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10 Science and Implementation

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The U.S. Endangered Species Act (ESA) relies heavily on science, and not surprisingly science has become a major battleground in the controversy surrounding its implementation (Doremus, this volume). Apparently, Congress hoped that ESA decisions could be made based on science alone and thereby insulated from politics (U.S. Congress 1982, 19). This hope was unrealistic for at least two reasons. First, science cannot answer with certainty many of the questions that must be answered in ESA decision making, especially in the time frames demanded by the statute. Second, while science has a central role in informing natural resource decisions, scientific information alone cannot "make decisions." Criticizing the science seems to be one outcome of hard policy choices (Mapes 2001; Boyle 2002; Dalton 2002; *Seattle Times* 2002; Stokstad 2002; Strassel 2002; Pianin 2003; *Sacramento Bee* 2003a and 2003b; Cart and Weiss 2004).

The ESA requires agency reliance on science in several areas: The secretaries of commerce and the interior must designate critical habitat based on the best available scientific data (ESA sec. 4(b)(2)); federal agencies must rely on the best available scientific and commercial data but ensure that their actions will not jeopardize the continued existence of listed species or adversely modify their critical habitat (ESA sec. 7(a)(2)); and recovery plans must adopt objective criteria for delisting (ESA sec. 4(f)(1)(B)(ii)). In requiring that decisions affecting endangered species be made primarily on the basis of science, Congress sought to insulate agencies from political pressure. Instead, perversely, intense political pressure has forced underground the agency policy choices inherent in science-based decisions (Doremus 1997).

Some scholars have argued that "better science" will not reduce the controversy surrounding the act. Instead, they call for more openness about the policy choices embedded in ESA decisions (Doremus 1997; Myer 2001; Yaffee 2006). The authors wholeheartedly agree, but we also believe that better scientific information and processes of eliciting and translating science can improve decision making under the act.

The ESA has been the subject of intense debate in the scientific literature in terms of its effectiveness in protecting species (Schwartz 1999; Boersma et al. 2001; Crouse et al. 2002; Scott et al. 2006, chap. 2). Federal agency use of scientific information in implementing the act was evaluated by the National Research Council (1995). In this chapter, we focus on the role of science in the act and how the agencies use science in practice. We address the following questions for each stage of the ESA process from listing through recovery planning: (1) What is the role of science, and what has agency practice revealed to be the difficulties of incorporating science? (2) How have the public and courts responded? (3) How could either the science or the process of providing science be improved? We also consider whether decision makers are prepared to make and explain decisions based on incomplete science. We close with suggestions for how scientists can better serve decision making under the act.

The Science Underlying Listing Determinations

Two biological questions are central to the listing process: What is the species (or biological unit) to be listed? And what is the species' likely risk of extinction? The U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) have developed interagency guidance on how to manage listing petitions (USFWS and NMFS 1996d, 1999d) but that guidance does not offer biological criteria to address the issues below.

What is a Listable Unit?

The Endangered Species Act protects "subspecies and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature" (sec. 3(15)). Four difficult science issues have emerged in practice: Do all subspecies have equivalent "significance" taxonomically? What is a distinct population segment (Waples, this volume)? How does hybridization between taxa affect species identification (Haig and Allendorf, this volume)? How should artificially propagated individuals be considered?

SPECIES AND SUBSPECIES

The accuracy and degree of revisions of taxonomic classifications at the subspecies level vary greatly among species. The U.S. Fish and Wildlife Service has frequently encountered situations in which it was uncertain whether a group of individuals should be classified as a distinct population segment, a subspecies, or even a separate species (e.g., interior least tern [USFWS 1985], lower Keys rice rat [USFWS 1991a], Mississippi gopher frog [*Rana capito sevosa*], California red-legged frog [*Rana aurora draytonii*] [USFWS 1996a], and California tiger salamander [*Ambystoma californiense*] [USFWS 2003c]). The listing determinations for the coastal California gnatcatcher (*Polioptila californica californica*) (USFWS 1993), dusky seaside sparrow (*Ammodramus maritimus nigrescens*) (Avise and Nelson 1989), and Florida panther (*Puma concolor coryi*) (Culver et al. 2000) aroused enormous controversy over the issue of whether the groups were significantly divergent from more common sister taxa to be considered subspecies and therefore listable units. The social and political fallout from these listing decisions continues today (e.g., Carlson 2003; *Miami Herald* 2003; Pfeifer 2003; Wilson 2003a). In some respects the controversy is misplaced because even if not considered subspecies, many of these population groups can be listed as distinct population segments (Stanford Environmental Law Society 2001). In other cases, new information about the lack of reproductive isolation may lead USFWS and NMFS biologists to conclude that a group of populations is neither a subspecies (contrary to a published classification) nor a distinct population segment, as in the case of the western sage grouse (USFWS 2004a).

DISTINCT POPULATION SEGMENT

The U.S. Fish and Wildlife Service and National Marine Fisheries Service have a joint distinct population segment (DPS) policy (USFWS and NMFS 1996e) that provides two tests of distinctness: (1) Is the population or group of populations markedly separate from other populations of the same species? (2) Is it significant? NMFS adopted a policy for designating distinct population segments of Pacific salmon and steelhead (NMFS 1991; Waples 1991, 1995), which relies on identification of *evolutionarily significant units* (ESUs) before the joint DPS policy was implemented (Waples, this volume). In delineating a DPS, agencies must establish the significance of intraspecific variation in life history, genetic, or morphological traits. It is important to determine the relationship of life history variants (e.g., races) to one another in order to decide into how many pieces a species could or should be divided for listing determinations (Waples, this volume).

The coastal California gnatcatcher illustrates the difficulty in determining the significance of within-species variation. The birds were originally identified as a subspecies based on bill size and shape, tail length, and overall coloration—all characteristics used by ornithologists to establish taxonomic classifications (USFWS 1993). These characteristics evolved since the last ice age, when the birds expanded northward from a refuge in Mexico—evolutionarily a very short time frame. Skeptical of the listing, private-sector interests sponsored research suggesting morphological variations may not be genetically based. In response, the USFWS proposed listing the coastal California gnatcatcher as a distinct population segment (USFWS 2003a). As a practical matter, in spite of a rash of new scientific information gathering and analyses, the listing of the gnatcatcher as a DPS rather than a subspecies has had little, if any, effect on the degree of protection it is afforded under the Endangered Species Act.

