

Ecosystem Services and Environmental Decision Making: Seeking Order in Complexity

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EDITOR'S NOTE

This paper is one of 8 articles generated from the SETAC Special Symposium: Ecosystem Services, from Policy to Practice (15–16 February 2012, Brussels, Belgium). The symposium aimed to give a broad overview of the application of the ecosystem services concept in environmental assessment and management, against the background of the implementation of the European environmental policies such as the biodiversity agenda, agricultural policy, and the water framework directive.

ABSTRACT

The Ecosystem Service Paradigm (EsSP) is increasingly a component or even an underlying principle of environmental policy, legislation and management internationally. The EsSP can be used to define links between human activities and ecosystems, and ecosystems and the services that in turn support and sustain those and other activities; this information can then be used to evaluate, justify or optimize decisions. However, how EsS within various practical applications and frameworks are applied, defined, quantified, modelled, valued and communicated ranges widely, potentially hindering their roles as cross-sectoral tools. For this paradigm to be useful for cross-disciplinary integration, it is important that practitioners in different fields are clear about what is meant and assumed when terms are used, and within what context assessments are being carried out. The logic behind practical applications of the EsSP can be explained by the EsS Decision Cascade, a three-part, iterative conceptual framework. Within the decision cascade, Ecosystem Service Decision Analysis (EsSD) defines the proposed policies or actions (scenarios), and the changes/pressures under consideration in different scenarios. Within the context laid out by EsSD, Ecosystem Service Assessment (EsSA) will then evaluate how such changes affect biophysical structure, and thus ecosystem function and services; Ecosystem Service Valuation (EsSV) then takes the results from these analyses and generates valuations to inform decisions; linking back to EsSD. EsS-based evaluations can expand the current risk-focused thinking behind ecological risk assessment (ERA) to consider trade-offs between a range of desirable and undesirable responses of a variety of ecosystem endpoints; such an assessment can be termed an Ecosystem Response Assessment (EcoResA), or if applied in a spatially explicit manner, an Ecosystem Regional Assessment (EcoRegA); understanding of such trade-offs is essential to inform decisions about more sustainable remediation, regulation and management of landscapes and resources. This paper describes “taxonomies” of various aspects of EsSP applications, based upon their decision context, perspective and assessment approach. It then examines, with a focus on European issues, a range of current and emerging regulatory and management applications to which the EsSP can be applied in light of this taxonomy. *Integr Environ Assess Manag* 2013;9:214–230. © 2012 SETAC

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INTRODUCTION

Although there remains some debate whether anthropogenic changes to the Earth's climate, land, ocean, and biosphere have reached a level that marks a new geological era (the Anthropocene) (Crutzen 2002; Zalasiewicz et al. 2011), the fact that human activities have substantially altered the environment at local, regional, and even global scales has been long recognized (Marsh 1864; Stoppani 1871–1873; Coates 1998). This has inspired attempts to manage and protect the environment since ancient times (Coates 1998; Steffen et al. 2011), but modern attention to environmental issues is

generally seen to have begun in the mid-19th century in response to impacts from the industrial revolution (Grove 1992).

Historically, much environmental management and regulation has been focused on single stressors (such as chemicals) or the protection of single species or resources (Apitz et al. 2006). Such sectoral management has had some notable successes. For instance, releases and levels of anthropogenic chemicals in air, water, soils, and sediments have been reduced substantially in much of the world over the last few decades, and some previously endangered species have been removed from the brink of extinction. However, the failure of many single-resource management strategies to protect the environment or even the sustainability of arguably renewable target resources is becoming clear. There is ample evidence of the unintended consequences of water policy in arid regions (Brauman et al. 2007), single-species management of fisheries

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(NEF 2011), and poorly focused farming policies and subsidies (Nature 2012; Redford and Adams 2009). Single-resource management that ignores the interdependencies between human activities and ecological systems eventually undermines even the renewability of target resources (Wenning and Apitz 2012).

Although there are often calls to turn back the clock and “restore” environments to pristine conditions, in reality, humankind and our actions are components of ecosystems. We have for millennia altered, and will continue to alter, the environment to obtain the water, land, and food needed to sustain our societies. Kapustka and Landis (1998) have argued that frameworks focused solely on restoration and recovery rather than goal-based management ignore the fact that ecosystems are nonlinear, have “memory,” and that change is inherent. Given global population and climate change projections, realistically, the challenge will be not restoration but the need to equitably and sustainably provide for the growing resource demands of a burgeoning population in a shifting habitat, while minimizing ecological damage. This is particularly critical along already extensively altered and exploited river basins, coasts, and estuaries, which must adapt not only to natural variability and stress but also to increasing levels of global, regional, and local-scale anthropogenic stresses and changes, including global warming, sea-level rise, acidification, eutrophication, pollution, invasive species, and habitat loss (Apitz 2007). Thus, there has been an emergence of more holistic management concepts based on the ecosystem approach (EsA), defined as a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way, based on scientific evaluation of the essential processes, functions, and interactions of organisms in their environment (CBD 1998). An essential component of the EsA is that it recognizes that humans, rather than being extrinsic to environmental systems, are an integral component of ecosystems (CBD 1998).

Clearly, then, ecosystems and human well-being are inextricably linked. In fact, the Millennium Ecosystem Assessment (MA 2005) contrasts the dimensions of human well-being (freedom of choice and action, security, good health, sufficient material wealth for a good life, and good social relationships) with their obverse, the dimensions of ill-being (powerlessness, vulnerability, ill health, material lack, and bad social relations), and defines the linkages between well-being and ecosystem services (EsS, defined as the benefits people obtain from ecosystems). The concept that the sustainability of human well-being and commercial development is dependent on the preservation of natural resources is certainly not new (Grove 1995), but given the importance of sustaining EsS for human well-being, the EsS concept is increasingly a component or even an underlying principle of environmental policy, legislation and management internationally. What these approaches have in common is that the assessment and valuation of ecosystem services, the benefits humans get from ecosystems, is a focus of the decisions they inform. Thus, if a paradigm is defined as “a world view, a general perspective, a way of breaking down the complexity of the real world” (Patton 1990), then the focus on EsS within frameworks can be seen as the application of an Ecosystem Services Paradigm (EsSP).

Although traditional market forces reward the often profligate consumptive use of renewable and nonrenewable resources, the effects of this consumption on habitat and

biological processes and functions are not fully captured in commercial markets (Costanza et al. 1997). Business, government, and other institutions can make better decisions relating to the use of land, water, and natural resources if these environmental costs are captured (Daily et al. 2009). The EsSP can be used to help quantify hidden, unanticipated, or ignored costs of a consumer-focused lifestyle (Wenning and Apitz 2012). Still, there are a number of philosophical and logistical concerns about the extent and manner in which the EsSP, with its market-based implications, rather than more “traditional” conservation values, should underlie environmental decision making (see Blacker [2012] and Redford and Adams [2009] for critiques and warnings about this approach).

As emergent properties of ecosystems, EsS are integrators of effects from multiple stressors and biophysical interactions at a range of spatial and temporal scales. The EsSP thus has the potential to provide a holistic approach providing connections between environmental issues, helping to join up various programs for a more integrated and sustainable management of the environment (MA 2005). However, the extent to which it does so depends on how it is applied; many applications of the EsSP can also be narrow and sectoral (Seppelt et al. 2011).

The EsSP provides an anthropocentric, ecosystem-focused framework describing the ecological and human costs and benefits of our choices about land and aquatic management. It can be used to define links between human activities and ecosystems, and ecosystems and the services that in turn support and sustain those and other activities; this information can then be used to evaluate, justify, or optimize decisions. Adapting and integrating those tools that have traditionally been used to address sectoral management within a broader approach that seeks to address EsS will require not only the development, adaptation, and validation of new approaches, but also cross-disciplinary collaboration at an unprecedented level (Apitz 2008a, 2006; Nicholson et al. 2009; Seppelt et al. 2011). Such integration may not only encourage better “single-issue” decisions, but it may also help move us closer to truly ecosystem-based decision making—using the concept of EsS as a “common currency” that, if used properly, provides insights into the true costs and benefits of management choices, and allows us to address management, habitat and service crosslinkages to make informed decisions that cross industries, regulatory frameworks, habitats, and scales.

