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Methodological and Ideological Options

Where is the consensus? A proposed foundation for moving ecosystem service concepts into practice

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ABSTRACT

Inconsistent terms, definitions, and classifications hinder advancement of the study and application of ecosystem services. A unified approach among disciplines involved in researching and implementing ecosystem services is imperative to moving concepts into practice. An operational definition needs to be adopted by the ecosystem service community as the basis of a classification system so that ecosystem goods and services may be measured by ecologists, valued by economists, and utilized by decision-makers. We propose a transdisciplinary approach centered upon shared principles, an ecosystem services definition, and a classification system. This shared foundation provides a common set of ecosystem goods and services that serves as the focus for and connection among multiple disciplines. This foundation is specific enough to be operational while remaining relevant to a multitude of ecosystem service objectives for which frameworks and implementation plans may be developed. Although numerous ecosystem service frameworks exist in the literature, many of them are non-operational or are focused toward a single discipline. An evaluation of these frameworks identifies knowledge gaps and suggests how we may advance ecosystem services into practice. Our evaluation demonstrates that foundational concepts (especially a definition and classification system, and community involvement) are often poorly addressed in ecosystem service frameworks.

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1. Introduction

The interconnectedness of humans and the environment has been acknowledged for thousands of years, but only within the last few decades have we begun to understand the effects human activities have on the environment and to recognize the extent to which humans and the environment are interrelated (Daily, 1997). As the body of knowledge on the relationship between the environment and society develops, so does an acute awareness of the importance of ecosystems to maintain and improve human well-being. The idea of public goods and services was first discussed in conjunction with ecosystems in the 1970s, and as the concept developed, the term "ecosystem service"[1] was introduced to describe the public *benefits* (def. an impact, positive or negative, on human welfare)[2] provided by ecosystems (Daily, 1997; Ehrlich and Ehrlich, 1981; Westman, 1977).

Since the introduction of the ecosystem services concept, numerous definitions have been developed, many of which are vague and necessitate interpretation by those using the definition. Some of the most commonly cited definitions for ecosystem services are listed in Table 1. Even within these few definitions, there is a marked variability in the philosophy supporting them. Ecosystem services are either directly equated to benefits provided by the ecosystem or associated with the *ecosystem attributes* (def. a biological, physical, or chemical characteristic or feature inherent to an ecosystem) that lead to benefits. This philosophical discrepancy may seem trivial, but if the definition is truly used as a guideline to identify ecosystem services, different suites of either purely ecological (equated to ecosystem attributes) or purely anthropologic (equated to benefits) services are attained. For example, clean water and fish may be identified as ecosystem services when ecosystem services are equated to ecosystem attributes, while reduced risk of acquired methemoglobinemia[3] or commercially-harvested fish may be identified as ecosystem services when ecosystem services are equated to benefits. In many cases, defining the term is avoided altogether by simply referring to

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[1] Goods are inherent in the term "ecosystem service" here and throughout this article.

[2] Definitions (abbreviated "def.") in this article are original to this document unless otherwise cited and are provided to enhance clarity of the language used throughout.

[3] Methemoglobinemia is most often associated with Blue Baby Syndrome, an inherited genetic blood disorder; however, an acute toxic form of methemoglobinemia (called acquired methemoglobinemia) can occur in infants, children, and adults as a result of exposure to nitrites and nitrates, among other chemicals and pharmaceuticals.

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Table 1
Definitions of ecosystem services and their sources commonly cited in the literature. The Philosophy column indicates whether the definition used in the article is that ecosystem services lead to (➔) or are the same as (=) benefits.

Definition of ecosystem services	Citation	Philosophy
…"the benefits human populations derive, directly or indirectly, from ecosystem functions."	(Costanza et al., 1997)	Ecosystem services = benefits
…"the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life."	(Daily, 1997)	Ecosystem services ➔ benefits
…"the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly."	(de Groot et al., 2002)	Ecosystem services ➔ benefits
…"the set of ecosystem functions that is useful to humans."	(Kremen, 2005)	Ecosystem services ➔ benefits
…"the benefits people obtain from ecosystems."	(MEA, 2005)	Ecosystem services = benefits
…"components of nature, directly enjoyed, consumed, or used to yield human well-being."	(Boyd and Banzhaf, 2007)	Ecosystem services ➔ benefits
…"the aspects of ecosystems utilized (actively or passively) to produce human well-being."	(Fisher et al., 2009)	Ecosystem services ➔ benefits
…"a range of goods and services generated by ecosystems that are important for human well-being."	(Nelson et al., 2009)	Ecosystem services ➔ benefits
…"Benefits that humans recognize as obtained from ecosystems that support, directly or indirectly, their survival and quality of life."	(Harrington et al., 2010)	Ecosystem services = benefits
…"a collective term for the goods and services produced by ecosystems that benefit humankind."	(Jenkins et al., 2010)	Ecosystem services ➔ benefits