How important is intraspecific variation to long-term persistence of the subspecies or species? Should relatively recently evolved forms be protected? Some observers (and plaintiffs) argue that the act is meant to protect morphologically unique forms as "distinct" population segments (Doremus 1997). Others suggest that the relevant inquiry should be whether, if lost, the variation could evolve again in a time span meaningful to humans (such as a few generations) (Ruckelshaus et al. 2002b; Waples et al. 2004).

Once a distinct population segment is delineated, scientists must assess the importance of different morphological or life history forms to the continued existence of the DPS (or species or subspecies) as a whole.

HYBRIDS

Hybridization between closely related taxa can create listing challenges, especially when one of the hybridizing species is common and the other rare (Haig and Allendorf, this volume). For example, the red wolf (*Canis lupus rufus*), which is listed as endangered under the ESA, may interbreed with the unlisted eastern gray wolf (*Canis lupus lycaon*) (Wayne and Jenks 1991; Dowling et al. 1992; Nowak 1992; Brownlow 1996). An equally vexing example is the westslope cutthroat trout (*Oncorhynchus clarki lewisi*), which hybridizes with introduced rainbow trout (*O. mykiss*) in the western United States (Allendorf and Leary 1988; Behnke 1992; Rubidge et al. 2001; Rubidge 2003; Taylor et al. 2003). In that case, after legal challenge and extensive discussion, the U.S. Fish and Wildlife Service decided not to list the trout despite a proposed policy on considering hybrids (or intercrosses) under the act (USFWS and NMFS 1996f; USFWS 2003f).

ARTIFICIAL PROPAGATION

Both the U.S. Fish and Wildlife Service and the National Marine Fisheries Service have had to consider artificially propagated individuals occurring in natural habitats (e.g., fish produced in a hatchery, captively bred birds). Until recently, both agencies judged the danger of extinction and the state of recovery based on naturally reproducing populations. NMFS has proposed a policy that considers the risk of extinction of species based on the combined artificially propagated and naturally produced components of populations (NMFS 2004a, 2005a). The proposal raises interesting policy and science questions. The policy side must address the acceptable degree of risk, both with respect to biological issues (such as likelihood of persistence) and management issues (such as the likelihood of continued funding for artificial propagation programs). On the science side, biologists must incorporate artificial propagation into extinction risk models despite poor data on breeding patterns, reproductive success, and movement of hatchery and wild fish. At the interface between science and policy, there is the question of the importance of a species' "evolutionary trajectory." Is a distinct population segment in danger of diverging from a natural evolutionary trajectory because of artificial selection also "in danger of extinction? Presumably it could be if the artificial selection makes it likely the distinct population segment will no longer be significant to the taxon (or evolutionarily significant, in the case of an evolutionarily significant unit; Myers et al. 2004).

PUBLIC AND COURT REACTION

Courts are generally unwilling to second-guess agency biologists when it comes to taxonomic classification or evaluation of extinction risk. The General Accounting Office reviewed sixty-four listing decisions by the U.S. Fish and Wildlife Service between 1999 and 2002 and found that peer reviewers "overwhelmingly supported" the science behind the decisions. Courts overturned only two listing decisions because of improper use of scientific data (GAO 2003). However, courts will intervene when judges believe the National Marine Fisheries Service or U.S. Fish and Wildlife Service have failed to follow the statute, regulations, or policies, or when the judge believes the agencies have failed to adequately explain the connection between the data and the conclusion. For example, a district court invalidated NMFS's decision to list naturally spawned but not hatchery-spawned Oregon coast coho salmon, even though the agency found them to comprise a single evolutionarily significant unit (*Alsea Valley Alliance v. Evans* 2001). A court of appeals threw out the USFWS's decision to list a population of the cactus ferruginous pygmy-owl (*Glaucidium brasilianum cactorum*) because the agency failed to explain how the population was "significant" and therefore a distinct population segment under the joint DPS policy (*National Association of Home Builders v. Norton* 2003). And a district court concluded that NMFS did not use the best available science when it relied on an outdated taxonomic classification for the killer whale (*Orcinus orca*) (*Center for Biological Diversity v. Lohn 2003*).

ADVANCING THE ROLE OF SCIENCE

The NRC review of use of science in the Endangered Species Act was supportive of the "evolutionary unit" concept (National Research Council 1995). Much of the ongoing scientific debate over DPS/ESU identification involves technical points, such as how best to describe evolutionarily significant variation for protection (summarized in Ruckelshaus et al. 2002b; Waples, this volume). Some observers feel the U.S. Fish and Wildlife Service and National Marine Fisheries Service have defined distinct population segments too narrowly (Doremus 1997), arguing that the Endangered Species Act was intended to protect populations that have aesthetic value, are keystone species within their ecosystems, or are in some other sense unique. The concern is that the rigid "scientific" approach embodied in ESU and DPS policies ignores other equally valid values that Congress intended to protect. The policies in most cases provide workable guidance in determining whether a species exists for purposes of the act.

Extinction Risk

Once the listable unit (i.e., species, subspecies, or distinct population segment) is identified, its risk of extinction must be estimated under section 4(a) of the Endangered Species Act (table 10.1). The act defines an "endangered species" to be "in danger of extinction throughout all or a signficant portion of its range" (sec. 3(6)) and a "threatened species" to be "likely to become an endangered species within the foreseeable future" (sec. 3(19)).

THE ROLE OF SCIENCE IN AGENCY PRACTICE

Risk evaluations are necessarily a combination of scientific analyses and policy judgments about the degree of "acceptable" risk and the time frames over which risk should be evaluated (Burgman 2005). Decision makers must then interject a judgment about whether a species' risk of extinction triggers the statutory definitions of "endangered" or "threatened."