The Society of Environmental Toxicology and Chemistry (SETAC) 5th Special Science Symposium held in February 2012 in Brussels canvassed the state of the science on ecosystem services and concluded that much needs to be done to bridge the gap between concepts and practice. How EsS within various practical applications and frameworks are applied, defined, quantified, modeled, valued, and communicated ranges widely, potentially hindering their roles as cross-sectoral tools. Knowing when and how to intervene to better manage ecosystems requires substantial understanding of both the ecological and the social systems involved (Nicholson et al. 2009), but experts in the disparate fields required to make integrated, EsSP-informed decisions often use very different models, language, and approaches. Just how complex the issue of language is in the sphere of EsS management can be seen in a review of the topic by Wild and McCarthy (2010); various groups are using different language to mean the same thing, as well as the same terms to mean different things, often with little explicit discussion of the definitions, assumptions and models

embedded in their work. As the EsSP is a concept that calls for the evaluation of the links between vastly different disciplines, this is not surprising. However, for this paradigm to be useful for cross-disciplinary integration, it is important that practitioners in different fields are clear about what is meant and assumed when terms are used, and within what context assessments are being carried out. Given the rapidly increasing application of the EsSP in arenas ranging from the scientific to the political, it is important that this clarity comes soon.

It should be noted that “conservation has a history of placing great faith in new ideas and approaches that appear to offer dramatic solutions to humanity’s chronic disregard for nature... only to become disillusioned with them a few years later” (Redford and Adams 2009); the confusing and sometimes conflicting ways in which various EsSP practitioners are using language and the lack of clarity of models and assumptions could put this paradigm at risk of a similar fate. This article describes “taxonomies” of various aspects of EsSP applications, based on their decision context, perspective and assessment approach. It then examines, with a focus on European issues, a range of current and emerging regulatory and management applications to which the EsSP can be applied in light of this taxonomy.

Practical applications of the EsSP: The EsS decision cascade

Applications of the EsSP are as diverse as the environmental problems, projects, and policies they address. However, if the EsSP is to be used to inform a decision, whatever the application, there is a conceptual flow that, implicitly or explicitly, underlies the process. A decision context, including the questions being asked, the options, scenarios, and changes being considered must be defined; changes, stocks, or flows of EsS within this context must be assessed; and these must be

valued in the context of a decision. This process has been called the EsS decision cascade (de Groot et al. 2002; Haines-Young et al. 2006a), although different authors have emphasized different steps, or levels, in this cascade. Figure 1 illustrates the EsS decision cascade, or the logic underlying the EsSP, that forms the basis of the discussions in this article. All practical EsS applications follow this cascade to some extent, though in many cases steps are assumed rather than explicitly addressed. Adapted from Haines-Young et al. (2006a) and de Groot et al. (2002), this version of the cascade emphasizes the need for iteration, the importance of decisions, and the need for an explicit discussion of decision context in the design, application, and communication of the EsSP. The level of complexity of the analyses linking steps or levels (represented in the boxes in Figure 1), and where one enters and leaves this cascade are context-dependent and can be iterative. In practical applications of the EsSP, separate practitioners may carry out different steps of this cascade, with varying levels of interaction, but effective applications require clarity about how information is to be transferred between levels. Clearly, EsS-focused research may be directed toward only one or a few of these steps, but even then, an articulation of the steps within the cascade from which the research takes inputs and to which it might deliver outputs will help ensure research relevance.

Although none of these steps can be viewed in isolation, for the sake of discussion, they are broken into 3 categories of analysis. For a given application, Ecosystem Service Decision Analysis (EsSD) defines the proposed policies or actions (scenarios), and the changes and pressures under consideration in different scenarios. Within the context laid out by EsSD, Ecosystem Service Assessment (EsSA) is used to evaluate how such changes affect biophysical structure, and thus ecosystem function and services; Ecosystem Service Valuation (EsSV)

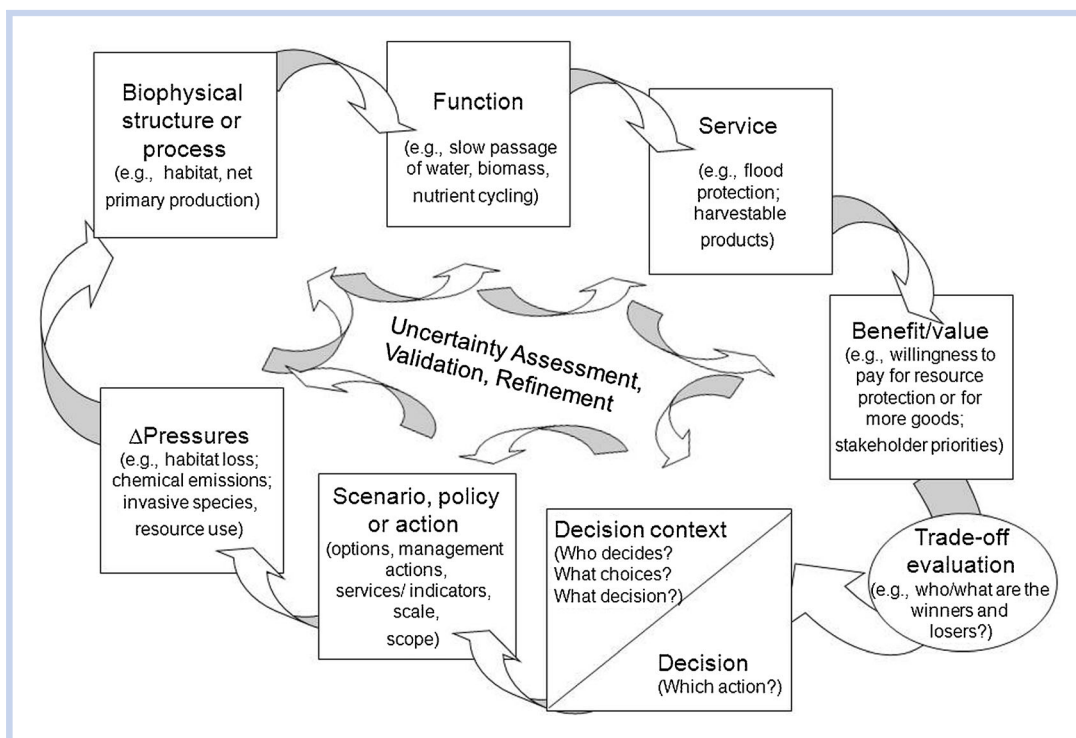


Figure 1. The logic underlying the Ecosystem Services Paradigm (EsSP)—the decision cascade. All practical applications of the ESS paradigm follow this cascade to some extent. The degree of complexity, and where one enters and leaves this cascade, is context-dependent—it can be iterative. Each box in the cascade can be described as a step or level that is addressed by various categories of EsS analysis (Table 1). Adapted from Haines-Young et al. (2006) and de Groot et al. (2002).

