are plagued with uncertainty. The North Pacific population of humpback whales alternates between high-latitude summer feeding areas in waters off Alaska, British Columbia, and California and low-latitude winter breeding grounds off Hawaii, Mexico, and Japan. Population structure of humpback whales is thought to be linked to matrilineal fidelity to feeding areas and the tendency of animals to return to traditional wintering areas. Although there is a strong suspicion that the population is increasing in abundance, no data on population trends currently exist. In 1997, the population was estimated to include approximately 6,000 animals based on mark-recapture methods using individually identified fluke photographs. Basic life history parameters are also not well known for North Pacific humpbacks; in general, humpbacks are thought to become sexually mature between 4 and 9 years of age, and the sex ratio is thought to be close to parity. Annual reproductive rates have been estimated on breeding grounds at 0.58 calves per year and at 0.38 calves per year on feeding grounds. The survival rates are not well known for this population; with reported rates ranging from 0.85 to 1.00 for different feeding groups in Alaska. Four basic types of data were identified as key to developing classification criteria for whales during the January 1997 workshop: abundance, trends in abundance, changes in distribution, and regulatory status. The classification criteria described in Table 2 are intended to supplement the first four factors specified in the ESA to determine a species' status (habitat loss, overutilization, disease or predation, regulatory mechanisms) and serve as an objective criterion for evaluating the fifth factor ("other influences"). Here I briefly discuss each of the five ESA factors in the context of humpback whale endangerment.

1. Present or Threatened Destruction, Modification, or Curtailment of Habitat

Habitat modification or loss is a difficult process to quantify for marine ecosystems. Coastal development, competition with fisheries for prey species, the introduction of pollutants and pathogens from waste disposal, and disturbance or pollution from oil, gas, or other mineral exploration and production may limit available habitat for humpback whales. While the precise impacts of these factors on humpback whale habitat are not well known, there is no evidence for a population-level effect of these influences on the humpback whale population.

2. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Although overutilization was a primary reason for listing the humpback whale as endangered, the species has been protected from commercial whaling since
TABLE 2. Classification criteria for North Pacific humpback whales

**Downlist from Endangered to Threatened**

1. All designated wintering and feeding areas will maintain a population size such that, over the next 10 years, there is a high probability that abundance will remain above a specified critical level (N_q).
2. An international regime is in place and is effective in regulating human-related disturbance and mortality.

**Downlist from Threatened to Delisted**

1. All designated wintering and feeding areas will maintain a population size such that, over the next 25 years, there is a high probability that abundance will remain above the threshold level for endangered (N_\text{end}).
2. An international regime is in place and is effective in regulating human-related disturbance and mortality.

1986 when the IWC established a zero catch limit. Nonetheless, it is possible that subsistence hunting, incidental entanglement in fishing gear, collision with ships, and disturbance or displacement caused by boat or air traffic may inhibit recovery. Data suggesting mortality due to entanglement in fishing gear or due to ship strikes are not currently adequate to infer effects on population status and recovery. Much of the gillnet mortality of large whales may go unobserved because whales swim away with a portion of the net or do not strand. Current regulatory mechanisms as defined by the MMPA and IWC are intended to minimize overutilization. There is currently no information that indicates any populations of North Pacific humpback whales are being overutilized.

**3. Disease or Predation**

Natural mortality agents such as disease, predation, parasitism, red-tide toxins, and ice entrapment are the primary causes of humpback whale mortality. To date, only one incident of natural mass mortality of humpback whales has been documented. In 1987 and 1988, at least 14 humpback whales died in Cape Cod Bay due to ingestion of mackerel infected by a dinoflagellate saxitoxin. Humpback whales are known to become infested with parasites, but there is no evidence for marked population-level effects of such infestations.

**4. Inadequacy of Existing Regulatory Mechanisms**

Since 1985/1986 for pelagic seasons and 1986 for coastal seasons, the IWC has imposed a moratorium on commercial whaling of large whales and has subsequently worked to develop a new regime for managing levels of harvest by commercial whalers should the moratorium be lifted. As described above, this regime is considered effective in regulating disturbance and mortality of humpback whales.

**5. Other Natural or Human-Caused Factors Affecting Continued Existence**

While the precise influence of each of the factors described above on the continued persistence of humpback whales is unknown, the combination of these factors is ultimately reflected in the population growth rate and the population size. The proposed classification criteria, as described below, encompass these factors by incorporating the uncertainty associated with our estimates population size and trend.

The downlisting criteria summarized in Table 2 make use of two thresholds: a low threshold below which a species is at severe risk of extinction, and a high threshold above which a species has escaped serious risk. This can be formalized by defining N_q as the quasextinction threshold, or the population size for which it is too late for management to prevent extinction. Second, we define N_\text{end} as the population level above which there is a negligible chance of falling below N_q in 10 years. We can define an even higher "risk-escaping" threshold as the threshold for threatened status (N_\text{th}). This level is defined as the population level necessary to maintain a high probability of remaining above N_q for 35 years. The criteria are intended to be applicable to a variety of types and levels of data quality and to incorporate a precautionary approach. Using this classification framework, N_\text{end} and N_\text{th} are case specific and dependent on available abundance, population structure, and trend data.