Qualitative approaches to estimating species risk, if transparent and systematic, can be as reliable as quantitative approaches (e.g., Keith et al. 2004; McCarthy et al. 2004). Neither the U.S. Fish and Wildlife Service nor the National Marine Fisheries Service regularly use widely accepted qualitative approaches to estimating extinction risk (IUCN 1994; NatureServe 2003). NMFS implemented its own risk evaluation matrix to assess the status of over fifty ESUs of Pacific salmonids (Wainwright and Kope 1999). This matrix accounted for diversity and spatial distribution in addition to conventional population status analysis (e.g., Allendorf et al. 1997; Shelden et al. 2001).

Quantitative extinction risk models (known collectively as *population viability analyses*, or PVAs) require information on population size, population growth rate, and variability in population growth rate over time (Dennis et al. 1991; Boyce 1992; Morris et al. 1999). The critical first step of identifying demographically independent populations is almost never done in PVAs despite evidence that ignoring population structure can cause grave errors in estimates of extinction risk (Morris et al. 1999). In a recent counterexample, NMFS identified independent populations before conducting viability modeling for Pacific salmonids (McElhany et al. 2000; Ruckelshaus et al. 2002a).

The data needed to parameterize even the simplest PVA models are almost always incomplete (Reed et al., this volume). Additional uncertainties arise with

Table 10.1 Key science-related provisions within the Endangered Species Act

ESA provision	*Science-related question addressed by provision*	*Further work needed on analyses pertaining to provision*	*Further work needed on application of provision*
4(a) Listing	Is there a "species"?	Improved definition of the "distinct population segment/evolutionarily significant unit" concept	Agency guidance on how to address hybridization, definition of taxonomic "significance," and artificially propagated individuals
4(a) Listing	What is the species' risk of extinction?	Improved definition of time scales, attention to multiple indicators of risk, methods of estimating rates of reproduction of at-risk species	Agency guidance on consideration of extinction risk and "significant portion" of range
4(b) Critical habitat designation	What habitat features are essential to species' conservation and how much habitat is needed for conservation?	Relationship between habitat quality/ quantity and species extinction risk	Agency guidance on designating critical habitat, how to weigh benefits/costs; consider sequence of application
7(a)(2) Federal consultation 10(a)(1)(B) Habitat conservation plans	What effect will a particular action have on species' survival or recovery? Does an action result in take, and if so, how much?*	Relative importance of different limiting factors in extinction risk; how effects of individual actions relate to whole population/species impacts	More-open science process in section 7 consultations; guidance on considering piecemeal vs. whole life-cycle approach
4(f) Recovery planning	What are the characteristics of a recovered species? What factors are limiting recovery? What habitat is essential to recovery?	All of the above	More public participation in policy oversight of the planning process

* This question also arises in section 9 enforcement actions, which are not addressed in this chapter.

model structure—for example, how to depict population responses at small sizes, the effects of density-dependent population regulation, and choice of a quasi-extinction threshold (Morris et al. 1999). For these reasons it is important to explore the sensitivity of PVA results to alternative assumptions (e.g., Dennis et al. 1991; Holmes 2001; Holmes and Fagan 2002), as NMFS has done for estimating the status of Pacific salmon and Steller sea-lions (*Eumetopias jubatus*) in listing and recovery decisions (Gerber and VanBlaricom 2001; NMFS 2003a; Puget Sound Technical Recovery Team 2002; Willamette–Lower Columbia Technical Recovery Team 2003).

Applications of PVA generally assume that past trends and variability in input parameters can be used to project future population dynamics. This is almost certainly an incorrect assumption given climate change, changes in human management of the landscape, introduction and spread of nonindigenous species, and changing rates and intensity of human-influenced catastrophes (e.g., fire, toxic, or oil spills). A promising approach is to use scenario planning whereby scientists ask whether an estimated risk of extinction (or any population outcome) changes under alternative views of future conditions (see "The Science Underlying Recovery Planning" in this chapter; Clark et al. 2001; Carpenter 2002; Peterson et al. 2003).

An emerging issue for the U.S. Fish and Wildlife Service and National Marine Fisheries Service is interpretation of the statutory definition of an endangered species as one that is in danger of extinction "throughout all *or a significant portion* of its range" (emphasis added). Recent practice has been to rely on the identification of a distinct population segment. Dissatisfied with some determinations not to list, plaintiffs have begun to challenge the agencies for failure to separately examine whether a species, subspecies, or DPS is in danger of extinction in at least a portion of its range (*Defenders of Wildlife v. Norton* 2001, 2002; *Environmental Protection Information Center [EPIC] v. National Marine Fisheries Service [NMFS]* 2004.) While the two agencies have not yet explicitly interpreted this statutory phrase, recent USFWS decisions have applied a biological test, similar to the significance test of the DPS policy, examining whether a population group is biologically significant even though it is not discrete (e.g., USFWS 1998, 2000). It is unclear whether the two agencies believe that a species in danger of extinction in only a portion of its range must be listed throughout its entire range (see *Marbled Murrelet v. Lujan* 1992).

PUBLIC AND COURT REACTION

Doremus (1997) suggested that the public reacts negatively to unbridled agency discretion in identifying species and determining risk of extinction. However, it seems this reaction is less about whether the U.S. Fish and Wildlife Service and National Marine Fisheries Service have misapplied science than it is an objection to protecting such creatures as rats and bugs, often against private interests. Courts tend to defer to agency listing determinations (GAO 2003), except when they conclude that the agencies failed to follow the statute or agency regulations. Although public comment on listing proposals often contests the agencies' analysis of extinction risk, the authors are unaware of any successful court challenges in that area.

ADVANCING THE ROLE OF SCIENCE

The U.S. Fish and Wildlife Service and National Marine Fisheries Service recently outlined criteria by which they will evaluate the effects of federal, state, and local conservation efforts when making listing decisions (USFWS and NMFS 2003b). These so-called "conservation measures" have been or soon will be implemented, although it is still too soon to evaluate their effects on extinction risk. The question is a scientific one that can be exceedingly challenging to address (see discussion in "The Science Underlying Recovery Planning" below).

