The 18 benefits of using ecosystem services classification systems

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Highlights

•Classification science provides value to fields with large datasets (e.g., health).
•Ecosystem services classification systems (ES-CS), and their principles, exist.
•ES-CS are used mostly in environmental accounting, not ES efforts more broadly.
•ES-CS use provides 18 benefits, far outweighing the costs of transitioning to ES-CS.
•Actionable steps to begin the transition to using ES-CS are discussed.

Abstract

Ecosystem services (ES) practitioners (e.g., researchers, policy makers) have been working to better define, measure, and value the ways that nature contributes to society. Because measurement techniques follow the labeling or identification of ES, precise identification is critical. This article reviews literature and consults experts in classification science and ES to determine the expected benefits of using ES classification knowledge (classification knowledge); ecosystem services classification systems (ES-CS) and their principles. An informal analysis of the costs of transitioning from the current ad-hoc approach—based on various ES lists—to using classification knowledge was conducted. 18 benefits of using classification knowledge were found, including allowing ES to be defined more easily and precisely, easing the transfer of knowledge among studies, and avoiding the need to recreate ES identification systems. Collectively, these 18 benefits should allow for more accurate and consistent definition of ES, thereby serving to improve communication and measurement of ES. Moreover, the expected benefits of using ES-CS outweigh expected costs of the transition. Practitioners can use ES-CS in whole, or in parts, as their research or their institutions warrant. Finally, a case study was conducted that shows how ES measures can be organized using ES-CS, delivering benefits to practitioners.

Keywords: Ecosystem services; Final ecosystem services; Classification systems; NESCS; CICES; Ecosystem services metrics

1. Introduction

The ecosystem services (ES) field depends on data and results being shared and readily understood by several disciplines—principally: ecologists, economists, accountants, planners, social scientists and policy makers. Driven by this need, ES practitioners (e.g., mappers, modelers, researchers, data professionals, economists, policy makers, ecosystem managers) have been exploring options for defining and measuring ES for years (Costanza et al., 2017). Throughout this exploration, the Millennium Ecosystem Assessment (MA) four types—supporting, provisioning, regulating, and cultural ES—have been the most common starting point (Haines-Young and Potschin, 2018).

While the “MA four types” provided a common set of concepts and definitions, the ES field has been advancing. Data needs and analytic approaches call for increased accuracy and precision (Costanza et al., 2017). This accuracy and precision are not readily supported by the MA four types because they fail to differentiate among the elements of ecological processes, ecological end-products that humans use, and the uses and users of those end-products (Boyd and Banzhaf, 2007, Haines-Young and Potschin, 2018, Rhodes et al., 2016, United States Environmental Protection Agency, 2015).

This differentiation among elements is enabled by the concept of final ecosystem services (FES) (Rhodes et al., 2016). FES defines when an ecological end-product transitions from being predominately ecological to being either 1) a predominately economic input that will often be combined with manmade capital to produce an economic benefit, or 2) something directly used or appreciated (Boyd and Banzhaf, 2007). FES are therefore considered flows from ecosystems to economic units (e.g., private companies, households) (Boyd and Banzhaf, 2007, United Nations, 2017).

For example, consider that for ocean fish to make it to market, a boat, fishing supplies, fuel, and labor are needed. The transition point, or ecological end-product—fish in ocean for harvest—occurs when the application of manmade capital makes the fish catchable by the fisher. The transition point is determined by who is using the ecological end-product. To the fisher, fish directly available for harvest is the FES, whereas to a tourist, fish for recreational viewing is the FES.

The FES concept is gradually being integrated into various ES lists, tools, and applications. In addition, coupling the FES concept with a hierarchical system for organizing data defined by best practices in classification systems science, allows for consistent differentiation among elements. The resulting ecosystem services classification systems (ES-CS) facilitate improved identification and measurement of ES in individual studies (Rhodes et al., 2016), and the interoperability of data and learning among practitioners (Villa et al., 2017). If a full

ES-CS cannot be used, employing some of the classification knowledge provides some of these benefits. Antecedents of classification knowledge dates to the 2004 release of the MA.

1.1. History of ecosystem services classification knowledge

Classification systems (CS) are hierarchical approaches for organizing information so that data may be easily compared (Hancock, 2013, U.S. Bureau of Labor Statistics, 2019). Examples include the Linnaean taxonomy (Bruno and Richmond, 2003), PhyloCode (Bruno and Richmond, 2003), and the UN Food and Agriculture Organization's Land Cover Classification System (Di Gregorio and Jansen, 2000). Classification systems provide each field with a common language that nests sub-groups in a hierarchy that is complete, mutually exclusive, consistent, and relevant to the practical needs of users (e.g., balanced among users' needs) and what they are defining and measuring, stable through time, and comparable to other classifications (see Fig. 1 for example of a hierarchy) (Fu et al., 2011, Hancock, 2013, Hoffmann and Chamie, 1999, Overhage and Suico, 2001, Wu, 1999). Classification systems also all have a thesaurus, vocabulary, and a flexible structure that balances stability with the needs of novel research (Hoffmann and Chamie, 1999, Overhage and Suico, 2001).

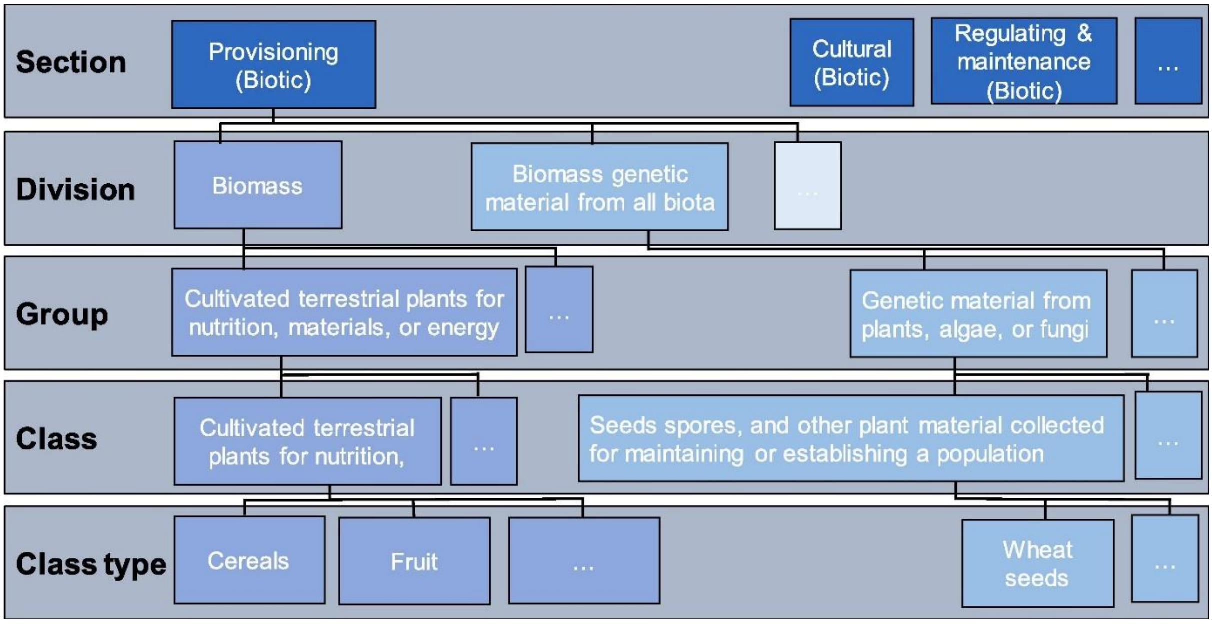

Fig. 1. CICES V5.1 hierarchical levels (Adapted from: Haines-Young and Potschin, 2018).

