Opinion

Ecological Function Analysis: Incorporating Species Roles into Conservation

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Effective conservation strategies must ensure that species remain not just extant, but able to maintain key roles in species interactions and in the maintenance of communities and ecosystems. Such ecological functions, however, have not been well incorporated into management or policy. We present a framework for quantifying ecological function that is complementary to population viability analysis (PVA) and that allows function to be integrated into strategic planning processes. Ecological function analysis (EFA) focuses on preventing secondary extinctions and maintaining ecosystem structure, biogeochemical processes, and resiliency. EFA can use a range of modeling approaches and, because most species interactions are relatively weak, EFA needs to be performed for relatively few species or functions, making it a realistic way to improve conservation management.

Highlights

Most current conservation strategies focus on preventing extinctions, but without explicit regard for the maintenance of sufficient abundance so that species can continue to interact with other species or impact the structure and function of their ecosystems.

We develop the concepts and tools for ecological function analysis (EFA), to measure and quantify the roles that species play.

EFA focuses on preventing cascading extinctions as well as maintaining ecosystem resiliency and critical biogeochemical processes. Because relatively few species have such strong ecosystem roles, EFA needs to be considered for manageable numbers of species and functions.

EFA is flexible and adaptive, making it a critical complement to species-based approaches in improving conservation management.

Species as Ecological Actors

Conservation planning remains largely focused on species viability and distribution. However, recent controversy over the goals and methods of conservation (e.g., [1]), and a need to ensure that conservation addresses all of the facets of biodiversity possible, make it urgent to have clear, actionable objectives that extend beyond these minimalist goals. Ecologists have long been interested in preserving species as ecological actors by trying to conserve 'ecologically effective densities' [2] – the minimum numbers of individuals required to maintain ecosystem functioning – but these goals have not been thoroughly incorporated into either the science of conservation biology or the strategic planning process. The developing framework for an IUCN Green List of recovered species recognizes ecological functionality as one of the three criteria for species recovery and ' . . . a critical element of an aspirational conservation vision' [3], while acknowledging that such functions can be difficult to assess.

Here we present a framework for quantifying **ecological function** (see Glossary) and integrating it into conservation planning. We try to circumvent what we perceive as three barriers that have hindered the more widespread incorporation of ecological functionality: (i) loose definitions of what it means; (ii) difficulty determining how to measure it; and (iii) bewilderment at choosing which of myriad possible ecological functions to try to conserve. These hurdles are nontrivial, necessitating a flexible approach that can support the objective of producing quantifiable and robust analyses of ecological function while accommodating differences in information availability.

We begin by defining 'function' somewhat more narrowly than has been done in the past, as performing a specified ecological role so as to: (i) prevent extinctions of other species (**secondary extinctions**); (ii) maintain major biogeochemical fluxes or pools; or (iii) significantly support ecosystem structure, stability, or productivity. In other words, we explicitly focus on strong interactions and roles that, as we discuss below, are much less common than weak

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interactions. Using this definition, we develop a conceptual outline for EFA, which we view as similar to and building on **PVA**. PVA projects the future dynamics of a population to assess the risks of that population falling below some level (quasi-extinction), while EFA uses the projected dynamics of a population to assess the risk of decline or failure of some ecological impact of that species. Relating the abundance of a species to its ecological function has been explored in the context of 'ecosystem function' studies (e.g., [4,5]), mostly based on small-scale experiments. Here we suggest expanding the development of these relationships to larger scales with free-ranging organisms, to enhance *in situ* conservation.

Which Functions to Conserve

All species interact with others in their community, so the millions of species on Earth could have billions of interactions among them. Given the rate at which biodiversity is declining [6] and that native species are shifting their ranges in response to climate alterations (thus interacting with new sets of partners), we cannot possibly hope to conserve – or even describe – more than a tiny proportion of these interactions before many of them are lost or altered.

