



The Contribution of Species to the Provision of Ecosystem Services

Marcello Hernández-Blanco

4.1 INTRODUCTION

Biodiversity is declining at an unprecedented pace, with more than 1 million species at the risk of extinction (IPBES, 2019), crossing the threshold of the safe operating space of the planetary boundary of biosphere integrity (Steffen et al., 2015). The scientific community has widely recorded the causes of biodiversity loss, including overharvesting, climate change, human population growth, habitat destruction, pollution, and invasive species (Wilson, 2016). Nevertheless, I would argue these are more the events and patterns in the iceberg model of systems thinking, and there is still a significant gap on the structures (i.e., what influences those trends) and mental models (i.e., our way of thinking towards biodiversity in terms of its multiple values to society) that underlines the causes of nature loss and degradation. At the heart of this global biodiversity

M. Hernández-Blanco (✉)
Conservation Strategy Fund, San José, Costa Rica
e-mail: ecoeconomics@marcello.life

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crisis is the undervaluation of nature, where markets, policies, and institutions are not considering the crucial dependency of society's well-being on ecosystem services (i.e., the benefits society obtains from ecosystems) (Costanza et al., 2011; Hernández-Blanco & Costanza, 2019) nor the key role that biodiversity plays in delivering them.

From a purely economic point of view, the undervaluation of biodiversity arises from a failure of the market to manage public goods in a sustainable way (Brander et al., 2012; Hernández-Blanco et al., 2024). A public good is something that everyone can enjoy without taking away from others (i.e., non-rival), and that no one can easily be excluded from using (i.e., non-excludable). For example, a clean environment benefits everyone, and one person enjoying it does not reduce its availability for others. This is different from private goods, like a cup of coffee, which can only be used by one person at a time and can be withheld from others (Barbier et al., 1997; Costanza, 2008). Markets are designed to work best with private goods—things that are individually used and controlled. However, much of natural capital—the world's stock of natural resources like forests, oceans, and biodiversity—functions as a public good. Because the benefits from natural capital are shared broadly and not easily limited to individuals, it is difficult for traditional markets to manage or protect them effectively (Brander et al., 2012).

Moreover, another key market failure affecting biodiversity protection is the lack of the internalization of externalities (both negative and positive) by economic activities. In other words, markets mostly do not reflect the full costs or benefits of a change in ecosystem health, including biodiversity. For example, the price of Chinook salmon does not account for the reduction in the population of this species, nor the impact that this reduction has on the health of other species such as killer whales (Williams et al., 2011), which in turn can impact economic activities such as whale watching (Van Deren et al., 2019). Another example is the price of agrochemicals; even though these are known to have a highly negative effect on insect pollinators such as bees, which causes lower crop yields (for those dependent on these species) (Hernández-Blanco & Chavez, 2022), their pricing does not account for this social and environmental impact, and, on the contrary, such chemicals are in fact heavily subsidized (UNDP-BIOFIN, 2024).

To overcome these market failures, scientists from across academic disciplines have conducted the economic valuation of natural capital at multiple geographical scales all over the planet for more than two

decades (Costanza et al., 2017), with the main goal of demonstrating how protecting, restoring, and sustainably using natural resources not only have positive outcomes in securing the health of ecosystems, but also the high return of investment that this will produce, therefore stabilizing the social and economic dimensions of development. These values will depend on human preferences (based on culture) and on how people perceive the impact of protecting or losing nature on their well-being (Turner et al., 2000), thus making it crucial to address in an integral way the multiple values that nature provide to people and the rest of nature (Pascual et al., 2022).

Ignoring the value of natural capital has caused a significant funding gap for nature conservation and restoration. In 2019, global annual spending on biodiversity conservation was USD \$124 to \$143 billion, against a total annual estimated biodiversity protection need of USD \$722 to \$967 billion per year, causing a financing gap of USD \$598 to \$824 billion per year (Deutz et al., 2020). On top of this lack of funding towards protecting Earth's life support system, governments around the world are subsidizing the destruction of nature, especially in sectors such as agriculture, fisheries, and energy (i.e., fossil fuels) (UNDP-BIOFIN, 2024).