Without CS, more time would be devoted to understanding how other researchers define and measure variables, and then to making these definitions appropriate to the research at hand (Bagstad, 2018, Delphi Group, 2002, Hlava, 2018, IDC, 2003, Sujatha et al., 2011, Vernau, 2005). It has been estimated that "knowledge workers," who manage large amounts of data, spend 20–35 percent of their time searching for information, with a 50 percent success rate (Bagstad, 2018).

Recognizing this, as early as 1987 leading thinkers were exploring categories of what we now call ecosystem services (de Groot, 1987). These were refined in 1997 (Costanza et al., 1997, Daily et al., 1997) and a more definitive list with four groups was published in 2002 (De Groot et al., 2002). The MA proposed four types of ES—supporting, provisioning, regulating, and cultural (Alcamo et al., 2003, Bolt et al., 2016). The MA four types improved on early

ES work, but also cautioned against considering this a classification system (Alcamo et al., 2003). Regardless, the MA four types gained widespread use in other assessments (HaMAARAG, 2018, UK National Ecosystem Assessment, 2011).

As the MA was released, FES was being defined (Boyd and Banzhaf, 2007) and practitioners began making distinctions in ES lists consistent with the FES concept. To start, The Economics of Ecosystems and Biodiversity (TEEB) revised the MA four types, in part, by separating ES from "benefits," because benefits to humans routinely involve combining ES with economically produced inputs (De Groot et al., 2010). A Common International Classification of Ecosystem Services (CICES), developed by the European Environment Agency, was the first hierarchical structure for classifying ES (Fig. 1) (Haines-Young and Potschin, 2013). Later, the United States Environmental Protection Agency (USEPA) published its Final Ecosystem Services Classification System (FEGS-CS) (Landers and Nahlik, 2013) that added beneficiaries to hierarchies (Fig. 2) (Haines-Young and Potschin, 2018). Soon after, the USEPA released the National Ecosystem Services Classification System (NESCS) (United States Environmental Protection Agency, 2015) that separated uses from users (Fig. 3) (Sánchez, 2018). Presently, FEGS-CS and NESCS are being integrated into "NESCS Plus" that will have an updated "environment" element and will allow for either a splitting or combining of use and user.

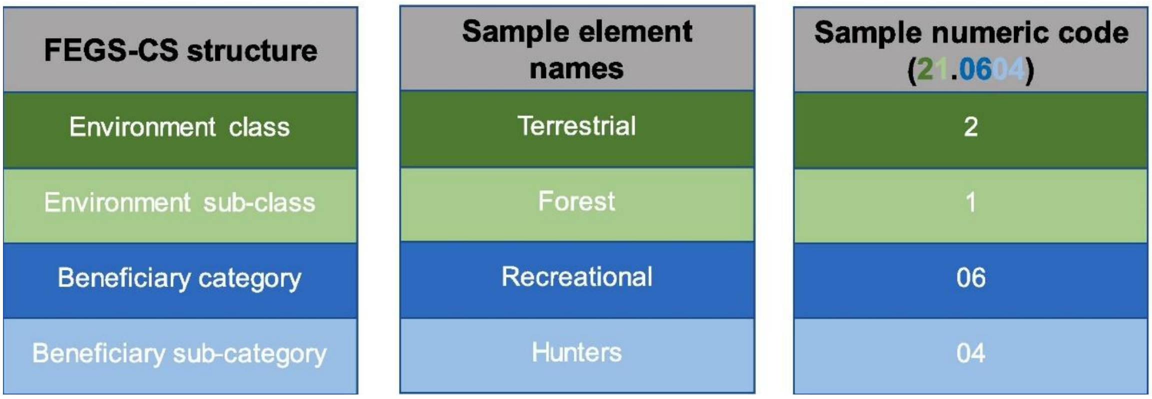

Fig. 2. FEGS-CS hierarchical levels, elements, and codes (Adapted from: Sánchez, 2018).

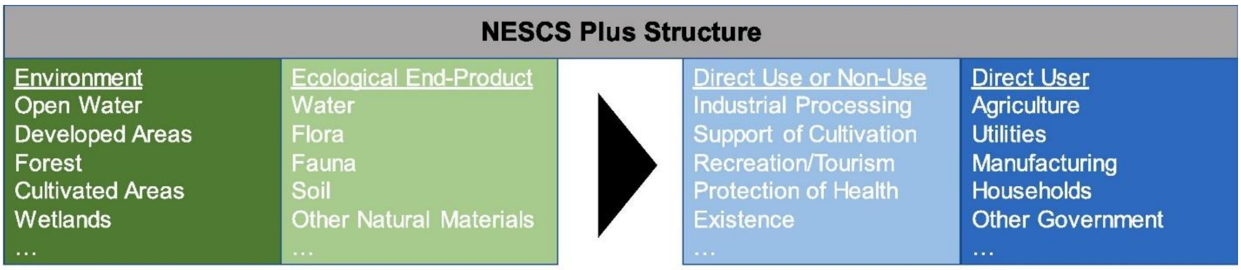

Fig. 3. Simplified NESCS Plus hierarchical levels and elements (Adapted from: United States Environmental Protection Agency, 2015).

In 2018, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) developed a list. Similar to the MA, IPBES explicitly acknowledged the multiple contributions nature makes to people, but argued that some valuation approaches (e.g., single currency, single indicator, single benefit) often fail to capture this diversity. IPBES defined 18 categories of Nature's Contributions to People (NCP) and called for them to be understood through the local, cultural context as bundles that result from experiences, places, or organisms that provide cultural or spiritual experiences. It seeks to consider knowledge from western science, indigenous peoples, and the local context equally in decision making (Díaz et al., 2018). Moreover, NCP embraces the diversity of ES lists and categories (Kadykalo et al., 2019).