The two agencies would be well served by adopting recommendations acknowledging that making listing determinations is not just a science exercise but has three important policy components: (1) the time period over which persistence should be measured, (2) the level of risk that results in a threatened or endangered finding, and (3) the burden of proof for demonstrating the effects of conservation measures. Such recommendations must be flexible enough to account for the inaccuracy of extinction risk estimates and for biological differences among species. For example, the time period over which extinction is considered may depend upon the inherent variability in demographic characteristics of a species or the ability of scientists to forecast long-term trends. Recommendations would need to leave room for decision makers and scientists to work together to understand the biological implications of alternative risk levels (e.g., modelers can illuminate for decision makers what a 0.99, 0.95, or 0.80 probability of extinction looks like) (Doremus, this volume).

Research is needed on how best to make population or species demographic parameter estimates from spotty census information (Reed et al., this volume). Abundance information for many species of conservation concern consists of presence/absence data, index counts, or censuses during a specific life stage that are easy to count, such as breeding aggregations. Making a determination about the viability status of a species requires that these sample data be translated into whole population or species counts. What are the best methods for making that translation? What are the advantages and pitfalls associated with different approaches to estimating species numbers from population subsamples?

Finally, accounting for environmental factors and species interactions that accelerate or mitigate downward population trends could significantly improve quantitative models of extinction risk (see also "The Science Underlying Recovery Planning" below; National Research Council 1995).

The Science Underlying Critical Habitat Designations

Within one year of listing, the U.S. Fish and Wildlife Service and National Marine Fisheries Service must designate critical habitat to the maximum extent prudent and determinable (table 10.1). The Endangered Species Act defines critical habitat as "the specific areas within the geographical area occupied by the species . . . on which are found those physical or biological features . . . essential to the conservation of the species," and "specific areas outside the geographical area occupied by the species . . . upon a determination by the Secretary that such areas are essential for the conservation of the species" (USFWS and NMFS 1999e, 31872). From this construction, the statute seems to contemplate an approach to critical habitat designation that favors occupied areas: the agencies first identify habitat elements essential to species conservation (for example, a particular type of tree for nesting, vegetation for forage or cover, gravel streambeds for spawning, etc.) and then designate areas within the species' present range where those elements are present. Only for areas outside the species' present range must there be a determination that the area itself is "essential for conservation." In practice, the agencies, plaintiffs, and some courts have blurred the two standards and require that all areas, occupied or unoccupied, meet the test for unoccupied habitat: the area itself must be essential for conservation. For example, in a case involving the Rio Grande silvery minnow (*Hybognathus amarus*), the court stated that critical habitat "must be limited geographically to what is essential to the conservation of the threatened or endangered species" (*Middle Rio Grande Conservancy District v. Babbitt* 2000). And in a case involving the Alameda whipsnake (*Masticophis lateralis euryxanthus*) the court observed that "critical habitat for occupied land is defined in part . . . as specific areas 'essential to the conservation of the species'" (*Home Builders Association of Northern California v. U.S. Fish and Wildlife Service* 2003).

The USFWS and NMFS have long maintained that critical habitat designation adds little to species protection (Clark 1999). Section 7 of the ESA requires federal agencies to ensure that their actions do not jeopardize species' continued existence and do not destroy or adversely modify their critical habitat. The two agencies have usually treated an action that adversely modifies critical habitat as also jeopardizing the species' continued existence, making the prohibition against adverse modification redundant. Agency regulations defining both jeopardy and adverse modification in similar terms (actions affecting "both the survival and recovery" of the species) have reinforced this approach. Critics point out that critical habitat designation is especially important for species protection in unoccupied habitat, where the USFWS and NMFS may be less likely to reach a jeopardy finding (Taylor et al. 2003, 2005). Two separate reviews examined effects of critical habitat designations on reported trends in species abundance and content of recovery plans, and the results were mixed (Clark et al. 2002; Hoekstra et al. 2002b; Taylor et al. 2003, 2005). Recent court decisions have invalidated the agencies' regulatory definition of adverse modification as not being sufficiently tied to conservation (*Gifford Pinchot Task Force v. U.S. Fish and Wildlife Service* 2004; *Sierra Club v. U.S. Fish and Wildlife Service* 2001). As future section 7 practice adjusts to the new legal rulings, the two tests may prove not to be redundant and the designation of critical habitat may indeed provide increased protection for listed species. The authors believe the current landscape is too unsettled to draw a reliable conclusion from past practice.

Critical habitat designations, where they have been made, have lacked meaningful analysis of the economic impact (see *New Mexico Cattle Growers Association v. U.S. Fish and Wildlife Service* 2001). Successful court challenges to designations (or lack of designations) have led to multiple requirements for the USFWS to designate habitat in very short time frames. Moreover, courts have ordered the agencies to consider economic impacts of designation, even if they are "coextensive" with the impacts of applying the section 7 jeopardy requirement (*New Mexico Cattle Growers Association v. U.S. Fish and Wildlife Service* 2001). This requirement is contrary to the best available science regarding economic analysis, which would require an estimate of the costs of designation based on a comparison of the world with and without the designation (Office of Management and Budget 2003).

In response, the U.S. Fish and Wildlife Service has vigorously objected to the requirement (e.g., testimony of Assistant Secretary of the Interior Craig Manson, [Manson 2003]). Past congressional efforts have failed to amend the ESA to change the timing of critical habitat designation to coincide with recovery planning instead of listing, but it remains a topic of congressional interest.

The Role of Science in Agency Practice

Section 4(b)(2) of the Endangered Species Act requires critical habitat designation to be based on the best scientific data available, although the U.S. Fish and Wildlife Service and National Marine Fisheries Service may exclude areas from designation if economic or other relevant impacts outweigh the benefits of designation. However, often agencies know little about species' habitat needs at the time of listing and thus identification of critical habitat is highly uncertain.

The agencies' joint designation of critical habitat for the Gulf sturgeon (*Acipenser oxyrinchus desotoi*) illustrates this. The two agencies examined the population structure and concluded that the seven extant populations were largely reproductively isolated. They reasoned that the populations at the extremes of the range are important for conserving genetic diversity and that the intermediate populations are important for connectivity, and concluded that all habitat currently occupied by the seven populations is essential for conservation (USFWS 2003i). Like the judgments made in analyzing extinction risk, these were clearly not made in a policy vacuum. The question of how many populations are needed for conservation and how much habitat each needs for conservation are not just scientific questions. The answers depend upon tolerance to risk and time scales over which the risk is considered.