In this chapter, I provide a theoretical framework for considering the economic value of the role a keystone species (i.e., a species that has a disproportionately large impact on its ecosystem relative to its abundance) has in contributing to the provision of ecosystem services. This will help inform more effective management strategies of natural capital, including conservation, restoration, rewilding, and the sustainable use of species. Furthermore, understanding the cascading negative effects to our well-being from losing keystone species due to anthropogenic drivers of change can provide a sound justification for the investments needed to protect and restore keystone species populations, as well as creating novel financial solutions.

4.2 ECOSYSTEM HEALTH AND THE PROVISION OF ECOSYSTEM SERVICES

The interaction of natural capital with human capital (the health, knowledge, and skills of people), social capital (the networks, traditions, trust, and institutions that help people connect and cooperate), and built capital (such as buildings, machines, and infrastructure) produces ecosystem

services, like clean air, fresh water, food, and climate regulation, among many others (Hernández-Blanco & Costanza, 2019). The provision of ecosystem services is also dependent on the condition of natural capital, which is often referred to as ecosystem health (Rapport, 1995). Costanza (1992) argues that an ecosystem is healthy if it is stable and sustainable, that is, if it is active and maintains its organization and autonomy over time and is resilient to stress.

Considering this definition, the main features of ecosystem health are vigor, organization, and resilience (Costanza, 1992; Hernández-Blanco et al., 2022). The vigor of a system is a measure of its activity or metabolism (i.e., all biological, chemical, and physical processes that occur within it to transform energy and cycle matter), and it can be measured through indicators such as gross primary production and net primary production. These indicators are used to determine different states of an ecosystem (e.g., comparing the metabolism in an un-stressed versus stressed state). The organization of an ecosystem refers to the number and diversity of interactions among the components of the system, which can be measured through its biological diversity and by the number and strength of pathways of exchange among components of the system (Pringle & Hutchinson, 2020; Quévreur et al., 2024). Finally, resilience refers to the ecosystem's ability to maintain its structure (i.e., organization) and function (i.e., vigor) in the presence of stress (Costanza & Mageau, 1999; Dakos & Kéfi, 2022; Gunderson, 2000; Mageau et al., 1995).

The role that organization and vigor play in providing ecosystem services is also addressed in the ecosystem service cascade proposed by Haines-Young and Potschin (2010), highlighting the production of ecosystem functions by the ecosystem structure which can lead to the provision of benefits to society. Although the ecosystem cascade has received critiques due to its over simplistic description of how social-ecological systems operate in reality, as well due to the over complication differentiating between ecosystem services and benefits (Costanza et al., 2017), Haines-Young and Potschin (2010) nevertheless provides a useful initial framework to start thinking of a way of linking both end points of natural capital assessment, from ecosystem health to ecosystem services.

Different ecological processes that produce the flow of ecosystem functions and potential ecosystem services determine the structure of the ecosystem, composed by the interaction of its abiotic and biotic components (i.e., producers, consumers, and decomposers) (Mace et al., 2012).

It is worth highlighting that the provision of ecosystem services is not entirely dependent on natural capital; it also depends on the rest of capitals mentioned previously (Fig. 4.1). Therefore, changes to ecosystem health are largely driven by changes in the system dynamics between biotic and abiotic components, as well as within biotic components. Although ecosystems are dynamic and therefore their health is too, their structures are maintained within the levels of the ecosystem's resilience and therefore the systems stay in a stable state. Significant stressors can move an ecosystem to another stable state by significantly altering its structure and resilience, and this new stable state could also have different functions and services (e.g., a healthy coral reef that provides ecosystem services such as food and recreation opportunities, versus one that was bleached due to abnormal high temperatures and that consequently does not provide services or it does with a very low magnitude).

Hernández-Blanco et al. (2022) propose a framework to estimate changes in ecosystem health and the provision of ecosystem services, composed by (1) a development or conservation policy (which could be at different geographical scales), (2) a series of management decisions (i.e., origin of the driver of change), (3) the driver of change itself, (4) the change in ecosystem health and, consequently, (5) the change in the provision of ecosystem services, and (6) their value. Therefore, a change in the value of the benefits we obtain from ecosystems is dependent (among other things) on the health of the system which, in turn, is dependent on the biotic and abiotic factors that define its structure. For example, a country could (1) promote an unsustainable agricultural production scheme, (2) based on excessive use of harmful agrochemicals, (3) which will produce a significant level of chemical pollution, (4) that changes one or more components of ecosystem health, such as biodiversity, (5) that provide key ecosystem services like pollination, (6) which will impact at the same time agricultural productivity (i.e., change in the ecosystem service value). This general framework applies for positive changes as well. The rest of this chapter explores the role of biotic components in providing ecosystem services.

