Pollination by a bumblebee, a type of ecosystem service

Humankind benefits from a multitude of resources and processes that are supplied by natural ecosystems. Collectively, these benefits are known as **ecosystem services** and include products like clean drinking water and processes such as the decomposition of wastes. While scientists and environmentalists have discussed ecosystem services for decades, these services were popularized and their definitions formalized by the United Nations 2004 Millennium Ecosystem Assessment (MA), a four-year study involving more than 1,300 scientists worldwide. [1]

This grouped ecosystem services into four broad categories: *provisioning*, such as the production of food and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and crop pollination; and *cultural*, such as spiritual and recreational benefits.

As human populations grow, so do the resource demands imposed on ecosystems and the impacts of our global footprint. Natural resources are not invulnerable and infinitely available. The environmental impacts of anthropogenic actions, which are processes or materials derived from human activities, are becoming more apparent – air and water quality are increasingly compromised, oceans are being overfished, pests and diseases are extending beyond their historical boundaries, and deforestation is exacerbating flooding downstream. It has been reported that approximately 40-50% of Earth's ice-free land surface has been heavily transformed or degraded by anthropogenic activities, 66% of marine fisheries are either overexploited or at their limit, atmospheric CO_2 has increased more than 30% since the advent of industrialization, and nearly 25% of Earth's bird species have gone extinct in the last two thousand years [2]. Society is increasingly becoming aware that ecosystem services are not only limited, but also that they are threatened by human activities. The need to better consider long-term ecosystem health and its role in enabling human habitation and economic activity is urgent. To help inform decision-makers, many ecosystem services are being assigned economic values, often based on the cost of replacement with anthropogenic alternatives. The ongoing challenge of prescribing economic value to nature, for example through biodiversity banking, is prompting transdisciplinary shifts in how we recognize and manage the environment, social responsibility, business opportunities, and our future as a species.

Contents

A brief history

The simple notion of human dependence on Earth's ecosystems probably reaches to the start of our species' existence, when we benefited from the products of nature to nourish our bodies and for shelter from harsh climates. Recognition of how ecosystems could provide more complex services to mankind date back to at least Plato (c. 400 BC) who understood that deforestation could lead to soil erosion and the drying of springs [3]. However, modern ideas of ecosystem services probably began with Marsh in 1864 [4] when he challenged the idea that Earth's natural resources are not infinite by pointing out changes in soil fertility in the Mediterranean. Unfortunately, his observations and cautions passed largely unnoticed at the time and it was not until the late 1940s that society's attention was again brought to the matter. During this era, three key authors – Osborn [5

], Vogt [6], and Leopold [7] – awakened and promoted recognition of human dependence on the environment with the idea of ‘natural capital’. In 1956, Sears [8] drew attention to the critical role of the ecosystem in processing wastes and recycling nutrients. An environmental science textbook [9] called attention to “the most subtle and dangerous threat to man’s existence… the potential destruction, by man’s own activities, of those ecological systems upon which the very existence of the human species depends”. The term ‘environmental services’ was finally introduced in a report of the *Study of Critical Environmental Problems* [10], which listed services including insect pollination, fisheries, climate regulation and flood control. In following years, variations of the term were used, but eventually ‘ecosystem services’ became the standard in scientific literature. [11]

Modern expansions of the ecosystem services concept include socio-economic and conservation objectives, which are discussed below. For a more complete history of the concepts and terminology of ecosystem services, see Daily (1997) [3].

Examples

Detritivores like this dung beetle help to turn animal wastes into organic material that can be reused by primary producers.

Experts currently recognize four categories of ecosystem services. [1] The following lists represent samples of each:

Provisioning services • food (including seafood and game), crops, wild foods, and spices• water• pharmaceuticals, biochemicals, and industrial products• energy (hydropower, biomass fuels) *Regulating services* • carbon sequestration and climate regulation• waste decomposition and detoxification• purification of water and air• crop pollination• pest and disease control *Supporting services* • nutrient dispersal and cycling• seed dispersal• Primary production
Cultural services
• cultural, intellectual and spiritual inspiration• recreational experiences (including ecotourism)• scientific discovery

To understand the relationships between humans and natural ecosystems through the services derived from them, consider the following cases:

