CONSERVATION POLICY

Endangered species recovery: A resource allocation problem

Explicit articulation of values and objectives is critical

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Many nations have laws to identify and protect imperiled species and their ecosystems. In the United States, actions taken under the Endangered Species Act (ESA) have prevented many extinctions, but few listed species have recovered to the point where they can have the ESA protections removed (*1*, *2*). One reason for this [among many (*3*)] is a shortfall in funding, raising a conundrum for agencies responsible for species recovery: Should resources be allocated toward species facing imminent extinction or species whose long-term survival can most benefit from investment? Some argue that the latter strategy is ethically unsound because it may abandon species with little hope of long-term recovery [for example, (*4*)], even when science suggests that the former strategy may miss opportunities to prevent species from ever experiencing the risk of imminent extinction (*2*). We suggest that framing recovery prioritization as a resource allocation problem provides a structure to facilitate constructive debate about such important questions. We discuss here the merits of an explicit resource allocation framework and introduce a prototype decision tool [(*5*); see supplementary materials for details] that we developed with the U.S. Fish and Wildlife Service (USFWS) to facilitate transparent and efficient recovery allocation decisions.

THE KNAPSACK PROBLEM

It is an inevitable consequence of limited resources that not all recovery efforts can be fully funded; therefore, some projects may be left behind. In some cases, managers make such choices (and neglect some projects) in ad hoc fashion, making implicit judgments about values and objectives with little transparency. We consider investment

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in endangered species recovery as a type of "knapsack problem" (*6*), in which a portfolio of recovery actions is chosen to best achieve a set of fundamental objectives, subject to a budget constraint. The science of decision analysis (*7*) provides tools to frame and solve such problems, allowing managers to allocate limited funds so that every dollar contributes as much as possible to the program objectives (*8*). Scenario-based decision-support tools can allow managers to compare how resource allocation strategies with different objectives, budgets, logistical constraints, and competing societal values may influence conservation outcomes and fundamental objectives before committing resources. Such approaches require decision-makers to clearly articulate objectives and constraints and to evaluate alternative allocation strategies to find which strategy best meets multiple objectives.

The first step in any structured resource allocation process is to identify which values the allocation seeks to reflect, because explicit articulation of objectives ensures transparent consideration of trade-offs among them. For investment in recovery, objectives may include minimizing the number of extinctions, maximizing the number of species recovered, favoring some species over others (owing to public support, taxonomic uniqueness, or other values), or minimizing the effect on other human activities (*6*, *9*). The ESA (and similar legislation in other countries) provides some guidance about the fundamental aims but usually not in enough specificity to guide allocation decisions across species and programs. Thus, the implementing agencies are left to define the objectives of recovery allocation themselves.

Even if the objectives for recovery actions were clearly articulated, deciding how to allocate limited resources to meet those objectives remains a vexing problem. First, the social, economic, and environmental values at stake are often contested and competing, requiring difficult trade-offs, even when resources are not limiting (*10*). Second, information on costs and benefits of different actions are hard to estimate and are often expressed as different metrics, making it difficult to weigh alternative allocation strategies (*10*). Third, the underlying complexity and uncertainty of the dynamic system (for example, regarding threats driven by climate change) means that effective implementation of conservation actions can be difficult to predict (*4*). Fourth, allocating resources (in the case of ESA) across more than 1500 federally listed species and thousands of individual recovery actions is a numerically daunting problem that cannot be solved transparently without a structured and explicit decision process. Fortunately, decision science provides tools to help overcome these challenges: Multicriteria decision analysis (*11*) allows a decision-maker to balance multiple objectives, and combinatorial optimization (*6*) allows the solution of complex knapsack problems.

