Expanding the field of ecosystem services practitioners—18 benefits from using classification systems (Version 1.1, March 2019)

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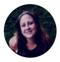

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SUSTAINABLE FLOWS
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Working Paper

Expanding the field of ecosystem services practitioners—18 benefits from using classification systems

Version 1.1, March 2019

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Executive summary

The community of ecosystem services (ES) practitioners (e.g., researchers, data professionals, policy makers) has been working to better define, measure, and value how nature contributes to society. Because measurement techniques follow the labeling or identification of an ecosystem service, the precision of this identification is critical. Ecosystem services classification systems (ES-CS) offered by the European Environment Agency and the US Environmental Protection Agency, for example, are likely to improve this precision.

Presently, the Millennium Ecosystem Assessment's (MA) four types (i.e., supporting, provisioning, regulating, cultural) is probably the most widely used definitional grouping. The MA four types are used directly and served as a basis for other groupings and categorizations of ES. Collectively, they are used on an ad-hoc basis, with practitioners drifting from the definitions offered by one grouping or using definitions from multiple groupings. The wide acceptance of this ad-hoc approach is likely disincentivizing adoption of ES-CS in research and decision making.

This said, the expected benefits of using ES-CS (e.g., US EPA's National Ecosystem Services Classification System, EU's Common International Classification of Ecosystem Services) greatly outweigh the costs of transitioning from an ad-hoc approach. The use of ES-CS offers eighteen benefits to practitioners. These benefits follow from defining ES with more precision, easing the transfer of knowledge among studies, and avoiding the need to recreate systems for defining and classifying ES.

Specifically, wide adoption of ES-CS is likely to create more precise and unified identification of ES among practitioners. Lessons from other disciplines show that wide adoption of ES-CS would almost inevitably spur unity in terminology, increase the accuracy in the selection of metrics, and usher more consistent use of valuation techniques. This consistency and specificity will improve scaling efforts, benefit transfers, and the interoperability of all ecosystem services data. Moreover, broad adaptation of ES-CS reduces the costs of and barriers to ecosystem services research while improving its credibility, thereby expanding the breadth of practitioners engaged in the field, as well as the depth of their research.

The enabling conditions for wide adoption of ES-CS exist. Practitioners who cannot immediately shift to using ES-CS for structural or institutional reasons will still benefit from using the principles that drive these systems. These principles can be adopted on an individual basis, taking advantage of the eighteen benefits ES-CS provide. Such a movement will help to make ecosystem services a more accurate, common, and compelling paradigm in policy making.

NOTE: A few practical questions related to the use of EC-CS are reviewed in Appendix 3: Frequently Asked Questions.

"To understand anything in science, things need to be named in a way that is understood universally."
—Convention on Biological Diversity[1]

Introduction

Progress in any field is enabled when commonly understood terms allow practitioners to more efficiently communicate and collaborate. This need is magnified when working across disciplines. The ecosystem services field depends on data and results being shared and readily understood by several disciplines, principally ecologists, economists, accountants, and policy makers.

To these ends, ecosystem services practitioners (e.g., researchers, data professionals, policy makers) have been exploring different ways to define and measure ecosystem services (ES) for over twenty years. Throughout this exploration the Millennium Ecosystem Assessment (MA)'s four types (i.e., supporting, provisioning, regulating, cultural) has been the most common starting point. The MA four types provided a common set of concepts and definitions, spurring a common body of knowledge.

But the ES field has been advancing. Data needs and analytic methods are growing more complex as calls for increased accuracy and precision escalate. The accuracy and precision desired are not readily supported by the MA's four types and the definitional groupings based on them. They do not sufficiently differentiate among ecological processes, ecological end-products that humans use, and the uses and users of those end-products.

Methods to address this critical differentiation exist. The concept of final ecosystem services (FES)—that defines when a product transitions from being predominately ecological to being predominately economic—is motivated by principles that when properly integrated with formal classification systems (CS)—help organize data, improving the accuracy and precision of analysis.

Ecosystem services classification systems (ES-CS) facilitate improved identification and measurement of ES in individual studies and interoperability of data and learning across the field. By employing formal hierarchies from ES-CS, ecosystem services will be more universally identified, avoiding common errors that can lead to poorly chosen metrics and double counting. In turn, this will help improve the precision of valuations, with use of ES-CS over time. As a result, benefit transfers, to choose one technique of many, will be more accurate. This paper maintains that embracing either ES-CS or their key principles, lowers the costs and complexity of ES analysis, allows more practitioners to enter the field, speeds progress in the field, and can expand the use of ES in decision making.

History of ecosystem services classification systems

When the concept of ecosystem services (ES) was popularized[a] in 1997's *Nature's Services*[2] and *Valuing Ecosystem Services,*[3] two lists defined them. One list had thirteen ES, the other seventeen, from which discussion to define, group, measure, and value ES grew. Today the utility of applying the principles of classification systems (CS) to the field is being discussed.[4]

Classification systems organize information so that data may be easily compared with other data.[5, 6, 7] CS are used in a wide array of fields; those related to ES include ecology, hydrology, economics, national accounting, and health. These fields require large amounts of data that are often collected, analyzed, and shared among independent practitioners. CS all have a:

1. *Hierarchy* of classification that nests sub-groups[b] in a way that is complete,[8] mutually exclusive, consistent, 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 [9, 10, 11, 12, 13, 14]
2. *Thesaurus* that lists all the terms related to the classification system[15]
3. *Vocabulary* that can be used to search the data[16]
4. *Flexible structure* that balances stability with the needs of novel research[17, 18]

Common examples[c] of CS include the Dewey Decimal System used in libraries, Linnaean taxonomy[19], PhyloCode,[20] the Globally Harmonized System of Classification and Labeling of Chemicals,[21] UN Food and Agriculture Organization's Land Cover Classification System,[22] and the International Standard Industrial Classification system.[23] These were developed because each community needed a common language, an easy way to share data and research findings with heterogeneous metrics, and because there was no natural law or existing process addressing these needs.[24]

Recognizing the need for a common language, the Millennium Ecosystem Assessment (MA) proposed four types of ES:

- *Supporting*—natural processes that help maintain other ES (e.g., nutrient cycling, primary production)
- *Provisioning*—the goods or products from ecosystems used by people (e.g., water, timber, food)
- *Regulating*—the benefits people receive from an ecosystem functioning to regulate natural processes (e.g., erosion control, temperance of flooding)
- *Cultural*—the nonmaterial human benefits from ecosystems (e.g., recreation, inspiration)[25]

The MA four types improved over the simple lists of ES offered in 1997, but the MA itself cautioned against considering it a classification.[26] Regardless, the MA four types quickly gained wide use. They were even adapted for national ecosystem assessments.[27, 28] The Economics of Ecosystems and Biodiversity (TEEB) revised[d] the MA four types along with bifurcating ES from "benefits," because benefits to humans routinely involve combining ES with economically produced inputs.[29]

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[a] Writing on the concept of ecosystem services dates to Plato, at least, and lists of ecosystem services emerged in the 1960s. However, popularization of the concept related to current discussions on ecosystem services started in 1997.