• In New York City, where the quality of drinking water had fallen below standards required by the U.S. Environmental Protection Agency (EPA), authorities opted to restore the polluted Catskill Watershed that had previously provided the city with the ecosystem service of water purification. Once the input of sewage and pesticides to the watershed area was reduced, natural abiotic processes such as soil adsorption and filtration of chemicals, together with biotic recycling via root systems and soil microorganisms, water quality improved to levels that met government standards. The cost of this investment in natural capital was estimated between $1-1.5 billion, which contrasted dramatically with the estimated $6-8 billion cost of constructing a water filtration plant plus the $300 million annual running costs. [12] • Pollination of crops by bees is required for 15-30% of U.S. food production; most large-scale farmers import non-native honey bees to provide this service. One study
[

13
]
reports that in California’s agricultural region, it was found that wild bees alone could provide partial or complete pollination services or enhance the services provided by honey bees through behavioral interactions. However, intensified agricultural practices can quickly erode pollination services through the loss of species and those remaining are unable to compensate for the difference. The results of this study also indicate that the proportion of chaparral and oak-woodland habitat available for wild bees within 1-2 km of a farm can strongly stabilize and enhance the provision of pollination services, thereby providing a potential insurance policy for farmers of this region.• In watersheds of the Yangtze River (China), spatial models for water flow through different forest habitats were created to determine potential contributions for hydroelectric power in the region. By quantifying the relative value of ecological parameters (vegetation-soil-slope complexes), researchers were able to estimate the annual economic benefit of maintaining forests in the watershed for power services to be 2.2 times that if it were harvested once for timber.
[
14
]

• In the 1980s, mineral water company Vittel (now a brand of Nestlé Waters) faced a critical problem. Nitrates and pesticides were entering the company’s springs in northeastern France. Local farmers had intensified agricultural practices and cleared native vegetation that previously had filtered water before it seeped into the aquifer used by Vittel. This contamination threatened the company’s right to use the “natural mineral water” label under French law.
[
15
]

In response to this business risk, Vittel developed an incentive package for farmers to improve their agricultural practices and consequently reduce water pollution that had affected Vittel's product. For example, Vittel provided subsidies and free technical assistance to farmers in exchange for farmers' agreement to enhance pasture management, reforest catchments, and reduce the use of agrochemicals. This is an example of a Payment for ecosystem services program.
[
16
]

Ecology

Understanding of ecosystem services requires a strong foundation in ecology , which describes the underlying principles and interactions of organisms and the environment . Since the scales at which these entities interact can vary from microbes to landscapes, milliseconds to millions of years, one of the greatest remaining challenges is the descriptive characterization of energy and material flow between them. For example, the area of a forest floor, the detritus upon it, the microorganisms in the soil and characteristics of the soil itself will all contribute to the abilities of that forest for providing ecosystem services like carbon sequestration, water purification, and erosion prevention to other areas within the watershed. Note that it is often possible for multiple services to be bundled together and when benefits of targeted objectives are secured, there may also be ancillary benefits – the same forest may provide habitat for other organisms as well as human recreation, which are also ecosystem services.

The complexity of Earth's ecosystems poses a challenge for scientists as they try to understand how relationships are interwoven among organisms, processes and their surroundings. As it relates to human ecology, a suggested research agenda [13] for the study of ecosystem services includes the following steps:

1. identification of *ecosystem service providers* (*ESP*s) – species or populations that provide specific ecosystem services – and characterization of their functional roles and relationships;
2. determination of community structure aspects that influence how ESPs function in their natural landscape, such as compensatory responses that stabilize function and non-random extinction sequences which can erode it;
3. assessment of key environmental (abiotic) factors influencing the provision of services;
4. measurement of the spatial and temporal scales ESPs and their services operate on.

Recently, a technique has been developed to improve and standardize the evaluation of ESP functionality by quantifying the relative importance of different species in terms of their efficiency and abundance. [17] Such parameters provide indications of how species respond to changes in the environment (i.e. predators, resource availability, climate) and are useful for identifying species that are disproportionately important at providing ecosystem services. However, a critical drawback is that the technique does not account for the effects of interactions, which are often both complex and fundamental in maintaining an ecosystem and can involve species that are not readily detected as a priority. Even so, estimating the functional structure of an ecosystem and combining it with information about individual species traits can help us understand the resilience of an ecosystem amidst environmental change.

Many ecologists also believe that the provision of ecosystem services can be stabilized with biodiversity. Increasing biodiversity also benefits the variety of ecosystem services available to society. Understanding the relationship between biodiversity and an ecosystem's stability is essential to the management of natural resources and their services.