RECOVERY ALLOCATION UNDER THE ESA

Very few federal and state agencies charged with management of endangered species have yet to adopt systematic methods for allocating recovery funds. Although the methods have existed in the academic literature for some time (*6*, *9*, *10*, *12*), it is challenging to implement them in any specific regulatory and institutional setting. With support from the National Socio-Environmental Synthesis Center, we worked with the USFWS to develop a tool to compare different funding allocation strategies for recovery of threatened and endangered species at the national and regional levels (*5*). This work was motivated, in part, by past critiques of USFWS recovery allocation processes [for example, (*13*)]. Our prototype Recovery Explorer tool (*5*) can be used, for instance, to examine how different values-based inputs (for example, desires for taxonomic representation or regional parity in funding) influence optimal allocation and recovery outcomes or the effect of uncertainty in technical inputs (for example, extinction risk or cost) on allocation and outcomes. The tool is meant to be exploratory, not prescriptive, allowing decision-makers to examine alternative approaches to resource allocation by making the important components of the decision process transparent.

Scientists face difficult decisions about how to allocate limited funding to the recovery of a few iconic and costly species (such as the black-footed ferret, facing page), and many lesser-known but less costly species (such as the Delhi Sands flower-loving fly, the deciduous tree *Kokia cookei*, and the Ozark hellbender, top to bottom, above).

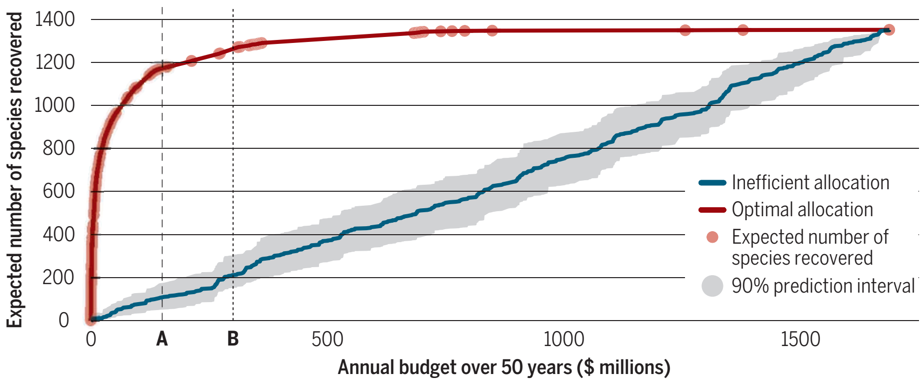
PHOTOS: (TOP TO BOTTOM) ERIC PORTER/USFWS; DAVID EICKHOFF/FLICKR/CC BY; JOEL SARTORE/CONTRIBUTOR/GETTY IMAGES

A fundamental tenet of decision analysis is to distinguish between science and values, and any decision-support tool requires both values-based and technical input. One of the advantages of a structured decision-making process is that the decisions and rationale regarding all of these components are made transparent. Values-based inputs to our decision framework include identification and specification of the recovery benefit metrics (for example, preventing extinction versus promoting recovery), the time frame over which benefits are measured, whether and how to weigh species differently to reflect taxonomic uniqueness or societal importance, and whether to constrain allocation to achieve parity across geographic regions. Science-based inputs include quantitative estimates of the benefit metrics with and without funding for each species, estimates of the cost of recovery for each species, and estimates of the likelihood of recovery conditional on funding for each species.

Our framework focuses on identifying cost-effective recovery plans, based on the assumption that managers want to complete the projects that achieve the most recovery benefit possible (however defined) with their available budget. The exact solution of knapsack problems requires combinatorial optimization, which is computationally expensive for large problems like this. An approximate solution can be found from the ranked list of project efficiencies, by adding plans from highest to lowest efficiency until the budget is exhausted (as in our algorithm) or by deleting plans from lowest to highest efficiency until the budget is achieved. This work represents the first effort to seek a solution to the specific problem of funding recovery efforts at the national scale in the United States, considering all species for which the USFWS has recovery plans.

