SPECIAL FEATURE: PERSPECTIVE

Setting the bar: Standards for ecosystem services

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Progress in ecosystem service science has been rapid, and there is now a healthy appetite among key public and private sector decision makers for this science. However, changing policy and management is a long-term project, one that raises a number of specific practical challenges. One impediment to broad adoption of ecosystem service information is the lack of standards that define terminology, acceptable data and methods, and reporting requirements. Ecosystem service standards should be tailored to specific use contexts, such as national income and wealth accounts, corporate sustainability reporting, land-use planning, and environmental impact assessments. Many standard-setting organizations already exist, and the research community will make the most headway toward rapid uptake of ecosystem service science by working directly with these organizations. Progress has been made in aligning with existing organizations in areas such as product certification and sustainability reporting, but a major challenge remains in mainstreaming ecosystem service information into core public and private use contexts, such as agricultural and energy subsidy design, national income accounts, and corporate accounts.

natural capital | mainstreaming | accounting | service provision | value

In the decade since the Millennium Ecosystem Assessment (1), there has been wide uptake of the concept of ecosystem services in both science and policy communities. In 2012, 118 countries became signatories to the formation of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), with a mission to assess the state of the planet's biodiversity, its ecosystems, and the essential services they provide to society. Statements about the importance of ecosystem services have been made by groups ranging from conservation organizations to corporations. Rapid progress also has been made in the science of assessing the provision of ecosystem services and its contribution to human well-being (e.g., refs. 2–7).

There is also widespread recognition of the importance of going beyond the concept to mainstreaming ecosystem services: the practice of routinely incorporating ecosystem services information into public and private decision-making processes (8–11). For example, the World Business Council for Sustainable Development states that an essential condition for creating a sustainable future is to "incorporate the costs of externalities, starting with carbon, ecosystem services, and water, into the structure of the marketplace" (12).

Even with progress in the research community and widespread recognition of the importance of ecosystem services, changing practice and management on the ground is a long-term project requiring successfully addressing a number of challenges (13, 14). The current economic system provides minimal incentives for businesses or consumers to conserve the natural capital necessary for the sustainable provision of services (15). The majority of ecosystem services have declined in recent decades (1) whereas a small subset of marketed services for which suppliers receive payment have increased, further highlighting the importance of mainstreaming (15).

One impediment to rapid mainstreaming of ecosystem services stems from the proliferation of definitions, conceptual frameworks, approaches, datasets, and models within the research community (1, 9, 16–29). A recent review of ecosystem service definitions found at least 10 different formulations (30). Although some confusion is to be expected in a dynamic and growing field, the lack of agreement in the research community makes it difficult for practitioners to know how to act. Most decisions makers do not have the time or the technical expertise to sort out conflicting claims in published literature and determine the best approach for their application.

In other fields, standards administered by a well-respected neutral organization such as the United Nations Statistical Commission or the International Standards Organization (ISO) created confidence in the use of scientific information and allowed for wide uptake. Here, we call for the establishment of standards for ecosystem services in hopes of achieving similar advances.

Such standards cannot come too soon. The demand for ecosystem service information is increasing rapidly. The International Finance Corporation, an entity in the World Bank that makes loans to the private sector, now requires information about impacts on ecosystem services in environmental impact assessments on loan applications (31). As of 2014, 43 financial sector businesses had signed the Natural Capital Declaration to "incorporate natural capital considerations into loans, equity, fixed income and insurance products, as well as in accounting, disclosure and reporting frameworks" (32). At least 69 countries have committed to accounting for natural capital in national income and wealth accounts (33). There is also rapid growth in the number of payments for ecosystem services (PES) programs and calls for including ecosystem services into development projects, land-use assessment, planning, and zoning (e.g., refs. 34–36).

The Cost of Confusion and Inconsistency

The current situation in ecosystem service science mirrors other nascent fields where scientific or technical information is relevant to policy or management. These cases show how a lack of standards impedes uptake of information and

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contributes to a lack of progress in fields ranging from macroeconomics to medicine.