[b] Flat CS are effective, but are simple lists of classification such as "gender: male, female" and cannot organize the complexity of ES because they do not capture hierarchical relationships (See endnote 64, Czúcz 2017).

[c] An extensive list of classification systems and resources can be found at http://www.taxonomywarehouse.com.

[d] For example, TEEB use the term "habitat" rather than "supporting."

A few years after TEEB was published, and following on the exclusion of "benefits," the European Environment Agency (EEA) printed a Common International Classification of Ecosystem Services (CICES)—that doubled the number of services in TEEB and offered a hierarchical structure for classifying ES (Figure 1).[30] It was the first formal ecosystem services classification system (ES-CS). CICES is currently in version 5.1.

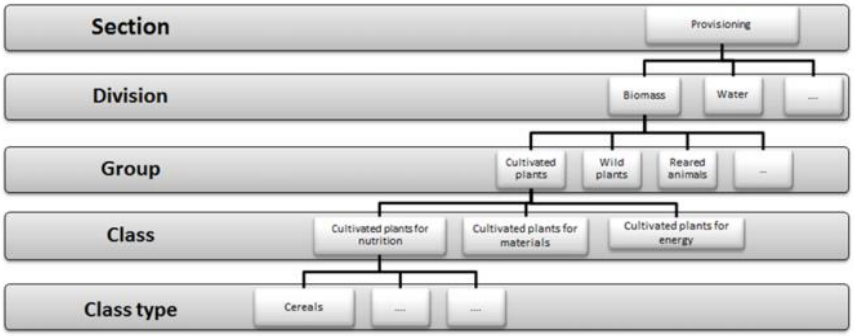


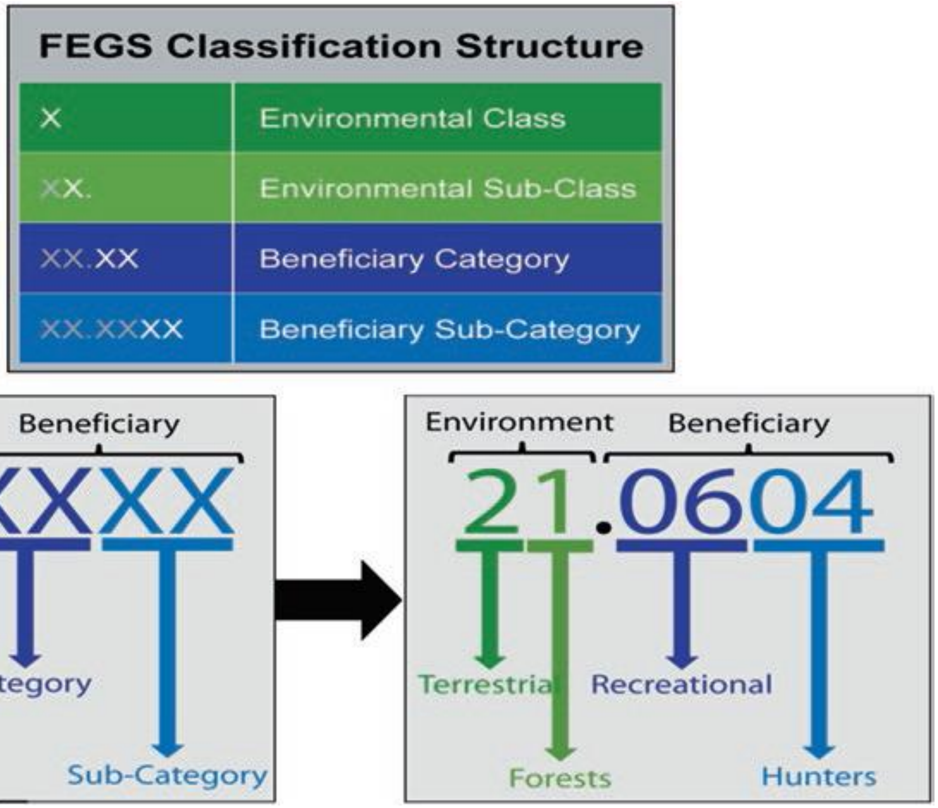
Figure 1 CICES V5.1 hierarchical levels[31]

The US EPA then released the Final Ecosystem Services Classification System (FEGS-CS),[32] and soon after the National Ecosystem Services Classification System (NESCS).[33] Both the FEGS-CS and NESCS include beneficiaries (Figures 2 and 3) in their hierarchies. The primary NESCS structure has been adopted for research exploring what natural capital accounts—a measure of the stocks and flows of natural resources—might look like for the US. FEGS-CS is being used to upgrade NESCS into NESCS Plus.

Similar to the MA, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) explicitly acknowledged the multiple contributions that nature makes to people, but argued that some valuation approaches (e.g., single currency, single indicator, single benefit) often fail to capture this diversity. While the IPBES scientific community acknowledges that decision making relies to a great extent on these "instrumental values,"[34] it supports the integration of multiple assessments of the value of nature to people in decision making.[35] In response, IPBES both defined eighteen categories of Nature's Contributions to People (NCP) and called for them to be understood through the local, cultural-context as bundles that "follow distinct lived experiences such as fishing, farming or hunting or from places, organisms, or entities of key spiritual experience such as sacred trees, animals or landscapes." NCP cannot be placed in a hierarchy, but seeks to consider knowledge from western science, indigenous peoples, and the local context equally in decision making.[36]

As FEGS-CS, NESCS, CICES, and NCP were advancing, the UK National Ecosystem Assessment produced "the first analysis of the UK's natural environment in terms of the benefits it provides to society and continuing economic prosperity."[37] It not only advanced accounting practices but influenced thinking around the globe.[38] It explicitly included final ecosystem services in its framework. [39]

In part to better support ecosystem accounting methodologies aligned with the principles of national accounts by recommending a single ES classification system, the United Nations Statistical Division group working on the System of Environmental-Economic Accounting (UNSD SEEA) facilitated workshops among experts representing the CICES, FEGS-CS, and NESCS and natural capital accounting communities. These workshops include discussions on how components of each ES-CS offer advantages to natural capital accounting. Details on these advantages can be found elsewhere (e.g. UNSD Meeting and Workshops webpage).[e] This paper is focused on the benefits that any ES-CS provides over other lists or groupings of ES. UNSD SEEA chose these three because they were the only ones with hierarchical structures and that embodied final ecosystem services (FES) thinking.[f]



FEGS Classification Structure

X	Environmental Class
XX.	Environmental Sub-Class
XX.XX	Beneficiary Category
XX.XXXX	Beneficiary Sub-Category

Figure 2 FEGS-CS hierarchal levels and coding [40]

“Final” in FES in the four ES-CS described above (i.e., CICES, FEGS-CS, NESCS, and NESCS Plus), refers to the point where an ecological product transitions from being predominantly ecological to being a predominantly economic input that will often be a) mixed with man-made capital to produce an economic benefit, or b) directly used or appreciated. FES are flows to economic units (e.g., private companies & businesses, households, public agencies & bureaus).[41, 42] Figure 3 shows how one ES-CS defines this flow of FES.