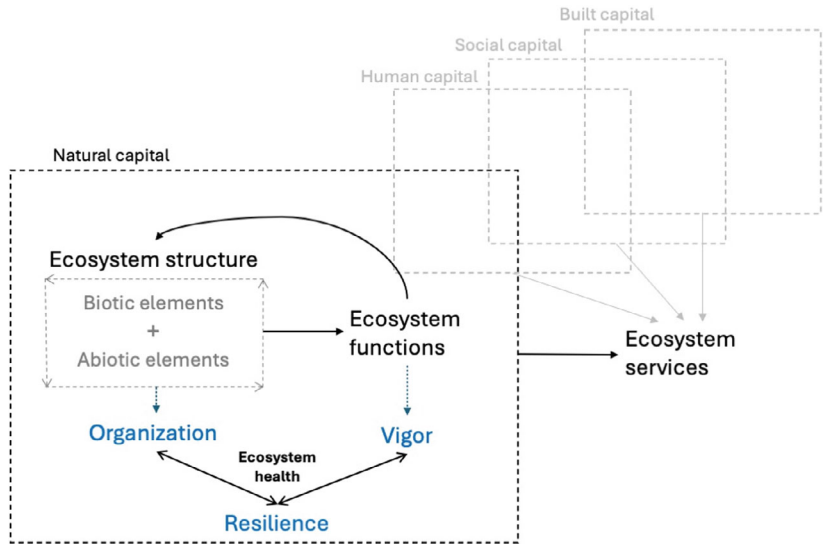


Fig. 4.1 Production of ecosystem services determined by the interaction of the four types of capital. In the case of natural capital, the ecosystem structure determines the ecosystem’s functions. The ecosystem’s structure and function are also measurable in terms of the organization and the vigor of ecosystem health, respectively, where resilience feeds back to affect ecosystem vigor and organization, and hence ecosystem functions (and ultimately the sustainability of ecosystem services). *Source* Author (2025)

4.3 THE ROLE OF SPECIES IN SUPPORTING ECOSYSTEM SERVICES

The provision of ecosystem services requires the whole ecosystem, which is not only defined by its components, but mainly by the interaction webs built within which species can potentially influence other species; these interactions can include both biological processes (e.g., competition, predation, and mutualism) and physicochemical processes (e.g., nutrients, impact on water limitation, and temperature) (Estes et al., 2011). Therefore, species that play a role in supporting ecosystem functions and services at the same time depend on other species and abiotic elements in the ecosystem (Mace et al., 2012). For example, in the case of pollination, pollinators such as bees in crops like coffee, depend on

healthy forests (e.g., without stressors such as agrochemicals or land use change) as their habitat (Ricketts et al., 2004).

Nevertheless, some scholars argue that species directly provide ecosystem services (Berzaghi et al. 2022a; Cook et al., 2020), but this is fundamentally incorrect. First, and the most obvious reason, is that species are not ecosystems, and therefore species cannot be compared with ecosystems at the level of provision of benefits to society. Second, a lack of understanding of the ecological dynamics behind the provision of ecosystem services forms the basis of this argument, and therefore this leads to the assumption that species can be entirely responsible for providing services (e.g., climate regulation). Finally, provisioning services (e.g., food, raw materials) are commonly the focus of economic valuations of species. For example, Cook et al. (2020) assess the benefits from whales such as meat and materials from the whale's bones and baleens. These uses derive from the extraction of one element (i.e., the species) from the ecosystem, which is often done in an unsustainable way. Following with the example of whales, seeing food as an ecosystem service from these marine mammals is similar to arguing that salmon provides a direct ecosystem service when it is fished, when in reality food provisioning is a service from the entire marine or freshwater system that sustain the populations of these fishes of commercial interest.