Before the 1930s, governments lacked basic information on economic performance. The Great Depression led governments to demand the reporting of economic statistics to speed recovery and avoid future depressions. Simon Kuznets led a team at the National Bureau of Economic Research in developing national income and product accounts for the United States. These accounts gained traction outside the United States through the design of new international institutions near the end of World War II and became international standards codified in the System of National Accounts (37). The System of National Accounts is updated periodically to reflect advances in methods, new data, or new circumstances, a process overseen by the United Nations Statistics Commission. The economic accounts provide an example of the role of standards in fostering broad uptake, even though the field continues to advance the underlying theory, methods, and data.

Similarly, life cycle assessment (LCA), now a formalized and standardized analysis, has not always been so. Energy crises and focus on waste reduction in the 1970s and 1980s led to a proliferation of methods for estimating a product's energy and material requirements and environmental impacts. Over time, these assessments coalesced into LCA. The early days of LCA provide a striking example of how lack of standards can lead to abuse in practice. Several product manufacturers were accused of manipulating LCA to make inappropriate marketing claims. In 1991, 11 state attorneys general sought to ban use of LCA until a uniform method was established to prevent abuse. LCA standards now exist and are updated regularly by the International Standards Organization (ISO).

A dramatic case of the failure to set standards, which contributed to needless illness and death, comes from the medical field. In 1847, Hungarian physician Ignaz Semmelweis made the link between physicians practicing with dirty hands and infant mortality. By instituting hand washing, Semmelweis reduced the rate of a common disease in newborns from 10% to 1%. His idea that hand washing could reduce disease was so controversial that Semmelweis was fired. His colleagues and wife believed he was mentally unstable, and he was admitted to an insane asylum. Although others after him, like Louis Pasteur, strengthened the science showing a link between cleanliness and reduced disease, it took nearly 150 y for this knowledge to be translated into standards. The first publication of national hospital guidelines did not occur until 1981 (38).

Standards

Simply put, a standard specifies what constitutes acceptable practice. Standards can be used to define terminology, determine which data, methods and approaches are acceptable, specify the degree of accuracy or certainty required, and specify the format for reporting results, among other things. Having widely agreed-upon standards facilitates adoption of best practices, allows for learning and rewards for good performance, and can improve the quality and reliability of results.

The use of standards may be mandatory (established to allow entities to meet statutory requirements) or voluntary (as in many certification schemes). In a few contexts, inclusion of ecosystem services information is already mandatory. For example, strict standards govern the exchange of carbon credits. Alternatively, corporate sustainability reporting is currently voluntary. The Sustainable Accounting Standards Board (SASB) publishes standards for sustainability accounting by corporations, but there is no regulatory requirement for corporations to adopt these standards. For these standards to become mandatory, an entity like the Securities and Exchange Commission in the United States would have to make them a requirement. Existing voluntary standards may evolve and become mandatory (e.g., the United Kingdom may adopt SASB standards in 2020 when corporations will be required to report on natural capital).

Use Contexts

There is no "one size fits all" set of standards for ecosystem services. Effective mainstreaming of ecosystem service information starts with the needs of a particular use context and defines an appropriate standard for that context.

We define a use context as a specific process undertaken by a specific entity for a specific purpose. Examples of use contexts include national income accounting, land-use planning, and corporate supply chain assessment.

Even when the underlying science needed is similar, the application of the information often differs by use case. For example, life cycle assessment and land-use planning both consider information about multiple ecosystem processes and impacts, but they organize information differently. LCA describes impacts through the supply chain of a particular product and may cross multiple geographies. Land-use planning relies on information about impacts at a particular place and may include multiple products. Although much of the underlying science applies to both LCA and land-use planning, applying the existing LCA standards to land-use planning, or vice versa, would not make sense.

Corporate accounts and national income accounts also require similar types of information, but separate standards supported by separate authorities exist for each. The International Accounting Standards Board maintains standards for income and asset accounting for businesses. In many countries, an in-country government agency modifies the international standard. In the United States, corporate accounting rules for publicly traded companies are administered by the Financial Accounting Standards Board (FASB) in accordance with regulatory oversight by the Securities and Exchange Commission. International standards for national income accounts are maintained by the UN Statistical Commission and cover an entire national economy. A government agency within each country administers the application of national income accounting standards for the country. The Bureau of Economic Analysis does this accounting in the United States. Incorporating ecosystem service information into these use contexts requires working with the appropriate organization to meet their needs. This approach is far different from assembling a group of experts to create a general framework for ecosystem service science in accounting contexts.