An estimate of N_q for humpback whales should represent the lower limit for a population, below which a population would have a high probability of extinction. Clearly this is a difficult parameter to estimate because empirical data are limited and theoretical approaches are currently in dispute. As an initial approach, I assumed an N_q value of 500 animals (Fig. 3). This number appears to be consistent with documented Allee effects in large whale populations. That is, northern right whales were reduced to numbers less than 500 each and have shown little or no sign of recovery while many other large whale populations have increased in number over the past several decades. The sensitivity to alternate assumptions about N_q was also investigated (Fig. 3).

To implement our approach, our uncertainty about the demographic rates that determine a population's discrete annual rate of growth, λ, is used to establish frequency distributions of population fates and in turn 5% chances of extinction either in 10 and in 25 years. There are many different methods for obtaining variance profiles for population fates. Given the lack of time series of abundance estimates for humpback whales, the solutions for N_\text{end} and N_\text{th} were based on a population growth model that incorporates uncertainty in demographic data and how the environment varies through time. A life table
with uniform distributions for age-specific survival and normal distributions for fecundity rates was used. Monte Carlo simulations were conducted in which survivorship and fecundity rates were drawn randomly from these distributions of demographic rates. By performing 1000 Monte Carlo simulations for each level of environmental uncertainty and estimated sampling error, one obtains a distribution of expected annual \( \lambda \)'s. Each of these \( \lambda \)'s is a stochastic rate of population change, meaning that it incorporates our uncertainty. The total distribution of \( \lambda \)'s generated in this manner allows us to identify particular starting populations for which 95% of the values will lead to an end population that stays above the extinction thresholds (i.e., less than 5% chance of extinction).

This method thus gives us a simple way of using what we know and are uncertain about regarding humpback demography to identify critical population thresholds. The final determination was simple: the current best population estimate of 6,000 was larger than the estimated threshold for endangered; however, the best estimate of current abundance was less than the estimated threshold for threatened. Therefore, our analysis would be consistent with a recommendation to downlist humpback whales in the North Pacific to a status of threatened.

One of the useful features of this new approach is that as uncertainty regarding population growth rate increases, the threshold level for threatened and endangered also increases (Fig. 3). Therefore, with less precise information it becomes more difficult to delist or downlist a population classified as endangered. It will be interesting to see the extent to which these listing recommendations change as more elaborate simulations are explored. Whatever the outcome, at least the train of reasoning is explicit, which is a vast improvement over simply requiring that the population needs to double within 20 years in order to be delisted.

**INTEGRATING BIOLOGY AND REGULATION IN ENDANGERED SPECIES CONSERVATION**

Uncertainty is the norm in population data for most endangered and threatened species. Perhaps as a result, the vast majority of decisions regarding species to be listed as threatened or endangered have lacked substantial biological information. As such, a key component of the proposed classification criteria is the identification of data indicating that species have recovered and are unlikely to become extinct within the foreseeable future. In setting conservation priorities for marine mammals, we need to develop an approach that (1) incorporates biological uncertainty in a risk-averse manner, (2) allows for consistent, yet species-specific listing decisions, and (3) identifies critical data needed to evaluate a population's status. With this emphasis, together with recognition that the scientific inputs to management decisions must be decoupled from cultural values, it should be possible to overcome some of the subjectivity related to endangered species conservation. We cannot say whether the proposed quantitative criteria proposed for humpback whales are the "right answer." At least by being explicit in our reasoning such quantitative approaches are subject to scientific scrutiny and rejection—they fit the model of science much better than arbitrary numbers. Integral in the future of establishment of conservation priorities for marine mammals is the development of explicit approaches; we can identify mistakes and learn from such approaches.

This article started by remarking on the unique "charisma" of marine mammals and the possibility that nonbiological factors might interfere with scientific reasoning when classifying species under the ESA. More general problems also haunt the listing decisions of all species, such as the absence of recovery plans and the lack of regulatory teeth or of clear goals for existing plans. One solu-
tion is the development of explicit quantitative criteria for determining when a species should be listed, delisted, or downlisted. There will be a wide variety of such quantitative approaches, only one of which has been described in this article. However, some sort of quantitative approach is probably necessary, if only to ground the debate in numbers that can be falsified and explicit algorithms that can be improved upon. Ultimately, a great deal of natural history needs to be learned about marine mammals and all endangered species to make rational conservation decisions. Probably most biologists appreciate the need for more biological information.

Less appreciated, perhaps, is the need to put that information into a quantitative framework that explicitly identifies thresholds for downlisting. Quantification in this case represents a synthesis and integration of what we know and do not know—it is the "integrative biology" that is too often missing from recovery plans and criteria for listing species.

REFERENCES


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