The approach I present in this chapter considers the network dynamics of nature, and therefore the value of species based on maintaining the balance and function of the system in order to keep providing benefits, rather on the disruption of this network. Haines-Young and Potschin (2010) briefly consider this approach, which calls for the incorporation of functional traits from species (especially keystone species) on ecosystem services assessments, since these traits determine the effect of species on ecosystem processes or services and their response to stressors (i.e., resilience) (De Bello et al., 2008).

Each species plays a different role in supporting different ecosystem services. As a starting point to develop a valuation approach of these supporting roles, I focus in this chapter on animals, recognizing that other organisms (e.g., plants, bacteria, fungi, and protists) also have a key role, while taking in consideration the fact that animals can impact significantly primary productivity. Animals, regardless of the type of ecosystem, species, or functional types, influence ecosystems mainly through (1) predation, (2) foraging, (3) frugivory and seed dispersal, (4) grazing effects, (5)

nutrient deposition (e.g., defecation, urination), and (6) ecosystem engineering (Estes et al., 2011; Roman, 2023; Schmitz & Sylvén, 2023). Each one of these ecological processes that influence ecosystems have different impacts in one or more ecosystem functions, mainly (1) biological control, (2) pollination, (3) carbon sequestration, (4) fire regulation, (5) water regulation, and (6) nutrient cycling. Finally, these ecosystem functions determine the provision of (1) food productivity, (2) water provision and regulation for different purposes, (3) climate regulation, and (4) disease control (Fig. 4.2 and Table 4.1).

These four ecosystem services that species support are regulating services (Costanza et al., 2017; Millennium Ecosystem Assessment, 2005; TEEB, 2018). Even in the case of food production, rather than categorizing it as a provisioning service, in this context I consider it a regulating service, since we are interested in the changes in food productivity from changes in the animal’s population. This analysis could include provisioning services as well, although this would be a different assessment

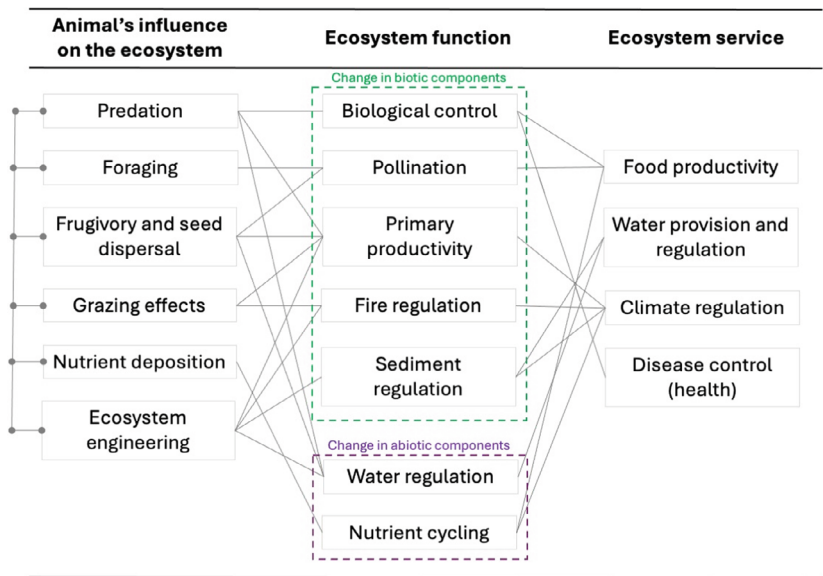


Fig. 4.2 Relational ways in which animals can influence ecosystems as well as the production of ecosystem functions and services. *Source* Author (2025)

Table 4.1 Examples of how species play a role in supporting the provision of ecosystem services (non-exhaustive list)