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 also determined by who is using the ecological end-product.[g] To the fisher, fish directly available for harvest is the FES, whereas to a tourist, fish for recreational viewing is the FES. Turning to agriculture, to a farmer, water up-take by crops from favorable rains is the ecological end-

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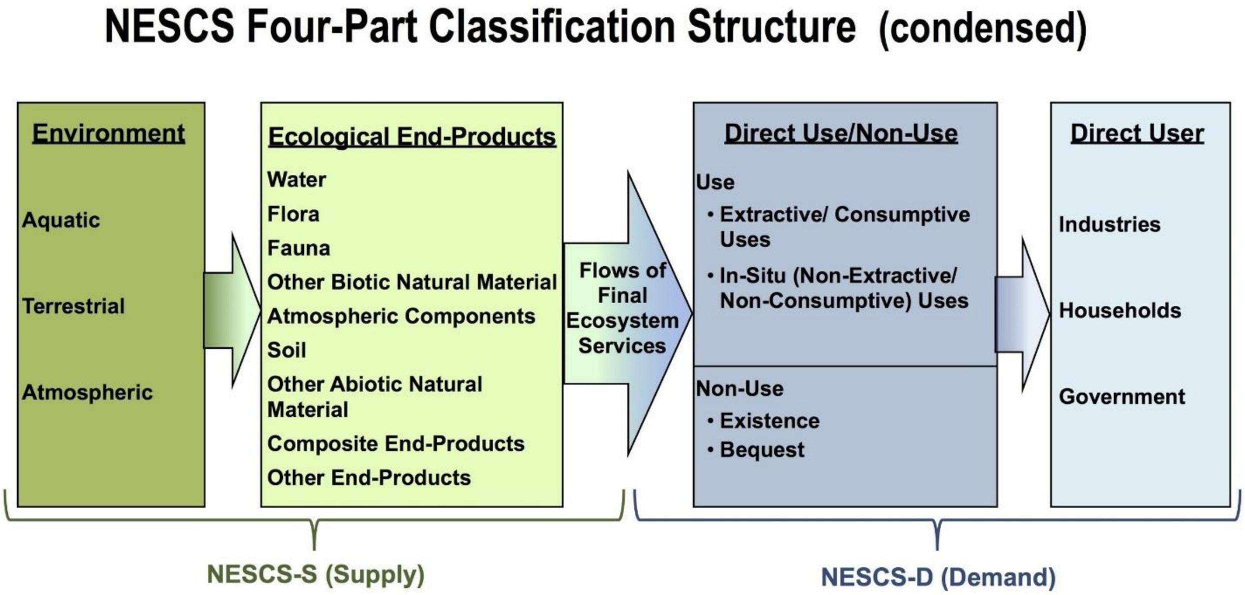
[e] This paper describes some structures and elements of CICES, FEGS-CS, NESCS, and NESCS Plus where appropriate. These are for descriptive purposes only and are not opinions on the relative merits of any ES-CS.

[f] Recent versions of CICES more fully incorporate the FES concept (as defined in this paper) than earlier versions.

[g] ES-CS define ecological end products differently, but all note its centrality to developing a hierarchy.

product that enters the agricultural economy. To a tourist, it is the view of the landscape the farm sits in that enters the tourism sector of the economy.

Figure 3 National Ecosystem Services Classification System hierarchical levels and elements[43]



There is an active debate on the relative merits of FES over ES (see Frequently Asked Questions, Box 2, and Box 3).[44, 45, 46] In addition, there are different interpretations of the boundaries of an FES and how they may be applied in different techniques (e.g., assessments, accounting, stakeholder engagement).[47, 48] Regardless, the only known way to construct a hierarchy that follows the formal rules outlined above (e.g., complete, mutually exclusive, exhaustive, consistent) is by using the FES concept. Unless an alternative is developed, FES based hierarchies stand alone.

Box 1: Intermediate ecosystem services vs. ecological conditions and functions

The term “intermediate ES” emerged in the field of economics in the early 2000s, but over the past decade, has been used increasingly in ecology.[49] As a result, the definition of intermediate ES has changed over time, spurred by the MA, the emergence of FES and refinement of environmental accounting methods. Nonetheless, intermediate ES have been defined as either ecological characteristics, components, functions, process or structures that support the provision of FES, to different degrees. In the example above, the availability of prey for the fish is one such characteristic.

There is active debate on the utility of using the term intermediate ES. Supporters note that it helps communicate the importance of maintaining ecosystem functions that are critical to an FES. They argue that the term intermediate ES is more powerful than terms such as ecosystem function or the function itself (e.g., mangrove nursery habitat). Alternatively, some critics consider the intermediate ES term a misnomer because ES must provide benefits to people, but intermediate ES only do this indirectly. Moreover, because intermediate ES include all the components of an ecosystem that contribute to FES,[50] to give it utility, the term should be restricted to a definition related to local contexts[51] or the degree of influence over a particular FES. However, these narrower definitions restrict the use of the term globally and with ES-CS.

These challenges helped spur the environmental accounting community to call for the intermediate ES term to be used only as ecological characteristics and processes that flow between or among ecosystems, or ecological assets in accounting parlance.[52] These are often difficult (but critical) to track, such as erosion from agricultural areas that contributes to sedimentation and eutrophication. As such, this precise definition helps ensure these important environmental conditions and functions are tracked and properly recorded in environmental accounts, while managing double counting and presenting a fuller ensemble of information to decision makers.

This paper uses the terms FES and ES purposefully. When referring to ES-CS, FES are assumed to be employed. Therefore, ecological characteristics and processes (e.g., the existence of milkweed for monarch butterfly viewing [viewers do not care about the milkweed], wind pollination) are not identified as FES. However, these ecological characteristics and functions are ES as defined by many lists and groupings that do not use formal hierarchies to order ecosystem services.

Box 2: Benefit relevant indicators versus ES-CS

"BRIs are measures that capture the connection between ecological change and social outcome by considering what is valued by people, whether there is a demand for the service, [and] how much is used…"[53] BRIs have a structure similar to FES, requiring both ecological [production] and economic [demand] measures based on the causal chains from ecological functions to human use of end-products.[54]

While comparisons between benefit relevant indicators (BRIs) and FES have been made,[55, 56] no formal, nor extensive comparison has been made between BRIs and ES-CS. This paper offers a few observations.

Principally, the BRIs structure does not provide a hierarchy. As a result, BRIs do not provide the benefits—described below—that ES-CS do. In particular, the ability to help unify the identification and measurement of ES and improve transfer of ES knowledge, is largely absent. Because of the similarities between BRIs and FES, practitioners familiar with BRIs should find the use of ES-CS relatively easy.

These four ES-CS also have nested hierarchical levels, elements, codes and names (Table 1). Differences among the ES-CS reflect design choices or biases.[57] Regardless of these differences, these ES-CS organize a great deal of information, allow practitioners to traverse the hierarchy, and define an FES by (a) the context (see Box 3) in which the ecological end-product is being used— and (b) by identifying elements of the FES within the ES-CS. Each of the elements, in turn, are associated with common names and numeric codes.