a specific ecosystem service or suite of services (e.g., Barbier et al., 2008; Hoehn et al., 2003; Le Maitre et al., 2007; Loomis et al., 2000; Maler et al., 2008; Mertz et al., 2007; Metzger et al., 2008). As a result of both the number of definitions and the ambiguity associated with them, the term "ecosystem service" has become a catchall phrase that is now used to refer to anything from or within an ecosystem that is beneficial to any living thing, a concern also raised by Seppelt et al. (2011). Fig. 1 illustrates the number of "ecosystem services" categorized into processes/functions, structural components, goods, human uses, or securities that have been cited in 25 publications that specifically named examples of what they considered to be ecosystem services, answering the question, "What do researchers think ecosystem services are?" It is evident that the term "ecosystem services" has been defined to represent a substantial number of things, which leads to the question, "What isn't an ecosystem service?" However, one commonality exists among all definitions; ecosystem services are associated with human benefits (Kline et al., 2009).

With the recognition of the growing importance of ecosystems to humans under the mounting pressures of global climate change, population growth, and resource depletion, natural and social scientists have been called to measure and value ecosystem services in a way that augments current mechanisms for preserving and protecting ecosystems (e.g., U.S. Antiquities Act of 1906, National Park Service Act of 1916, National Environmental Policy Act of 1969, the land stewardship of groups like The Nature Conservancy) and for regulating the sustainable use of things that ecosystems support and produce (e.g., the U.S. Clean Water and Endangered Species Acts, cooperatives of fisherman like the Maine Lobster Council). This can be accomplished by (1) quantifying and communicating the contribution of ecosystem services to human well-being; (2) evaluating trade-offs among various ecosystem services, and between ecosystem services and services generated through human efforts; and (3) including the value of ecosystem services in a nation's accounting system and related economic decision making (de Groot et al., 2010; Kremen and Ostfeld, 2005; Le Maitre et al., 2007; Nicholson et al., 2009; Palmer and Filoso, 2009).

It is clear that the concept of ecosystem services encompasses both environmental and human elements; hence, transdisciplinary approaches are crucial to ecosystem service research. *Transdisciplinary* (def.) approaches are exemplified by frequent communication and shared effort among two or more traditional disciplines based on a common, discipline-transcending theory from which language, concepts, and methods are developed to solve problems beyond the confines of a single discipline (van den Besselaar and Heimeriks, 2001). Discipline-bound paradigms prevent interaction and congruency between natural and social scientists (Carpenter et al., 2009), and create a disconnect between the ecosystem services ecologists measure, those economists value, and those the public care about (Barbier, 2007; Boyd and Banzhaf, 2007; Cowling et al., 2008; Fisher et al., 2009; Turner and Daily, 2008).

In one of the most comprehensive transdisciplinary efforts to date, the Millennium Ecosystem Assessment (MEA) documents the global status and trends in ecosystem condition and services and the consequences on human well-being (MEA, 2005). The collaboration of hundreds of experts from different disciplines represents a landmark venture that advanced ecosystem services to the forefront of science and policy. To address ecosystem services, the MEA presented a *classification system* (def. an organized structure for identifying and organizing ecosystem services into a coherent scheme) composed of four classes of ecosystem services: regulating, supporting, provisioning, and cultural. These categories serve as a heuristic tool for organizing ecosystem services in a way that allows for an effortless grasp of how specific ecosystem goods and services generally relate to benefits.

Perhaps the greatest problem that the ecosystem services community still faces is that members are addressing ecosystem services independently. Many ecosystem service quantification and valuation studies have been conducted in different ecosystems and at different scales (e.g., local, regional, and national) around the world (e.g., Costanza et al., 1997; Engle, 2011; Guo et al., 2001; Jenkins et al., 2010; Loomis et al., 2000; Wilson and Carpenter, 1999; Woodward and Wui, 2001). The approaches and methods vary so much among

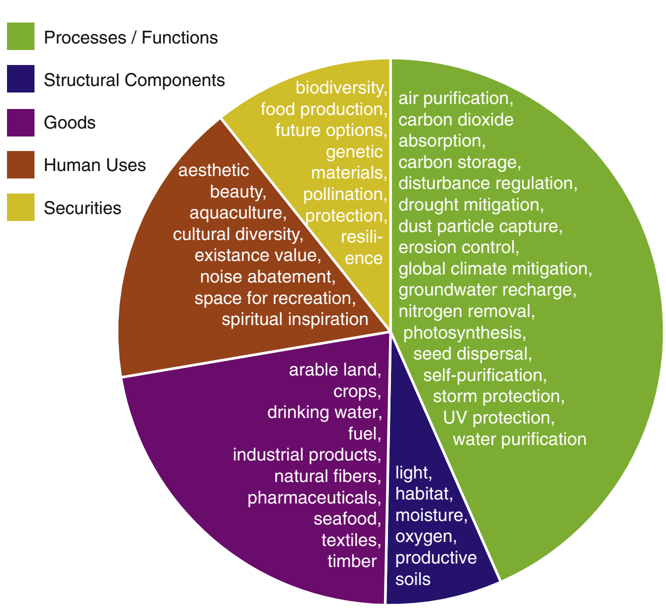

Fig. 1. Examples of "ecosystem services" cited in 25 publications categorized by processes/functions (43%), structural components (7%), goods (22%), human uses (17%), or securities (11%). Categories and assignments of "ecosystem services" to specific categories were determined by the authors of this article. Each pie piece represents the relative abundance of cited "ecosystem services" that occur in that category.