Table 1. Categories of analysis required in applications of the EsSP, their purpose, and characteristics^a

Categories of EsS analysis	Purpose and characteristics	"Steps" or "levels" in the EsS paradigm cascade involved in analysis (from Figure 1)									
		Decision context	Scenario, policy, or action	Δ pPressures	Biophysical structure or process	Function	Service	Benefit/value	Trade-Off evaluation	Decision	
Decision analysis (EsSD)	Begins and ends any EsSP application										
	Provides the basis of assessment by defining decisions assessments are to inform										
	Identifies scenarios, policies or actions that are to be evaluated										
Assessment (ESSA)	Follows valuation										
	Is based on specific current conditions or scenarios of change										
	Evaluates the links between biophysical structure, function, and service provision										
Valuation (ESSV)	Addresses human benefits and values of EsS in a decision-relevant context										
	Can be monetary or nonmonetary										
	Identifies costs, benefits and trade-offs to inform decisions										

EsS = Ecosystem Service; ESSA = Ecosystem Service Assessment; EsSD = Ecosystem Service Decision Analysis; EsSV = Ecosystem Service Valuation.

^aThe steps or levels in the EsS decision cascade (Figure 1) that each category of analysis encompasses are shaded in grey. For a given application, EsSD defines the proposed policies or actions (scenarios), and the changes and/or pressures under consideration in different scenarios. Within the context laid out by EsSD, EsSA will then evaluate how such changes affect biophysical structure, and thus ecosystem function and services; EsSV then takes the results from these analyses and generates valuations to inform decisions; linking back to EsSD.

takes the results from these analyses and generates valuations (monetary or nonmonetary) to inform decisions, linking back to EsSD, where a trade-off evaluation is used to inform decisions. Table 1 describes these categories of analysis, and the steps from the EsS decision cascade (Figure 1) that are encompassed in each category.

These 3 categories of analysis are interdependent, but there is often little interaction or overlap of expertise between practitioners of these different levels of analysis. As information passes between steps, results are often aggregated, translated, or simplified to provide indicators of relevance to the next level. This is entirely appropriate and necessary, but it is important that the context, models, assumptions, and translations carried out at each level are critically assessed and made transparent, that uncertainty and variability are clearly communicated, and that model outputs are validated. As models are refined, uncertainties are reduced, and priorities evolve, the relevance of these changes throughout the decision cascade should be evaluated, and approaches should be adapted, but this requires clear communication and integration between practitioners carrying out different analyses. To facilitate this communication, the sections below define and describe the essential components of a range of

approaches to the categories of analysis illustrated in Figure 1 and Table 1.

EsSD

A first step in the development of any application of the EsSP is an evaluation of the decision context and the role that EsS will play in the decisions. As can be seen in Table 1, EsSD addresses decision context, identifies scenarios, policies, or actions under consideration, and defines the pressures, stressors or changes that may result from those scenarios that will be considered. EsSD also links EsSV to decisions via trade-off evaluation. Important aspects of these steps in the analysis are described below.

Decision context

Assessment should be designed to be relevant to the type of decision being made by the eventual “consumers” of the EsS-based analysis. How the EsS are assessed, valued, and communicated depends on what decision makers’ statutory, regulatory, and socio-economic drivers are, and thus what choices are available to them. Decision makers can be public entities such as policy makers and regulators, or they can be private entities such as companies, stakeholder groups and nongovernmental organizations (NGOs). Table 2 describes

Table 2. Policies or actions that can be used by public and private entities to protect, enhance, prioritize, or draw attention to EsS—the policy or action “toolbox” for environmental management^a

Policy or action options	Description	Examples
Prescription	Regulations requiring landscape management actions, standards, etc.; mitigation or cleanup requirements	Environmental requirements for developers and farmers; environmental quality standards; NRDA/ELD (public)
Property rights	Privatization and allocation of resources; can be backed by prescription or be voluntary or private	Fishing permits, tradable emissions
Penalties/rates	Charges that make certain actions more expensive, or rates to protect from consequences	Grazing charges; charges on CFC use; carbon taxes; liability insurance rates (private)
Persuasion/education and outreach	Various public education campaigns; by government in support of selfregulation, by companies to enhance image or support higher costs, by stakeholders and NGOs to advocate a policy or approach	Educating landowners on the consequences of land management practices (e.g., Soil Conservation Service); educating tourists on coral reef importance and protection; fair trade and organic products
Persuasion/compliance	By stakeholders, to provide context for a risk assessment, argue a point, or to advocate a proposed action or development within a regulatory context	EsS-based risk assessment at a contaminated site; Net Ecosystem Service Assessment for mitigation or remediation (private); EsS-based advocacy for standards, or approval
Payments*	Subsidies or direct payment to compensate private landowners for actions which benefit the public but are not captured by regular markets	Often called payments for ecosystem services (PES) can be use-restricting or asset-building*
*Use-restricting	Pay parties not to use resources (such as farm land or forest)	REDD, REDD+ (reducing emissions from deforestation and degradation)
*Asset-building	Pay property owners or users for more sustainable asset use	Catchment sensitive farming (UK)

CFC = chlorofluorocarbon; ELD = European Environmental Liability Directive; EsS = Ecosystem Service; NGOs = non-governmental organizations; NRDA = Natural Resource Damage Assessment; PES = Payments for Ecosystem Services; REDD = Reducing Emissions from Deforestation and Degradation; UK = United Kingdom. ^aAdapted from Salzman and Thompson (2007), which focused on the policy toolkit available to public entities.

Table 3. Categories of EsSD—these define the context within EsS that can be used to inform various decision types that can lead to policies or actions^a

EsSD category	Purpose	EsSD subcategory	Uses for EsS
Decisive	Considers EsS gains and losses in cost-benefit analysis in advance of decisions about a given project or policy	Trade-off	Used to optimize decisions by informing choices that balance preference criteria Used to provide basis for environmental cost-benefit analysis into decision makers' evaluations
		Participative	Used as a basis for discussion, allowing an open debate of EsS parameters and assumptions, to negotiate and define projects that balance interests
		Allocation	Used to identify scenarios and areas that contribute the most to EsS Used to define priorities for investment and to allocate conservation efforts
Technical	Is used after a choice of policy or project has been made to adjust the economic (or in the case of the broader decision cascade, also technical) instruments that will be used to implement a decision	Reference	Used to establish levels of damage compensation needed either to mitigate anticipated damage or remediate damages caused by accidents or other actions
		Tariff-setting	Used to determine prices such as willingness to pay fees and payments for ecosystem services (PES)
Informative	Is not applied directly to decisions, but it used to contribute to discussions, modify points of view or communicate aspects of decisions	Advocacy	Used for awareness-raising about EsS preferences Used to encourage the uptake of EsS considerations in public choice
		Justification/evaluation	Used by stakeholders to promote a given course of action Used to evaluate the rationality of a decision a priori Used to test a decision a posteriori
		Accounting	Used to inform decision makers or the public about the state of natural capital

EsS = Ecosystem Service; EsSD = Ecosystem Service Decision Analysis.

^aAdapted from Bille et al. (2012), which focused on applications of EsS valuation for public entities.

different policies or actions that can be used to protect, enhance, prioritize or draw attention to EsS; this is the policy or action “toolbox” (Salzman and Thompson 2007) for environmental management. Table 3 describes the ways in which EsS can be used to inform various decision types that can lead to these policies or actions. The types of actions available to public and private entities, whether EsS-informed or otherwise, differ, as does the type of EsSA and EsSV required to inform these actions.

When the EsSP is being applied to inform or design a public policy instrument, EsS-based assessment can be used to predict how various policies or approaches will affect the viability and sustainability of target EsS at the site-specific, regional, national, or global scale. It can also be used to set penalties or prices, allocate access or resources or develop policies or communication tools. Public bodies may set out specific assessment or compliance frameworks for regulatory compliance or permit applications.

However, many public agencies and regulators have narrow statutory obligations and strict guidelines within which they can

make regulatory or policy decisions. Although there is a general move toward more holistic management of ecosystems, many specific regulatory programs and decisions are still focused on single issues, and individuals within one program may have no decision authority outside their remit. For example, an agency focused on developing policy tools to enhance water resources may not have decision and assessment criteria that consider the effects (positive or negative) of policy on other EsS in the catchment, and regulations that require that management options should be selected solely on the basis of chemical-based risk criteria and/or cost will have little scope to consider EsS. In these cases, broader EsS-based assessment may play a role in identifying cross-program risks and opportunities and can be used for advocacy, collaboration, and outreach, as well as to justify regulatory change. An understanding of the drivers and remit of decision makers helps ensure that EsSA and EsSV are developed and aggregated in a manner that is relevant to the decision at hand.