Table 1 Generic ES-CS terms used in this paper

	Specific ES-CS terms and examples		
Term used in this paper	**CICES**	**FEGS-CS** (to be retired)	**NESCS and NESCS Plus** (to be retired) (from FEGS-CS and NESCS)
Hierarchical level[*] (each has nested sublevels)	Section, Division, Group, Class, Class Type	Environmental Class, Environmental Sub-Class, Beneficiary Class, Beneficiary Sub-Class	Environment, Ecological End-Products, Direct Use/Non-Use, Direct User
Example elements of the FES (element)[**]	Provisioning, Biomass, Wild Animals, Terrestrial, Nutrition	Terrestrial, Forest, Recreational, Hunting	Forest, Fauna, Hunting for Consumption, Households
Code	1.1.6.2	21.0604	21.3.1106.2
Example of the FES the system names	Food from wild animals	Recreational forest hunting	Animals in forests, hunting for household consumption

[*] A hierarchical level is a "holon"—each level is a whole for the level below and a part for the level above. This means that each holon level defines the boundaries of the level below. Users of ES-CS can move among higher and lower hierarchical levels confident that each level is properly nested and therefore (1) mutually exclusive from the other hierarchical levels and (2) consistent within that level. For example, the CICES's Division "Biomass" will only contain plants and animals, and not soils or habitats.[h]

[**] Practitioners employ the hierarchy of an ES-CS to identify the FES of interest. Traversing the span of the hierarchy as one would go through a checklist helps prompt the practitioner not to overlook potential FES of interest. CICES intends a narrowing from the general to the specific (within Provisioning, Regulating and Maintenance, and Cultural), whereas the FEGS-CS, NESCS and NESCS Plus require the selection of elements that must be matched together to meet their identification criteria for an FES.

UNSD SEEA workshops are ongoing to select or develop an ES-CS useful over the long term for ecosystem accounting purposes. Parallel discussions on the relative merits among ES-CS have been taking place in the literature and at A Community on Ecosystem Services (ACES),[58, 59] at a High Level Discussion on Ecosystem Accounting,[60] at a workshop on natural capital accounting,[61] the Natural Capital Coalition,[62] and at other forums. Finally, as is described in detail later in this paper, practitioners have started drawing from ES-CS principles, specifically using the:

1) Structure of ES-CS to label ES
2) Metrics associated with elements in an ES-CS

Applying these principles effectively turns ES into FES and aligns and creates more explicit and appropriate choice of metrics. These principles are already being used to derive or identify FES and their elements without explicitly using ES-CS.[63, 64, 65] This is discussed later in this paper.

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[h] Figures 1, 2, and 3, present different ES-CS hierarchical structures. CICES used the MA four types as its starting point for developing the hierarchies. FEGS-CS, NESCS and NESCS Plus used descriptions of FES flows—from the environment to the beneficiary—as the basis of its holons. In NESCS and NESCS Plus, there are four parallel holons. The first holon is Environment and the top level of that hierarchy could be labeled A1, Ecological End-Product may be labeled B1, through to Direct Users, D1. The second hierarchical level within Environment is Classes that could be labeled A2 and after that Forests A3, etc. In the FEGS-CS, using this same rule for parallel and nesting holons, the four listed hierarchical levels might be called A1, A2, B1 and B2. In the CICES, each listed hierarchical level is a nesting for the next, so A1, A2...A5.

The ad-hoc approach to defining and grouping ES

Despite these efforts to advance the use of ES-CS, many practitioners continue to define ES differently from study to study. There are examples of practitioners selecting definitions from among groupings and classification systems and even customizing the definitions for individual studies.[66] Within this disorder, the MA four types appears to be the most frequently used definition, grouping, or classification of ES.[67]

Hesitance within the field to adopt ES-CS (i.e., CICES, FEGS-CS, NESCS, NESCS Plus) may have a few causes. ES practitioners may:

1. *Anticipate little impact from not adopting an ES-CS* on the ability to receive funding, publish research, or engage in policy discussions due to low demand for ES-CS based research.
2. *Perceive few benefits to any specific project,* as practitioners appear to believe they fully understand FES or have grown accustomed to ambiguous definitions of ES and their measures (e.g., indicators, indices). As a result, a study's scope can influence the measures selected.[68] While there is an argument—mirrored in other fields—that with enough data and computing power, inferences can be made about the data,[69] many view ES as being more illustrative than empirical. This is especially true with ES research focused on ecosystem functions.[70]
3. *Read standards and guidance documents (e.g., IFC Performance Standard, Natural Capital Protocol) as not endorsing ES-CS* and providing little guidance on the level or rigor, leaving practitioners to use the MA four types and treating an ES assessment as an insignificant requirement
4. *Be unaware how best to integrate and scale ecological, social, and economic data and measure ES,*[71] both of which are enabled by ES-CS as is described below
5. *Have, through staff training, tools and systems development, case studies, and marketing materials* passively adopted MA or TEEB groupings
6. *Seek to deliver data and analysis that is readily recognized by local stakeholders alone*, rather than also aligning these with an ES-CS
7. *Find value in understanding ES as "boundary objects"* where flexible definitions of ES are valuable[72]
8. *Not understand the advantages of "full spectrum" ES classification* that accommodates all FES
9. *Experience fatigue from engaging in similar efforts* to standardize terms, systems, and procedures such as satellite data, metrics, and monitoring and evaluation procedures; for which funding is often limited and which are generally more successful in smaller fields with less diversity of disciplines[73]
10. *Perceive the costs of implementation to be high,* including:
    a. Updating research, tools, and techniques to be consistent with a formal ES-CS
    b. Traversing the learning curve, especially if there is no assisted or automated means for application such as an online ES-CS selection tool or pre-tagged data sets
    c. Learning how to numerically code or tag ES with the ES-CS and principles[74] of data stewardship
    d. Sorting through any inconsistent application of ES-CS to date by other practitioners and possibly absorbing the costs of transition without clarity on the field's direction[75]
11. *Have concerns—however valid—about ES-CS* and how they function in practice

As a result, few are using ES-CS, 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. Many tools, databases, publications, and guidance documents mention ES-CS, but have been reticent to endorse them.[76] Practitioners define and group ES differently, sometimes even if they are working for the same institution.[77] Other practitioners choose definitions of ES from different groupings or classifications systems and even change their definitions.[78] Moreover, some research actually measures things other than what the authors purport to study.[79]

This ad-hoc approach has merit. ES provide multiple values to multiple beneficiaries[80] that are integrated into decision making in different ways.[81] Depending on the decision making context, consideration of either the qualitative or quantitative ES values may be appropriate.[82] Over time, the ad-hoc approach could help change social norms and eventually lead to changes in practices[83]—ecosystem functions may become an ever larger factor in decision making,[i] even without ES-CS. There has already been some movement in this direction.[84]

This said, there are increasing calls among practitioners for ES-CS. Many have concluded that improved definitions and terms are required for the success of ES approaches.[85, 86, 87, 88, 89] Indeed, practitioners have been using international standards for years. The ISO 14007 standards provide guidance for “determining environmental costs and benefits”, while 14008 defines acceptable practice for “monetary valuation.”[j] Further, investments by the European Environment Agency, US EPA, Chinese Academy of Sciences, China’s Ministry of Ecology and the Environment (previously known as the Ministry of Environmental Protection[k]), UNSD SEEA, and leaders in natural capital accounting are generating ES-CS and FES based tools and applications which speaks to the importance practitioners places on ES-CS. These tools and applications include using ES-CS:

- To support implementation of the EU Biodiversity Strategy to 2020 (via the EU MAES and INCA projects)[90]
- In structuring the US EPA’s EcoServices Model Library so that it provides analysis of FES not just ES[91]
- To develop at least 4 customized versions of CICES for specific studies[92] that help reduce the total number of FES and use locally appropriate terms
- To help define beneficiaries for US EPA’s Superfund program[93]
- To guide structural components of the ESMERALDA database[94]

Finally, research is increasingly referencing “final ecosystem services” relative to “ecosystem services” since FES were first described in 2007[95] (Chart 1).