these studies that it is questionable if they can be compared or aggregated (Brander et al., 2006; Van Houtven et al., 2007; Woodward and Wui, 2001). Inappropriate definition, construction, and use of classification systems, such as the one produced by the MEA, result in inconsistent lists of services, a disconnection between identified ecosystem services and human well-being, inability to cross disciplinary boundaries, and double-counting of services (Boyd and Banzhaf, 2007; Fisher et al., 2008, 2009; Hein et al., 2006). Development of a single definition of "ecosystem service" and a classification system that facilitates the identification of ecosystem services and a strategy to help guide research development in a way that is meaningful to natural and social scientists, and the public is imperative to moving ecosystem services from a concept to a practice. Currently, there is no such system and no consensus. In this article, we present an *approach* (def. underlying philosophy leading to guiding principles from which to address ecosystem services in a repeatable manner) that we believe is a strong step toward this consensus and report on an evaluation of 11 ecosystem service frameworks to assess research areas that need to be strengthened.

2. From Concept to Practice

We propose an explicit, rational process by which ecosystem service concepts are developed, advanced, and moved into practice (Fig. 2). We hypothesize that this process is critical to successfully meeting objectives set for ecosystem service research and for moving the results into the realm of policy, planning, and decision making in a timely fashion through the focus on the production of an implementation plan. While we believe this process is most useful when it is utilized from the beginning of the conceptual phase, it may also improve mature ecosystem service studies by helping strengthen, refine, and achieve consistency among the underlying concepts.

Identifying objectives and guiding *principles* (def. a set of fundamental rules) is the basis for defining and identifying ecosystem services and for drafting a classification system. As exemplified by the arrows in Fig. 2, the development and testing of the classification system may expose flaws in the guiding principles, which can be refined for consistency. Likewise, refinement of the classification system may necessitate a more precise definition of ecosystem services.

Once ecosystem services are defined and can be identified and organized in accordance with a classification system, objectives, and guiding principles, a framework is designed. We define an ecosystem service *framework* (def.) as a structure that includes the relationships among a set of assumptions, concepts, and practices that establishes an approach for accomplishing a stated objective or objectives pertaining to ecosystem services. For example, if an objective is to measure ecosystem services, then the framework should address the relationships among a set of assumptions, concepts, and practices that lead to measurements of ecosystem services. Some commonly cited ecosystem service objectives, for example, are (1) measuring, quantifying, and valuing ecosystem services for inclusion in a strategy to prioritize restoration and protection, (2) aggregating ecosystem services over space and time for land use planning, (3) evaluating trade-offs among management options, and (4) developing an ecosystem service accounting system.

The final step in moving ecosystem service concepts into practice is to create an *implementation plan*, or (def.) explicit methods and approach by which an ecosystem service framework can be executed. In creating an implementation plan, new details may emerge that need to be incorporated into the framework for completeness and to achieve internal integrity.

Through the feedback and refinement process discussed above and illustrated in Fig. 2, the most basic notion of ecosystem services – a definition – becomes *operational* (def. used in a repeatable, consistent, and meaningful way) (see Section 5 for a more detailed discussion of this term). We believe that a common conceptual foundation (i.e., principles, definition, and classification) would allow for better communication, collaboration, and understanding both within and outside the ecosystem service community. Using the steps of this process as an outline in the following sections, we propose general ecosystem service principles, an operational definition, and a classification system that are relevant to a variety of ecosystem service objectives and could serve as this shared foundation.

3. Developing a Foundation: Guiding Principles and Objectives

The guiding principles under which our approach has been developed are:

Principle 1. Measuring, quantifying, valuing, and/or accounting for ecosystem services requires a wholly collaborative effort among natural scientists, social scientists, and decision-makers.

Principle 2. Ecosystem processes and functions produce ecosystem services, while people, groups, or firms (hereon referred to as "individuals") actualize ecosystem services by utilizing them in consumptive and non-consumptive ways.

Principle 3. Defining, identifying, and classifying a complete, but non-duplicative, set of ecosystem services is the foundation of a transdisciplinary approach.