The redundancy hypothesis

The concept of ecological redundancy is sometimes referred to as *functional compensation* and assumes that more than one species performs a given role within an ecosystem. [18] More specifically, it is characterized by a particular species increasing its efficiency at providing a service when conditions are stressed in order to maintain aggregate stability in the ecosystem. [19] However, such increased dependence on a compensating species places additional stress on the ecosystem and often enhances its susceptibility to subsequent disturbance. The redundancy hypothesis can be summarized as "species redundancy enhances ecosystem resilience". [20]

The rivet hypothesis

Another idea uses the analogy of rivets in an airplane wing to compare the exponential effect the loss of each species will have on the function of an ecosystem; this is sometimes referred to as *rivet popping*. [21] If only one species disappears, the efficiency of the ecosystem as a whole is relatively small; however if several species are lost, the system essentially collapses as an airplane wing would, were it to lose too many rivets. The hypothesis assumes that species are relatively specialized in their roles and that their ability to compensate for one another is less than in the redundancy hypothesis. As a result, the loss of any species is critical to the performance of the ecosystem. The key difference is the rate at which the loss of species affects total ecosystem function.

The portfolio effect

A third explanation, known as the *portfolio effect*, compares biodiversity to stock holdings, where diversification minimizes the volatility of the investment, or in this case, the risk in stability of ecosystem services. [22] This is related to the idea of *response diversity* where a suite of species will exhibit differential responses to a given environmental perturbation and therefore when considered together, they create a stabilizing function that preserves the integrity of a service.

[23]

Several experiments have tested these hypotheses in both the field and the lab. In ECOTRON, a laboratory in the UK where many of the biotic and abiotic factors of nature can be simulated, studies have focused on the effects of earthworms and symbiotic bacteria on plant roots. [21] These laboratory experiments seem to favor the rivet hypothesis. However, a study on grasslands at Cedar Creek Reserve in Minnesota seems to support the redundancy hypothesis, as have many other field studies. [24]

Economics

Further information: environmental economics , ecological economics , environmental ethics , deep ecology

There is extensive disagreement regarding the environmental and economic values of ecosystem services. Some people may be unaware of the environment in general and humanity's interrelatedness with the natural environment, which may cause misconceptions. Although environmental awareness is rapidly improving in our contemporary world, ecosystem capital and its flow are still poorly understood, threats continue to impose, and we suffer from the so-called ‘tragedy of the commons’. [25] Many efforts to inform decision-makers of current versus future costs and benefits now involve organizing and translating scientific knowledge to economics, which articulate the consequences of our choices in comparable units of impact on human well-being. [26] An especially challenging aspect of this process is that interpreting ecological information collected from one spatial-temporal scale does not necessarily mean it can be applied at another; understanding the dynamics of ecological processes relative to ecosystem services is essential in aiding economic decisions. [27] Weighting factors such as a service’s irreplaceability or bundled services can also allocate economic value such that goal attainment becomes more efficient.

Management and policy

Although monetary pricing continues with respect to the valuation of ecosystem services, the challenges in policy implementation and management are significant and multitudinous. The administration of common pool resources is a subject of extensive academic pursuit. [29] [30] [31] [32] [33]

From defining the problems to finding solutions that can be applied in practical and sustainable ways, there is much to overcome. Considering options must balance present and future human needs, and decision-makers must frequently work from valid but incomplete information. Existing legal policies are often considered insufficient since they typically pertain to human health-based standards that are mismatched with necessary means to protect ecosystem health and services. To improve the information available, one suggestion has involved the implementation of an *Ecosystem Services Framework*

(ESF [34]), which integrates the biophysical and socio-economic dimensions of protecting the environment and is designed to guide institutions through multidisciplinary information and jargon, helping to direct strategic choices.

Novel and expedient methods are needed to deal with managing Earth's ecosystem services. Local to regional collective management efforts might be considered appropriate for services like crop pollination or resources like water. [13] [29] Another approach that has become increasingly popular over the last decade is the marketing of ecosystem services protection. Payment and trading of services is an emerging worldwide small-scale solution where one can acquire credits for activities such as sponsoring the protection of carbon sequestration sources or the restoration of ecosystem service providers. In some cases, banks for handling such credits have been established and conservation companies have even gone public on stock exchanges, defining an evermore parallel link with economic endeavors and opportunities for tying into social perceptions. [26] However, concerns for such global transactions include inconsistent compensation for services or resources sacrificed elsewhere and misconceived warrants for irresponsible use. Another approach has been focused on protecting ecosystem service 'hotspots'. Recognition that the conservation of many ecosystem services aligns with more traditional conservation goals (i.e. biodiversity) has led to the suggested merging of objectives for maximizing their mutual success. This may be particularly strategic when employing networks that permit the flow of services across landscapes, and might also facilitate securing the financial means to protect services through a diversification of investors. [35] [36]