As these ES-CS and lists were advancing, the UK National Ecosystem Assessment produced an analysis of the benefits that the natural environment provides to people and to economic prosperity (UK National Ecosystem Assessment, 2011). The Assessment advanced environmental accounting practices needed for this analysis, in part, by including FES in its framework. This influenced other accounting efforts, such as those in Australia (CSIRO, 2012).

To consolidate all this innovation for use in environmental accounting, the United Nations Statistical Division System of Environmental-Economic Accounting (SEEA) facilitated numerous workshops. They included developing "Logic Chains" for ten frequently used ES.[1] The exercise intended to create a more consistent application of terms (e.g. FES) among ES-CS that will be refined for a final SEEA framework due for release in 2020.

Amidst this development, CICES and NESCS Plus stand out as the only true classification systems. Other lists may include some learning from classification science, but do not follow the rules of classification science (e.g. complete, mutually exclusive, consistent, relevant). Each ES-CS has hierarchical levels containing unique elements with associated common names and numeric codes (Table 1). Differences between the ES-CS reflect design choices or biases (Hancock, 2013) that need to be appropriately considered (Jarić et al., 2019). As a result of embodying this classification science, ES-CS organize a great deal of information. They allow practitioners to traverse the hierarchy, define an FES by the context in which the ecological end-product is being used, and by identifying elements of the FES.

Table 1. ES-CS terms used in this paper with example.

	Specific ES-CS terms and examples	
Terms used in this paper	CICES	NESCS Plus (FEGS-CS is being used to update NESCS into NESCS Plus)
Hierarchical level (each has nested sublevels)	Section, Division, Group, Class, Class Type	Environment, Ecological End-Products, Direct Use/Non-Use, Direct User
Example elements of the FES (element)	Provisioning, Biomass, Wild Animals, Terrestrial, Nutrition	Forest, Fauna, Hunting for Consumption, Households
Code	1.1.6.2	21.3.1106.2
Example of the FES the system names	Food from wild animals	Animals in forests as hunted for household consumption

Practitioners have started employing ES-CS and their principles. By identifying ES with the structures of ES-CS and applying metrics associated with elements of the ES-CS, the ES is effectively turned into an FES (Bell et al., 2017, Jiang et al., 2015, Jiang and Ouyang, 2016).

These principles, and the ES-CS themselves, can be understood as ES classification knowledge (classification knowledge). This classification knowledge has not only impacted lists, but also tools and applications.

For example, the European Environment Agency, USEPA, Chinese Academy of Sciences, China's Ministry of Ecology and the Environment, SEEA, and leaders in natural capital accounting are now generating FES based tools and applications. Further, ES-CS and their principles are being used to support implementation of the EU Biodiversity Strategy to 2020 (Pfisterer and Schmid, 2002), structure the USEPA's EcoServices Model Library (United States Environmental Protection Agency, 2019a, United States Environmental Protection Agency, 2019b), help define beneficiaries for USEPA's Superfund program (United States Environmental Protection Agency, 2017), guide structure of the ESMERALDA database (Union, 2019), and as a basis for exploring the creation of natural capital accounts. Finally, researchers are increasingly using the term "final ecosystem services;" according to a Google Scholar search, the term was used five times in 2007 (the year it was defined) 26 times in 2010, and 130 times in 2017.

However, there has not been a review of the barriers to and benefits from using classification knowledge. Moreover, there has been no comparison of these benefits to the costs of transitioning to using ES-CS. This article researches these questions, discusses the implications of the results, and conducts a case study demonstrating the results found in the online supporting material.

2. Method

To help understand why classification knowledge, ES-CS in particular, is rarely used, what the impact of broad use would be, and how these benefits compare to the costs of transition, the appreciative inquiry method (Stowell, 2013) was employed in six steps. This method is effective at capturing knowledge where knowledge is well defined and accepted by a community (Stowell, 2013). This is the case for experts in environmental accounting, who have been developing and using ES-CS, and CS experts working outside the ES field.

In step one, literature was reviewed, and experts interviewed to determine the barriers to CS use and the benefits of using CS in other fields (e.g., economics, health). Two practitioners in classification systems were selected for their breadth of CS experience. These and all other interviews included the same five questions: 1) What are the benefits to using CS, 2) What are the barriers to using CS, 3) What are the costs of transitioning to using CS, 4) What common mistakes are made when developing CS, and 5) What common mistakes are made when transitioning to using CS? Follow up questions were asked for clarity, including request for examples. The literature review included searches for gray publications and journal articles. The following search terms were used in Google and Google Scholar: "classification systems and benefits," "classification systems and barriers," "transitioning to using classification systems," and "classification systems and ecosystem services." Relevant publications from the first 100 results from each search were read. From these interviews and literature review, two frameworks were combined into a table of the benefits of a CS (Table 2).

Table 2. 18 benefits of using ES-CS, organized by generic and functional benefits.

		Generic benefits		
		Defining data (e.g., FES, metrics, valuation techniques, encoding data)	**Discovering data (e.g., repurposing, integrating, applying to decision making, building datasets)**	**Avoid recreating CS**
Functional benefits	**1.Unifying language**	1.Improved collaboration within and among disciplines (e.g., ecologists, economists, accountants, policy makers)	2.Increased recall and precision when searching for research and data 3.Improved ability to communicate science	4.Eliminates need to create elements and hierarchical levels
	2.Understanding how all the elements of the CS interrelate	5.Quickly identify complementary elements of an FES 6.Quicker identification of research needs	7.Better understanding of what is left out of an analysis	8.Easier incorporation of new learning into the field
	3.Improved identification of elements, metrics and analytical techniques	9.Lower number of mislabeled FES, loose-fitting metrics, and weakly appropriate valuation techniques 10.Reduced risk of double counting and no FES "loss" in accounting	11.Certainty that FES and metrics were properly identified	
	4. Improved knowledge transfer	12.Greater likelihood that research will be repurposed 13.Simplified data encoding (tagging)	14.Facilitated data integration among studies, datasets, and models	15.Greatly reduces need for creating systems that integrate data across studies and datasets
	5. Improved knowledge management	16.Reduced cost of new employee training	17.Reduced cost associated with employee loss	18.Likely eliminates need for organizations to create ES-CS

For the second step, candidate benefits for each cell of the table were identified by finding examples from interviews, literature, and needs of practitioners in the primary ES disciplines—mapping, modeling, valuation, policy, and accounting. Interviews were held with sixteen ES practitioners. The questions mentioned in step one were asked, as well as specific questions related to each experts knowledge (e.g., accounting, natural resource damages). Benefits were verified by finding examples in the ES field from literature and interviews. If examples could not be found, they were only included in the table if they could be found in other fields (e.g., health) and professional judgement determined that the benefit was likely to be realized in the ES field with broad use of ES-CS. Finally, drafts of the table of benefits and narratives on the benefits were circulated to the sixteen experts that were interviewed. Their input provided an iterative process verifying the benefits that is reflected in this article.