However, we do not view EFA as having to tackle the entirety of ecological functions, because most species interactions and roles do not strongly affect other species or communities. Ecologists have long recognized that in many communities only a handful of species stand out for their strong ecological impacts; for example, keystone species [7], ecosystem engineers [8], foundation species [9], important mobile links (cf. [10]), and taxa with significant impact on biogeochemistry (e.g., [11]). While we still have few good analyses that fully quantify the distribution of interaction strengths within communities, virtually all such assessments demonstrate strong asymmetry both at the level of species, with some species having disproportionate influences [9,12], and for specific interactions, with few interactions strong and most weak (e.g., [7,13,14]). Although species clearly differ from one another in their traits, and therefore in the details of how they interact with other species, at the level of how species affect, for example, the population growth rate of an interaction partner or the strength of a biogeochemical flux, many of these nuances become relatively unimportant [15].

Beside ecological considerations, selection of which functions to conduct EFAs for will depend on a variety of logistical, financial, and societal factors. (The same as is true in choosing which species to prioritize for viability assessment.) The literature on conservation triage highlights how the strategic allocation of funds can maximize the number of species with successful recovery [16]. These same principles of triage could be extended to ecological functions, allowing us to maximize the number of functions conserved for a given budget. In some cases, we might be able to prioritize based on direct comparisons of functional strength. The functional roles of two pollinators, for example, can be compared in terms of their impacts on the extinction risk of a shared host flower species. However, many functions (e.g., see Table 1) are measured in different units. So, while decisions about which functions warrant EFA can and should be informed by ecological and budgetary considerations, they will also entail a degree of subjectivity based on societal values and politics – as do nearly all prioritization decisions in conservation. We do not try to answer all of the questions posed by the complex challenges of defining ecological function, but rather propose a foundation on which to base further developments.

We are not stating that only strongly interacting species are worthy of conservation. All species warrant our conservation concern, as fellow citizens of a shared planet. Our argument is that critical ecological functions should be another facet of biodiversity that we try to conserve [17] – in tandem with protecting the taxa (for a host of other reasons) and the habitats in which they

Glossary

Ecological function: a species interaction or ecological role whereby a species or group of species (functional group) prevent secondary extinctions or **endangerment**, maintain a biogeochemical flux or pool, or support ecosystem productivity.

Functional group: a group of related or unrelated taxa that perform the same function in a community. This could be a guild (e.g., 'frugivores') or a subset of a guild (e.g., 'frugivores that disperse large-seeded tree species').

Functional redundancy: when two or more species perform similar ecological roles; antonym, functional complementarity.

Hysteresis: when multiple levels of ecological function can exist at a given species population density, based on the history of population trends.

Population viability analysis (PVA): quantitative estimation of extinction risk in a population of a single species as a function of intrinsic demographic attributes, extrinsic forces, environmental variability, and interactions among these factors.

Secondary endangerment: when local or global loss of one species directly causes significant local or global deterioration in the conservation status of an erstwhile interaction partner.

Secondary extinction: when local or global loss of one species directly causes the local or global loss of an erstwhile interaction partner.

Table 1. Variables That Might Be Used in Different EFAs[a]