Private entities and NGOs have a smaller toolbox at their disposal, so EsSA carried out for their purposes may have a

different focus. The tools available to them for EsSP implementation are persuasion, property rights (to some extent), and payment. In many cases, EsSP application will be carried out as one aspect of regulatory compliance—either to provide context to a risk assessment, to argue a point, or to advocate a proposed action or development. EsSD may be used for public outreach, to enhance a company's image or to justify a higher cost to consumers. NGOs may use EsSD to advocate a policy or approach. Whoever is making decisions, the role of EsSD depends on the nature of the decision and who is advocating, supporting or implementing it.

Articulation of scenarios, policies, or actions—problem formulation

Once a decision context has been defined, then the scenarios, policies or actions under consideration must be laid out to guide problem formulation for EsSA. Specific details of options or management actions are context-specific but need to be laid out in enough detail to ensure EsSA relevance. The scale and scope of the decision to be informed, and of the analyses used to inform it, must be defined. Depending on the question or decision being informed, EsSA may be designed to evaluate and/or quantify specific EsS and the stressors and pressures that affect them (e.g., for informative/accounting EsSD) or it may be designed to evaluate, given various scenarios under consideration, what stressors and pressures are generated, and how these affect specific EsS. In either case, it is necessary to determine which services will be considered, what indicators may be used to represent these services, and what pressures, stressors, and/or changes are anticipated within scenarios.

EsSD context, then, lays out what EsSA must evaluate. For example, if the objective is to evaluate the extent of damage to determine liability due to environmental damage (e.g., technical/reference EsSD), EsSA/EsSV will have to determine the baseline or reference state of EsS before the damage under consideration occurred, and the extent of damage; the options or scenarios under consideration are scoped in terms of baseline and impacted conditions. If the goal is to determine the extent of remediation or mitigation (e.g., decisive/tradeoff EsSD), EsSA/EsSV should evaluate the EsS costs and benefits of various management scenarios, the options or scenarios under consideration are the various mitigation or management options, and their consequences. If the objective is to develop a policy or approach to enhancing specific EsS (e.g., water quality or soil retention; decisive/allocation EsSD), then the effects of various types or extents of management should be evaluated; these management approaches are the scenarios under consideration. An evaluation of a specific chemical use (e.g., decisive/tradeoff or informative/justification EsSD) could evaluate the EsS effects specifically of that chemical (positive and negative), or it could compare the effects of use to the effects of plausible alternatives and/or mitigation scenarios.

Scale of EsSA

The scale and scope of EsSA (and EsSD) are also critical. An EsSA scoped to look at effects at the local scale will not necessarily result in the same decision as one set at a larger scale. Not only do EsS generation, use, and effects operate at a range of scales, but so also do economic and sociopolitical systems. Management of land to enhance or optimize a given set of EsS may protect those EsS on site or downstream, but in the case of

use-restricting approaches, they may just move practices to another region. Such issues should be considered when assessment goals are set out, and when scenarios are developed. Management actions and policies may be implemented at the site-specific scale, but the effects of those actions are driven by smaller scale biophysical conditions and are aggregated at higher scales—these cross-scale interactions are not always easy to predict (Apitz 2012). It is a good idea, when evaluating systems, to examine at least the 2 scales adjacent to the scale of interest—those above and below the focal scale (Wu and David 2002; Colnar and Landis 2007).

Selection of EsS and indicators

The Millennium Ecosystem Assessment (MA) provides a catalogue of provisioning, regulating, cultural and supporting EsS (MA 2005); these are often seen as a starting list of services to consider in an EsSA. Rather than focusing specifically on the MA list of services, de Groot et al. (2002) provide a list of ecosystem functions that in turn provide a broad range of goods and services. They warn that the MA list contains both direct services and also functions that are necessary to provide those services and warn that valuations should be carried out with caution to avoid double counting. Haines-Young et al. (2006a) conclude that the MA list can be seen as a set of “service themes”; how they are considered and valued will be context-specific, and that the challenge is to describe and understand, for a specific question or problem, the nature of the EsS “production line” that is represented in the EsS cascade.

Although not all studies can evaluate all EsS, this argues for an up-front, project-specific identification of priority EsS. Rather than focusing on service categories, others have pointed out that a function (or service) does not have value (in an anthropocentric sense) until it provides benefits to humans (Boyd and Banzhaf 2005), and thus objectives and management priorities for a specific landscape should be the starting point. Along these lines, EsS of interest have been identified based on regulatory drivers (Apitz et al. 2010), or river basin, landscape, or regional objectives (Landis 2005; Paetzold et al. 2009; Kapustka and Landis 2010), to provide a degree of context to studies. The International Finance Corporation (IFC) provides a checklist for Ecosystem Service Reviews (ESR) of projects, largely based on the MA list (IFC 2012). They specify that scoping to identify priority EsS should be carried out via literature reviews and consultation with affected communities (stakeholders). Two categories of EsS are identified: 1) Type I, EsS over which a decision maker or organization has direct management control or significant influence, and on which impacts may adversely affect communities, and 2) Type II, EsS over which the a decision maker or organization has direct management control or significant influence, and on which the project directly depends. EsS within these 2 categories should be included in EsSA; others can be left out. Interestingly, the focus of the ESR categories is only on adverse impacts, and does not, as laid out, support the concepts of asset-building (EsS enhancements of projects), or other EsS-enhancing approaches or trade-offs. Thus, if an EsSA is to be designed to identify trade-offs and opportunities, as well as risks, this approach should be broadened to also consider potential EsS benefits from planned projects, policies and management actions in its classifications.

Ultimately, the selection of services to be considered depends on the question being asked, regional priorities and the context and scale of scenarios envisioned. For high-level analyses, broad EsS categories, such as “fisheries” and “transport” might be

appropriate; more detailed biophysical assessments may focus on functions such as nutrient cycling or pollination. The selection of EsS or their indicators should be relevant to the questions at hand, responsive to the scenarios being considered and comprehensive enough to capture all relevant positive and negative effects of scenarios. Although multiple functions or endpoints may eventually be aggregated into single values later in the analysis, EsSA should consider any relevant effect pathway. For instance, although it can be argued that pollination, soil retention, and other functions might be eventually be subsumed into crop yield during a valuation process, if specific management actions being considered affect these functions differently, they should be separately evaluated in the EsSA.

In programs in which the EsSP is being used as an added layer of relevance and integration to already established methodologies, EsS are often linked to more standard assessment endpoints (Munns et al. 2009). These assessment endpoints are considered service providing units (SPUs); as such they can be seen as indicators of EsS provision (Chapman 2008). This has the potential to provide relevance to studies and to facilitate cross-sectoral integration. However, in some cases, by only addressing, at a new level, those stressors, endpoints and processes that have traditionally been evaluated, such approaches run the risk of creating “self-fulfilling prophecies” in which the most important processes are determined to be those most studied ones, simply because other have not been evaluated (White et al. 2006). In their review of EsS studies, Seppelt et al. (2012) observed that the vast majority of studies considered 5 or fewer EsS, with almost 25% considering only 1; more than 50% of studies considered EsS in isolation, without considering feedback or interactions between services. One could be forgiven for concluding that these are not studies following the EsSP in its truest sense, but rather relabeled single- or narrow-issue studies, which run the risk of leading to single-stressor or single-resource management under a different name.