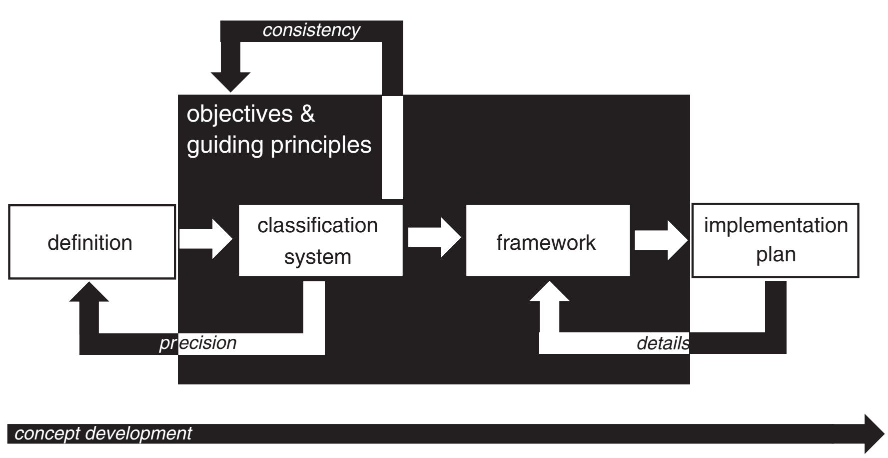

Fig. 2. The process by which ecosystem service concepts move into practice, including feedbacks among the steps that help to inform and strengthen the overall products.

Principle 4. Because individuals actualize ecosystem services, their involvement (either direct or indirectly) in identifying ecosystem services and contributing to the framing of the research and the implementation plan is crucial.

These guiding principles may be used to support a variety of ecosystem service objectives although they most strongly support measuring and accounting for ecosystem services in a manner that is conducive to policy development and decision-making.

4. Finding Consistency: Defining and Classifying Ecosystem Services

Defining “ecosystem service” in a manner that connects to multiple disciplines and the public while maintaining a clear and precise objective has proven extremely difficult, as reflected in journal articles that have addressed the issue (Table 1; Boyd and Banzhaf, 2007; Fisher et al., 2009; Haines-Young and Potschin, 2010; Seppelt et al., 2011; Wallace, 2007). A recent survey conducted by The Nature Conservancy (Metz and Weigel, 2010) revealed that problems pertaining to ecosystem service terminology reach beyond the research community, affecting public opinions as well. Survey participants across the U.S. were dissatisfied with the term “ecosystem service” altogether. They preferred the term “nature” to “ecosystem” and felt disconcerted by the idea that “nature exists to serve humans”.

In an effort to articulate a precise, useful, and objective definition for “ecosystem services”, Boyd and Banzhaf (2007) present the concept of *Final Ecosystem Goods and Services (FEGS)* (def.) as “components of nature, directly enjoyed, consumed, or used to yield human well-being”. The term “final” is used to emphasize the ultimate (i.e., last) biophysical entity in nature used by individuals to acquire a [human] benefit. The interests of individuals may be active (e.g., the individual physically interacts with the ecosystem through an activity) or passive (e.g., despite that the individual may never visit the ecosystem, it is still important to the individual that the ecosystem remains intact). In addition, individuals can benefit from (i.e., associate value with) an ecosystem in multiple ways and, therefore, may represent multiple types of beneficiaries. *Beneficiaries* are (def.) categories of ways in which people benefit from ecosystems, whether via active or passive consumption or appreciation merely through awareness of ecosystem services, resulting in an impact on human welfare. A *beneficiary approach*, (def.) the classification of ecosystem goods and services by beneficiary categories, can be used to organize (i.e., classify) FEGS.

We adopt this definition of FEGS because we believe it is the best available foundation for a classification system for the purpose of measuring, valuing, and communicating ecosystem services, and others seem to agree (Fisher et al., 2008, 2009; Haines-Young and Potschin, 2010; Johnston and Russell, 2011; Ott and Staub, 2009; Staub et al., 2011). The particular strengths of the FEGS approach to defining ecosystem services are that it:

- Avoids much of the ambiguity associated with other definitions by restricting ecosystem services to the things in an ecosystem with which beneficiaries directly interact. The specificity of this definition abates personal interpretation and promotes repeatable identification of ecosystem goods and services; in other words, different people using the FEGS definition to identify ecosystem goods and services are likely to attain the same results.
- Eliminates double-counting ecosystem services. Many other definitions and examples of ecosystem goods and services often include ecosystem processes and the ecosystem entities with which people may or may not directly interact. For example, the MEA (2005) identifies both primary production (Supporting Service) and wood and fiber (Provisioning Service) as ecosystem services, despite the fact that without primary production, wood and fiber would not exist. Although photosynthesis is an essential ecological process, an additional issue is that it likely does not resonate with many beneficiaries. Double-counting causes problems for the valuation of ecosystem goods and services (de Groot et al., 2002; Fisher et al., 2008, 2009; Hein et al., 2006; Johnston and Russell, 2011; Wallace, 2007). Because the definition for FEGS specifically addresses only direct interactions between beneficiaries and the ecosystem, double-counting and the associated confusion is minimized.
- Encourages natural and social scientists to collaborate by connecting ecosystem services to both ecological features and beneficiaries. FEGS integrate the environmental features important for (a) natural scientists to quantify, (b) social scientists to qualify and validate, (c) economists to value, and (d) policy managers to incorporate, all the while accounting for those environmental aspects that directly affect human well-being (i.e., the public). A shared set of FEGS among natural and social scientists and policy managers provides a common language through which transdisciplinary interaction may occur, effectively bridging the gap among disciplines.
- Can be understood by the public (i.e., non-scientists) without translation or interpretation because FEGS are determined by beneficiaries. Allowing beneficiaries to identify ecosystem attributes from which they benefit is the first step to successfully identifying FEGS. Furthermore, expressing ecosystem goods and services in terms familiar to the public – a common language – may result in greater awareness and involvement among the public and ecosystem service research and policy.