In the third step, the cost of transitioning to an ES-CS was captured from the interviews and literature review described in steps one and two. Professional judgment, including precedent from other fields, was employed to qualitatively weigh costs of transition to the 18 benefits, rather than attempting a quantitative valuation exercise. While a cost-benefit analysis was not done between using ES-CS and using lists, the principle costs of not using lists were identified and discussed along with mitigation strategies.

Fourth, ES-CS principles were derived from the literature and interviews. Key components or antecedents of ES-CS (e.g., ecological end-products, beneficiaries) were summarized in a working paper for review.

In the fifth step, a working paper was promoted by posting on ResearchGate and LinkedIn, and presenting at A Community on Ecosystem Services 2018 conference. Feedback received was incorporated into this article. This iterative, appreciative inquiry method allowed for an increasingly refined understanding of 18 benefits, the barriers to using ES-CS, and the costs of transition.

Finally, a case study was conducted that compared a survey of definitions and measures of pollination to demonstrate how two ES-CS would define the FES and organize its measures. The case study is presented in the Supporting Online Material.

3. Results

The literature review and expert responses found both pragmatic and philosophical barriers to using classification knowledge. However, it was also found that by employing classification knowledge, ES-CS in particular, ES will be more consistently identified, helping to avoid common errors (e.g., poorly chosen metrics, double counting), improving the precision of valuations, and delivering 18 total benefits. Moreover, the costs of transitioning to using ES-CS are outweighed by the expected benefits.

3.1. Barriers to using classification knowledge

Despite increasing use of classification knowledge, the MA four types appears to be the most frequently used list or ES-CS (Haines-Young and Potschin, 2018). Hesitance to adopt ES-CS is likely caused by practitioners:

1. *Anticipating little impact from not adopting an ES-CS* on the ability to receive funding, publish research, or engage in policy discussions;
2. *Perceiving few benefits to projects*, as practitioners seem to believe they understand FES or have grown accustomed to ambiguous definitions and measures of ES. As a result, a study's scope can influence the measures selected (Czúcz et al., 2018). While there is an argument that with enough data and computing power, inferences can be made (Clarke, 2018), many view ES as being more illustrative than empirical (Ainscough et al., 2019). This is especially true with ES research focused on ecological functions and processes (Czúcz et al., 2018).
3. *Reading standards and guidance documents (e.g., IFC Performance Standard, Natural Capital Protocol) as not promoting classification knowledge, nor specific ES-CS*, or providing little guidance on required rigor, helping render ES assessments as insignificant;
4. *Being unaware how to best integrate and scale ecological, economic, and social data and measure ES* (Preston and Raudsepp-Hearne, 2017), both of which are aided by classification knowledge, ES-CS in particular;
5. *Having passively adopted MA based lists* through staff training, tools, systems development, case studies, or marketing materials;
6. *Seeking to deliver data and analysis that is readily recognized by local stakeholders alone*, rather than also aligning these with classification knowledge;
7. *Finding value in understanding ES as "boundary objects"* where flexible definitions of ES are desired—the most dogmatic version of which may be seeing no utility in using classification knowledge as a form of guided pluralism that can help bridge different philosophical and normative views (Ainscough et al., 2019, Steger et al., 2018);
8. *Considering FES distinct from ES*, rather than a refinement of the concept or an optional subset, and therefore not consulting literature and guidance on classification knowledge;
9. *Confusing the identification of an FES with measurement or valuation of that FES* (Ainscough et al., 2019). This may lead a practitioner to incorrectly believe that labeling an ES and using an ES-CS mandates a measurement or valuation technique that limits understanding of the entire ES to a user. Or that if monetary valuation is inappropriate, that the ES will be excluded from the assessments (Ainscough et al., 2019).
10. *Not understanding the advantages of "full spectrum" ES classification* that accommodates all FES;
11. *Experiencing fatigue from engaging in similar efforts* to standardize terms, systems, and procedures such as satellite data, metrics, and monitoring and evaluation procedures (Villa et al., 2017); and,
12. *Perceiving the costs of implementation to be high.* Costs could include: updating research, tools, and techniques; learning how to numerically code ES with an ES-CS (Wilkinson et al., 2016); sorting through inconsistent application of ES-CS by other practitioners; or absorbing the costs of transition without clarity on the field's direction (Hlava, 2018).

Partly as a result, few practitioners are using classification knowledge, leaving the field to an "ad-hoc approach" to defining, grouping, or classifying ES. This includes new research, but also meta-analyses and interregional assessments that often seek to unify knowledge among studies. Practitioners define, group, and measure ES differently (Bartholomée and Lavorel, 2019)—sometimes even within institutions—or even change the definitions of particular groupings (McDonough et al., 2017). Moreover, some research measures ES other than what authors purport to measure (Czúcz et al., 2018).

Nevertheless, there has been progress integrating ES into decision making with the ad-hoc approach that is built on various MA based lists (Costanza et al., 2017). Over time, the continued use of the ad-hoc approach could help change social norms and practices. For example, developing frameworks that embody classification knowledge without explicit knowledge of their roots (Bartholomée and Lavorel, 2019), gradually incorporating them into practices (Houdet, 2017) as standardization has clear benefits (Galler et al., 2016). It is also possible that bringing a clearer understanding of the expected benefits from the use of ES-CS will spur their broad use.

3.2. The benefits of classification systems

Classification systems offer five functional benefits including: 1) a unifying language (Vernau, 2005); 2) an understanding of how all the elements (see Table 1) of the CS interrelate (Bruno and Richmond, 2003); 3) an improved identification of elements, metrics, and analytical techniques (Vernau, 2005); 4) an improved knowledge transfer among research efforts (Vernau, 2005); and 5) improved knowledge management (Vernau, 2005). These benefits stem from savings associated with defining data, discovering data, and with not recreating systems (Clarke, 2018, Hlava, 2018). These three generic benefits—defining, discovering, and not recreating—are cross referenced with each of the five functional benefits with regards to ES-CS (Table 2).

3.2.1. Unifying language

A common set of readily understood terms improves collaboration within a discipline (Benefit 1), increases recall and precision in data discovery by both people and machines (Benefit 2) (Clarke, 2018), makes it easier to communicate science (Benefit 3), and reduces incentives to remake vocabulary or invent new CS (Benefit 4).

Many have called for ES practitioners to advance a unifying set of terms (Benefit 1) that can be easily recalled (Benefit 2) (Crossman et al., 2013, Guerry et al., 2015, Neale et al., 2018, Seppelt et al., 2012, Wong et al., 2015), building on the touchstone that the MA four types brought about. ES-CS are likely capable of extending this unifying language to each element that together define an FES (see Table 1). The NESCS Plus example in Table 1 defines the elements of forest, fauna, hunting, and household consumption. Each element is nested in a formal hierarchy ensuring that each level of the hierarchy is complete, mutually exclusive, and consistent with every other element in the hierarchy. Moreover, each element and its FES has a unique numeric code, similar to the codes of the International Standard Industrial Classification System (United Nations, 2002). This coding increases recall and precision (Benefit 2) as is demonstrated by the UK e-Government Metadata Standards that sped access to accurate information across the bureaucracy (Vernau, 2005).