EsSA

Underlying all approaches of EsSA is the assumption that the sustainability of ecosystem services is dependent on functioning ecosystems. In simple terms, ecosystem functions and services are most sustainable when organisms are diverse, although the specific relationships between function and biodiversity are not always clear cut (Munns et al. 2009). For instance, Wall (2004) concluded that functional diversity was more important than species diversity in sustaining soil and sediment ecosystem services, and Solan et al. (2004) and Raffaelli et al. (2003) have found a range of diversity/function relationships in marine systems. It is clear, however, that specific organisms or ecosystems, which can be seen as SPUs, have specific biological and physical (biophysical) requirements. Even if entirely pristine and natural, biophysical conditions perfect for one SPU may not be appropriate for another. For example, a meadow, although perfect for some pollinators, will not support fish. Thus, when we manage systems to enhance specific EsS or bundles of EsS (either by restoring “natural” conditions or optimizing conditions for selected services) other functions, organisms, SPUs, and services are affected, on site and in connected environments. EsSA, then, must evaluate, for selected scenarios, how policies or actions will release stressors, change biophysical conditions at various scales, and how this will affect (whether positively or negatively) priority EsS at the scales of interests.

Depending on the decision context, the manner, and level of detail, in which these links are assessed differs in various practical applications of the EsSP. EsSAs fall into a number of categories, based on their perspective and basis, whether they are top-down (starting with high-level, often qualitative estimates of EsS) or bottom-up (deriving semiquantitative or quantitative estimates of EsS from the evaluation or modeling of supporting processes), and what type of assessment approach is carried out. Once the context of an EsSP application is laid out, then there are a range of tools, models and approaches that can be used.

Assessment perspectives

Haines-Young and Potschin (2007) have defined 3 perspectives from which EsS can be evaluated: habitat-based, service-based, and place-based perspectives. The characteristics, strengths and limitations of each are summarized in Table 4. Both habitat- and service-based EsSA are useful tools for top-down assessments. They can be used to assess national or regional service or natural asset stocks and trends, support strategic assessments and help evaluate the impacts of large-scale planning and development, and can link easily to valuation steps, but standard approaches and transparency are essential. However, for the more quantitative assessment required to choose between remediation, disposal, mitigation, or liability options, or to identify trade-offs between specific landscape use or management options, there is a need to address in greater detail the links between pressures, biophysical conditions, functions, and services. In these cases, neither the service- nor the habitats-based perspectives are sufficient. In reality, the ability of landscapes to provide services is place- and context-specific; to address these issues quantitatively requires a place-based (Haines-Young and Potschin 2007) or landscape-based (de Groot et al. 2009; Kapustka and Landis 2010; Raudsepp-Hearne et al. 2010; Everard 2011) perspective.

Ecosystem service provision (and resilience or vulnerability) is dependent on spatial relationships—the connectivity between adjacent habitats or those connected via the hydrocycle, the concentration and distribution of stressors, and the human use and value of various habitats and services. For instance, habitat and biodiversity in rivers is affected by sediment balance, which is in turn affected by river management, as well as the interactions between landscape conditions (weather, slope, soil type) and management practices that affect soil-sediment balance and thus sediment quality, quantity, and location (Apitz 2012). Fine sediment in spawning gravel can damage fisheries; the same sediments are essential downstream for wetlands. A wetland downstream of a city may be valued for its water purification services, whereas a coastal one may be more important to humans for its role coastal protection, but both may play roles in climate regulation and providing fish nurseries that may or may not be considered by communities. Similarly, the provisioning of hydrologic services is as dependent on the timing of water delivery and transport as on its quality and quantity (Brauman et al. 2007). How these services are valued and affected by other land uses or stressors will be place-specific, both for the locations that affect processes and the locations at which services are delivered.

Landscape-based approaches better address crosslinkages, place-based issues, and stakeholder values, but they can be more complex to carry out. That said, there are a range of tools and approaches being developed to address complex interactions at the landscape and watershed scale at various levels of

Table 4. Summary of EsS assessment perspectives^a

Assessment perspectives	Basis	Strengths	Limitations	Levels in cascade	Top-down or bottom-up	Qualitative/quantitative
Habitats-based	<ul style="list-style-type: none"> - Treat habitats as SPU - Map habitat; extent equated with service provision - Focus on conservation or biodiversity status of habitat types 	<ul style="list-style-type: none"> - Good policy relevance - Have been used to indentify national scale conservation issues - Focus of many programs aimed at ecological assets 	<ul style="list-style-type: none"> - Does not evaluate service cross-linkages - Assumes all benefits in proportion to habitat scale or type - Less effective at determining services other than biodiversity - Does not evaluate service-specific responses to management 	<ul style="list-style-type: none"> - Jumps from biophysical structure to service or value - Assumes rather than evaluates function link - Major pressure evaluated is habitat loss 	Top-down	Qualitative or semiquantitative
Service-based	<ul style="list-style-type: none"> - Habitats provide biophysical conditions, but not focus - Service-by-service assessment - Service extent equated to presence of biophysical conditions 	<ul style="list-style-type: none"> - Can frame an assessment of benefits of ecosystems - Provides a qualitative basis for evaluating the effects of human action (adverse and beneficial) 	<ul style="list-style-type: none"> - Links or interactions between services may be unclear - Does not allow multifunctional characteristics of ecosystems to be considered - Does not consider the role of peoples' needs and preferences 	<ul style="list-style-type: none"> - Jumps from biophysical structure to service or value - Assumes rather than evaluates function link - Changes in pressures, if evaluated, are qualitative 	Top-down to bottom-up	Qualitative or semiquantitative
Place- (or landscape-) based	<ul style="list-style-type: none"> - Focus on the dynamics of services associated with a particular place - Look at spatially-explicit interactions between habitat, land cover and management 	<ul style="list-style-type: none"> - Allow for site-specific evaluation of service cross-linkages and effects of actions - Can focus on services and outputs prioritized by stakeholders 	<ul style="list-style-type: none"> - Generally more data intensive 	<ul style="list-style-type: none"> - When qualitative, jump from biophysical structure to service or value - When quantitative, can evaluate function-service link 	Bottom-up	Qualitative-quantitative

EsS = Ecosystem Service; SPU = Service Providing Unit.
^aDeveloped based on Haines-Young et al. (2006b).

detail. Increasingly, probabilistic approaches such as the application of Bayesian belief networks (Ayre and Landis 2012; Barton et al. 2012) and other tools are proving useful for addressing complex systems. An assessment of these issues often requires spatially explicit data sets, although the level of detail needed varies with application. Haines-Young and Potschin (2007) observed that in the United Kingdom, data resources for such an approach remain fragmented; this is no doubt true in other regions as well. When, however, data are available, such approaches can provide more place-relevant top-down or more mechanistic bottom-up approaches in which the site-specific EsS implications of specific management policies and options can be evaluated. These can include simple or detailed biophysical and ecological models, but should address interactions between management actions envisioned in scenarios, the stressors or biophysical changes they will result in, and how this might affect ecosystem function and service provision, in a spatially explicit manner. Depending on the assessment context, changes can be evaluated over various spatial and temporal scales, but it is important that care is taken to ensure that the data and models used are appropriate to the focal scale, and that the approaches pay attention to the hierarchical relationships between different types of spatial units (Wu and David 2002; Haines-Young and Potschin 2007).

Assessment approaches

There is a vast and rapidly expanding literature on the links between pressures, biophysical conditions, ecosystem functions, and services, and very many approaches to these questions depending on the system, scope, scale and context of the questions under study. An understanding of this literature in the context of a project is important, but a full review is outside the scope of this article, which seeks to identify some broad categories of EsSA for practical applications of the EsSP. In that context, there remain almost as many approaches and tools as there are applications, but there are a few distinct categories of approaches; an articulation of their similarities and differences may help facilitate cross-project integration.