As emphasized above, putting Boyd and Banzhaf's (2007) definition of FEGS into practice through a classification system requires that ecosystem goods and services are identified by beneficiaries. For example, an individual visiting a wetland specifically to bird watch benefits from the birds that may be viewed; therefore, one FEGS provided by the wetland to the birdwatcher (the beneficiary) is the presence of birds that may be viewed. Even though habitat provisioned by the wetland, habitat condition, presence or absence of water, and many other ecosystem characteristics and processes influence the presence of birds, the beneficiary, in this case, is directly and ultimately interacting with the birds – not the habitat – to acquire a change in welfare. The birds are the FEGS (Ringold et al., 2011). A second example: water of sufficient quality for explicit beneficiaries (and there are many) is a FEGS. Many types of beneficiaries (e.g., crop irrigators, livestock producers, agricultural and industrial processers, municipal and residential drinking water consumers, subsistence users, etc.), interact with aquatic ecosystems to extract water to support their welfare (Ringold et al., in review). The ability of the ecosystem to remove toxins from and cycle nutrients in the water is an important ecosystem function related to the quality and the provision of ecosystem services but is not the entity with which the individuals interact; the clean water is the FEGS.

Boyd and Banzhaf's definition of FEGS is practical but not yet operational. However, efforts, such as the guidelines for identifying FEGS developed by Johnston and Russell (2011), are a step toward operationalizing Boyd and Banzhaf's definition. Providing another example of how the FEGS concept is moving toward operational use, a group of researchers from the U.S Environmental Protection Agency (USEPA) lead the development, with the help of many others, of a beneficiary approach classification system and has used it to identify FEGS provided by several different ecosystems. This classification system was evaluated in two interdisciplinary workshops sponsored by the USEPA in which natural and social scientists discussed and identified indicators of FEGS for streams (Ringold et al., 2009; Ringold et al., in review) and for wetlands and estuaries (Ringold et al., 2011).

5. What Are We Working With? A Review of Ecosystem Service Frameworks

We have presented a process by which ecosystem service concepts can be moved into practice and proposed guiding principles, an operational definition, and a classification system to use as a foundation for this process. From this foundation, a multitude of objectives may be addressed by developing objective-specific frameworks and implementation plans. Although we are not aware of any broad-scale published ecosystem service implementation plans, there are numerous published frameworks. The development of many of these frameworks was motivated by new thought sparked by the Millennium Ecosystem Assessment (MEA), and as the concepts and ideas regarding ecosystem services are explored, more frameworks will be generated. Each framework may have its own specific objective, with general applications ranging from systematizing or organizing ecosystem services (de Groot et al., 2002; Fisher et al., 2009; Kremen and Ostfeld, 2005; Rounsevell et al., 2010), valuing ecosystem services (Hein et al., 2006; Wainger and Mazzotta, 2011), quantifying ecosystem services (Paetzold et al., 2010), and mainstreaming ecosystem services into social behavior or policy/management decisions (Cowling et al., 2008; Daily et al., 2009; Maynard et al., 2010; Turner and Daily, 2008; Wainger and Mazzotta, 2011). Even though some of these ecosystem service frameworks have been published and commonly cited in the literature for nearly a decade, we have not seen evidence that these frameworks are commonly used in practice. In fact, it seems that an increasing number of frameworks are being proposed, but few move beyond establishing vague concepts.

Criteria for designing frameworks reside in the objective — what is the final product and what is it supposed to do? The framework is the logical and realistic means by which the elements are put together so the defined objectives are adequately met and incorporated in the implementation plan. Regardless of the fact that frameworks are often designed to meet varying objectives, there are broad characteristics that an ecosystem service framework may exhibit that foster practicality while still addressing specific objectives for which it was designed. We propose that there are a minimum of six characteristics that should be incorporated into an ecosystem service framework for it to be operational (Table 2):