Ecosystem services and business

Ecosystem services degradation can pose a number of risks to corporate performance as well as provide business opportunities through ecosystem restoration and enhancement. Risks and opportunities include:

Operational Risks such as higher costs for freshwater due to scarcity or lower output for hydroelectric facilities due to siltationOpportunities such as increasing water-use efficiency or building an on-site wetland to circumvent the need for new water treatment infrastructure
Regulatory and legal
Risks such as new fines, government regulations, or lawsuits from local communities that lose ecosystem services due to corporate activitiesOpportunities such as engaging governments to develop policies and incentives to protect or restore ecosystems that provide services a company needs
Reputational
Risks such as retail companies being targeted by nongovernmental organization campaigns for purchasing wood or paper from sensitive forestsOpportunities such as implementing and communicating sustainable purchasing, operating, or investment practices in order to differentiate corporate brands
Market and product
Risks such as customers switching to other suppliers that offer products with lower ecosystem impacts or governments implementing new sustainable procurement policiesOpportunities such as launching new products and services that reduce customer impacts on ecosystems or participating in emerging markets for carbon sequestration and watershed protection other products
Financing
Risks such as banks implementing more rigorous lending requirements for corporate loansOpportunities such as banks offering more favorable loan terms or investors taking positions in companies supplying products and services that improve resource use efficiency or restore degraded ecosystems

Many companies are not fully aware of the extent of their dependence and impact on ecosystems and the possible ramifications. Likewise, environmental management systems and environmental due diligence tools are more suited to handle “traditional” issues of pollution and natural resource consumption. Most focus on environmental impacts, not dependence. Several newly-developed tools and methodologies can help the private sector value and assess ecosystem services. These include the Corporate Ecosystem Services Review (ESR), [37] Artificial Intelligence for Ecosystem Services (ARIES), [38] and the Natural Value Initiative (NVI). [39]

See also

- Biodiversity
- Deep ecology
- Diversity-function debate

- Ecological economics
- Ecological effects of biodiversity
- Ecological goods and services
- Ecosystem
- Ecosystem ecology
- Environmental ethics
- Environmental finance
- Existence value
- Forest farming
- Nature's services
- Non-timber forest products
- Payment for ecosystem services

References

1. ^ a b Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington. 155pp.
2. ^ Vitousek, P.M., J. Lubchenco, H.A. Mooney, J. Melillo. 1997. Human domination of Earth's ecosystems. Science 277: 494-499.
3. ^ a b Daily, G.C. 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington. 392pp.
4. ^ Marsh, G.P. 1864 (1965). Man and Nature. Charles Scribner, New York. 472pp.
5. ^ Osborn, F. 1948. Our Plundered Planet. Little, Brown and Company: Boston. 217pp.
6. ^ Vogt, W. 1948. Road to Survival. William Sloan: New York. 335pp.
7. ^ Leopold, A. 1949. A Sand County Almanac and Sketches from Here and There. Oxford University Press, New York. 226pp.
8. ^ Sears, P.B. 1956. "The processes of environmental change by man." *In*: W.L. Thomas, editor. Man's Role in Changing the Face of the Earth (Volume 2). University of Chicago Press, Chicago. 1193pp.

9. ^ Ehrlich, P.R. and A. Ehrlich. 1970. Population, Resources, Environment: Issues in Human Ecology. W.H. Freeman, San Francisco. 383pp. - see p.157
10. ^ Study of Critical Environmental Problems (SCEP). 1970. Man's Impact on the Global Environment. MIT Press, Cambridge. 319pp.
11. ^ Ehrlich, P.R. and A. Ehrlich. 1981. Extinction: The Causes and Consequences of the Disappearance of Species. Random House, New York. 305pp.
12. ^ Chichilnisky, G. and G. Heal. 1998. Economic returns from the biosphere. Nature 391: 629-630.
13. ^ a b c Kremen, C. 2005. Managing ecosystem services: what do we need to know about their ecology? Ecology Letters 8: 468-479.
14. ^ Guo, Z.W., X.M. Xio and D.M. Li. 2000. An assessment of ecosystem services: water flow regulation and hydroelectric power production. Ecological Applications 10: 925-936.

15. ^ Hanson, C, J Ranganathan, C Iceland, and J Finisdore. (2008) The Corporate Ecosystem Services Review (Version 1.0). World Resources Institute.