Resource level assessment (REsSA). For natural capital assessments, there is a need to quantify or map the extent (and potentially trajectories) of resource availability and provision. For projects that seek to determine damage, liability, restoration, or compensation issues, there is a need for data on resource and/or service levels under baseline conditions (in the absence of damage) and to predict trajectories of recovery after restoration or remediation. For habitat equivalency approaches (Efroymsen et al. 2004), this is usually done by developing a single metric for each habitat or resource modeled. Assessment of current state, baseline levels, and recovery and compensation levels are often based on evaluations of historical data, professional judgment, literature reviews, and stakeholder input. These assessments can range from qualitative to quantitative, and, where historical data are not available, may be informed by models and extrapolations. The focus of such assessments is an estimate of resource levels in time and/or space, rather than a mechanistic evaluation of specifically what drives changes (although this may be assumed).

Ecosystem Response and Regional Assessment (EcoResA and EcoRegA). In this assessment approach, the EsSP enhances or underlies traditional ecological risk assessment (ERA) by linking endpoints to EsS, or EsS-relevant indicators, biophysical

processes, or functions. Simple approaches involve a translation of standard ERA endpoints to their role as SPU (Chapman 2008; Munns et al. 2009). Although many ERA approaches only address negative effects (risks), there are a growing number of approaches that also evaluate desirable or positive impacts on endpoints (e.g., Apitz et al. 2010). Assessment should focus on the trade-offs between these ecosystem responses; such an approach can be termed Ecosystem Response Assessment or EcoResA. Such approaches should be more useful in evaluating EsS cross-linkages that result in tradeoffs between landscape management choices than those that focus on negative impacts alone. Even more complex approaches can be spatially explicit, addressing the effect pathways between multiple stressors, endpoints, and habitats using adaptations of the Regional Risk Model (Landis 2005), or habitat-focused risk such as Potential Effects Analysis (WDNR 2007); these can be considered Ecosystem Regional Assessment (EcoRegA). The feature that distinguishes an EcoResA or EcoRegA approach is that the focus is on identifying and quantifying effect pathways (both desirable and undesirable) between stressors and endpoints. As such, these approaches do not directly quantify changes in service or resource levels. These changes can, however, be modeled or inferred based on EcoResA and EcoRegA outputs, or the relative magnitudes of risk can be fed directly into valuations.

EsS-based life cycle assessment (Eco-LCA). Eco-LCA evaluates the full scope of EsS impacts (gains and losses) for all aspects of a proposed policy, product or development. In its developing form (Zhang 2008), this is a highly quantitative approach that focuses primarily on the use of energy and provisioning services, due to the lack of equivalently quantitative data on other categories of EsS. Zhang et al. (2010) point out the need for research to provide greater quantitation of other factors such as regulating, cultural, and supporting services at an equivalent level of detail to that available for provisioning services. However, these complex, engineering-based models are highly quantitative, and transformation of these parameters into equivalent units will most likely introduce a great degree of uncertainty. One can question whether it is more important to be highly quantitative but possibly not relevant (by leaving out important factors), or whether less quantitative, but broader scope assessments might provide very different answers about what products, options, or scenarios might be most sustainable. Thus, there is scope to develop more qualitative or semiquantitative Eco-LCA approaches to help define the full scope of EsS losses and gains as a result of proposals, policies, and scenarios. Such approaches may help expand the scope of assessments, as well as identify data gaps and uncertainties. In the context of regional planning, strategic assessment or scoping for liability assessment, such an approach may help “map” potential scenarios, vulnerabilities, and issues that may merit further evaluation.

EsSV

Reviews of EsSV approaches can be found in a number of documents (NRC 2005; Defra 2007; Stahl et al. 2008). The valuation of EsS is a rapidly expanding field of study, and a review of it is outside the scope of this article. It is important to note, however, that most of the approaches for EsSA described above address changes in EsS as a result of various scenarios, not absolute service provision. As such, the decisions are informed by differences in marginal, rather than absolute value. Although the focus of discussion in some groundbreaking articles on

EsS (Costanza et al. 1997), absolute values of many EsS are difficult to determine and may not be relevant in many decision contexts.

Policy choices, and the benefits and costs associated with them, imply changes in environmental quality or the level of environmental services (e.g., changes in ecosystem goods and services); the valuation exercise is the quantification of the value of those changes (NRC 2005). An understanding of this may make it easier to translate from different assessment approaches to valuations, but it is important to be clear about the scope and basis of those assessments. An assessment that identifies relative effect pathways is conceptually different than one that evaluates stock changes over time using historical data. EsS valuation approaches are designed to integrate and aggregate such disparate measures, but transparency is essential. The basis of model inputs is important, and, even if not always at the front of a final evaluation, should be accessible to decision makers when required.

Net Ecosystem Service Assessment (NESA) (Nicolette et al. 2011) compares the net differences in EsS gains and losses between specific scenarios. NESA does not directly assess these gains and losses but rather synthesizes inputs from EsSA approaches to compare the EsS implications of specific scenarios. NESA focuses on key EsS and processes that may differ between scenarios and often projects these gains and losses over time to predict net benefits. Often EsSA outputs are aggregated for NESA. NESA thus represents a bridge between EsSA and EsSV. For instance, in habitat equivalency assessment, units such as discounted service hectare-years are used to determine resource-to-resource equivalency (Efroymsen et al. 2004).

On the other hand, when the objective of the study is not restoration or compensation but to evaluate crosslinkages, multifunctional landscapes or trade-offs between a range of management or policy options, then a broader range of EsS and other outputs should be compared. Ultimately, if monetary valuations will follow, services will need to be prioritized, weighted, valued and aggregated, but intermediate levels of information can also be essential to the decision process. Given that landscapes provide bundles of services, a separation, rather than aggregation, of services can provide great insight into options, a greater opportunity for stakeholder engagement, and a greater opportunity to articulate and optimize trade-offs between a range of landscape and aquatic management options.

Uncertainty in assessments and decisions

An important element that must link assessment, valuation, and decisions is a clearer communication of variability in systems and uncertainties in the models of them. EsS frameworks evaluate potential changes in complex, multidimensional systems. Such systems are highly variable and interactions are uncertain. No model can be more accurate than its most uncertain parameter (Kapustka and Landis 2010); as we move along the EsS cascade from scenario development to assessment and finally to valuation, uncertainty propagates in each step. Thus, EsS frameworks should only be as complex as they need to be, based on the context of the decision and the uncertainty of processes. In many cases, a more broadly scoped but more qualitative assessment may be more relevant than a highly quantitative one that focuses on the wrong (or an insufficient subset of) processes. Once broader assessments identify key processes, uncertainties, and data gaps, more detailed studies can focus on critical issues.

Uncertainty can be addressed in various ways during EsS studies—precautionary approaches can focus on worst-case scenarios, models can address probabilities, or scenarios can be evaluated to examine end-members, likely ranges of response, or to define plausible scenarios. Whatever the approach, however, uncertainty should be addressed and clearly communicated to stakeholders and decision makers; this is too often not done. The extra work and open communication required may be seen as a deterrent to some, but falling back on simpler frameworks that provide a feeling of certainty but are too narrow to support sustainable decisions is not an option. Although our approaches to regulating even single resources and single stressors are often predicated on the assumption that we understand and are able to predict how these systems behave, Wagner (1995) has stated that "...contemporary science can provide only partial answers to pressing environmental problems, (but that) this limitation is esoteric and often escapes the lay observer." Thus, the development of standards and tools can fall victim to a "science charade" in which "the capabilities of science are susceptible to ...overstatement" (Wagner 1995); even seemingly "simple", environmental problems have a tendency to surprise us. A balance must be sought between boldness of ambitions and humility in communication.