One of the more contentious debates surrounding critical habitat designation concerns the consideration of economic costs of designation by the U.S. Fish and Wildlife Service and National Marine Fisheries Service and their discretion under section 4(b)(2) of the ESA to exclude areas from designation if the benefit of exclusion outweighs the benefit of designation. The two agencies have only recently begun to apply economic analysis in their designations, and their use of the science of economics is not well developed. Their past practice of collapsing the jeopardy and adverse modification requirements into a single test has complicated the economic analysis. Furthermore, at the time of listing, information is lacking on land use patterns and how economic activities would be modified as a result of section 7 consultations.

Public and Court Reaction

Provisions in the Endangered Species Act for critical habitat designations have proven a major flash point for both advocates and critics of species protection (e.g., *Sacramento Bee* 2003b; Wilson 2003b; Cart and Weiss 2004). For advocates, the provisions give them their strongest tool for protecting habitat. For critics, the provisions are among the few places in the statute where economics comes into play, making them a rallying point for the development-regulated community. Further, many landowners assume that when private land is designated as critical habitat the federal government is in effect "taking" their property and will restrict its use. And, finally, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, arguing that critical habitat designation adds nothing to species protection, have resisted designating habitat altogether or have simply designated habitat without sufficient analysis (Patlis 2001). It is not surprising, therefore, that the agencies often fail to make critical habitat designations and when they do, the designations frequently end up in court (GAO 2003).

The courts have responded to such treatment with impatience, chastising agency reluctance to designate critical habitat and ordering that designations be completed expeditiously. Further complicating the situation are court decisions finding the agencies' regulatory definition of adverse modification invalid. The lack of guidance by the two agencies and a growing number of court opinions make the situation still more uncertain.

Advancing the Role of Science

There are promising biological approaches that could be used to at least partially address the question of how much occupied and unoccupied habitat is needed for species persistence (Hanski 1999), but the data requirements are daunting. For instance, population matrix models can be used to address the question of how changes in survival at particular life stages affect overall population dynamics or persistence (Caswell 2001). One example of such an application with a listed species is the endangered Kemp's ridley sea turtle (*Lepidochelys kempii*), in which matrix models suggest that the survival of subadults and adults in the ocean was most critical to overall population status (Heppell et al. 1996; Heppell and Crowder 1998). Another approach is to predict how changes in habitat will impact species status based on empirical habitat suitability models (e.g., Jenkins et al. 2003). Unfortunately, we have limited ability to directly address the question of critical habitat—what habitat conditions or amounts significantly affect life-stage-specific survivals?

The science of economics also could contribute to improving the designation process. Section 4(b)(2) of the Endangered Species Act requires the U.S. Fish and Wildlife Service and National Marine Fisheries Service to consider the impacts of designation and balance the benefits of exclusion against the benefits of designation. Federal guidelines recommend putting the two types of benefits into the same metric in a cost-benefit framework (Office of Management and Budget 2003). Although information may be readily available that allows economic impacts to be quantified and monetized, quantifying the benefits to species from critical habitat designation is more difficult.

Thus, best economics practice would have the agencies measure the incremental impact and benefit of designation; the courts, however, have ruled otherwise (*New Mexico Cattle Growers Association v. U.S. Fish and Wildlife Service* 2001). How should the agencies proceed in this situation? Best economic practice would have them conduct a formal cost-benefit analysis, yet the short statutory time frames, limited information and resources, and considerable latitude for discretion suggest formal cost-benefit analysis may be neither possible nor necessary. One observer has suggested that approaches other than cost-benefit analysis, such as a cost-effectiveness framework, may be more appropriate (Sinden 2004). This recommendation is consistent with Office of Budget and Management guidance in cases where benefits are difficult to monetize (such as benefits to health or the environment).

The National Research Council recommended identification of habitat critical to survival at time of listing and designating the rest of critical habitat at the time of recovery planning (National Research Council 1995). These changes would require legislative reform of the act, but tying critical habitat designation to recovery planning has many proponents. The Department of the Interior has gone on record supporting such a connection (Manson 2004). The General Accounting Office recommends that the USFWS and NMFS adopt guidance on critical habitat designation (GAO 2003).

Until the agencies amend the regulatory definition of adverse modification, it will be unclear what standard they are applying in their section 7 consultations and whether they continue to view the prohibitions against jeopardy and adverse modification of critical habitat as providing redundant protection. Guidance on the economic analysis called for in the act would also help the USFWS and NMFS expedite designations. In particular, criteria for determining whether consideration of economic or other relevant impacts outweigh the benefits of designation would be helpful.

The Science Underlying Limitations on Federal Actions

When a federal agency intends an action that may affect a listed species, it must consult with the listing agency (table 10.1). For actions that adversely affect the species, the agency provides its biological opinion as to whether the action as proposed is likely to jeopardize the continued existence of a listed species or adversely modify its critical habitat. If the agency's opinion is that the action is likely to cause jeopardy or adverse modification, it must offer a reasonable and prudent alternative. The statute requires that all agencies "shall use the best scientific and commercial data available" in fulfilling the consultation requirement.

Analysis of jeopardy and adverse modification is one of the most common tasks required of the U.S. Fish and Wildlife Service and National Marine Fisheries Service yet one in which the standards are most obscure (Rohlf 1989, 2001). The statute does not define jeopardy or adverse modification. The two agencies have adopted regulatory definitions of these terms (USFWS and NMFS 1999e), but their consultation handbook lays out an analytical approach that does not track the regulatory definitions. The regulations define "jeopardize the continued existence of" to mean "to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species" (USFWS and NMFS 1999e, 31872). Adverse modification is defined as an alteration that "appreciably diminishes the value of critical habitat for both the survival and recovery of a listed species." By these definitions the agencies need to compare the likelihood of a species survival and recovery with and without the proposed action to establish jeopardy, and to compare the value of critical habitat with and without the proposed action to establish adverse modification.