Turning to communication, practitioners have long struggled to explain the ES paradigm and its advantages (Goldman et al., 2016, Polasky et al., 2015). Even the terms “biodiversity” (Meinard et al., 2019, Reyers et al., 2012) and “ecosystem services” have been called opaque (Metz and Weigel, 2010, Reyers et al., 2012)—especially in regards to distinguishing ecological functions from ES or FES. Some have opined that this confusion diminishes the quality and quantity of media coverage on biodiversity (Legagneux et al., 2018). ES-CS can improve communication by increasing clarity and consistency in terms (Benefit 3), and may yield surprising benefits. For example, policy makers in the UK gained an understanding of the economic and health benefits that flow from ecosystems through their use of CICES, and posed a question that scientists had not formulated—in a warming world, when does additional urban green infrastructure no longer reduce the heat island effect (Haines-Young, 2018)?

ES-CS have also been beneficial in stakeholder engagement, helping communicate the distinction between ecological functions and FES (Benefit 3) (MacNair et al., 2014). These communication advantages hold better for trade off analysis (e.g., comparing land management options) than they do for national accounting applications, where the scale is larger and stakeholder interests are more diffuse (Posner et al., 2016). Moreover, it is the quality of this communication and the way it incorporates multiple perspectives, rather than the rigor of empirical science, that determines its influence on policy making (Posner et al., 2016). Discussed below, linking the ES-CS structure with stakeholder understanding of ES is powerful in framing decision making. Finally, with the adoption of ES-CS, practitioners can avoid duplicating ES-CS or struggling to frame how elements of an ES-CS are related (Benefit 4).

3.2.2. Understanding how all the elements in the CS interrelate

Use of CS should enable a quick understanding of how one element in a CS relates to all other elements in that CS. This speeds the identification of key variables (Benefit 5), highlights what is absent from a study (Benefit 7), helps identify research needs (Benefit 6), and facilitates the incorporation of new learning back into the CS and research field itself (Benefit 7).

An oversimplified example demonstrates how these same advantages apply to ES-CS. When analyzing water use by industry, a researcher could start with an industrial facility and identify the approximation of the ecological end-product, freshwater. The researcher could then turn to an ES-CS and be guided to identify the ecosystems (e.g., river, forest, wetland; Fig. 3) from which the water may be extracted (Benefit 5). Along with using the ES-CS to identify the use and users (e.g., industrial manufacturing), it draws the researcher to a list of other potential users from households to subsistence farmers (Benefit 6). The ES-CS, in this case, helps speed identification and builds assurances that the identified FES is accurate. Moreover, someone wishing to complement this study might quickly identify “analyzing freshwater use for subsistence farming” as a research gap (Benefit 8). In the same way, decision makers can more easily identify such a gap in reports and either consider a wider range of benefits related to freshwater or request additional research. ES-CS supported gap analysis can also be applied to tools such as ecological models, evidenced by one survey that used ES-CS to identify needs for additional ecological models (Canfield, 2017).

ES-CS have already started integrating new learning (Benefit 8), similar to CS improvements in other fields (Carlson and Dermer, 2016, de Carvalho et al., 2007, Murphy, 1998, Overhage and Suico, 2001). CICES is in version 5.1, with recent changes being spurred in part by the SEEA workshops (EEA, 2017). The USEPA ES-CS are in their third revision, as FEGS-CS and NESCS are being integrated into NESCS Plus. At launch, NESCS Plus will have one hierarchical level for the element ecological end-product. User input will guide development of subgroups and refinement over time. This constant improvement reduces costs and errors across the field because any update to an ES-CS becomes the standard for all users of the ES-CS.

3.2.3. Improved identification of elements, metrics, and analytical techniques

CS help practitioners define research items (Benefit 9) without inadvertently including related items in that definition (Benefit 10), in part, because CS can be readily updated. This specificity encourages the selection of quality metrics and analytical techniques for each element (Benefit 10) and improves credibility of the metrics and analysis (Benefit 11).

EC-CS define FES to the element (Table 1), which carries through to the selection of metrics, monitoring protocols, and valuation techniques (Benefit 10) acting like a funnel, guiding practitioners from a general set of metrics to more specific ones. Using NESCS Plus as an example (Fig. 3), starting with the environment "grasslands," a large set of metrics and monitoring protocols are available. If ducks are the end-product, the set of metrics and monitoring protocols is reduced. Moving to the use side of this example, hunting, the number of metrics are again large. Incorporating the user, household consumption in this example, the best metrics and valuation techniques are more obvious. Similarly, recreational fishing has one set of data and metrics associated with it, and commercial fishing another (Jiang et al., 2015, Rhodes et al., 2018). These examples demonstrate that by using ES-CS, many mistakes associated with selection can be eliminated (Benefit 10). In addition, it builds confidence that FES and metrics were not selected in err (Benefit 11).

There are 5 common mistakes that proper application of an ES-CS can help eliminate:

1. *Not identifying a direct user* and therefore tending to label ecological processes as FES (Benefit 10). A grassland may provide habitat for native pollinators, but without a farmer or gardener planting specific pollination dependent species nearby, or the existence value of the grassland or its species being recognized, it can only be considered a potential ES (Bagstad et al., 2013).
2. *Mistaking an economic input for an FES* (Benefit 10). Crops require physical and human capital such as seeds, farm equipment, and labor, and therefore, crops are already incorporated in economic accounts.
3. *Misidentifying an ecosystem characteristic, process, or function as an ecological end-product* (Benefit 10). The existence of grassland habitat, the degree of habitat fragmentation, and the diversity of food sources for native bees are all part of an ecological production function that enables the end-product of native bees.
4. *Failing to distinguish between a use and a user* (Benefit 10). The FES drinking water does not sufficiently identify the user; the metrics, monitoring protocols, and analysis differ for a hiker, subsistence resident, and municipal water system. This distinction may not affect an individual study, but using an ES-CS helps other researchers effectively reuse the data.
5. *Choosing an FES without identified metrics* (Benefit 10) because the ES chosen is not being used by others.

In addition, use of ES-CS helps to:

6. *Reduce the risk of double counting* by ensuring that every FES is unique (Benefit 10). ES practitioners have developed techniques to address double counting (Fu et al., 2011). Use of ES-CS reduces the need for these techniques.