Given the complexity and uncertainty inherent in these systems, ecosystem-based frameworks cannot predict certain outcomes, but they can be used to identify driving processes, pinpoint key uncertainties and predict potential outcomes of plausible scenarios. Rather than promulgating a "myth of certainty" (Apitz 2008b), such an approach can help inform strategic decisions that will be sound in a range of plausible futures (Schwartz 1991), and allow for adaptive strategies. The literature on landscape management (Kapustka and Landis 2010) and adaptive ecosystem management (Rogers 1998) can provide tools, lessons, and warnings against the consequences of hubris.

Applications of the EsSP

Whether explicitly addressed or not, all management and policy choices result in EsS trade-offs. The EsSP provides a thread by which cross-sectoral decisions can be informed. EsS principles underlie any assessment of ecological or socio-economic sustainability—formally addressing them can provide a clear basis for discussion. There are a range of well-established tools and approaches for various aspects of EsS-based analysis, but specific framework design should be informed by the question being asked, the information available and the values of stakeholders. Table 5 describes a range of current and emerging applications of the EsSP, in light of the decision, policy, and assessment taxonomies developed in this article. This list is by no means comprehensive but reflects a range of applications that were the subjects of discussion at recent SETAC sessions, short courses, and workshops.

National ecosystem and natural capital assessments

National (UKNEA 2011), regional (MAG-ACQUE 2010), and global (MA 2005) inventories of ecosystem services or natural capital tend to focus on mapping of resources, risks, and objectives; land use or habitat types are mapped to services. They can be largely qualitative or semiquantitative, and can be used to map and characterize trends in EsS or report the state of systems. Given the diversity of EsS that such approaches seek to synthesize, the quantity, quality, and basis of data used to address the status of different types of EsS may differ; some may

Table 5. Summary of EsSP applications, based on their purpose, as well as policy and decision context, assessment perspective, and type

EsSP application category	Purpose	Policy/action options	EsSD category	H, S, or P	Potential assessment type
National ecosystem and natural capital assessments	National, regional, and global inventories of ecosystem services or capital	Persuasion/education and outreach	Informative/accounting; once developed, can play a role in various decisions	H, S	REsSA
Local, regional, or strategic planning	Evaluation of the environmental consequences of plans, policies, programs and projects	Various	Various	H, S, P	REsSA, EcoResA, EcoRegA
Environmental and social impact assessment	Evaluation of potential environmental and social impacts, including impacts to ecosystem services, from planned developments, to secure funding from lenders	Persuasion/compliance	Decisive; informative/justification	H, S, P	REsSA, EcoResA, EcoRegA, Eco-LCA
Environmental damage	Determining the scale of measures to adequately offset legacy contamination, or threatened releases endangering natural resources	Prescription (public); persuasion/compliance (private)	Technical/reference (public); informative/justification (private); decisive/allocation	H, S, P	EcoResA
Sustainable remediation/disposal	Evaluation of trade-offs of alternative remediation options considering a range of scenarios, actions and changes so that EsS outcomes can be optimized	Persuasion/compliance (private)	Informative/justification (private)	S, P	REsSA, EcoResA
Liability insurance	Environmental risk and liability review of facilities to identify and quantify possible insurance exposures due to potential environmental damage	Penalties/rates	Technical/reference (private)	P	EcoResA, EcoReg
Environmental security	Resilience planning to guard against human impact and environmental degradation from natural and manmade disasters	Various	Technical/reference (public); decisive	P	REsSA, EcoResA, EcoRegA, Eco-LCA
Product safety	Evaluation of EsS impacts of product manufacturing or use for licensing	Prescription (public); persuasion/education and outreach (public) or compliance (private)	Decisive/tradeoff (public); informative/justification (private)	H, S, P	EcoResA, EcoRegA, Eco-LCA

H = habitat-based; S = service-based; P = place-based; EsS = ecosystem service; EcoResA = ecosystem response assessment; EcoRegA = ecosystem regional assessment; Eco-LCA = ecosystem service-based lifecycle assessment; REsSA = resource-level ecosystem service assessment.

extrapolate results from bottom-up models and studies; others may be largely top-down and descriptive. However, due to their scope and scale, they may not have the level of detail to help predict individual EsS response to specific management actions or scenarios, nor do they address EsS cross-linkage and site-specific issues. Rather, they can help identify priorities or objectives of high-level approaches.

Local, regional, or strategic planning

The principle of integration is embedded in the European Treaty, which requires all other policy areas to take full and proper consideration of the European Community's environmental objectives when making policy decisions (EC 2001a). Thus, the Strategic Environmental Assessment (SEA) Directive (EC 2001b) was developed to ensure that environmental consequences of certain plans and programs are identified and assessed during their preparation and before their adoption. In contrast with environmental impact assessments (EIAs) (EC 1985), which are required to determine the consequences of proposed projects, SEA requires examination of the impacts of decisions above or below the project level. Although the directive does not specifically invoke ecosystem concepts, it does require the consideration of significant effects on "issues such as biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage including architectural and archaeological heritage, landscape and the interrelationship between the above factors."

On land, EsSA can play a role in the assessment of changes in agricultural policy and management (Turbé et al. 2010; EA 2011), catchment management plans (Apitz 2012), major infrastructure, and other regulatory and planning issues. Similarly, the EsSP is increasingly being applied to fisheries management and policy (NEF 2011), integrated coastal planning and management, and marine spatial planning (Atkins et al. 2011). As regional planning and policy are broad issues, it is difficult to predict what the specific decisive focus of the EsSP will be in a given assessment, but it is to be expected that large-scale projects might be informed by REsSA, whereas the evaluation or selection of specific alternatives or plans will require landscape-scale EcoRegA or Eco-LCA to identify crosslinkages, trade-offs, and key issues and uncertainties, followed by EsSV to help select options with stakeholder input.

The EsSP can better inform joined-up and cross-sectoral planning, identifying win/win opportunities and hidden dangers. For example, to help the UK Environment Agency develop and evaluate a range of policies and programs of measures to manage sediment as a stressor in Water Framework Directive compliance, (Apitz et al. 2010) developed a multiple-scale, adaptable sediment regional risk assessment (SRRA) model, which uses site-specific and regional information to estimate the relative importance of various effect pathways (source-stressor-endpoint) in various habitats and regions for the catchment of choice. This multiple-scale model was designed to calculate the relative risks and benefits of sediment-associated stressors to a range of river basin objectives or services as a function of industry, land use, endpoint, habitat or region in a spatially explicit manner, either retrospectively (to evaluate sediment sources, risks, and benefits regionally) or prognostically (to evaluate the basin-scale risks and benefits of landscape management policy changes and targeted mitigation options). Such an approach helps policy and decision makers evaluate the potential effects of landscape- and basin-scale plans and policies.

Environmental and social impact assessment

To secure funding from lenders (e.g., World Bank), development plans must comply with the International Finance Corporation (IFC) Sustainability Framework (www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/IFC+Sustainability/Sustainability+Framework), which is globally recognized as a benchmark for environmental and social impact assessment (ESIA) in the private sector. Projects under consideration can be site- or local-level (e.g., mining, power stations) or can be linear plans (e.g., roads or pipelines) affecting ecosystems at local, regional, national, and international levels. New IFC guidelines incorporate an EsS approach and provide good practice for sustainability and risk mitigation, including supply-chain management, resource efficiency and climate change, business and human rights, and allow for a more holistic approach to impact assessment. If literally interpreted, the guidance focuses only on negative effects on EsS, although an analysis of benefits could be used for decisive applications if projects are to help enhance sustainability. Most assessments are top-down and qualitative, although, over time, it can be expected that more quantitative approaches will be developed (IEMA 2011). EcoResA, EcoRegA and Eco-LCA tools can be used to assess potential effects of alternative options of development projects; specific options can be evaluated and compared using EsSV tools.