<i>Species Role on Supporting Ecosystem Services*</i>	<i>Example</i>	
1 Predation—Biological control—Disease control	Decrease in lions and leopards in sub-Saharan Africa has led to the increase of olive baboons, which transmitted intestinal parasites to humans	Brashares et al. (2010)
2 predation—Primary productivity—Climate regulation	Salamanders reduce invertebrate populations leading to increased leaf litter retention, increasing carbon storage	Best and Welsh (2014)
3 predation—Sediment regulation—Water regulation	Large predators maintain riparian plant communities and river morphology	Beschta & Ripple (2012)
4 predation—Primary productivity—Climate regulation	Sea otters control herbivory pressure from sea urchins on kelp forests	Estes & Palmisano (1974)
5 foraging—Pollination—Food productivity	Forest-based pollinators increased coffee yields by 20% within 1 km of forest, as well as improving coffee quality by reducing the frequency of peaberries by 27%	Ricketts et al. (2004)
6 grazing effects—Fire regulation—Climate regulation	Rinderpest decimated native ungulate populations in the late 1800s, causing an increase in plant biomass, fueling wildfires during the dry season	Holdo et al. (2009)
7 nutrient deposition—Primary productivity—Climate regulation	Whale feces transport limiting nutrients from the aphotic to photic zones, enhancing primary productivity and carbon sequestration, a process often called “the whale pump”	Roman & McCarthy (2010)
8 ecosystem engineering—Primary productivity—Climate regulation	African forest elephants reduce the density of trees smaller than 30 cm in diameter while moving through the forest and foraging, leading to the increase in the proportion and the average size of late succession trees with a higher carbon density	Berzaghi et al. (2022b)

(continued)

Table 4.1 (continued)

<i>Species Role on Supporting Ecosystem Services*</i>	<i>Example</i>	
9 ecosystem engineering—Sediment regulation—Multiple services	Burrows from fiddler crabs support the growth and production of the white mangrove	Smith et al. (2009)

*Sequence from the animal’s influence on the ecosystem to the production of ecosystem functions and services

because it would assess the extraction of the components from their ecosystem, rather the analysis on how the dynamics of these components support the provision of benefits. One could also consider cultural services, but from an economic point of view, the methods currently available to assess these services do not properly reflect the role of biodiversity in supporting those services (Farnsworth et al., 2015).

Nevertheless, it is worth highlighting that estimating the economic value of activities based on species, especially umbrella species (i.e., species whose conservation indirectly benefits a wide range of other species within their habitat or ecosystem), such as in Wei et al.’s (2018) assessment of the ecosystem services provided by giant panda reserves in China, can be an effective complement to this approach for policy making. In this particular example, instead of valuing pandas through their recreational and tourism benefits (estimated through a benefit transfer function based on contingent valuation surveys), and bequest and existing values (through contingent valuation), the approach I present here could focus, for example, on estimating the value of the influence of pandas on the ecosystem through bamboo consumption and its impact in these reserves in altering and/or maintaining the health of the ecosystem of these areas so they can provide different ecosystem services, such as those that Farnsworth et al. (2015) value (e.g., climate regulation, hydrologic benefits, and sediment retention)

It is worth saying that these interactions do not happen linearly or in isolation, making the examples of Table 4.1 a simplification of reality, but it is useful nevertheless for the purposes of better understanding the economic value of these species. Many of these interactions will produce a mix of ecosystem functions that depend on them (e.g., predation on herbivores to maintain plant biomass).

Also, it is important to take into consideration the timeframe and the main supplier of the ecosystem service. For example, Berzaghi et al. (2022) consider the carbon stored in the elephant populations, which is arguably more a flow than a stock, since this carbon will only be kept in the animals while they are alive (~60–70 years), and will end up in different stocks or flows depending on the pathway it follows after the animal dies. For example, carbon could accumulate in the ground, which I would then account as the contribution of elephants through nutrient deposition to nutrient cycling or primary productivity. On the other hand, part of the carbon could also transfer to other animals through consumption. Therefore, we need to model the potential pathways and quantities of stocks and flows of carbon so we can take this type of role into consideration.

Another key point to address in assessing the role of species in supporting the provision of ecosystem services is the role that keystone species play, which are the majority of examples in Table 4.1. Through their activities and abundance, keystone species have a disproportionately high impact on the stability of the ecosystem structure (Paine, 1969), and therefore on the production of ecosystem functions. Keystone species therefore maintain the health of an ecosystem by maintaining its structure and vigor, which in turn determines ecosystem's resilience. One of the most assessed roles of keystone species is their dynamic influence on the trophic level, often producing a cascade of effects (i.e., trophic cascades), which can be direct (e.g., predation) or indirect (e.g., behavioral changes) (Paine, 1995), as is the case in the majority of examples on predation in Table 4.1. Nevertheless, other types of keystone species that should also be considered into an economic analysis of the role of species in supporting ecosystem services are ecosystem engineers (examples 8 and 9 from Table 4.1), mutualists (example 5 from Table 4.1), and herbivores (example 6 from Table 4.1).