In practice, however, the agencies seldom take that approach, and their consultation handbook lays out a different chain of logic. The handbook directs the agencies to consider the status of the species, the environmental baseline, the effects of the action, and cumulative effects to determine whether the species is likely to survive and recover (USFWS and NMFS 1999e). It does not say what the agencies should do after summing up those factors. If the species is not expected to survive and recover, how much must the action under consultation contribute to that failure before it is considered jeopardy? Or, less likely, if the species is expected to survive and recover, does it matter how much modification occurs to the species' remaining habitat? Analysis of adverse modification of critical habitat is further complicated by two circuit courts invalidating the regulatory definition, as discussed previously.

In addition to offering opinions on jeopardy and adverse modification, the USFWS and NMFS must issue an incidental take statement authorizing a given level of take associated with the proposed action. Where the action involves habitat modification (for example, a grazing allotment), the agencies must determine what level of take will be associated with the habitat modification. Although such a determination must be made based on scientific analyses, it is very difficult for scientists to quantify a species' response to habitat alterations, especially smaller-scale changes in habitat.

This is an area in particular where science is inadequate to answer the questions asked. Agencies often lack information to predict the effect an action is likely to have on a listed species. Furthermore, risks are generally cumulative and assessing the effect of each individual action on species status is exceedingly difficult. Finally, threats come from many different actions in different sectors, forcing the agencies to make a choice about how much of the conservation burden should fall on a given sector (box 10.1).

The Role of Science in Agency Practice

The variety of agency action considered in section 7 consultations is extremely diverse, as are the species affected. We offer a few examples in box 10.1 to draw lessons from agency practice.

BOX 10.1 Examples demonstrating the role of science in implementing section 7 limitations on federal actions under the Endangered Species Act

Example 1: Addressing Scientific Uncertainty

The manner in which inevitable scientific uncertainty is incorporated into section 7 consultations is key to using science to inform sound decisions. In the high-profile case of Bureau of Reclamation operations on the Klamath River Basin water management project, the National Research Council was brought in to help resolve what many characterized as a scientific dispute (Cooperman and Markle 2003). The NRC's final report (National Research Council 2004a) highlights several recommendations aimed at reducing the uncertainty in the biological conclusions by the the two agencies that the Bureau's proposed actions will not jeopardize the listed species. Recommendations include the following: (1) the U.S. Fish and Wildlife Service and the National Marine Fisheries Service are urged to complete recovery plans for the two species that should identify how research and monitoring will support species recovery and facilitate identification of what actions are allowed under section 7 and 10 consultations, (2) scientists should be allowed sufficient time to publish key research findings in peer-reviewed scientific journals, (3) a diverse team of "cooperators" should be convened for designing ecosystem-based management actions that have local support for implementation, and (4) experiments should be conducted to test the effectiveness and feasibility of specific remediation strategies (National Research Council 2002b, 2004a).

In another example, NMFS was thwarted in an attempt to deal with uncertainties associated with future allocation of necessary conservation actions among sectors in the Columbia River Basin, home to twelve species of endangered salmon and steelhead whose migrations are affected by operation of the power system. In 2000, NMFS issued a biological opinion on operation of the Federal Columbia River Power System (NMFS 2000a). To explain how it allocated the conservation burden, NMFS and the other federal agencies involved presented a conceptual recovery plan (NMFS 2000b) describing the necessary assumptions about continued harvest restrictions into the future if the sum of impacts on listed fish was to avoid jeopardy. This opinion was invalidated by a district court finding that the agency improperly relied on assumed future actions that were not "reasonably certain to occur" (National Wildlife Federation v. NMFS 2003), leaving in question the ability of the agencies to consider the "big picture" when section 7 biological opinions have implications for allocation of take.

Example 2: Considering Actions in Isolation

For many species it is the cumulative effect of many actions that have led to their imperilment and it is difficult for the Services in a section 7 consultation to make the case that a single small action, when added to the many other small actions, jeopardizes the species' continued existence. In the case of water withdrawals from the Columbia River, NMFS did issue a jeopardy opinion to the Corps of Engineers on the basis that Columbia River flows were already below species' needs in many years, the cumulative impact of withdrawals contributed to those low flows, and there was no mechanism in place to limit future withdrawals. Even though the withdrawal under consideration was very small compared to overall flows in the Columbia, NMFS concluded the proposed action would jeopardize Columbia River salmon and steelhead because of the cumulative effect of past and future withdrawals (NMFS 1998). This decision stirred considerable controversy in the Basin, leading Washington's Department of Ecology to appeal to the NRC, asking the NRC to review the science supporting flow levels in the Columbia. Although the question put to the panel was framed in terms of the incremental risk posed by a very small incremental degradation in flows, the panel resisted being drawn into answering the narrow question. In its preliminary findings, the panel appears to support the analysis that because flows currently are inadequate, even small increases in water withdrawals will increase risk (National Research Council 2004c).

Advancing the Role of Science

The agencies need to provide clear guidance regarding general standards for jeopardy and adverse modification. The U.S. Fish and Wildlife Service and National Marine Fisheries Service could also provide clearer guidance on individual species, for example on identifying critically low population levels, viable population levels, and allowable levels of take. Standards should allow for scientific information to be taken into account along with the policy considerations.

As with all sections of the act, a life-cycle framework for estimating the potential effects of an action on species status would appear to be the best way to adequately address the question posed in section 7. Whether that life-cycle framework is quantitative or qualitative is less important than adopting a life-cycle perspective. In general, because of the inherent scientific uncertainty in estimating the biological consequences of numerous, small-scale actions, section 7 consultations should be treated as experiments that are monitored and adjusted as needed over time (see box 10.1).

The Science Underlying Limitations on Private Actions

The Endangered Species Act prohibits any person from taking a member of a listed species (sec. (a)(1)(B); box 10.1). Take is defined broadly to include harm, and harm can include destruction of habitat to the extent it actually injures or kills individual animals. Science comes into play when a party seeks an exception to the take prohibition under section 10 (habitat conservation plans, or HCPs) or section 4(d). Regardless of the legal avenue, the standard is similar—the proposed take cannot result in jeopardy to the species' continued existence or the destruction or adverse modification of its habitat.