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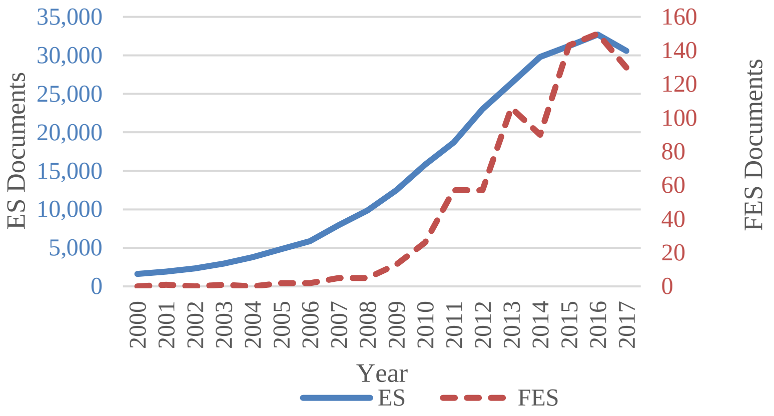
[i] The extent of ES integration into decision making can be measured by (1) comparing the frequency that monetary values are used in healthcare policy versus environmental policy debates and (2) the degree to which ES are included in impact assessments, life cycle assessments, corporate valuations, among other environmental approaches, tools, and orthodox techniques of environmental science.

[j] These standards do not focus on ES frameworks and definitions but seek to align the ES applications and techniques with other ISO standards.

[k] The Chinese government is the world’s largest investor in ES and is developing a FES based national accounting system, the Gross Ecosystem Product (GEP), as well as other more targeted accounting systems (e.g., for its National Key Ecological Function Zones).

Chart 1: ES and FES documents per year

Google Scholar hits (25 May 2018)



Most importantly, detailed below, experience with CS in other fields suggests that adoption of ES-CS will be successful and speed the incorporation of ES in decision making, making ecological functions a greater part of decision making.

Benefits of classification systems

While CS themselves cannot change political, social, and economic decision making, they can speed progress. Looking outside the ES field, research and decision making would have been hampered by the absence of CS. More time would have been devoted to understanding how other researchers defined and measured key variables and then making these definitions appropriate to the research at hand. CS offer five functional benefits, including a:

1. Unifying language[96]
2. Understanding how all the elements (see Table 1) of the CS interrelate[97]
3. Improved identification of elements (see Table 1), metrics, and analytical techniques[98]
4. Improved knowledge transfer[99]
5. Improved knowledge management[100]

These benefits are significant. Recent studies note that:

- Knowledge workers spend 20-35 percent of their time searching for information, with a 50 percent success rate[101, 102]
- Data collection and preparation—by some estimates—is 60 percent of the time needed for environmental modeling[103, 104]
- A logistics consultancy saved $5-6 million in productivity with a CS[105]
- Reuters saved $90 million with a CS[106]
- CS are “vital” for business IT, and 70% of organizations develop them improperly and therefore do not achieve a return on their investment[107]
- One poor CS costs 10,000 organizations $10 million annually[108]
- One communication firm noted that an improved “search and retrieval system” would save $24 million annually[109]

These benefits stem from savings associated with “defining data,” “discovering data,” and with not “recreating systems.” [110, 111] Because CS organize an expansive breadth of information, practitioners need not explore literature for updated terms—they are readily updated in the CS. The CS implicitly directs users toward the best metrics and data encoding practices. Improved data discovery increases confidence when researching and offers greater ease when integrating disparate studies and supporting computerized data discovery especially among disciplines and fields. Finally, individuals and institutions no longer need to recreate the systems and structures the CS provide.

These three generic benefits—defining, discovering, and recreating—are cross referenced with each of the five functional benefits with regards to ES-CS (Figure 4).

1. Unifying language

Any field's advancement depends on having a common set of readily understood terms. This improves collaboration among disciplines (a. in Figure 4), increases recall and precision in data discovery by both people and machines (b. in Figure 4), makes it easier to communicate science (c. in Figure 4), and reduces incentives to remake vocabulary or invent new CS (d. in Figure 4).

Consider two simple examples. One person may use the word "pail," another "bucket" when referring to the same object. "Mercury" can refer to a planet, a metal, a car, a mythical god, or a recording company. A unifying language encourages everyone to use the same term, or terms that can be linked. A search for "pail" should have strong recall, pulling references to "pail" and "bucket." Searches also need to be precise, so that data gathering on planets finds relevant studies.[112]

For the North American Industry Classification System (NAICS) and the International Standard Industrial Classification System (ISIC),[113] both central to economic research and reporting, conventional economic activities are numerically coded. This helps researchers trace economic activities through an economy and over time. A different information challenge was posed when the United Kingdom's Freedom of Information Act 2000 required that responses to data requests occur within twenty days. This promoted development of the e-Government Metadata Standards that created common terms across government and allowed information to be accessed with relative ease.[114] Finally, CS ease the communication of science. With regards to NAICS, this means every activity is given a clear descriptor. Major Kitchen Appliance Manufacturing (#335223) and Measuring, Medical and Controlling Devices Manufacturing (#2224512) are easily understood. Journalists and policy makers can find precise definitions online.

Similarly, ES practitioners need a unifying set of terms (a. in Figure 4) that can be easily recalled (b. in Figure 4).[115] The MA's four types of ES served practitioners well, providing a touchstone and helping ensure that human benefits were not conceptually separated from the ecological systems that enabled them.[116] ES-CS could bring the community closer together, knitting interests among practitioners, especially among ecologists and economists, while improving recall and precision in data discovery (b. in Figure 4).

Moreover, the hierarchal nature of ES-CS is likely capable of extending this unifying language to each of the elements (see Table 1) that together define an FES.[l] For example, in Table 1 NESCS provides clarity on the FES "fauna in forests, hunting for household consumption" and to each of its elements (i.e., forest, fauna, hunting, 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.

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[l] Both ES and FES are used purposefully throughout this paper. FES can be considered a subset of ES; an FES is always an ES, some ES are not FES.