We reviewed a number of important use contexts and representative standards-settings organizations although we did not attempt to be comprehensive for either use contexts or organizations. We found that standards-setting organizations exist for virtually all important use contexts for which ecosystem service information is relevant (Fig. 1).

For most use contexts, standards exist but do not incorporate ecosystem services (Fig. 1, brown cells). For example, risk assessment standards for companies consider how natural resource supplies and social factors affect the company's risk but not how ecosystem services affect risk. Some ecosystem service information is included in standards for other use contexts (Fig. 1, light blue cells). For example, product LCAs often include greenhouse gas emissions, as do many corporate sustainability reports, but ignore a range of other ecosystem services. The UN Statistical Commission has adopted standards for incorporating environmental information into a separate System of Environmental-Economic Accounts (39). Ecosystem service information, however, is not included in the System of National Accounts. Current standards capture the bulk of relevant ecosystem service information in only a few cases, such as fisheries management (Fig. 1, dark blue cells). Ecosystem-based management

User	Use Context	Information Base: Definition of terms and approach (1)	Information Base: Methods for evaluating provision of goods and services (2)	Information Base: Methods for evaluating values (3)	General Standard Setting Entity	Ecosystem Services Standards Entity
Governments	**national income & wealth accounts**				UNSC, GA	
	land use and/or development planning				GA	GA
	environmental impact assessment				IAIA, GA	CBD
	mitigation (environmental offsets)				BBOP, CDM, GA	
	agricultural subsidies				GA, WTO	
	mining subsidies				GA, WTO	
	water pricing				GA, IBNET	
	electricity pricing				GA, CEER, ERRA	EPRI
	property tax				GA, TAF	
	(flood) disaster response				GA	TNC
	risk assessment				ISO	ICES
	fisheries management				GA, UN	ICES
	environmental-economic accounts				UN SC, GA	WAVES
	public lands management				GA	GA
	payments for ecosystem services				GA, UN-REDD	FE
Corporations	**supply chain analysis**				ISO, CSCMP	NVI
	risk assessment				ISO	NCD
	corporate accounting				IASB, GA	NCC, NCD
	corporate sustainability reporting				GRI	SASB
	life-cycle assessment				ISO, LCI	LCI
	product certification				ISO	RA

Fig. 1. Subset of use contexts for ecosystem service standards. Dark blue cells indicate that standards exist that allow for consideration of most ecosystem services in all parts of the use context. Light blue cells indicate that standards exist for some, including some ecosystem services in all parts of the use context or all services in some parts of the use context. Brown cells indicate that standards exist but almost never include ecosystem service information. Gray cells indicate that there are not widely agreed-upon standards. BBOP, Business and Biodiversity Offsets Program; CBD, Convention on Biological Diversity; CDM, Clean Development Mechanism; CEER, Council of European Energy Regulators; CSCMP, Council of Supply Chain Management Professionals; EPRI, Electric Power Research Institute. ERRA, Energy Regulators Regional Association; FE, Future Earth; GA, government agencies; GRI, Global Reporting Initiative; IAIA, International Association for Impact Assessment; IASB, International Accounting Standards Board; IBNET, International Benchmarking Network for Water and Sanitation Utilities; ICES, International Council for the Exploration of the Sea; ISO, International Organization for Standardization; LCI, Life Cycle Initiative; NCC, Natural Capital Coalition; NCD, Natural Capital Declaration; NVI, Natural Value Initiative; RA, Rainforest Alliance; SASB, Sustainability Accounting Standards Board; TAF, The Appraisal Foundation; TNC, The Nature Conservancy; UN, United Nations; UN-REDD, United Nations REDD Program; UNSC, United Nations Statistical Commission; WAVES, Wealth Accounting and the Valuation of Ecosystem Services; WTO, World Trade Organization. Modified with permission from the US Forest Service Forest to Faucet Program.

has fostered the inclusion of ecosystem service science in standards for fishery management. On the other end of the spectrum, there are cases where standards do not yet exist (Fig. 1, gray cells). Many use contexts lack standards for assessing the monetary value of ecosystem services.