7. S*implify natural capital accounting* by helping ensure that ES are not “lost” in accounting (Benefit 10). Accounting standards require that the supply and use of ES be recorded as equal—they are credits and debits in an account. Because FES must have a direct user, only the potential ES that are used are counted. This satisfies the accounting rule that the supply of FES cannot be higher than the amount consumed or used (United Nations, 2017), and no ES are “lost.”

These seven benefits follow from simply using an ES-CS (Benefit 9, 10), creating more accurate definitions of ES, and building confidence in a study’s metrics (Benefit 11).

3.2.4. Improved knowledge transfer

Data and research can be more easily shared or repurposed (Benefit 12) because of the functional benefits of a unified language; an understanding of how the elements in the CS interrelate; and the improved identification of elements, metrics, and analytic techniques. These functional benefits combine to make data easier to encode, tag, or semantically annotate (Benefit 12); allow results to be more easily integrated among multiple studies, datasets, and models (Benefit 14); and reduce the need to recreate systems for data integration (Benefit 15) (Allen and Sriram, 2000, Würth, 2019).

The standardized codes and names of an ES-CS speed and simplify the process of identifying, describing, and coding ES in a new study (Benefit 13) (Reyers et al., 2012). The terms for standardized ES or ES elements are then more likely to be found when searched, especially in the gray literature. Therefore, they are more readily incorporated into new efforts (Benefit 14). ES-CS also serves as a basis for integrating research, even if studies were not focused on ES, through the “concept matching” method (Benefit 14) (Czúcz et al., 2018). Moreover, use of ES-CS over time reduces the need for these data integration methods (Benefit 15).

This said, the greatest knowledge sharing benefits from using ES-CS are likely for scaling exercises, long-term studies, regional assessments, and similar analytical techniques which require interoperability of large datasets often from multiple studies, geographies, and disciplines.

3.2.4.1. Interregional assessments

Integrating research across geographies (Schröter et al., 2018) is challenging because the ES production, flow, and consumption may have been analyzed by different researchers, using different ES definitions, metrics, measurement techniques, and even languages. An ES-CS serves as a central set of definitions linking the production and consumption data from the region (Benefit 14), while eliminating the need for researchers to develop such a system (Benefit 15).

3.2.4.2. Benefit transfers

Use of ES-CS is likely to reduce error rates in benefit transfers (20–50 percent is presently considered good) (Boyle and Parmeter, 2017) and drive greater similarity of characteristics and methods related to the elements of an ES-CS (see Table 1) among reference and policy sites (Sinha et al., 2018), improve reference site valuations over time that are used for transfers (Sinha et al., 2018), and enable better data management (described below under the header "Dataset, models, and tools").

The functional benefits of unifying language; understanding how all the elements of the CS interrelate; and improved identification of elements, metrics, and analytical techniques (Benefit 1, 2, 5, 6, 7, 12, 13) encourage similarity of characteristics—measurement and valuation techniques used among reference and policy sites in benefit transfers. This is accomplished by better delineation and consistency of in naming ES, beneficiaries, measurements, and valuation techniques. For example, use of ES-CS would spur similar definitions for the:

1. *Environment or ecosystem type* (e.g., water body versus freshwater rivers);
2. *Ecological end-product* (e.g., pollination versus native insects available for pollination);
3. *Ecosystem condition or ES metrics* (e.g., soil carbon content versus yields as a measure of soil health); and,
4. *Uses and users* (e.g., non timber forest products for collection for commercial sale versus collection for household consumption).

In turn, this specificity spurs use of more similar metrics, measurement methods, and valuation techniques as is described in Section 3.2.3 *Improved identification of elements*. With the expanded use of ES-CS in primary research, over time these similarities will grow, facilitating the accuracy of benefit transfer work (Benefit 13, 14).

3.2.4.3. Meta-analysis

Similar techniques are used beyond transferring economic values. Combining results from several studies can yield insights on ecological and economic phenomenon so that better generic production functions can be built (Howe et al., 2014, Olander et al., 2017, Woodward and Wui, 2001, Worm et al., 2006). As with benefit transfers, the more uniform the definitions and metrics for different elements of an FES are, the lower the need for complex statistical solutions, and the more precise results will be (Benefit 13, 14) (Gerstner et al., 2017, Popic et al., 2013, Wong et al., 2015).

3.2.4.4. Datasets, models, and tools

The advantages to individual studies can be extended to databases, datasets, models, and related tools (Benefit 14). While inherently a gradual process, there is precedent from other fields where data standards (e.g., Findable, Accessible, Interoperable, and Reusable [FAIR]; Linked Open Data) were implemented (Villa et al., 2017) and yielded unanticipated benefits (Clarke, 2018, Martínez-López et al., 2019, Wilkinson et al., 2016). ES practitioners have already seen similar benefits (Bartholomée and Lavorel, 2019). For example, the USEPA's EcoService Tools Library (United States Environmental Protection Agency, 2019a, United States Environmental Protection Agency, 2019b) that used predefined ecological end-products of an ES-CS (Newcomer-Johnson, 2018) for structure that helps users find ecological models for specific end-products. Similarly, the USEPA's EnviroAtlas (United States Environmental Protection Agency, 2019a, United States Environmental Protection Agency, 2019b) is pairing FES in ES-CS with metrics in EnviroAtlas (Neale et al., 2018). The ARtificial Intelligence for Ecosystem Services (ARIES) (Martínez-López et al., 2019) is a modeling platform being built to support the vision of a semantic web (Berners-Lee and

Hendler, 2001). It allows for computer automated workflows that link models and data without added knowledge from the user (Martínez-López et al., 2019). This process relies on the organization and storage of data in both human and machine readable formats (OGC, 2019), which use of an ES-CS supports.

Such a transformation to FAIR standards of a semantic web could begin with encoding of existing datasets (e.g., Environmental Valuation Reference Inventory, Natural Capital Toolkit, Ecosystem Valuation Toolkit) (Canada, 2019, Economics, 2019, Natural Capital Coalition, 2019) Terms in these databases could be tagged that reference the data concepts, FES, and their elements (Neale et al., 2018). Next, tools such as the Integrated Biodiversity Assessment Tool (IBAT) (UNEP-WCMC, 2019), USEPA's EnviroAtlas (United States Environmental Protection Agency, 2019a, United States Environmental Protection Agency, 2019b), InVEST, and MIMES (Neugarten et al., 2018) could add data tags and provide outputs aligned with ES-CS. Finally, these data and models could be integrated into ecological-economic models, analysis of the environmental impacts of trade flows, and other more complex models (Benefit 13, 14).

3.2.4.5. Business environmental accounting

Adopting an ES-CS would support the integration of ES in both management and financial accounting systems. Historically, these disciplines focused on the physical and monetary dimensions of negative environmental impacts (e.g., solid waste, air emissions) and non-product outputs (e.g., replacement costs of wasted raw materials) (Burritt et al., 2002, Schaltegger et al., 2000). Using ES-CS, practitioners could save time and costs in exploring the ES dependencies of companies, their suppliers, and clients. Notably, through the development of integrated FES–financial accounts (Houdet et al., 2014), the importance of ES in specific business accounts and associated transactions could be modelled, accounted for, and disclosed (Benefit 13, 14).