Function	Independent variable	Proximate response variable	Ultimate response variable	Example	Refs
Zoochorous seed dispersal	Frugivorous animal density	Number of zoochorous tree seeds dispersed Seed dispersal distance	Extinction risk of zoochorous tree species	Overhunted forests lose critical seed-dispersing animals, which can drive secondary extinction of trees	[32]
			Forest carbon storage	Overhunted forests can exhibit shifts in tree species composition that decrease the overall aboveground biomass	[11]
Predation	Predator density	Herbivory rate	Extinction risk of herbivore-vulnerable plant species	Mammalian carnivores drive shifts in the abundance of non-thorny plants	[33]
		Prey density	Primary consumer diversity	Lizard predators drive rapid declines in spider diversity	[34]
			Plant productivity	Insectivorous vertebrates increase productivity in agroforestry systems	[35]
Zoonotic disease buffer	Large mammal density	Density of infected ticks	Probability of zoonotic disease transmission	Declines in vertebrate populations increase zoonotic disease risk for humans	[36,37]
Phosphorus (P) transport	Large mammal density	Transport rates of P	Plant productivity or diversity	Extirpation of large mammals decreased P transport and plant productivity in the Middle East	[38]
Pollination	Pollinator density	Seed set in outcrossing plants	Extinction risk of outcrossing plants	Loss of insect-pollinated plants occurred in conjunction with loss of bees and hoverflies	[39]
Ecosystem engineering	Ecosystem engineer density	Amount of structural habitat modification	Community diversity	Burrowing species can increase the abundance and diversity of other burrow-dwelling species in the community	[8]
Foundation species	Mangrove forest cover	Wave force during storms	Shoreline erosion	Foundational tree species can affect consumer diversity and ecosystem function in a variety of biomes	[9]
		Abundance of juvenile fish	Inshore fishery productivity		

[a]Much of the species interaction literature addresses proximate response variables; we argue that EFAs will be much more effective by focusing on ultimate response variables.

occur – and in particular that clearer analysis of species functions can make overall biodiversity protection more effective. These points have been raised before, but practical approaches to actually doing EFA have remained elusive. Assessing ecological function should be a fundamental part of conservation planning that complements both species- and habitat-based approaches, but that does not redirect conservation away from the paramount goal of saving species from extinction.

Principles of EFA

While the diversity of conservation settings and objectives precludes a simple formula for EFA, the following principles should be useful for developing robust and feasible assessments of ecological functioning.

(i) Ecological functions can be complex. Previous approaches to measuring ecological function have tried to determine thresholds in population density above which functions were fulfilled and below which they were lost [2]. While valuable as a starting point, focusing on minimum population densities is problematic because it does not easily incorporate stochastic dynamics and assumes that species interactions and functions are essentially binary. While nonlinear effects of abundance on function are common, thresholds abrupt enough to render a function completely binary are likely to be rare. (In addition, abundance itself is a conservation value and is not binary [18].) We argue that the roles of species or **functional groups** (Box 1) should be assessed via more nuanced EFA than by minimum density thresholds whenever possible.

(ii) Not all interactions or species roles constitute important ecological functions. As discussed above (see 'Which Functions to Conserve'), most of the interactions that species engage in will have limited or negligible impacts on other populations, community structure, and ecosystem processes. We argue that the reason for conserving functions is not to preserve every facet of communities and ecosystems in their current state, but instead to prevent secondary extinctions and impediments to critical ecosystem processes and therefore to facilitate community and ecosystem resilience.

(iii) EFA must be flexible in its modeling complexity, employing the best quantitative analyses possible given the available information. Assessing extinction risk in just one species can be challenging and require substantial amounts of data: the difficulty in understanding how continuous changes in abundance in one species would affect the numbers of its interaction partners is vastly greater. However, as with PVA, EFA could range from relatively simple to highly sophisticated analyses depending on the exact questions to be answered and the data available (Box 1).

(iv) EFA should be adaptive so that inferences can be updated with changing ecological conditions and increasing data. The importance of many functions is likely to vary spatially and may shift in response to climatic or other global changes. Therefore, EFAs should not be one-off assessments but should be continually updated as new data become available, ecological conditions change, or new management issues arise. This use of EFA is analogous to the approach of population viability management, which uses PVA approaches tightly linked with ongoing monitoring and management [19].

Box 1. Data Availability and Model Complexity

Data on the details of many ecological functions simply do not exist and will not become available in any conservation-relevant time frame. We can still assess function in these instances by comparing function in areas where a strongly interacting species is extant versus extirpated (see Figure 2A in main text). We could also employ simulation-based models (e.g., [37]) or data from ecologically similar species. While simplified models may be necessary in cases of limited data availability, we reiterate that assessments of the ecological functions themselves should not be reduced from ultimate to proximate metrics of function (see 'Appropriate Response Variables' and Table 1 in main text).