The Role of Science in Agency Practice

The U.S. Fish and Wildlife Service and National Marine Fisheries Service face the same challenges in permitting take that they face in consultations with federal agencies. However, consultations between federal agencies are relatively fluid and can be reinitiated when circumstances change or new information becomes available. Private parties, on the other hand, often seek a long-term commitment from the two agencies. In an effort to encourage more landowners to protect endangered species, the USFWS and NMFS adopted a series of policies offering assurances that agreements with the federal government would be lasting, for example through the "No Surprises" rule (USFWS and NMFS 1998) and safe harbor agreements (USFWS 1999f, 1999g, 2001, 2003h; Bean et al. 2001).

Advancing the Role of Science

The opportunities for improving the use of science under sections 10 or 4(d) are similar to those under section 7—that is, if the U.S. Fish and Wildlife Service and National Marine Fisheries Service encourage transparent evaluation of the cumulative effects of actions, in light of the overall effect of other actions throughout a species' life cycle, better decisions under these sections of the act should result.

Under sections 7 and 10 (and also under section 4(f), recovery planning, discussed below) three key ecological relationships must be established: (1) landscape-level processes that drive environmental factors imperiling a species, (2) relationships between critical environmental factors and species status, and (3) effects of actions that can directly or indirectly affect species status. To establish these relationships with certainty will require years of scientific study. Meanwhile, identifying data or information critical to such estimates will improve current decision making (e.g., Burgman 2005). Scientifically designed monitoring and adaptive management of habitat conservation plans is also desirable but currently absent from most (Kareiva et al. 1998).

The Science Underlying Recovery Planning

The Endangered Species Act requires the U.S. Fish and Wildlife Service and National Marine Fisheries Service to adopt recovery plans for listed species (table 10.1) but does not specify a time frame within which plans must be completed. A recovery plan is expected to describe the biological conditions necessary for recovery of the species, or the state under which the species can be delisted. Recovery plans do not have any regulatory effect, but they can be used to coordinate and guide the agencies' decision making in section 7 and 10 consultations or in issuing take permits across a species' range. The act has minimal requirements for recovery plans: they must specify objective, measurable criteria for delisting, specific actions that will achieve those objectives, and an estimate of the time and cost involved in completing the actions.

The Role of Science in Agency Practice

Science has a clear role in determining the objective, measurable criteria that will lead to delisting. It should also be used to identify factors limiting recovery and determine the biological consequences of site-specific management actions aimed at recovering the species.

The National Marine Fisheries Service provides a general recovery planning document that outlines principles for plan development and content (NMFS 1992). Subsequently, NMFS wrote a document providing additional guidance on specific technical issues concerning recovery planning for the twenty-six listed ESUs of Pacific salmon (McElhany et al. 2000; Ruckelshaus et al. 2002b). It addresses several fundamental questions, including (1) What was the historical population structure of an ESU? (2) What are the characteristics of a viable population for each of the historically independent populations in an ESU? (3) What are possible configurations (which might differ from historical conditions) of the spatial distribution, risk status, and diversity characteristics of populations across a viable ESU? and (4) What actions are needed for recovery of an ESU? Answers to questions 2 and 3 provide viability criteria for populations and ESUs, and analyses underlying question 4 allow for evaluation of alternative actions and their predicted effects on population and ESU status.

The U.S. Fish and Wildlife Service approaches recovery planning differently than the National Marine Fisheries Service. Rather than establishing species-based viability criteria and identifying which actions can achieve those criteria, the USFWS focuses technical analyses in recovery planning on threats to species viability and the actions needed to alleviate them. Most plans describe recovery criteria in qualitative rather than quantitative terms, although listed species whose recovery plans contained quantitative criteria were more likely to be improving (Gerber and Hatch 2002).

Because of the complexity of predicting cumulative effects of any recovery actions, the National Marine Fisheries Service is incorporating scenario planning into its estimates of the likely effects of habitat, hatchery, and harvest management actions on the population status of listed salmon (Ruckelshaus et al. 2002b). Land- and water-use scenarios are being elicited from watershed councils in addition to climate projections, providing greater confidence in the proposed recovery plan.

Advancing the Role of Science

The science underpinning recovery plans and their implementation needs improvement (Clark et al. 2002). Given the current state of knowledge, science is best used to evaluate the relative merits of alternative actions rather than to provide "the answer." Collaboration with policy and planning staff who will influence implementation of actions is important (Rinkevich and Leon 2000; Wondolleck and Yaffee 2000; Brick et al. 2001; Yaffee 2006). Given the uncertainty of recovery efforts, management actions should be treated as experiments that are monitored with vigilance (Boersma et al. 2001; Crouse et al. 2002).

The need for more basic natural history information for informing decisions under the ESA cannot be overstated. What constitutes a reproductively isolated group of individuals for a given species? In which habitats does a species occur throughout its life cycle, and what are its survival rates in alternative habitat types? What is the relative reproductive success of pairings between alternative life history types (table 10.1)?

Conservation scientists have called for greater attention to multispecies and ecosystem effects in recovery plans (USFWS and NMFS 1994b; Miller 1996). The potential importance of such community and ecosystem-level effects to species recovery is great, as illustrated by north Pacific whaling effects on sea otters in Alaska (Springer et al. 2003), ecological functions provided by grizzly bears (Pyare and Berger 2003), and predation by Caspian terns (*Sterna caspia*) on juvenile salmon in the Columbia River (Roby et al. 2003). How to incorporate community- or ecosystem-level effects in a recovery plan is not clear, and Clark et al. (2002) caution that multispecies plans may in fact reduce the focus on individual species to the detriment of their conservation status.

Finally, clearer agency guidance on what constitutes "acceptable" risk would improve recovery planning, as would clearer explanation of how uncertainty in biological conclusions is accounted for in decisions and whether there are differences between jeopardy and recovery standards.

How Can Scientists Improve ESA implementation?