3.2.4.6. Scaling

ES-CS organize information in ways that support scaling, the application of research from one geographic or temporal scale to another, while also enabling the extraction of lessons from analysis conducted at various scales (Czúcz et al., 2018). Specifically, they:

1. *Drive greater accuracy in scaling analysis* because the overall data are more accurate and decomposable, or modular. Discussed above and detailed in the 3.2.4.2 *Benefit transfer* section, ES-CS supports the consistent identification of FES and the selection of metrics and analytical techniques for each element. Eventually, practitioners will have a more powerful suite of research and data for scaling exercises.
2. *Inform the selection of scales* by directing users to locate ES production and consumption (Raudsepp-Hearne and Peterson, 2016). These boundaries are likely to define a study's focal scale;
3. *Encourage greater consistency in defining the appropriate scales for analysis over time.* With more unified FES and metrics, there is likely to be more consistent definition of scales over time. The "breaking points" where spikes or rapid increases in scale analyses (e.g., scale variance, hierarchical partitioning, spatial statistics) should be consistent among FES within similar ecological systems (e.g., temperate coastal marsh). Hence, the effort necessary to define scales should decrease;

4. *Help ensure that FES are not "lost" in scaling.* Cultural FES, for example, can be non-existent at coarse scales but the strongest FES at small ones (e.g., sacred grove). With a local FES defined, practitioners are guided to analyze at that scale.
5. *Improve communication with decision makers and stakeholders* as ES production and consumption are analyzed at the appropriate scale for decision making, especially with regards to direct land management decisions (Raudsepp-Hearne and Peterson, 2016).

3.2.5. Improved knowledge management

The common pool of knowledge that CS create reduces the need for organizations to invest in their own systems. Knowledge is transferred throughout the community of practice through the CS. This reduces the learning curve for new employees who have fewer internal systems to absorb and the cost to the organization when employees depart (Goldman et al., 2016, Vernau, 2005). The complexity of not just ES research, but the broader ecosystem and natural resources management field, has trained a cadre of experts steeped in techniques for managing ecosystems for specific outcomes, such as wetlands for migratory birds. ES-CS would enable universities, conservation organizations, land trusts, land managers, investors, government agencies, and consultancies to share knowledge more efficiently (Benefit 16, 17, 18).

3.3. The cost of transitioning from an ad-hoc to an ES-CS approach

The 18 benefits of using an ES-CS approach will make ES easier to understand, reduce research expenses, and expand the quality and quantity of ES research. These outweigh the costs of transitioning away from the ES lists based, ad-hoc approach as many costs are sunk, manageable with CS best practices, or dwarfed by the benefits from organizing knowledge in ES-CS.

The most dramatic cost is the outright failure to standardize use of ES-CS. The more likely scenario is a slow transition, rather than immobilization, as environmental accounting depends on ES-CS and leading multilateral, EU, US, and Chinese state institutions have endorsed ES-CS or its principles.

There are sunk costs (excluded from this cost-benefit analysis) (Boardman et al., 2018) in development of ES-CS borne by the European Environment Agency, USEPA, SEEA, and members of the environmental accounting community. However, stakeholder involvement in these efforts reduces costs of promoting and updating ES-CS. ES-CS are already being promoted in primary journals, international leadership institutions, and forums (e.g., A Community on Ecosystem Services (Finisdore et al., 2016, Rhodes et al., 2106.), workshops on natural capital accounting (Irwin and Schaltegger, 2015), and by the Natural Capital Coalition (NCC, 2016). Nonetheless, promotion costs remain (Murphy, 1998).

Next, ES-CS need to be integrated into specific datasets and tools (e.g., defining ecological end-products) (Hlava, 2018, Murphy, 1998). Data search and retrieval systems need to be built and promoted (Hlava, 2018). While there are costs to updating the ES-CS and related tools over time (e.g., recoding data), experience demonstrates they are outweighed by the benefits (Murphy, 1998). The cost of transition will be easier with an ES-CS because the majority of knowledge will already be organized.

There are cultural, identity, and social issues related to the choices made in developing the CS (Vernau, 2005). Biases can be managed by updating ES-CS in accordance with ANSI/NICO Z39.19 and ISO 25964 standards that embody best practices for CS design (Hlava, 2018). Updates to the ES-CS are supported because ES-CS were designed for flexibility. Moreover, having more than one ES-CS helps accommodate for multiple perspectives that can be reconciled among ES-CS with “concept matching” methods (Clarke, 2018, Czúcz et al., 2018, Fisher et al., 2009).

Finally, in some instances, CS have encouraged specialists to communicate among themselves rather than with other specialists in a given field (Vernau, 2005). This appears more relevant to CS such as the International Classification of Diseases (Carlson and Dermer, 2016), where specializations form around diseases. Discussions among practitioners are more difficult to enter because of the sparse use of ES-CS (Goldman et al., 2016).

The primary cost—professional judgement of the authors suggests more than 90 percent—lies in updating ongoing research, models, tools, datasets, and related ES infrastructure (Table 3).

Table 3. Costs of transitioning from ad-hoc to an ES-CS approach versus the 18 benefits.

Costs	Benefits
• Promotion through existing ES networks and institutions; • Updating ongoing research, tools, and databases; • Updating the ES-CS; • Building search systems for ES-CS elements and FES; • Managing cultural, identity, and bias issues (e.g., ISO process)	• 18 benefits (Table 2)

Beyond the scope of this paper is highlighting any costs of foregoing the use of other ES lists. We review the primary costs below in Section 4. *Discussion.* They are beyond the institutional costs of moving from using lists to ES-CS.

4. Discussion

Use of ES classification knowledge—ES-CS and their principles—delivers 18 benefits (Table 2). The more closely the rules of constructing CS are followed (e.g., consistent, complete), the more likely the 18 benefits will fully manifest. The best pathway from using the ad-hoc approach to using classification knowledge will vary for any one individual or institution.