The process of developing even a simple EFA could also help identify areas where targeted field experiments could fill critical data gaps. There are several frameworks for combining datasets from observational studies and small-scale, targeted experiments into larger-scale understandings of the reciprocal importance of mutualistic species [38] or the function of ecosystem engineers [8].

In other instances, sufficient data may be available to model how continuous changes in population density affect function (see Figure 2B in main text) and to add complexity and realism to the EFA. Where data are available, factors such as density dependence, time lags, **hysteresis**, and other considerations should be incorporated via, for example, coupled demographic models of interacting species.

With appropriate data, context dependency in ecological functions can also be incorporated. Ecological functions can shift in response to environmental changes [39] and can depend on which other taxa are present in the community. Organisms are shifting their distributions increasingly rapidly, causing communities to reassemble [40]. There are likely to be instances when a species ceases to be functionally important because another species arrives that serves the same ecological role. Some functions such as predation [41] and nutrient transfer [42] can even be served by humans in lieu of the native fauna that they replaced. Just as PVAs should be best conducted adaptively [19], EFAs would be most useful and robust if regularly re-run to incorporate new data and updated understanding of the structure of the community.

Appropriate Response Variables

Following from our focus on strong interactors and important ecological roles, EFA should be based on ultimate response variables that are direct measurements of ecological function. For example, the importance of a frugivorous bird should not be measured by how many seeds it disperses or how far it takes them (proximate variables), but by how the population density of the bird affects the population densities and extinction probabilities (ultimate variables) of the plants whose seeds it disperses [15]. While this is a daunting challenge, we believe that it is also more attainable than is often perceived by conservation biologists and that attempting to describe and quantify these ecological relationships even without complete information could help distinguish critical from weak species impacts. Examples of proximate and ultimate response variables in ecological functions from a variety of systems are shown in Table 1.

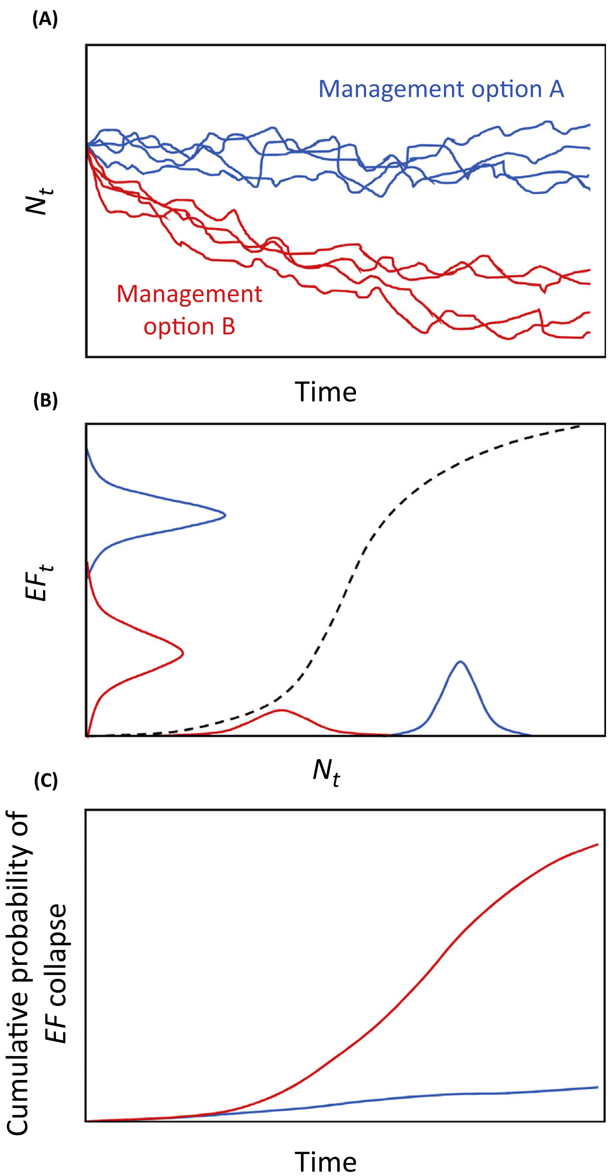
Measuring species interactions and roles in the field can be immensely difficult, so it is unsurprising that most of the literature on interactions uses proxies rather than true measures of interaction strength or function (Table 1). The problem is that these proxies are often weakly related or unrelated to actual ecological function or secondary extinction risk [15]. The expanding literature on network models is even redefining interaction strength as simply the number of interaction partners that a species has, or the number of species that 'depend' on it [20]. However, such dependence is not actually measured in a population demographic sense and cannot be simply inferred from food web structure. Pollinator impacts on plant seed set, for example, might not alter secondary extinction risk if the plants are facultatively selfing or can rapidly evolve to become so ([15], see references therein). Similarly, predator influence on herbivory rates would not change plant carbon sequestration if browsing were compensatory to other sources of plant damage and mortality (cf. [15] and references therein). Whether there are ways to predict *a priori* the ecological functions of numerous species simultaneously remains an important direction for research (see Outstanding Questions).