Environmental damage and sustainable remediation

EsSP considerations are well established in support of programs such as Natural Resource Damage Assessment (NRDA) in the United States (Efroymson et al. 2004; Munns et al. 2009). In the EU Environmental Liability Directive (EL) (EC 2004) damage is defined as "a measurable adverse change in a natural resource or measurable impairment of a natural resource service that may occur directly or indirectly"; projects such as REMEDE (<http://www.envliability.eu/>) identified tools such as those used in the US NRDA programs for European application. The of focus natural resource damage (NRD) analyses is on determining the scale of measures to adequately offset legacy contamination, or threatened releases, endangering natural resources. The European ELD establishes a framework for the prevention and remediation of environmental damage for incidents that have occurred since April 2007. Assessment is generally site-based risk or impact assessment complimented by REsSA and EsSV to determine environmental liability and mitigation and/or remedial actions to rectify the damage. In the case of ELD, the remedy should reflect a predamage baseline condition.

The EsSP allows for an evaluation of trade-offs of alternative management options considering a range of scenarios, actions, and changes so that EsS outcomes can be optimized. In terms of ELD-type decisions, the expectation is for resource-to-resource compensation and mitigation. NESAs-type analysis can be used to help select sustainable options and predict EsS losses and gains over time (Nicolette et al. 2011). Sustainable remediation frameworks increasingly address the range of effects of potential remedial options, balancing potential negative effects from remedial actions (including habitat loss, C emissions, releases, and residuals) against positive effects (both resulting from contaminant removal and any habitat enhancement) and against risks and benefits of leaving contaminants in place (further information can be found at Sustainable Remediation Forum UK (<http://www.clare.co.uk/>)). EcoResA approaches can

predict effect pathways of a number of scenarios or approaches; when integrated over time, EsSV can help inform decisions that balance a range of EsS-based priorities. In a contaminated sediment scenario, evaluations of dredged material disposal options based on EsS may suggest that trade-offs can be made between low levels of contaminant risk and issues such as habitat enhancement, flood protection, and other objectives.

Liability insurance and environmental security

Driven by the European ELD (EC 2004), facility and operations managers are increasingly seeking appropriate insurance and other risk transfer measures for corporations; in some European member states, this is mandatory. In addition, YLS (2009) identified ELD-relevant contingent liabilities that could result from secondary releases during or after dredged material removal, transport, treatment, and disposal, and suggested that insurance, contractual, and legal instruments could be used to address these liabilities. Apitz and Black (2010) concluded that these issues, and their potential costs, should be included in comparative assessments to select dredged material management strategies. As stated above, the ELD explicitly requires the preservation and/or restoration of “natural resource services” as well as compensation for lost services; similar requirements exist for NRDA in the United States and in many regions, including areas of South America, Africa, the Pacific, and Asia.

At a larger scale, the need for resilience planning to provide environmental security, which “...involves actions that guard against environmental degradation to preserve or protect human, material, and natural resources at scales ranging from global to local in a sustainable manner,” (Wenning et al. 2007) is increasingly clear following the massive costs, in economic and human terms, of recent hurricanes, tsunamis, earthquakes, nuclear accidents, and terrorist activities.

Regardless of the driver, such approaches require a phased approach. EcoResA can help identify potential exposure pathways to a range of natural resources and assess potential risks, as well as ranking them to prioritize high to low-risk sites. EsSV can then help select and cost a range of options to remedy damage and estimate insurance provision.

Product safety

The European Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) has provisions for socio-economic assessment under REACH (EC 2006). Similar regimes exist in the United States (Toxic Substances Control Act; <http://www.epa.gov/oppt/tsca8e/index.html>), Canada, Japan, Taiwan, China, Korea, and Switzerland and are under proposal in India. For authorization of substances of very high concern (i.e., persistent, bioaccumulative, toxic) industry has a responsibility to demonstrate arguments for authorization and regulators have a responsibility to justify product use restrictions. The European Chemicals Agency (ECHA) provides socio-economic analysis guidance (ECHA 2012 and references therein), which could include an EsS approach, but few published case studies exist. European Scientific Committees recently consulted on improved risk assessment approaches using “value relevant impacts on humans and ecosystems” to inform risk management decisions (EC 2011). Nonetheless, there is scope for the development of such approaches.

The Framework Directive on the Sustainable Use of Pesticides (<http://ec.europa.eu/environment/ppps/home.htm>) sets minimum rules for the use of pesticides in the EC.

The current focus is on plant protection products, but scope will increase to include biocides. Recently, the European Food Safety (EFSA) adapted its risk assessment guidance to embed an ecosystems approach in food safety, crop protection policy and pesticide regulation (EFSA 2010). By requiring the consideration of ecosystem services in the registration process for new and existing agricultural chemical products, EFSA is challenging the ecotoxicology, ecology, and agricultural communities to address both product safety and farming practices in a broader context. The fact that they have also produced ecosystem-based guidance on the evaluation of the impacts of plant pests themselves EFSA (2011) sets the stage for broad-based decision making that allows for a shift from traditionally narrow, toxicology-based regulation of chemicals, to a framework in which the unavoidable need for sustainable food security can be balanced against potential risks to other resource endpoints. The absence, as yet, of a definitive, systematic assessment approach is not unusual; investment in models and tools generally follow after regulatory or commercial demands create a market for them, but the EsSP provides a context for comparative analyses. EcoResA can be used to identify impact pathways for pest control scenarios with and without the use of pesticides under consideration; EsSV can compare the net losses and gains of various scenarios.

CONCLUSIONS

Seppelt et al. (2011) observed a lack of clarity, consistency, breadth and integration in a majority of the EsS studies they reviewed. They recommended a “holistic ideal” for EsS research, which, at a minimum, requires 1) biophysical realism of ecosystem data and models, 2) consideration of local trade-offs, 3) recognition of off-site effects, and 4) comprehensive but critical involvement of stakeholders within assessment studies. Without these criteria, conclusions cannot be seen as scientifically valid or free from bias, with them, EsS studies should support evidence-based environmental management (Layzer 2008). For practical applications of the EsSP to be relevant and useful, they should, to the extent possible, also follow these ideals within the context and scope of the project.

The interactions between landscape and aquatic management and biophysical conditions generate a bundle of ecosystem services at managed and impacted sites, but these also affect the viability and sustainability of EsS at a range of scales from the site-specific to the global (Apitz 2012). These interactions are complex and our ability to predict and manage them is limited. Extensive research is underway to better understand the mechanisms behind many of these interactions, but in real, dynamic systems, significant uncertainties will remain. In the vast majority of frameworks that use EsS concepts to inform decisions, EsS delivery and impacts are, at their root, only qualitatively or semiquantitatively assessed, but given the complexity and scientific uncertainty of multistressor, multiendpoint, multiscale ESS interactions, it is unlikely that qualitative but broad-based assessments are less meaningful than those that address a less extensive range of parameters more quantitatively.

Given that no model can generate results more certain than its least certain or precise parameter (Kapustka and Landis 2010), complex frameworks should be designed in a tiered and iterative manner in which hypotheses about dominant processes can be examined, and where more detailed understanding can be applied as it evolves. This requires that even if EsS frameworks include seemingly quantitative

valuation steps (whether these are monetary or not) it is important that the underlying approaches, assumptions, tools and models are transparent and accessible. How one ranks potential risks and benefits to various receptors, goods, and services is a policy decision, but it is essential that sound science is developed and clearly communicated to inform such decision frameworks. Although there is no “one size fits all” approach to the application of the EsSP, there is a need for greater clarity about how such issues are addressed within and between applications; a first step in this process is the development of a common, cross-sectoral vocabulary that allows for communication, or even integration, across EsS frameworks, management sectors, and, ideally, between science and applications. The taxonomies proposed in this article, largely adapted from those used by a range of “consumers” of EsS information, may help practitioners of EsSA and EsSV ensure relevance of their analyses and better understand and communicate with those who will be making decisions based on them.

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