Turning to communication, practitioners have long struggled to explain the ES paradigm and its advantages.[117] Even the term "ecosystem services" has been called opaque[118]—especially in regards to distinguishing ecological functions from ES or FES—a problem that helped bring the term "natural capital" into vogue. Some have opined that this confusion diminishes the quality and quantity of media coverage on biodiversity.[119] Environmental journalists note that "Crafting clear careful definitions of data is the responsibility of the researcher."[120]

ES-CS can help by driving clarity and consistency in terms (c. in Figure 4), yielding surprising benefits. UK policy makers, through their use of use of CICES, gained a firm understanding of the economic and health benefits that flow from ecosystems. They then posed a question that scientists had not yet considered—in a warming world, when does additional urban green infrastructure no longer reduce the heat island effect?[121]

ES-CS have also proven beneficial in stakeholder engagement, to help communicate the distinction between complex ecological functions and FES.[122] These communication advantages generally hold better for trade off analysis (e.g., such as comparing different management options for a park) than they do for national accounting application, where the scale is larger and stakeholders' interests are more diffuse. 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.[123] Discussed in the conclusions below, linking the ES-CS structure with local stakeholders' understanding of ES is powerful in framing decision making.

Noted above, practitioners are using different definitions for ES, choosing definitions from among lists, groupings, and ES-CS, and even modifying these definitions as they see fit. In effect, new ES lists, groupings, and definitions are being developed. With the adoption of ES-CS, practitioners can avoid duplicating ES-CS or struggling to reframe how elements organized in an ES-CS are related (d. in Figure 4).

Figure 4 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**	a. Improved collaboration within and among disciplines (e.g., ecologists, economists, accountants, policy makers)	b. Increased recall and precision when searching for research and data c. Improved ability to communicate science	d. Eliminates need to create elements and hierarchal levels
	2. Understanding how all the elements of the CS interrelate	e. Quickly identify complementary elements of an FES f. Quicker identification of research needs	g. Better understanding of what is left out of an analysis	h. Easier incorporation of new learning into the field
	3. Improved identification of elements, metrics and analytical techniques	i. Lower number of mislabeled FES, loose-fitting metrics, and weakly appropriate valuation techniques j. Reduced risk of double counting and no FES “loss” in accounting	k. Certainty that FES and metrics were properly identified	
	4. Improved knowledge transfer	l. Greater likelihood that research will be repurposed m. Simplified data encoding (tagging)	n. Facilitated data integration among studies, datasets, and models	o. Greatly reduces need for creating systems that integrate data across studies and datasets
	5. Improved knowledge management	p. Reduced cost of new employee training	q. Reduced cost associated with employee loss	r. Likely eliminates need for organizations to create ES-CS

These 18 benefits help enable:

- Ease of understanding ES
- Reduced cost of ES research
- Ease of entry into the ES research field
- Improved quality and quantity of ES research

That support:

Expanded use of ES in decision making by governments, corporations, and land managers

2. Understanding how all the elements in the CS interrelate

CS should enable a quick understanding of how one element of a CS relates to all others. This speeds learning (e. in Figure 4), highlights what is absent from a study (g. in Figure 4), helps identify research needs (f. in Figure 4), and facilitates the incorporation of new learning back into the CS and research field itself (h. in Figure 4).

CS are comparable to a book's table of contents, providing structure for a complex body of knowledge. Effective CS require properly structured hierarchal levels (see Table 1) that are mutually exclusive and consistent. Perhaps most importantly, the CS must be complete, accommodating all possible elements in the field (see Table 1 for examples of elements in ES-CS). An element in one hierarchal level should relate to elements in other hierarchical levels through defined relationships among the CS hierarchies, not by overlapping with elements in other levels.[124, 125]

Done properly, the CS structure yields tremendous insight. The Linnaean CS, for example, contains information on systematics and phylogeny. Having a common name for the northern red snapper (*Lutjanus campechanus)* is useful. Knowing that it falls within the genus *Lutjanus* helps a researcher unfamiliar with species but perhaps familiar with the Brazilian snapper (*Lutjanus alexandrei*) understand that this is likely a predatory species that harbors parasites.

This contextualization enabled by CS also illustrates what is left out of an analysis. This can help researchers identify complementary studies on a particular subtopic of a CS. It also provides clarity to decision makers reviewing research products. They can easily reference what is omitted from a study. For example, a decision maker reviewing an economic study that used NAICS could quickly compare the study with the full list of NAICS industries, and know which were excluded.

CS speed the incorporation of new knowledge throughout a field. CS are central in science to describing the world and using these descriptions to develop and test hypotheses.[126] The updated knowledge is reflected in a revised CS. The Standard Industry Classification was updated with NAICS in 1988—spurred by the North American Free Trade Agreement—to included new industries (e.g., data management).[127] Similarly, the International Statistical Classification of Diseases and Related Health Problems (ICD) allows researchers to universally define a disease, its symptoms, and causes. Through use across the health field, data on symptoms and causes of a disease can be more efficiently compiled, speeding the testing of the hypothesis embodied in the ICD. The ICD has been updated eleven[128] times in just seventy years, helping it maintain, and possibly expand, its relevance.[129]

An oversimplified example demonstrates how these same advantages apply to ES-CS. When analyzing water use by industry, a researcher could start with a type of industrial facility and the rough 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) (see Figure 3) from which the water may be abstracted (e. in Figure 4). 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 (f. in Figure 4). 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 (g. in Figure 4). 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. One survey used ES-CS to identify the ecological models needed to complement the 150 already in use.[130]

This structure that ES-CS provide, also creates a starting point for developing quality controls or check-lists. They can help practitioners and policy makers determine if the appropriate breadth and depth of analysis of ecological end products, uses, and users have been considered. And if items have been omitted, such guidance could offer practitioners room to explain if data shortages or other practical matters prevented consideration.

Finally, ES-CS have already started integrating new learning (h. in Figure 4). CICES is in version 5.1. The most recent iteration was spurred, in part, by the SEEA workshops.[131] The FEGS-CS is being used to upgrade NESCS into NESCS Plus. This constant improvement drives down research costs and errors because any update to an ES-CS becomes the standard for all users of the ES-CS, not only those that are familiar with the new learning. Effectively, resources are pooled, driving research forward.

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

This organization of a field's body of knowledge described in the previous section, directly improves practitioners' identification of the elements (Table 1) within a hierarchy and their ability to select appropriate metrics for these elements. This not only improves the quality of individual studies but builds confidence in a study's data and analysis.

One simple example is the distinction in NAICS between full-service and limited-service restaurants—the latter being fast food restaurants where patrons generally pay before eating. This clear distinction helps researchers quickly label the establishment and standardizes the identification across researchers, geographies, and time periods. As a result, tracking of spending between the two types of restaurants is eased. Moreover, CS often have numerical coding to support data management and retrieval.[132, 133]

The consistency of this naming and coding correlates with the modularity of the data—the greater the consistency, the less effort required to align data from multiple sources. Full consistency in all studies would largely eliminate data manipulation needs and greatly simplify systems and methods for integrating data.