Finally, it is worth noting that the contribution of species to the ecosystem health and ecosystem services is multispatial, since one species can play a role in different types of ecosystems through different biological functions, which can have an economic impact, especially for local communities. For example, the parrot fish spends the majority of its time grazing on algae and other calcified surfaces in coral reefs, keeping the health of the ecosystem and therefore its resilience (Bellwood & Choat, 1990; Bonaldo et al., 2014). In their absence, the system would shift to another stable state (i.e., dominated by algae), and hence there would

be a significant change in some ecosystem functions, such as the provision of habitats for these and many other species, as well as in high valuable ecosystem services as tourism and recreation and as the provision of food (UN Environment et al., 2018). Aside from the role of grazers on coral reefs, parrotfish are also ecosystem engineers, playing a key role as bioerosion agents and therefore producing large quantities of carbonate sediment as a by-product of their grazing (Morgan & Kench, 2016). For example, in the Maldives, parrotfish generate more than 85% of the 5.7 kg/m² of new sand-grade sediment produced on the outer reef flat each year (Perry et al., 2015). This way, parrotfish contribute to the building of these islands that many people visit every year, and therefore their role on beaches also has a significant value (Fig. 4.3).

Stock and flow analyses can explain this multispatial influence on ecosystems for some species. For example, the supply (flow) of guano in Perú depends on the population (stock) of birds (e.g., Guanay Cormorants, Peruvian Pelicans, and Peruvian Boobies) producing guano (stock) (the nutrient deposition role). At the same time, the population depends on food availability, which in this case can come from different ecosystems, and therefore these stocks are multispatial. The case of guano collection is different from the other examples I have provided, which are

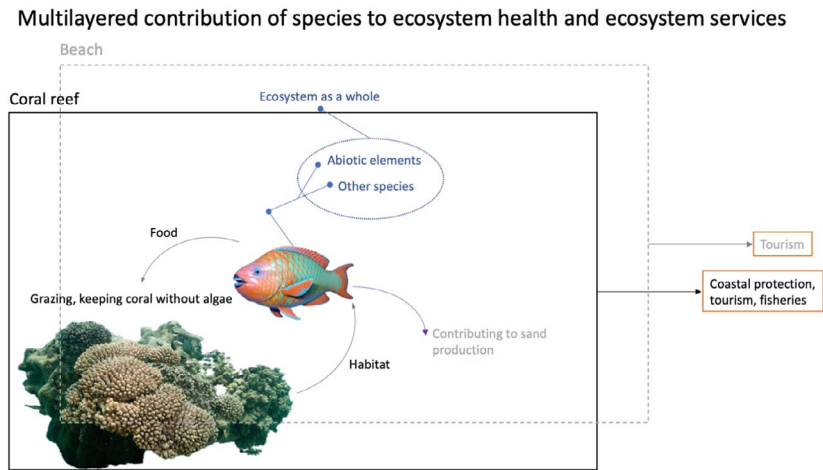


Fig. 4.3 Multispatial influence of parrotfish on two ecosystems, supporting the provision of different ecosystem services in each. *Source* Author (2025)

Multilayered contribution of species to ecosystem health and ecosystem services

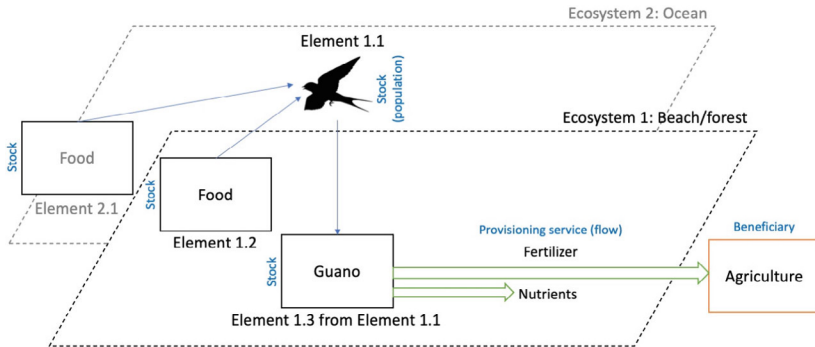


Fig. 4.4 Stock and flow schematic analysis of the multispatial influence of seabirds on terrestrial and marine ecosystems, which supports the production of guano that is used as a fertilizer in agriculture. *Source* Author (2025)

based on the support of regulating services, and in this case the analysis would be on the provisioning service of fertilizers for agriculture (Collins, 2022). Beyond the provisioning service, among other roles we could consider from seabirds (e.g., seed dispersal, predation), the nutrient deposition role is an interesting example of the multispatial influence of species because it links the dynamics of two ecosystems, where seabirds exports nutrients from the ocean (where they feed) to land (where they nest), and therefore it is a key nutrient subsidy for the health of latter (Fig. 4.4).