Developing these pathways will be iterative and influenced by institutional practices. Experiences from other fields shows that individual adoption of the CS relies on there being clear demand from users and champions of the CS, such as government agencies or coalitions (Hlava, 2018, Murphy, 1998). In their absence, the following actions are recommended:

1. Integrate stakeholder understanding of the "benefits of nature" with ES-CS, ensuring analysis and policy recommendations are technically strong and readily understood by stakeholders.
    a. It is constructive to appeal for the values and preferences of stakeholders to be included in ES assessments (Ainscough et al., 2019). There are differences among beneficiaries and practitioners whom have unique epistemological, theoretical, and methodological perspectives on ES (Ainscough et al., 2019). Because beneficiaries often resist analysis that refers to the value of nature if it is divorced from its cultural context (Díaz et al., 2018), assessments need to include these perspectives in a way that ensures stakeholders' understanding of the utility of natural systems (Maynard et al., 2015) is considered, not just those of practitioners (Maynard et al., 2015).
    b. Stakeholder understanding of the benefits of nature can be "matched" with an ES-CS (Ainscough et al., 2019, Jiang and Ouyang, 2016). For example, stakeholders may identify a forest as a source of water. Practitioners can help stakeholders identify the use and users of the water as well as the underlying ecological characteristics and processes. Use of the ES-CS can also exist in a study's technical appendices, for use in stakeholder engagement or policy discussion when appropriate.
    c. A similar process can be used among practitioners. One may want to value an ES without consideration to any specific use. Others may encourage valuation based on specific cultural and economic uses. ES-CS can be used to define elements common in both valuation techniques. This serves as common reference and increases the potential for data discovery and reuse.
2. *Ensure biodiversity is appropriately embedded in research, analysis, and communications.* The totality of biodiversity conservation goals may not be incorporated into ES or FES driven efforts (Bolt et al., 2016, Reyers et al., 2012). For example, intrinsic values or important biodiversity unrelated to FES production may be excluded. If this biodiversity information is relevant, it should be included following emerging guidance documents (Bolt et al., 2016, Houdet et al., 2019). The use of an ad-hoc or ES-CS approach need not impact the degree to which biodiversity is considered.
3. *Separate the identification of FES from all other aspects of the assessment.* Failure to recognize this separation can result in an inaccurate identification of an FES and the erosion of the 18 benefits (Table 2). There are several ways this happens, and the strategies for addressing these errors can help bridge divides among stakeholders with different cultural, philosophical, or methodological perspectives.
    a. The first mistake that is often made is letting the FES dictate the selection of metrics, rather than informing them. For example, a researcher may be experienced in measuring pollination based on the "marginal increase in yield from improved pollinator habitat." This could spur "increased yield" to be the definition of the ES (Liss et al., 2013). In FES parlance, "increased yield" is a measure of an economic benefit. Alternatively, defining the FES as "the presence of fauna (pollinators) that support cultivation of farmer's crops," does not limit a researcher from using "increased yield" as a proxy, should resources for developing an ecological model for abundance of pollinators be absent.
    b. Second, the opposite mistake is made when practitioners avoid ES-CS, assuming that a particular ES is ill suited. For example, a wetland's ability to filter water is an ecological condition or process in an ES-CS. As with all

elements in an ES-CS, it can be measured and these measures are often critical to stakeholders. The ES-CS reminds users, for example, that wetland water filtration is not an FES, and that the marginal contribution of filtration to the FES represents its value to users of the filtered water.

c. A third group of errors relate to practitioners viewing FES having a one-to-one relationship to ES. In fact, several FES can be used to approximate one ES, or vice versa (especially for regulating services in CICES). A beneficiary group may understand the ES "viewing" salmon as one FES. However, the ecological end-product, "the presence of salmon," may relate to several uses including "spiritual practices," "aesthetic appreciation," and "recreation," while still not being a complete representation. Moreover, measurement or valuation can be done on the totality of these FES, or some combination of individual FES.
d. The fourth error group relates to avoiding novel terms or conducting novel research without using ES-CS. Because they are based on classification science, ES-CS are inherently flexible. Their long-term, iterative development processes accommodate new learning. For example, if researchers are uncomfortable with the terms of an ES-CS, they can substitute their own while maintaining the ES-CS structure. Feeling uneasy about labeling the Indigenous Australian *Tanderrum* (Dempster, 2007) ceremony as a "spiritual ceremony," a researcher could identify it as a "welcoming ceremony" or "unique experience." The ES-CS terms for environment, end-product, and user would remain unchanged. These new uses may later be standardized in an updated ES-CS.
e. These examples show how proper definition of an FES makes research and data more discoverable and interoperable. ES-CS are entirely consistent with measurement of most cultural, ceremonial, and spiritual uses of the environment, whether using qualitative, quantitative, or monetary valuation techniques. They are each appropriate in different instances (Pascual et al., 2017) and can be applied across elements of an FES.

4. *When not using an ES-CS, clearly define the environment, ecological end-product (or CICES equivalent), the use, and user* (Wong et al., 2015). This will help nurture the transition to ES-CS while facilitating data interoperability.
5. *Where practical, use an ES-CS.* Referencing an ES-CS is a quick process that yields benefits to the researcher and other practitioners.
6. 6*Promote the adoption of ES-CS* among colleagues and leadership organizations (e.g., national governments, multilaterals, journals) to build momentum.

5. Conclusion

Similar to other disciplines, our ability to create ES information has outpaced our ability to manage it, and the vernacular for the ES field is still being developed (Ainscough et al., 2019). Ecological analyses are often opaquely linked to human use of the environment (Johnston et al., 2013) and the use of past knowledge in new studies is often limited. In addition, economic models and valuation techniques are rarely well linked to ecological analysis (Olander et al., 2017, Preston and Raudsepp-Hearne, 2017). As a result, ES analyses often fail to inform governments and business on their practical choices (Olander et al., 2017).

ES classification knowledge provides a language and structure to link ecological and economic disciplines, advancing ES research and its application to decision making. With a unifying language, researchers will be better prepared and capable of sharing research, developing interoperable datasets and tools, and improving institutional knowledge. Moreover, by making data, models, and tools using FAIR Data Principles and semantic annotation, the data discovery benefits will grow in unexpected ways. As a result, decision makers will have access to more comparable data and the ES field at large will develop evidence linking public and private sector decision making to ecosystem change and on through to human wellbeing more quickly. ES assessments will move from on-off exercises toward being part of a stream of comparable information with greater utility.

However, a move toward standardization could risk polarizing practitioners (Ainscough et al., 2019). We discussed a few strategies for managing these perspectives exists, and FES identification is only one part of any assessment. Nonetheless, this identification, even if it is only a reference point in a study, provides benefits to all practitioners. More research on how multiple ES philosophies and methods can coexist with standardized ES identification is needed. Use of the Linnaean taxonomy in conservation and the matching concept among practitioners (Czúcz et al., 2018) may be instructive. Another starting point may be exploring how NCP's novel concepts (Kadykalo et al., 2019) can be addresses, at least partially, with ES-CS.

Regardless of the speed with which practitioners adopt ES-CS or their principles, the movement toward a common understanding of FES is underway. This trend has been instilling precision in the distinction among biodiversity, ecological processes, ecological end-products, FES, and the benefits associated with ES. Ultimately, simplified and more unified CS and related tools for data management, modeling, and valuation will help ES analysis ensure that ecological functions are better considered in decision making.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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