1. *Ecosystem Service Definition and Classification System* — A definition of "ecosystem services" and a classification system for identifying and categorizing ecosystem services are the conceptual foundation of an ecosystem service framework. A classification system should be systematic, complete, non-duplicative, and consistent (i.e., reproducible results are attained).
2. *Transdisciplinary* — Ecosystem services are inherently transdisciplinary, and as such, an ecosystem service framework should engage the shared efforts of natural scientists and social scientists using theory that bridges these individual disciplines. In doing so, the language, terms, concepts, and methods used for the framework should transcend any single discipline to reach natural scientists, social scientists, and non-scientists.
3. *Community Engagement* — The connection between the ecosystem and human well-being is a vital element in developing an ecosystem service framework. *Community engagement*, (def.) involvement of individuals, groups, and/or firms that have an interest (active or passive) in the ecosystem(s), should be included as a major component of ecosystem service identification and/or validation. Optimally, the community should be included in open dialog early in the framework development process to identify, classify, value, and/or quantify ecosystem services. Ignoring those who are inextricably connected to ecosystem services altogether will result in a dysfunctional framework once put into use.
4. *Resilient* — Ecosystem services are not static; concepts, perceptions, and awareness of ecosystem services will evolve as new information and knowledge is attained and as social values change. Ecosystem services themselves can be affected by social attitudes, the economy, environmental conditions, and policy and management decisions. Therefore, an ecosystem service framework should include adaptive strategies to be flexible and resilient enough that changing viewpoints, environmental landscapes and conditions can be incorporated into the framework over time and policies do not render the framework obsolete.
5. *Cohesive and Coherent* — An ecosystem service framework represents the underlying assumptions, concepts, and practices (hereon, just "assumptions") pertaining to a stated objective and demonstrates how the assumptions relate to one another. For an ecosystem service framework to be potentially operational, it must be cohesive and coherent. In other words, the underlying assumptions should be conceptually-sound and the overall framework should be organized logically and realistically — failure to meet any of these conditions severely compromises the potential of a framework to be operational.
6. *Policy-Relevant* — The goal of implementing an ecosystem service framework is to take nature's benefits into consideration when developing regulations and policy and making land use decisions. As such, an ecosystem service framework should have the potential to be policy-relevant. Although policy and decision-making may not be explicit in a framework, the information gained through applying the framework should help improve policy and management decisions by identifying and informing the ecological outcomes of various possible decisions.

Four of these characteristics, transdisciplinary, resilient, cohesive and coherent, and policy-relevant are based on specific recommendations called for in Carpenter et al. (2009). We discussed many supporting reasons for why an ecosystem service definition and classification system are important aspects of developing an ecosystem service framework, and we posit that these characteristics should be explicitly addressed in an ecosystem service framework. We also propose that because ecosystem services are implicitly connected to human use, community engagement is crucial to the development process of an ecosystem service framework.

These six characteristics have been incorporated into existing ecosystem service frameworks to differing degrees. We determined that there is a range to which these characteristics have been incorporated in frameworks. This range is reflected in the detailed statements in Table 2. The criteria are organized systematically, with those that address the most basic foundational concepts on the left to those that address the approach and [potential] implementation of the framework on the right. Using the statements listed in Table 2 to systematize the evaluation process and reduce individual bias, we (each of the four authors of this article, hereon referred to as "examiners") reviewed 11 peer-reviewed ecosystem service frameworks. These frameworks were chosen because they are frequently cited in the ecosystem service literature or recently published. Generally, the approach presented within these articles has been explicitly defined by the authors as a "framework". For each of the criteria, a rating of 0 to 4 was assigned by each of the four examiners, with 0 indicating that the criterion was completely absent from the framework and 4 indicating that the criterion was strongly represented. Before performing the framework review, we minimized any subjectivity in choosing criteria and accompanying statements by revising Table 2 according to comments provided in an external review by several natural and social scientists.

The four examiners conducted an independent appraisal of the 11 published, peer-reviewed frameworks. Each of the six criteria was considered relative to each framework. Ratings were assigned by choosing the statement that most accurately described the extent to which each criterion was addressed. Best judgment was used to evaluate criteria in cases where authors of the framework articles inferred ideas pertaining to a criterion but may have not specifically discussed it. The four independent scores for each criterion were averaged but not weighted. PASW Statistics 18 for Windows was used to run descriptive statistics and a General Linear Model (GLM) with Tukey post-hoc tests to determine whether there were significant differences

Table 2
Specific criteria and associated statements used to evaluate peer-reviewed ecosystem service frameworks. Ecosystem services are abbreviated as "ES" in the statements. Scores range from 0 (completely lacking from the framework) to 4 (strongly addressed in the framework).