4.4 GENERAL METHODOLOGICAL FRAMEWORK TO ESTIMATE THE ECONOMIC VALUE OF SPECIES TO SOCIETY

The value of ecosystem services is the relative contribution of ecosystems to well-being (Turner et al., 2016). One can express this contribution in various units (any units of the four types of capitals), where monetary units are often the most used and convenient since most people understand values in these units.

Valuation allows a more efficient use of limited funds by identifying where environmental protection and restoration is economically most significant, also supporting the determination of the amount of compensation that should be paid for the degradation and/or loss of ecosystem services and improving the financial mechanisms (e.g., incentives) for the conservation and sustainable use of natural capital (e.g., payment for ecosystem services) (de Groot et al., 2012).

One can also estimate the value of ecosystem services by determining the cost to replicate them by artificial means (Costanza et al., 1997), for example calculating how much it would cost for farmers to pollinate their crops artificially. It is useful to attempt to calculate the impact on human well-being from changes in quantity or quality of natural capital that can occur due to different development decisions.

Valuation is therefore a tool for evaluating the trade-offs required to achieve a shared goal. These trade-offs are currently addressed mainly through marketed goods and services (e.g., fuel or food) using commodity prices, leaving out of the equation other goods and services that do not have a price but that contribute equally or even more greatly to human well-being (e.g., coastal protection, erosion prevention, pollination, and intrinsic values) (Turner et al., 2016). Moreover, economic literature has not extensively assessed the role that species play in supporting these services. I propose the following general methodological framework to estimate the economic value of this role, consisting of a five-step process.

Step 1. Select the species of interest

The first step is to choose the species whose contribution to ecosystem functions will be valued economically. This can be done in different ways, and can also depend on the context and policy objectives of which the study is embedded in, but the following selection criteria can provide some guidance: (1) Status of the population (especially if it is vulnerable or endangered), (2) potential changes in population in the future, (3) whether the species is a keystone species and/or umbrella species, (4) if there are already ecological and economic data that can be used in the analysis, and (5) the level of dependency from human beneficiaries on the functions that these species support.

Step 2. Set the spatial scope

This involves setting the physical and ecological limits within the ecosystem(s) of interest. The range of the selected species needs to be mapped, considering all the possible biotic and abiotic components of the structure of the system (1) in which the species depend on, and (2) have an impact on (recognizing that on many occasions these two would be the same). It is important to recognize that the limits of the study will be arbitrary to some degree since such limits do not really exist in nature.

Step 3. Identify the role the species play in supporting ecosystem

functions.

From an economic perspective, this means estimating the supply. A dynamic ecological model can identify the interactions of the targeted species with other biotic and abiotic elements of the ecosystem. This could also include, among other things, a trophic dynamics analysis (i.e., understand the transfer of energy and nutrients across different trophic levels in an ecosystem). The goal is to identify the roles of the species (as Table 4.1 lists) in supporting ecosystem functions in the spatial scope of the study, or to determine if the species has an impact on a partial or complete bundle of functions (e.g., sea otters protect the entire bundle of functions and services provided by kelp forests).

Step 4. Identify the main beneficiaries of the supported functions

The beneficiaries of the functions supported by the selected species represent the demand, which will lead to the identification and prioritization of the ecosystem services. The role of the species will be then a portion of the value of these ecosystem services.