Embedding Scientific Information Within Use Contexts

As laid out in Fig. 1, standards for each use context would ideally address (*i*) definition of terms and approach, (*ii*) data and methods for assessing ecosystem services provision, and (*iii*) methods for assessing value.

Definitions of Terms and Approach. Clear definitions of basic terms (ecosystem function, ecosystem service, natural capital, supply, benefit, value) could serve as a universal starting point for all use contexts. Knowledge of ecosystem components and functions is needed to understand the provision of ecosystem services, but these functions are not equivalent to services (40). For example, many models exist for mapping the quantity and quality of surface water, but few continue on to represent water-related services (41). The Forest to Faucet program (US Forest Service) demonstrates how these connections can be made for a specific use context. The Forest Service shows how forest management can augment surface water yields to end users (Fig. 2*B*), rather than simply tracking overall water supply (Fig. 2*A*). Creating maps of overall water supply versus forest contribution to end users requires different methods and different input data. Although both approaches are scientifically valid, only one is relevant to the use context.

A broad definition of ecosystem services might be "the goods and services produced by ecosystems that benefit humankind" (42). This definition implies that ecosystem services can flow from ecosystems of any type, including natural systems, agricultural lands, urban parks, or plantation forests. Some use contexts may focus on a subset of ecosystem services, such as those produced by relatively natural systems. This focus does not change the broad definition of the term but narrows the scope for this particular use context. Clear definitions already exist for many basic ecosystem service terms within disciplines, particularly in economics (capital, service, supply, benefit, value, wealth, welfare), and some relevant terms, such as value (43), have numerous definitions in different disciplines and contexts. Standards would help clarify which definitions are relevant in each use context.

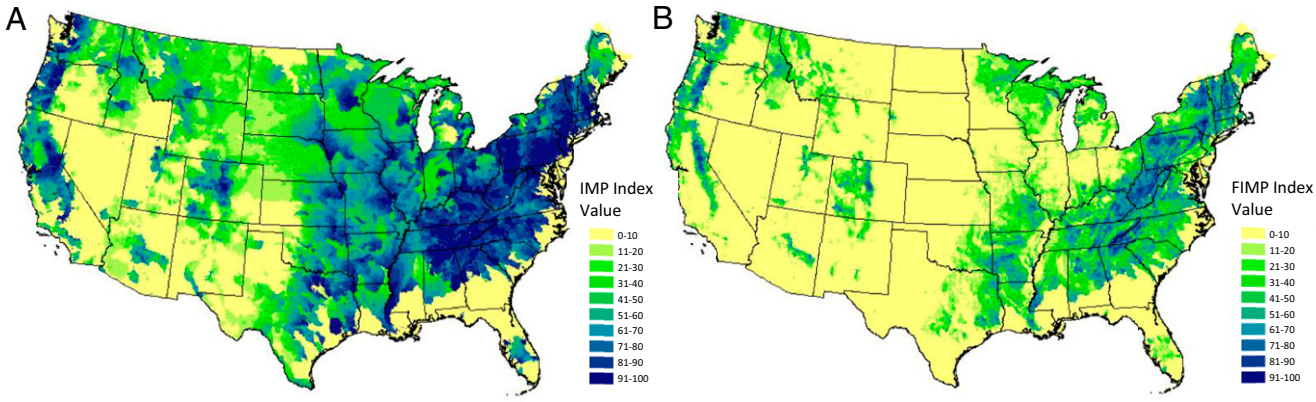

Fig. 2. Important areas for surface water supply (*A*) and forest importance for surface water supply (*B*). Modified with permission from the US Forest Service Forest to Faucet Program.

Standards are useful for defining the methods and approach in a particular use context. Standards can be used to identify what ecosystem services to include, the relevant geographic and temporal scale, and tolerable levels of uncertainty (44).

Data and Methods for Assessing Ecosystem Service Provision. Standards can identify appropriate data and methods for measuring, describing, quantifying, and mapping ecosystem services. Standards can also define appropriate design of monitoring systems and protocols for data collection and storage.