The contributions of academic and agency science to ESA implementation have been unevenly distributed among topical areas. Quantitative analyses to identify units for conservation and to estimate species viability (or, conversely, risk of extinction) have received the lion's share of attention in the scientific literature (fig. 10.1). These methods are not without controversy but are relatively well tested and many of their limitations have been discussed (Waples, this volume; Boyce 1992; Akçakaya et al. 1999; Coulson et al. 2001; Brook et al. 2000, 2002; Ellner and Fieburg 2003). Unfortunately, due to a lack of data, such quantitative approaches are useful for only a small fraction of rare, threatened, or endangered species.

The science of characterizing degrees of imperilment using qualitative approaches also has improved since 1973 (e.g., IUCN 1994; Akçakaya et al. 2000; NatureServe 2003), and greater attention to these methods would be helpful in ESA decisions for a majority of the species considered (Keith et al. 2004; McCarthy et al. 2004).

Analytical methods to address the remaining questions asked in the ESA implementation process have barely emerged in the scientific literature (fig. 10.1). In particular, the science underlying identification of the effects of actions on species status lags far behind. Such analyses are needed to address questions under sections 7 and 10 (i.e., do these actions significantly reduce the species' like-

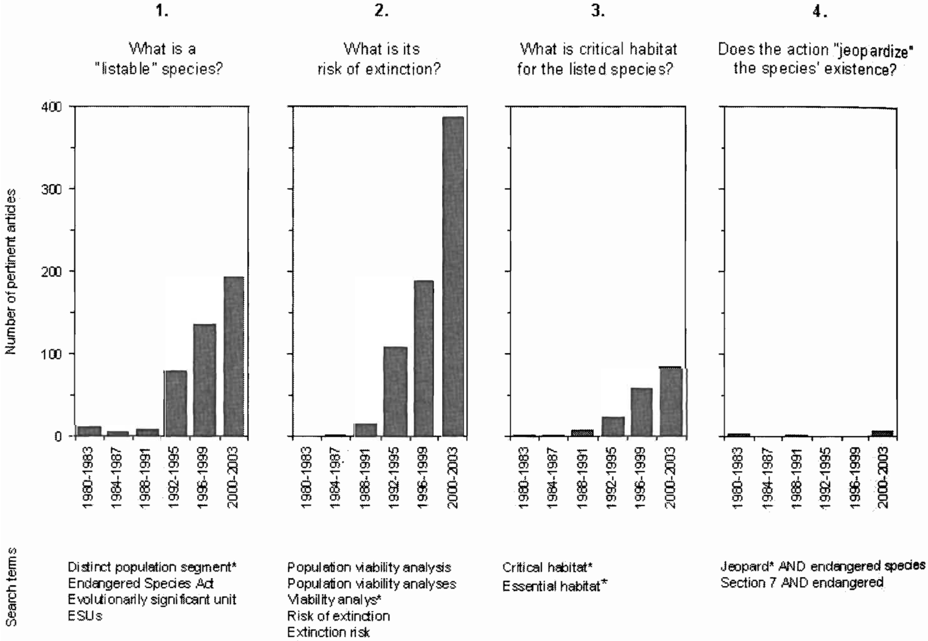

Figure 10.1. Articles that address scientific questions posed under the Endangered Species act, published between 1980 and 2003 and appearing in the ISL Web of Science's Science Citation Index Expanded Database. Search terms pertaining to each science question are listed below each panel.

lihood of survival and recovery?), section 4(b) (i.e., what habitat quantities and qualities are necessary for the survival and recovery of the species?), and section 4(f) (i.e., what actions are sufficient to achieve species viability criteria?). The needed research is challenging, time consuming, and difficult to generalize across species and locations. Especially lacking are empirical or analytical studies of the effects of specific actions on particular life stages and population dynamics.

Communication between scientists and decision makers is critical. Simple in concept, interaction between the groups is complicated in practice by the different worlds they inhabit—scientists can say "I don't know" and acknowledge that some scientific questions require years to answer, while decision makers must act within the limited time frames mandated by the Endangered Species Act, often on the basis of incomplete information. This can lead to frustration on both sides. We believe that the effort to communicate is well worth the trials involved (Ruckelshaus et al. 2002b). Previous studies have highlighted the need for help from conservation scientists that allows decision makers to more effectively link basic biology or ecology to management decisions (Floyd 2001; Clark et al. 2002). Approaches such as those developed under decision theory (Clemen 1996; Burgman 2005) and multicriteria mapping (Arrow and Raynaud 1986; Bana e Costa 1990) are potentially useful, but we found no examples applying these tools in decision making under the Endangered Species Act.

Science can have a significant impact on decisions made under the ESA as long as it isn't relied upon to be the sole arbiter in decisions (Doremus 1997; see Yaffee 2006). Scientists need to clearly explain to decision makers how science can (and cannot) inform their choices. Scientists and decision makers should be willing to participate in public forums where data, analytical approaches, and assumptions can be openly discussed. It is a rare manager of endangered species who will communicate through forums to which scientists are accustomed, such as the published literature (e.g., Rosenberg 2002). If scientists are free to interact with policy- and decision makers in processes designed to encourage open exchange, the result will be a clearer understanding of the need for an appropriate role of science in solving species protection challenges.

It is critical that discussions between scientists and policy makers and those involving the public clearly state the scientific basis for a result and any additional policy determinations brought to bear in making a decision under the act. To improve scientific credibility and agency decision making, scientists and decision makers must clearly distinguish between facts and assumptions and how each drives the results. If they fail to do so, laypersons will challenge the facts, rather than question the assumptions.

Because the act poses biological questions that almost always must be answered with imperfect information, scientists should encourage implementation of alternative actions as experiments. Furthermore, carefully estimating what we can learn from experiments before launching into controversial sets of actions is well worth the effort (e.g., Paulsen and Hinrichsen 2002), as is carefully monitoring the results. In the end, to enhance protection of species under the Endangered Species Act, biologists must get involved. Such involvement is not without potential costs (e.g., Halpern and Wilson 2003), but conducting sound research is not enough to protect a species if the results from a beautiful biological study sit in a journal, unread.

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