How EFA Works

We envision EFA as comprising several linked analyses. First are projections of the numbers or densities of the focal species, as is done in PVA, to generate estimated numbers and risks of falling to low abundance levels under one or more management regimes or impact scenarios (Figure 1A). These projections will often include different management, climate, or land use scenarios and other extrinsic controls of population dynamics such that numbers at time $t + 1$ (N_{t+1}) will be a function (f_N) of multiple variables: $N_{t+1} = f_N(N_t$, climate, management, etc.). Second, a quantitative model is developed to link focal species abundance (N_t) or functional group abundance (Box 2) to an ecological function (EF) (Figure 1B). Given predicted distributions of numbers at some point in the future under a specific management regime, the distribution of predicted ecological function values can then be estimated (Figure 1B). Finally, for some ecological functions, a clear point of collapse – equivalent to a quasi-extinction threshold in a PVA – can be usefully defined. In such cases, the cumulative probability of ecological function loss into the future can be estimated (Figure 1C).

These linkages can be envisioned and analyzed as simple relationships within each time step, such that EF_t is a function of, for example, N_t, climate, and land cover. For many functions, however, realistic relationships will involve time lags, averaging across multiple years, and nonlinearities. Examples of how these functions could be constructed for different functions include the following.

Function = extinction risk of another species. If the ecological function of concern is the number or density of another species, f_{EF} may take the form of a full demographic model for the



Trends in Ecology & Evolution

Figure 1. An Outline of Common Steps in Ecological Function Analysis. (A) Stochastic abundance over time (N_t) is first estimated for a focal species under two management options. (B) The relationship (broken line) between abundance and ecological function (*EF*) can then be estimated. Given predicted distributions of numbers at some point in the future under a specific management regime (red and blue distributions on the abscissa for management options A and B, respectively), the distribution of predicted ecological function (*EF*) values can then be estimated (red and blue distributions on the ordinate). (C) Finally, the probability of the function collapsing under each management scenario can be predicted into the future.

responding species with the focal species being an environmental driver of demography. For example, if seed dispersers increase recruitment rates of a forest tree, such a model will be needed to assess effects on tree densities (Figure 2) and may reveal substantial time lags in response to shifting disperser densities.

Box 2. Functional Redundancy and Complementarity

Ecological function can be measured for a single species or a group of functionally similar species (functional group). In low-diversity systems with little **functional redundancy**, it will often make sense to model the function of a single species. The impact of moose (*Alces alces*) in Wyoming, for example, on woody plants and therefore the structure of passerine bird habitat [43] is not replicated by other species in the system. By contrast, the persistence of many woody plants in the tropics depends on seeds being dispersed by vertebrate frugivores, but the role of any particular vertebrate is often redundant with others in the community [13].