Criteria	Lacking 0	1	2	3	Addressed 4
Ecosystem service definition & classification system	• There is no definition, OR • only a general definition (i.e., vague, double-counting issues) is provided.	• A general definition is provided, AND • the text includes examples of ES or places ES in context of other definitions to help clarify the general definition.	• Only a clear, precise definition (specific enough to lead to consistent ES identification, avoids double-counting) is provided.	• A clear, precise definition is provided, AND • the text includes hypothetical examples and/or protocol for using the definition to classify ES.	• A clear, precise definition and classification system are provided, AND • use of the classification system has been demonstrated (i.e., set of ES are included in text).
Transdisciplinary	• Only a single discipline is represented, AND • there is use of discipline - specific language and terms.	• Major disciplines (e.g., ecology, economics) are identified, BUT • only a single discipline is represented using discipline - specific language and terms.	• Several disciplines are included, BUT • collaboration is not explicitly encouraged (i.e., "information hand -off" is promoted).	• Several disciplines are included and explicitly encouraged to collaborate, BUT • discipline-specific language and terms are still used.	• Several disciplines are included and explicitly encouraged to collaborate, AND • language and terms can be interpreted across many disciplines.
Community engagement	• Individuals (i.e., people, groups, and firms) are not considered.	• Individual perspectives are identified as an important consideration, BUT • individuals are not queried about ES.	• Individual perspectives are identified as an important consideration, AND • individuals are queried about ES.	• Individuals are identified and queried about ES, AND • scientists facilitate discussion.	• Individuals actively participate through open dialog with each other and with scientists early in the process of framework development.
Resilient	• The framework is restricted by linearity or details, AND • it lacks flexibility in the event of changing conditions.	• The framework is so general or detailed that changes in conditions would not have an impact on the framework.	• The framework mentions the potential for changing conditions, BUT • it is not flexible and could still be compromised by changes in conditions.	• The framework is only operational in the short-term because it includes re - evaluation (i.e., restarting from the beginning) as a method for incorporating change.	• The framework is operational in the long-term because it is adaptable to changing conditions.
Cohesive & coherent	• The underlying assumptions of the framework are untested or based upon scarce information, AND • it is not organized logically or realistically.	• The underlying assumptions of the framework are untested or based upon scarce information, BUT • it is organized logically and realistically.	• The framework is conceptually sound, BUT • it is not organized logically or realistically.	• The framework is conceptually-sound, AND • it is organized logically and realistically.	• The framework is conceptually sound and organized logically and realistically, AND • its use has been demonstrated.
Policy-relevant	• Policy (and/or decision - making) implications are not considered in the framework.	• Policy (and/or decision - making) is mentioned as a future implication, BUT • policy issues are not specifically addressed.	• Policy (and/or decision - making) is a minor component of the framework.	• Policy (and/or decision - making) is a major component of the framework.	• Policy (and/or decision - making) is a major component of the framework, AND • specific policy needs are addressed.

Criterion is... 0 - completely lacking; 1; 2; 3; 4 - strongly addressed

Evaluative Criteria

Framework	Ecosystem Services Definition & Classification System	Trans-disciplinary	Community Engagement	Resilient	Cohesive & Coherent	Policy-Relevant
de Groot et al. 2002	1.8	2.8	1.0	2.6	2.5	1.5
Kremen & Ostfeld 2005	1.0	1.0	0.5	0.8	1.5	2.1
Hein et al. 2006	3.0	2.3	1.5	2.3	3.3	1.0
Cowling et al. 2008	1.1	2.8	2.0	3.3	1.8	2.5
Turner & Daily 2008	0.8	1.8	0.8	2.0	0.5	2.5
Daily et al. 2009	0.3	3.0	1.8	3.5	2.8	4.0
Fisher et al. 2009	2.8	1.8	1.3	2.8	2.5	2.0
Maynard et al. 2010	2.3	4.0	3.8	3.5	3.8	3.5
Paetzold et al. 2010	1.3	1.3	2.0	2.8	1.0	2.5
Rounsevell et al. 2010	0.3	1.3	1.0	2.8	1.9	3.3
Wainger & Mazzotta 2011	2.0	3.3	1.0	3.3	2.8	3.3

Fig. 3. Comparison of 11 peer-reviewed ecosystem service frameworks using six criteria (columns) effective frameworks should meet. Each framework was rated using a 0–4 scale, with 0 (completely white box) indicating that the associated criteria is completely lacking from the framework and 4 (completely black box) indicating that the framework strongly addresses the associated criteria. Numbers represent the mean score (n = 4) assigned via an independent review conducted by each of the four authors of this article (hereon referred to as "examiners"). The shading of each box was determined by rounding the mean score to the nearest whole number. Completely white (0) and completely black (4) boxes represent a smaller point spread (≤0.5) than the other shades, and it should be noted that these extremes are more discerning (i.e., the examiners' scores were in agreement).

among the scores of four examiners for each criterion or overall criteria scores. This evaluation is used as a tool to discuss the evolution of ecosystem service frameworks, recognize knowledge gaps, and identify how frameworks may be improved in the future.

The mean score for each criterion and framework is displayed in Fig. 3. The shade of each box in this figure was determined by rounding the mean score to the nearest whole number; therefore, completely white (0) and completely black (4) boxes represent a smaller point spread (≤0.5) than the other shades. In other words, for a framework to attain one of these discerning scores, the examiners' scores had to be in agreement. A total of 264 scores were assigned (one score for each of the six criterion by each of the four examiners for each of the 11 frameworks) — resulting in 66 means. The scores of the four examiners within the same criterion were not significantly different ($p = 0.348$, GLM author∗criteria), indicating that the four examiners independently scored each criterion similarly. This may be partially due to the systematic process (i.e., detailed statements, Table 2) by which the frameworks were evaluated. However, given the fact that the examiners refrained from discussing the frameworks with each other prior to conducting the evaluations and the wide range of objectives covered within this particular set of frameworks, the relative consistency in evaluations indicates that these evaluations are unbiased and likely repeatable.