16. ^ Perrot-Maître, D. (2006) The Vittel payments for ecosystem services: a "perfect" PES case? International Institute for Environment and Development, London , UK.
17. ^ Balvanera, P. C. Kremen, and M. Martinez. 2005. Applying community structure analysis to ecosystem function: examples from pollination and carbon storage. Ecological Applications 15: 360-375.
18. ^ Walker, B.H. 1992. "Biodiversity and ecological redundancy." Conservation Biology 6: 18-23.
19. ^ Frost, T.M., S.R. Carpenter, A.R. Ives, and T.K. Kratz. 1995. "Species compensation and complementarity in ecosystem function." *In*: C. Jones and J. Lawton, editors. Linking species and ecosystems. Chapman and Hall, London. 387pp.
20. ^ Naeem S. 1998. "Species redundancy and ecosystem reliability" Conservation Biology 12: 39–45.
21. ^ *a* *b* Lawton, J.H. 1994. What do species do in ecosystems? Oikos 71: 367-374.
22. ^ Tilman, D., C.L. Lehman, and C.E. Bristow. 1998. Diversity-stability relationships: statistical inevitability or ecological consequence? The American Naturalist 151: 277-282.
23. ^ Elmqvist, T., C. Folke, M. Nyström, G. Peterson, J. Bengtsson, B. Walker and J. Norberg. 2003. Response diversity, ecosystem change and resilience. Frontiers in Ecology and the Environment 1: 488-494.
24. ^ Grime, J.P. 1997. "Biodiversity and ecosystem function: The debate deepened." Science 277
25. ^ Hardin, G. 1968. The tragedy of the commons. Science 162: 1243-1248.
26. ^ *a* *b* Daily, G.C., T. Söderqvist, S. Aniyar, K. Arrow, P. Dasgupta, P.R. Ehrlich, C. Folke, A. Jansson, B. Jansson, N. Kautsky, S. Levin, J. Lubchenco, K. Mäler, D. Simpson, D. Starrett, D. Tilman, and B. Walker. 2000. The value of nature and the nature of value. Science 289: 395-396.
27. ^ DeFries, R.S., J.A. Foley, and G.P. Asner. 2004. Land-use choices: balancing human needs and ecosystem function. Frontiers in Ecology and the Environment 2: 249-257.
28. ^ Farber, S.C., R. Costanza and M.A. Wilson. 2002. Economic and ecological concepts for valuing ecosystem services. Ecological Economics 41: 375-392.
29. ^ *a* *b* Ostrom, E. 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge. 279pp.
30. ^ Dietz, T. E. Ostrom and P.C. Stern. 2003. The struggle to govern the commons. Science 302: 1907-1912.
31. ^ Pretty, J. 2003. Social capital and the collective management of resources. Science 302: 1912-1914.
32. ^ Heikkila, T. 2004. Institutional boundaries and common-pool resource management: a comparative analysis of water management programs in California. Journal of Policy Analysis and Management 23: 97-117.
33. ^ Gibson, C.C., J.T. Williams and E. Ostrom. 2005. Local management and better forests. World Development 33: 273-284.
34. ^ Daily, G.C. 2000. Management objectives for the protection of ecosystem services. Environmental Science & Policy 3: 333-339.
35. ^ Balvanera, P., G.C. Daily, P.R. Ehrlich, T.H. Ricketts, S.Bailey, S. Kark, C. Kremen

and H. Pereira. 2001. Conserving biodiversity and ecosystem services. Science 291: 2047.

36. ^ Chan, K.M.A., M.R. Shaw, D.R. Cameron, E.C. Underwood and G.C. Daily. 2006. Conservation planning for ecosystem services. PLoS Biology 4: 2138-2152.
37. ^ Hanson, C, J Ranganathan, C Iceland, and J Finisdore. (2008) The Corporate Ecosystem Services Review (Version 1.0). World Resources Institute. http://www.wri.org/project/ecosystem-services-review

38. ^ http://esd.uvm.edu/
39. ^ http://www.naturalvalueinitiative.org/

External links

- US Forest Service - Ecosystem Services
- COHAB Initiative on Health and Biodiversity - Ecosystems and Human Well-being
- Millennium Ecosystem Assessment
- Earth Economics
- The ARIES Consortium
- The Ecosystem Marketplace
- IUCN (World Conservation Union) on EcoSystem Services
- Green Facts (Non Government Organisation) Glossary re: Eco-system Services
- World Resources Institute: Ecosystems
- Water evaluation and planning (WEAP) system for modeling impacts on aquatic ecosystem services