Extensive data on the environment (45) and human health and well-being [e.g., the UN Food and Agriculture Organization (FAO), the World Bank, the United Nations Children's Fund (UNICEF), and the World Health Organization] are regularly collected. However, few of these data inform us about the contribution of nature to human well-being. For example, UNICEF regularly reports on child malnutrition rates, and these data are used in the distribution of aid funds, the allocation of health system resources, and tracking the impacts of social policies on nutrition. However, we cannot easily use child malnutrition data to monitor how fisheries management or sustainable use of forests contributes to household nutrition via increased consumption of fish or bushmeat. Data standards and monitoring protocols for ecosystem service provision lag behind other fields (46), and their creation would advance efficient collection of data for ecosystem service applications.

Methods for Assessing the Value of Ecosystem Services. There is a similarly broad set of methods available for measuring, describing, quantifying, and mapping the value of ecosystem services (i.e., their contributions to human well-being). This set includes quantitative and qualitative methods that express the diverse components of human well-being in both monetary and nonmonetary terms, such as impacts on health or livelihoods.

Environmental economics provides clear recommendations for the application of economic valuation methods for ecosystem services (18). There is agreement that measures of total economic value should include both market and nonmarket values and should avoid double counting (47). For example, counting both the value of pollinators contributing to agricultural output and the value of agricultural output would double count. These widely accepted principles could be incorporated into standards for ecosystem services information in accounting contexts.

There is less agreement about the appropriateness of economic methods to capture all important components of human well-being in specific contexts. For example, national income and wealth accounting uses income-based measures rather than welfare-based measures used by environmental economists (37). Questions also arise about whether economic methods can adequately measure the value of cultural services (48).

Another set of issues revolve around the use of benefits transfer: applying estimates derived from research done in one location to other locations. One common approach for benefits transfer uses results from prior studies to assign a per-hectare value for an ecosystem type and then multiplies the per-hectare value by the number of hectares at the new study site (49). This area-based approach has been criticized for not accounting for factors affecting the supply or demand for particular services at particular sites, which determine the value of services (e.g., refs. 50 and 51). An alternative approach uses ecological information to estimate a flow of a service at a site, which is then combined with benefits-transfer information about the value of various services given site-specific factors that affect demand (e.g., refs. 2, 5–7, and 52). There are also disagreements about whether cost-based measures, such as replacement cost, are valid measures of value. Standards for different use contexts could define what methods are appropriate for particular applications.

All valuation methods have limitations and assumptions that may or may not be appropriate in a given use context. The scientific community has not made much progress in matching the strengths and limitations of various valuation approaches with the specific requirements of different use contexts. A recent review of over 300 papers from the last 20 y found that poor quality and inconsistencies in methods made it impossible to draw conclusions about the impacts of protected areas on human well-being (53). This result represents a clear absence of alignment in thinking around the appropriate use of valuation methods in this particular use context.

The Current State of Information in Use Contexts. A general pattern emerging from various use contexts shown in Fig. 1 is the division between economic assessments (e.g., national income and wealth accounting, corporate accounting, loan risk assessment) and environmental assessments (e.g., environmental impact assessment, LCA, corporate sustainability assessments, product certification). The economic assessments typically have standards for assessing the value of goods and services, which in principle should make it easier to incorporate information about the value of ecosystem services. However, economic assessments typically focus on market values and exclude nonmarket values, thereby ignoring

a large fraction of ecosystem service value. On the other hand, environmental assessments prominently feature ecosystem impacts, capturing the biophysical side of ecosystem service provision. Such assessments typically do not frame impacts in terms of the delivery of goods and services or the value of these services.

The gulf between environmental assessments and economic assessments aptly illustrates the challenge in establishing use-specific standards that capture the full realm of relevant ecosystem service science (Fig. 1, dark blue cells). The one notable exception occurs in fisheries, where environmental impacts have a fairly direct impact on the economic returns of the fishing industry. Successful mainstreaming of ecosystem service information will make clear many other connections between nature and people.

The Way Forward

Our review of the adoption of ecosystem information in use cases shows how much work remains (Fig. 1). There is little adoption of ecosystem services into core use contexts for either the private or public sector (Fig. 1, bold rows). Use contexts where extensive uptake of ecosystem service science has happened are more marginal to basic government and corporate decision making. For example whereas there are standards for subsidies targeted specifically at ecosystem services, such as Reducing Emissions from Deforestation and Forest Degradation (REDD+), ecosystem services are not considered in most government subsidies focused on core sectors such as agriculture, energy, and mining. Although there are efforts underway to capture natural capital in satellite environmental-economic accounts, these accounts will have little impact on core national accounts and the calculation of key economic indicators like gross domestic product (GDP).