Assessing functional redundancy in the field can be difficult. Such determinations can be made using demographic data collected in the field, but this is time and labor intensive. Recently, careful delineation of functional groups has been achieved using combined spatial and network analysis. This approach has revealed, for example, that primates play a key role in the regeneration of animal-dispersed trees in Thailand that is not replaced by birds [14].

For an EFA based on a functional group, an analysis of how changes in density (the number of individuals across species) affect function could also incorporate differences among species because taxa are usually extirpated in nonrandom order. For example, large-bodied vertebrates are almost always the first to be removed in overhunted tropical forests, and these species often provide the most effective seed dispersal [44]. So, a graph of frugivore density versus seed dispersal would again be nonlinear, this time by implicitly incorporating changes in species composition.

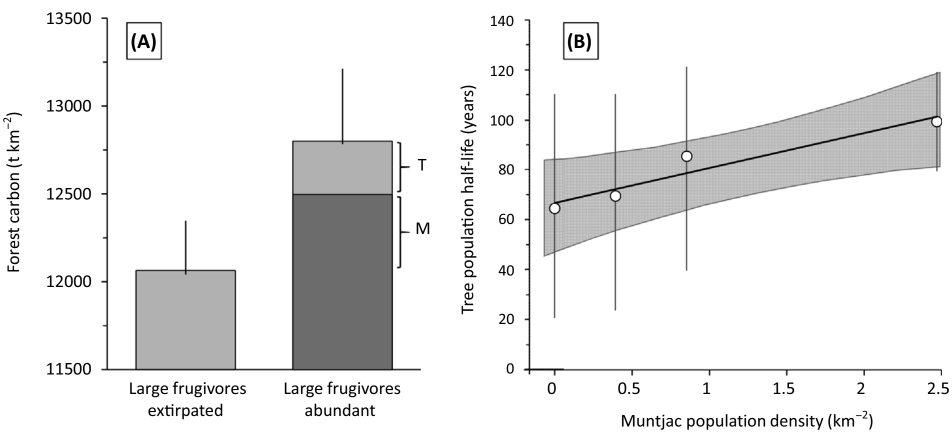


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Figure 2. Example Ecological Function Analyses for (A) a Functional Group or (B) a Species of Seed-Dispersing Mammal. In (A), frugivores affect mean (±95% confidence interval) carbon storage in the Brazilian Amazon (estimates based on data in [11]); the bracket labeled M quantifies the ecological function of large ateline monkeys, the bracket labeled T shows the marginal value of tapirs (*Tapirus* spp.). In (B), the density of muntjac deer (*Muntiacus vaginalis*) affects the population trajectory of the zoochorous tree *Choerospondias axillaris* in Southeast Asia, with half-life used as a deterministic metric of tree extinction risk; estimates (circles; based on data in [35,36]) with 95% confidence intervals are shown, along with the mean trend and 95% confidence band of the regression.

Function = nutrient transfer. A f_{EF} could simply translate focal species abundance into ecosystem productivity, for example, via a loss function. In such cases, short-term variation in focal species abundance may be relatively unimportant, such that time-averaged abundance (e.g., long-term trends) may best predict effects on ecological function.

Function = stability in the face of disturbance. The f_{EF} may need to track how size distributions of focal species change over time (e.g., mangroves that dampen storm surges) and then translate numbers and sizes into the ability of the population to increase resistance to disturbance. Here, EFA would involve assumptions about the biophysical attributes of the population when faced with different storm intensities.

Given that the quantitative techniques underlying PVAs are highly developed, by far the most difficult aspect of EFA will be in measuring the relationships between population density and function (cf. [21]). For this reason, EFAs have to be extremely flexible in their data requirements – something that already characterizes PVAs. Box 1 presents a framework for how the complexity of an EFA can be tailored to data availability and Box 3 provides an example.