Generally, the criteria were better addressed in articles that were published more recently. Within the four ecosystem service frameworks published in 2010 or later, mean scores of 3.0 or higher for any criterion were achieved in 9 instances (Fig. 3). On the other hand, the 7 reviewed frameworks published from 2002 to 2009 only strongly met criteria in 6 instances. In fact, this evaluation reveals an interesting temporal pattern that occurs among the frameworks; in the earlier years, frameworks better address the first two criteria, which are foundational concepts, while the more recent articles have shifted away from discussing definitions and transdisciplinary approaches and instead show strength in meeting the "Resilient", "Cohesive and Coherent", and "Policy-Relevant" criteria. This suggests that some of the critical concepts that have been stressed throughout the ecosystem service literature (i.e., Carpenter et al., 2009) are being incorporated into the more recent frameworks. These three criteria in addition to "Transdisciplinary" also received the highest scores of all the criteria, with "Resilient" and "Policy-Relevant" addressed the strongest in the reviewed frameworks, closely followed by "Transdisciplinary" and "Cohesive and Coherent".

It is immediately evident from Fig. 3 that two of the criteria, "Ecosystem Services Definition and Classification System" and "Community Engagement", consistently received the lowest scores of any of the criteria. In fact, these two criteria scored significantly lower than the other four criteria ($p > 0.001$, GLM criteria). More than half of the reviewed framework articles failed to define ecosystem services altogether or only provided a vague, general definition. However, two frameworks, Hein et al. (2006) and Fisher et al. (2008), discussed the definition and classification of ecosystem services at length, providing a clear, precise definition that could possibly lead to consistent ecosystem service identification. The definition presented in Fisher et al. (2008) is derived from Boyd and Banzhaf (2007), while Hein et al. (2006) describe a classification system that carefully avoids double-counting. The constant flux of the definition of "ecosystem services" and the associated confusion may be a contributing factor to the lack of specific definitions in the majority of reviewed articles, but this is even more reason to establish a clear, precise definition and classification system for ecosystem services that fits set goals and objectives.

The active incorporation of individual perspectives or consideration of beneficiaries in the development of the ecosystem service framework was another key concept of ecosystem services that was repeatedly overlooked in the reviewed frameworks. Individuals were often identified as an important part of the framework development process as evident by the numerous scores between 1.0 and 2.0 in the "Community Engagement" category. However, only one framework, Maynard et al. (2010), actually actively collaborated with more than 140 individuals (e.g., people from the government, university, and non-government that have an interest in the regional ecosystems) as part of the framework development process, which is reflected in the mean score of 3.8 that was awarded to Maynard et al. in the "Community Engagement" category. Even though individuals are often recognized as an important component of ecosystem service framework development, this evaluation reveals that very few frameworks actively incorporate individual perspectives into the process in a tangible way. In the case of Maynard et al., the broad participation of individuals in the framework process has facilitated its acceptance and implementation. The need for community engagement is a significant gap that should be addressed in future frameworks.

Aside from strongly meeting the "Community Engagement" criteria, the framework described and used by Maynard et al. (2010) received consistently high scores for 5 of the 6 criteria. (Note that to score a mean of 4.0, all four examiners had to independently assign a score of 4.0.) The frameworks proposed by Wainger and Mazzotta (2011) and Daily et al. (2009) also received high scores (above 3.0 in 4 of the 6 criteria). A common short-coming among each of these highly scored frameworks is a clean, consistent definition and classification system. Could these notable frameworks be strengthened even more by establishing a definition and classification system? We are confident that they can.

6. Conclusions

This ecosystem service framework review demonstrates that foundational concepts – especially an ecosystem service definition and classification system and community engagement – are often poorly addressed in ecosystem service frameworks. Implementation issues, such as resilience, cohesiveness, and policy-relevance, have been increasingly incorporated into recent ecosystem service frameworks. This indicates that the development of ecosystem services is moving ahead on a poor foundation and may be one reason for the delay in moving ecosystem services from concept into general practice. Although the process by which ecosystem service concepts move from research into practice may seem obvious (e.g., Fig. 2), crucial steps are frequently omitted or ignored altogether, resulting in a framework with limited application. In some cases, the logical progression of steps may have been followed, but the foundational concepts of the framework were inconsistent, flawed, or lacked detail. Establishing an operational definition and classification system that facilitates the identification of ecosystem services and a strategy that helps guide research development in a way that is meaningful to natural and social scientists and the public is imperative to moving ecosystem services from concept to a practice. The FEGS approach, which includes an operational definition and classification system, is a strong candidate for a component of a foundation that could help align the ecosystem service community and support the research needed to make consideration of ecosystem services a viable part of environmental decision-making and managing for sustainability.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.ecolecon.2012.01.001.

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