Example of the benefit of optimal allocation

At an annual budget of $150 million (dashed line A), inefficient allocation of resources would recover about 104 species, whereas an optimal allocation is predicted to recover 1168 species. When annual funding is doubled to $300 million (dotted line B), the number of species recovered under the optimal allocation strategy increases to 1242. Data are from the U.S. Fish and Wildlife Service's database on recovery plans (*https://ecos.fws.gov/ecp0/ore-input/ad-hoc-recovery-actions-public-report-input*). Methods used to generate the "optimal allocation" curve are described in the supplementary materials; the "inefficient allocation" curve is based on a random selection of species for funding (mean and 90% prediction intervals).



ENCOURAGING CONSTRUCTIVE DEBATE

Use of the resource allocation framework has the potential to identify how more species can be recovered over time while preventing an equal or greater number of extinctions than less-efficient decision processes (see the figure), given a fixed budget. The framework can also demonstrate the expected gains from increased funding or, conversely, the expected losses from decreased funding. These two questions can be addressed simultaneously within a common framework for discussion.

Debate about how to value the outcomes of recovery allocation is contentious, passionate, and important. Explicit resource allocation tools provide a way to investigate alternative valuing systems, allowing users to compare the outcomes of focusing on imminent risk or long-term potential, of favoring charismatic or keystone species over others, and even of seeking a balance among such objectives. The approach we have developed with the USFWS allows such a conversation to begin. There are other features that might need to be added in future versions, such as the ability to use a benefit metric that weights multiple objectives. Such additions will be most valuable if they arise from deliberations by potential users.

Outside the United States, there have been sizable increases in recovery funding where managers responsible for species recovery and the agencies setting policies and budgets have developed and used such tools (*12*). For example, in New South Wales, an Australian state with >1000 threatened species, a transparent prioritization process demonstrated the responsible use of funds, showed benefits expected from a change in funding, and led to an unprecedented $100 million in additional funding (*14*). We believe that if similar decision processes were used to inform work under the ESA, alternative allocation strategies could maintain the success of the ESA at preventing extinctions while achieving far more recoveries at current levels of investment.

Some critics of applying a prioritization approach to endangered species suggest that instead of worrying about divvying up limited funds as species move toward extinction, we should be developing ecosystem-based approaches to address the root cause of species endangerment. We agree that a focus on mitigating threats is needed and further suggest that a transparent and cost-effective resource allocation will provide greater confidence in the use of funds and articulate what could be gained from increased investment, allowing agencies and conservation partners (for example, philanthropists, volunteers, and nongovernmental organizations) to evaluate, and possibly increase, their investment (*15*).

Underlying any allocation method is a set of predictions about how investment in a portfolio of species will result in the desired outcomes. As a first prototype, we used information from existing recovery plans and assumed that if actions suggested in those plans are undertaken, they will result in recovery of the species at the estimated cost. This assumption may not be warranted for all species. Further, we have assumed that species are largely independent and investment in one does not promote recovery of another, but there are cases where such synergies are possible. We have also only investigated full investment in each species, but partial investment might also be a valuable approach. Thus, a technical question arises for the USFWS and other agencies wishing to use such a resource allocation method: Are more detailed estimates of the costs and probability of success required?

Values-based judgments are embedded in any important public decision. It is up to society to determine the relative priority of investment in conservation of threatened and endangered species. The role of conservation scientists is to work with practitioners to guide decisions that are most likely to meet stated objectives and communicate associated risks and opportunities. Transparent tools for examining the effect of different allocation strategies on the outcomes of recovery spending allow agencies and the public to explore the effects of these choices. Resource allocation is not about saving some species and letting others go extinct; it is about finding a way to better order the work so that as many species as possible are recovered given the limited resources available at any moment in time. Embracing a thoughtful and consistent approach to the allocation of recovery funding improves the transparency in decisions, which is important when analyzing myriad management options under the ESA. ■

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SUPPLEMENTARY MATERIALS

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