One facet of EFA that is of central importance for improved conservation efforts is the ability to quantify lag times in the degradation of ecological functioning with the decline of important species. While the concept of extinction debt is now central in the analysis of ongoing habitat

Box 3. Pacific Salmon and EFA

Among the best-understood examples of how population densities relate to ecological function is the upstream delivery of marine-derived nutrients (MDNs) by Pacific salmon, as well as other effects of the fish on multiple aspects of stream, terrestrial vertebrate, and forest ecology [45,46]. Specific functions claimed for salmon – which are supported with varying strength and using a range of methods – include increasing densities of bird and mammal species [47], fertilization and enhanced plant growth in upland habitats [48], and enhanced stream productivity. What makes salmon an especially good example of EFA is the ability to directly quantify the relationship between salmon numbers and their ultimate ecological responses (Figure I) (e.g., [49]).

The functional effects of salmon also highlight several aspects of EFA that could apply in many other systems. First, some effects of salmon on upland systems also depend on the presence of other species – most notably bears – that spread MDNs away from spawning sites and hence magnify the overall functionality of salmon [50]. Dependence of ecological function on the presence of other species is likely to be common across systems. Second, one clear ecological function of salmon is the presence of the fish themselves: they are important prey for many other species, including humans, and are key predators as well. In this sense, the positive density dependence of depleted salmon runs [51] points to a nonlinearity of ecological function based on the demography of the focal species itself. Finally, work on salmon in California, where runs are highly depleted, has shown that even in highly modified landscapes with abundant agriculture, essential ecological functioning may remain, with wine grapes receiving 18–25% of their nitrogen from marine sources in sites adjacent to even modest runs, likely via consumption of salmon by terrestrial consumers and defecation of the nutrients in the uplands [52]. This suggests that some ecological functions can remain robust even in the face of strong gradients in human land use and degradation.

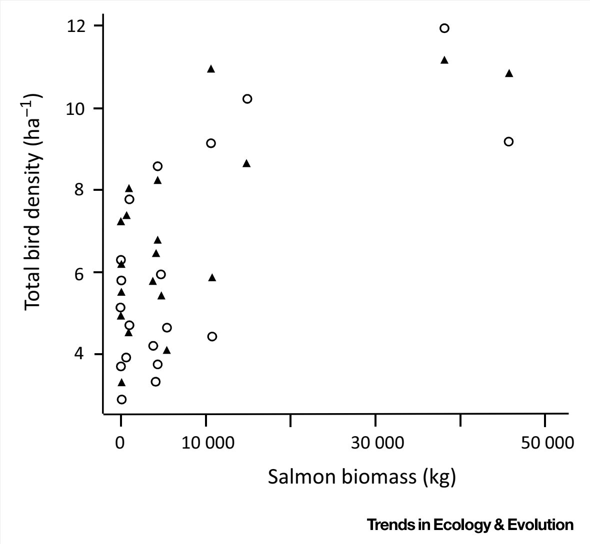

Figure I. An Ecological Function of Salmon Is Supporting Breeding Bird Abundance. Here, total density of breeding birds in estuaries is correlated with the 3-year-averaged combined biomass of salmon species in the Heiltsuk First Nation traditional territory in the Great Bear Rainforest, British Columbia [47]. Bird abundances are from 2008 (open circles) and 2009 (triangles). Adapted from [47].

loss, there could often be equivalently long delays in ecological function loss as key populations decline. EFA provides a means to quantify and thus recognize these time-delayed costs of population declines.

Although the focus of EFA is on population density, differences among individuals, as well as density-dependent behavior, are key issues to consider [22] and can be incorporated into EFA. Declining population density, often driven by human exploitation, can alter organismal traits and behaviors [23]. For example, fishing in flooded savannahs preferentially removes the largest-bodied individuals whose foraging behavior provides the most-effect seed dispersal [24]. Here the relationship between frugivore density and tree extinction risk would be distinctly nonlinear. Importantly, even an explicit focus on population density still implicitly incorporates intraspecific differences.