Much of this lack of progress stems from the large gap between the work of scientists on ecosystem services and the needs of policy makers and managers in particular use contexts. Although we, the authors of this paper, have our own views on the best use of ecosystem service science in many use contexts, we do not think that our views, or those other researchers, have the necessary breadth, weight, or credibility to gain the confidence of users of ecosystem service information. Many existing ecosystem service frameworks fail to appreciate the need for different standards in different use contexts, seeking instead to develop a "blueprint" for all applications (e.g., ref. 27). Further problems arise when approaches that work well in one use context are applied in other use contexts for which they are inappropriate. For example, Seppelt et al. (54) suggest the need for a standard approach to ecosystem service assessment that includes stakeholder engagement and scenario analyses. Such an approach is relevant for spatial planning, but not for national income or corporate accounting. Simultaneous efforts by multiple groups of researchers to define a generic ecosystem service approach without engaging in dialogue with policy makers and managers has resulted in a proliferation of frameworks, definitions, typologies, models, and methods that has confused practitioners and slowed uptake.

We think rapid progress toward mainstreaming ecosystem services is best served by engaging science with existing standard-setting organizations. Having scientists engage with well-respected influential standard-setting organizations provides a two-way flow of information (*i*) from policy makers and managers to the science community on what information is needed and in what form, and (*ii*) from the science community to policy makers and management with credible and relevant ecosystem service information. In the few cases where there is not an obvious existing standards organization, there is an open role for the scientific community to propose an entity to do so. Such an entity would then convene the appropriate working groups to consolidate best available science and to advance new or expanded standards.

There are several current opportunities that could accelerate the application of ecosystem services information. Here, we focus on two such opportunities. First, the Natural Capital Declaration has convened relevant actors in the finance sector to create standards for consideration of natural capital. However, the scientific community is not engaged in this process in an organized fashion. Rapid progress could be made by convening experts who can translate current ecosystem service thinking in ways relevant for the financial sector. Second, US federal government agencies have created a wealth of information on ecosystem services, but this information has not yet coalesced into a cohesive set of approaches or fundamentally changed government policies or practices. The Office of Management and Budget (OMB) could accelerate progress across the federal government by (*i*) having the Office of Information and Regulatory Affairs require assessment of ecosystem service impacts in benefit–cost analyses of major new rules and (*ii*) requesting information on ecosystem service impacts in agency budget requests. OMB could facilitate the adoption of best practices on ecosystem service assessment in a similar manner to what is done currently in benefit–cost analysis and budgetary review.

Final Thoughts

Although we have focused on adopting standards as an important step to mainstream ecosystem service information, we recognize that it is just one step among many. Further steps include changes in people's perceptions of the value of nature. Progress is evident here: One recent public opinion poll found that 90% of American voters said the value of nature for society is "extremely important" or "very important" (55). Translating this general understanding of nature's value to specific steps required to mainstream ecosystem service information requires dedicated leadership willing to invest political capital and real resources able to overcome opposition from vested interests that stand to lose from a clear accounting of ecosystem services (56).

One argument against setting standards is that doing so may stifle creativity and slow scientific progress ("let a thousand flowers bloom"). We are not recommending standards for use within the scientific research community. Experimentation with new methods and alternative applications of existing methods will continue to enrich our understanding of ecosystem services and their relevance to different use contexts. However, this proliferation of methods, approaches, definitions, and frameworks in the ecosystem service science community needs to be partnered with standards that codify agreement on best practices and approaches. These standards, together with operational guidance and training, are necessary for building the community of practitioners and their ability to use ecosystem service information. As experimentation and exploration lead to improved understanding, standards can be periodically updated to reflect dynamic, evolving science. For example, life cycle assessment and national income and wealth accounts have continued to evolve as the scientific fields informing them have progressed.

The time is ripe for rapid uptake of ecosystem information in a broad array of important use contexts. Use context-specific standards will enable broad-scale adoption of ecosystem services, especially into core use contexts. The two immediate opportunities we have identified provide ready use contexts at the core of public and private decision making.

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