These same benefits are gained using an ES-CS (i. in Figure 4). Because each FES (all FES are ES) and its hierarchal levels (see Table 1) are precisely defined into nested hierarchies, FES rarely overlap.[m] The MA's provisioning ES of "fish," is understood through an FES lens as being when the ecological end-product fish is catchable by a fisher. There is a web of ecosystem interactions generating and supporting the fish before the catch, and a myriad of economic actions that can occur after. The fish may be caught by commercial or recreational fishers, each having different values associated with the activity (e.g., income, recreation, views along the river). A quick reference to an ES-CS that directly or indirectly includes beneficiaries ensures that all these distinctions can be captured among practitioners (see Appendix 2, Example 1).

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[m] For example, a study of ES values of a farm to the farmer that does not use an ES-CS for identification may sum values of mild temperatures, rainfall, soil quality, and crops. But because the crop yield is largely dependent on the previous three ES, double counting of ES values is likely. In some ES-CS, crops themselves are not identified as a FES to the farmer.

ES-CS also have numeric codes that differ by the FES element (Table 1). Duck hunting in grasslands for household consumption has a clearly different code than aesthetic appreciation of ducks in wetlands. This allows researchers to easily label and encode for reuse of the data, increasing the impact of any one study. This encoding instills confidence in the identification of the FES and its metrics while also easing use of that study's data (k. in Figure 4).

This precision carries through to the selection of metrics, associated monitoring protocols, and valuation techniques (i. in Figure 4). ES-CS function like a funnel, guiding practitioners from the general set of metrics to more specific ones, based on each element (see Table 1). Using NESCS as an example (Figure 3), starting with a grassland environment, a large set of metrics are available. If ducks are the end-product, the available metrics and monitoring protocols shrink. Moving to the use, 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, others.[134] This process focuses practitioners on the metrics and valuation techniques of importance to the study, rather than aggregate ES groups in which some percentage of the FES may lie.

Without an ES-CS, a seasoned practitioner may habitually select the best metrics and valuation techniques for a particular study. Their selection is also likely to be informed by the precision needed for a study, budgetary concerns, the deadline for analysis to be complete, and other contextual issues (see Box 3). These items aside, ES-CS would help eliminate much of this work and the mistakes associated with it (i. and j. in Figure 4), reducing the barriers to entry for a relative novice. In addition, it builds confidence that FES and metrics were properly identified (k. in Figure 4).

There are common mistakes that proper application of an ES-CS can eliminate. These mistakes include:

1. *Not identifying a direct user*[n] and therefore tending to label ecological processes as FES (i. in Figure 4). A grassland may provide habitat for native pollinators, but without 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.[135]
2. *Mistaking an economic input for an FES* (i. in Figure 4). Crops require an extensive amount of physical and human capital from seeds to farm equipment to labor, and therefore crops are already incorporated in economic accounts. Hired pollinators, such as rented bees, are also economic inputs, not FES.[o]
3. *Misidentifying an ecosystem characteristic, process or function as an ecological end-product* (i. in Figure 4). 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. Native bees provide the FES of wild pollination to a farmer or gardener.

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[n] Identification of beneficiaries is done directly within the FEGS-CS, NESCS, and NESCS Plus hierarchies, or for CICES, by drawing from the context.

[o] Conversely, wild pollinators such as ground nesting bees are an ecological end-product that enable the FES of pollination for farmers or gardeners. Some argue that the capacity of a farming area to provide habitat for wild pollinators to thrive can be recorded as a condition of the area; others argue that this "pollination habitat" itself should be identified as an ES. Additional FES for farmers are rainfall, soil quality, and temperatures for crop production.

4. *Failing to distinguish between a use and a user* (i. in Figure 4).[p] The FES drinking water does not sufficiently identify the user. The metrics, monitoring protocols, and analysis for a hiker, subsistence resident, and municipal water system differ. The care in this distinction may not affect an individual study focused on subsistence residents, but using an ES-CS would allow future researchers or national data collectors to more effectively use the data.
5. *Choose an FES without identified metrics* (i. in Figure 4). CS allow faster selection of quality metrics for many ES. In the absence of ES-CS, metric selection may start from a far wider range of candidates and will likely take more time to qualify.

While also helping to:

6. *Reduce the risk of double counting* by ensuring that every FES is unique, or discrete (j. in Figure 4). ES practitioners have developed techniques to address double counting that are likely to be used less frequently with ES-CS.[136]
7. *Simplify natural capital accounting* by helping ensure ES are not "lost in accounting" (j. in Figure 4). 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 actually used are counted. Thus, the accounting rule, "the supply of [FES] cannot be higher than the quantity [of FES] consumed or otherwise used"[137] is satisfied, and no ES are "lost."[q]

All these benefits follow from simply using a well-developed ES-CS (i. and j. in Figure 4), saving time and removing barriers to integrating ES into decision making. Readers of studies that employed an ES-CS will have confidence that the identification of the FES and selection of metrics is more likely to be correct (k. in Figure 4).[138]

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[p] All ES-CS acknowledge the need to distinguish between use and users with varying degrees of specificity.

[q] Exploring an area's management options (e.g., trade-off analysis, cost-benefit analysis) can project how these flows may change, while also maintaining a simplified natural capital account of the current ES flows.

Box 3: Considering context and metrics when using an ES-CS

Using ES-CS in isolation of the complex environmental, social, and economic context of a geography can be problematic. There are multifaceted environmental relationships that occur before an ecological end product leaves an ecosystem and intricate interactions related to the appreciation or use of that end product. ES-CS support the identification and measurement of FES and require these contextual considerations be fully incorporated into research, accounting, and policy decisions. Among the items that should be considered are the:

- *Ecosystems*: Most ecological end products are produced by multiple ecosystems. Drinking water extracted from a river on the coast may start as mountain snowpack. Most FES require multiple ecosystems. Raptors may cull rodents for a farmer, but also require healthy ecosystems along their migratory routs (e.g., grasslands, woodlands, rivers). Views appreciated by tourists may rely on forests, rivers, and grasslands. Some ES-CS require the selection of a single ecosystem type in which the ecological end product is used or appreciated. This is required in natural capital accounting. It is the "natural capital" that produces different ecological end products. Regardless of the FES identified by the ES-CS, practitioners should consider the totality of the ecosystems that are appropriate for the effort. In most cases, this means including in the analysis those ecosystems that are relevant to the ecological end products of interest to users (see endnote 142, Sinha, et Al. 2018).
- *Geographic boundaries*: ES assessments invariably require analysis within a defined geography. Because ecological end products are usually determined by interactions among ecosystems, defining these boundaries is difficult. Practitioners should balance the need for analyzing the totality of ecological systems with their budgets, deadlines, and the degree to which larger boundaries influences the ecological end product (s) of interest. (see endnote 142, Sinha, et Al. 2018).
- *Time boundaries*: Similar to geographic or ecosystem boundaries, FES assessments usually require defining temporary boundaries. These should also be based on relevance to the beneficiaries. (see endnote 142, Sinha, et Al. 2018).
- *Beneficiaries*: The direct user of an ecological end product is typically just one stakeholder with an interest in that end product. A water utility may be governed by regulations that differ from the water quality demanded by households. Likewise, consumers may have interests in the nutritional context of food that may differ from the soil quality considerations of farmers. Considering all key stakeholder interests may be critical for advancing policies and practitioners should consider them as is appropriate for decision making.