Concluding Remarks: Incorporating EFA into Policy

A survey of 13 policy statements in statutes and conventions that include species conservation reveals a variety of approaches to defining how conservation targets should be set, including demography, economic benefit, cultural benefit, and evolutionary potential [25]. Despite this, the preponderance of opinion among conservation biologists seems to be that viability should be measured in terms of demography and genetics. This assumption took hold early in the history of modern conservation, reflecting the expertise of genetics and captive breeding among the founders of the discipline as well as the clarity in defining conservation goals (i.e., avoiding complete extinction). A seminal paper in 1981 [26] cemented this understanding, although Soulé [27] identified the biblical character Noah as the first to understand that his charge to conserve species meant the demographic mandate to recruit one male and one female of each species. It is therefore unsurprising that ‘viable’ has come to be seen by most researchers and policymakers as defining only demographically and genetically intact species as are usually analyzed via PVA, which Soulé has called the ‘flagship technology of Conservation Biology’ [28].

Despite this, over the past four decades conservation biologists have retained an interest in a broader definition of viability [29,30]. This view of the ecological dimension of viability is also found in some conservation policies, with, for example, the Convention on International Trade in Endangered Species of Wild Flora and Fauna setting as its goal ‘ . . . to maintain that species throughout its range at a level consistent with its role in the ecosystems in which it occurs . . . ’ (Article IV; https://www.cites.org/eng/disc/text.php#IV). Within the EU’s Habitat Directive, there continues to be discussion on whether demographic viability should continue to be the standard or whether ecological viability is required as well [31].

Policies to conserve ecologically viable populations have been discussed in the literature ranging from shellfish reef restoration and salmon restoration to rewilding and de-extinction. The IUCN’s *Guidelines on Creating Proxies of Extinct Species for Conservation Benefit* state that ‘If the objective for the creation of a proxy of an extinct species is the derivation of a functional equivalent able to restore ecological functions or processes that might have been lost as a result of the extinction of the original species, then the positive justification should be ecological, and in its absence “de-extinction” would seem unjustified’ ([32], see p. 10). Most recently, Akçakaya and colleagues [3] have proposed three dimensions to the recovery of a species, one of which is ‘functionality’, whereby a fully recovered species is one that ‘exhibits the full range of its ecological interactions, functions and other roles in the ecosystem’.

Setting population targets is a social and political process rather than an inherently scientific one [25]. This is a key point to make as we argue for the inclusion of EFA as an additional tool for setting conservation targets. It is likely that the use of such a tool will increase the population size required for species conservation. The existing policy process has already shown that policy-driven targets can be several times lower than those derived by evidence-based methods [33,34]. Yet it is vital that, as we learn more about the ecological functions of species, we have tools in hand to create conservation targets that allow for the maintenance of such functions for the benefit of both biodiversity and humans.

Outstanding Questions

Are there strong generalities about the types of interactions or species that disproportionately drive ecological function in different communities? Are these generalities strong enough to base management actions on, especially in understudied systems?

How biased will EFAs be that are based on limited data? This could be assessed in well-studied systems, by comparing the management implications of complex EFAs (e.g., those where function is assessed as a continuous function of population density) versus simple EFAs (e.g., where function is measured when the species is simply present versus absent).

Are there ways to assess ecological roles via network models that incorporate the realism of environmental stochasticity, finite resources, and the context dependency of interaction strengths?

For species thought to have disproportionate ecological importance that occur across multiple communities, do many have strong ecological functions in different settings? If so, targeting them for analysis and conservation could offer multiple benefits.

What is the congruence between management recommendations based on species viability assessment versus ecological function? Are there ways to increase this congruence?

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