Step 5. Conduct the economic analysis

Finally, depending on the function that the species supports, there are two types of economic methods that are the most appropriate to use (Farnsworth et al., 2015). On one hand, production approaches estimate the economic value of the service based on its impact on

economic outputs, such as in the case of an increase availability of nutrients from the whale pump and its impact on the productivity of the local fishing industry. On the other hand, cost-based approaches, such as replacement cost (e.g., public health strategies to substitute the biological/disease control that species such as lions perform at no monetary cost to humans) and avoided cost (e.g., species like beavers can significantly support healthy ecosystems, such as wetlands, which mitigate damage to public and private property from extreme weather events), can also estimate the role of species on the provision of ecosystem services (Hernández-Blanco & Costanza, 2019; Turner et al., 2016) (Table 4.2).

The main goal is to measure the change of benefits under different scenarios using the dynamic ecological model from Step 3. Both natural and anthropogenic drivers of change can modify the stocks and flows of this model, which will impact the species population and consequently the value of species contribution to the provision of ecosystem services. Examples of scenarios that can be modeled include Business-as-Usual (baseline scenario that assumes current trends and practices continue without significant changes), rewilding efforts, conserving current population, population decrease (at different levels), and local extinction, among others. Ideally, participatory approaches to scenario planning with a wide set of actors will complement the modeling of the selected scenarios, including especially the beneficiaries of the services dependent on the selected species for the assessment, and those who might bear the costs of the changes in the species population (including human-wildlife conflicts).

There are other similar methodological approaches in the literature, most notably the one from Daniels et al. (2018). Nevertheless, the approach I present here differs in two main points. The first one is that

Table 4.2 Economic valuation methods to use for each of the ecosystem services described in this analysis that are dependent on the role of one or more species

<i>Ecosystem Service Supported by Selected Species</i>	<i>Production Approach</i>	<i>Cost-Based Approaches</i>
Food productivity	X	
Water provision and regulation	X	
Climate regulation		X
Disease control		X

Daniels et al. (2018) focus on functional groups rather than species, which can represent both benefits and limitations. The second difference is that their approach considers only marketed services, while the approach presented here considers both marketed and non-marketed services.

4.5 CONCLUSION

Traditional economic frameworks have largely neglected the value of species' contributions in maintaining ecosystem health and supporting the provision of critical ecosystem services that benefit people and the rest of nature, which results in severe market failures and a persistent underfunding of conservation efforts. To address this, I provide a detailed explanation of how to assess the role of a species in the production of benefits to society, based on the concept of ecosystem health, rather than isolating a species as the sole unit of analysis of ecosystem services. Although I focused primarily on animals, especially keystone species, the analytical framework developed here can apply to other organisms as well (e.g., flora, bacteria, and fungi). The framework includes a five-step general method to value economically these contributions and therefore helps to close the research gap on this topic.

The use of economic values derived from the contribution of species to the provision of ecosystem services requires some important considerations. First, one should not conceive valuation assessments as an end in itself; rather, they need to be directed towards a policy or business decision (Barbier et al., 1997). For example, species contributions to human well-being can be considered in decisions such as the costs and benefits of rewilding, climate change mitigation, and adaptation strategies and trade-offs in changing production schemes (e.g., conventional agriculture versus regenerative agriculture), among many others. Second, economic assessments should not be the only tool or criteria considered in making a decision about nature conservation. Therefore, these assessments need to incorporate other key criteria such as the intrinsic value of species and ecosystems in terms of culture and spiritual benefits, particularly for Indigenous peoples and local communities (de Groot et al., 2006). Pluralistic value frameworks such as the one from IPBES (2022) provide an important guidance on balancing the different types of values that people assign to nature depending on different life frames.

The recognition and valuation of the contribution of species to the provision of ecosystem services is fundamental to developing novel financial solutions for their conservation, restoration, and sustainable use. For example, the framework that I present here can help create biodiversity credit schemes based on rewilding land and seascapes with keystone species in ecosystems where they are critically endangered or locally extinct. By proving the economic benefits of rewilding and protecting keystone species, this framework can also support financial tools aimed to compensate and/or help adapt people and their livelihoods from higher interactions with wildlife (i.e., human-wildlife conflicts) that are the result of a significant increase of the individuals of a population of animals (e.g., increase of wolf population would demand higher costs for cattle ranchers in terms of fencing) from these efforts.

Applying the framework described here, both from an ecological and socio-economic perspective, has the ultimate goal of helping society visualize a symbiotic development with nature, with a true local and global stewardship of each component and interaction between species and ecosystems that sustain Earth's life support system for the prosperity of people and the rest of nature.

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