These items influence metric selection. ES-CS are relatively new, and many metrics for FES are in development. Existing datasets may contain only proximate measures or indicators. (These proximate measures may have more utility than metrics defined by dogmatically applying FES thinking [see endnote 142, Sinha, et Al, 2018].) For example, the ecological end product "fish available for harvest" is not found broadly in databases. Data on existence of habitats, water quality metrics, among other indicators are. These can be used as proxy measures or serve as inputs to models that estimate the ecological end product.

4. Improved knowledge transfer

This precision in identifying elements and associated metrics, coupled with the confidence that CS instill, makes research more likely to be transferred or repurposed; data easier to encode, tag, or semantically annotate; results cheaper to integrate among multiple studies, datasets, and models; and reduces the need to recreate systems for data integration.

An analogy for how CS enable data transfer or modularity comes from manufacturing. The American National Standards Institute (ANSI) and International Organization for Standards (ISO) developed specifications related to the size, length, performance, and other attributes of a multitude of products, with each product type assigned a unique number. ISO's code 10642 refers to a hexagonal socket countersunk head screw made of various widths, depths, and countersink angles.[139] This standardization and ease of reference allows manufacturers to use a single product across entire portfolios, develop diverse supply chains, and speeds product innovation.[140]

ES-CS, by using the organizing principles of hierarchies, facilitates knowledge transfer across data, methods, models, and studies.

This has immediate implications for new research. If an ES-CS is employed, it can more readily be incorporated into work by other practitioners (l. in Figure 4). In addition, the ES-CS can be used as a basis for incorporating past research. CICES was used to advance the "concept matching" method that pairs indicators from previous studies—even studies not focused on ES—with indicators identified by CICES.[141] This concept matching can dramatically expand the range of available studies and data for a particular research track. It can be used to incorporate research done with a different ES-CS, an ad-hoc ES system, and even studies not focused on ES. This said, use of ES-CS over time reduces the need for these data integration systems and methods (o. in Figure 4).

The greatest knowledge sharing benefits from using ES-CS are likely for scaling exercises, long-term studies, regional assessments, cost-benefit analysis, life cycle assessment, multi-criteria analysis, benefit transfer, meta-analysis, and similar analytical techniques (l., m., and n. in Figure 4). A few are considered below.

Interregional Assessments

Integrating research across geographies[142] is challenging because the ES production, flow, and consumption may have been analyzed by different researchers, using different ES definitions, metrics, and measurement techniques. ES-CS allows a researcher to code or tag ES production elements (see Table 1) from one existing study, then to code FES consumption elements using data from another study. The ES-CS serves as a central set of definitions linking the data from the region (n. in Figure 4).

Benefit transfers

Benefit transfer methods support analysis when data are scarce at the site of interest, but necessary data were generated elsewhere or at different times. These methods help when the cost and time investment for primary ES research is unavailable, and can thereby make ES a more common part of decision making. Central to success, however, is reducing the variability or prediction errors these methods yield. Best in class studies have an error rate of 20 percent and 50 percent is considered good.[143] This is insufficient for many decisions.

To minimize error rates, researchers use function transfer methods (e.g., meta-function transfer, preference function transfer) that allow the characteristics and methods from studies of reference sites to be adjusted to the conditions at the policy site. For example, reference sites may have different geographic sizes, ecological conditions, or have stakeholders with different income levels. Studies may have used different methods, such as valuation techniques that measured use, non-use, or the total value of an ES.[144] Accommodating for these differences has been shown to improve the accuracy of transfers.[145]

Use of ES-CS is likely to reduce error rates over time through (1) greater similarity of characteristics and methods related to the elements of an ES-CS (see Table 1) among reference and policy sites,[146] (2) improved reference site valuations—over time—that are used for transfers,[147] and (3) better data management. Data management is described below under the header *Dataset, models and tool.* Improved valuation result from the three functional benefits of *Unifying language, understanding how all the elements of the CS interrelate,* and *improved identification of elements, metrics and analytical techniques.* These benefits (a., b., e., f., g., I., j., and k. in Figure 4) encourage both similarity of characteristics—through better delineation and consistency of services and beneficiaries—and methods—measurement and valuation techniques—used among reference and policy sites.

For example, broad use of ES-CS would spur similar definitions of the:

1. *Environment or ecosystem type* (e.g., water body versus freshwater rivers in an ES-CS)
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 other definitions of soil health)
4. *Uses and users* (e.g., non timber forest products for collection for commercial sale versus collection for household consumption)

This improvement should grow over time and is only related to the ES-CS elements (see Table 1). In turn, this specificity spurs use of more similar metrics, measurement methods, and valuation techniques as is described in section 3 *Improved identification of elements* above. With the expanded use of ES-CS in primary research, over time these similarities will grow, and the accuracy of benefit transfers increase (m. and n. in Figure 4).

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.[148, 149, 150, 151] As with benefit transfers, the more uniform the definitions and metrics of different elements of an FES are, the lower the need for complex statistical solutions and the more precise results will be (m. and n. in Figure 4).[152, 153]

Datasets, models, and tools

The advantages to individual studies can be extended to databases, datasets, models, and related tools. While inherently a gradual process, there is precedent from other fields where standards for data interoperability[r], [154] have been implemented. FAIR (Findable, Accessible, Interoperable, Reusable) and Linked Open Data (LOD) standards have been yielding unanticipated benefits, [155, 156, 157] though broad use among practitioners should increase the quality, speed, and breadth of broader scientific discovery.
Practitioners have already seen some in the US EPA's EcoService Tools Library (Library), [158] the US EPA's EnviroAtlas[159] and the work of ARtificial Intelligence for Ecosystem Services (ARIES).[160]

The Library makes specific reference to ES-CS, helping users find ecological models for specific end-products. ES-CS simplified development of this portion of the Library by clarifying the ecological end-points.[161] In the absence of a CS for the entire suite of ecological variables used by ecological modelers, developers needed to create a Variable Classification Hierarchy that

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[r] With regards to data, interoperability refers to the ability of information to be reused and linked across and beyond the institutional and disciplinary contexts.

defined them.[162] Within the hierarchy, ES-CS could deepen specificity in Category 5, Ecosystem Attributes and Potential Supply of Ecosystem Services.[163] Moreover, consistency among ES-CS would simplify improvements to the Library.[164]

EnviroAtlas is developing a crosswalk between the list of Final Ecosystem Services Goods and Services from FEGS-CS and the list of metrics in EnviroAtlas. It eases the identification of metrics for use with EC-CS. In addition, the EnviroAtlas team is developing a relationship browser linking the FEGS-CS and CICES. Effectively it will identify the nearest FES of each ES-CS. [165] Both will improve access to ES-CS data sources and support practitioners in their use of ES-CS.

ARIES is an ES modeling platform is being built to support the vision of a semantic web[166] where ecosystem data and models are shared based on FAIR Data Principles, [167] Open Linked Data standards, and semantic annotation that allow for collaborative, cloud-based model and data sharing that is content aware, promoting proper data and model reuse by letting users encode the time, place, scale, and scientific questions that the data and models can answer.[168] Moreover, the semantics structure of ARIES allows for computer automated workflows linking models and data without added knowledge from the user.[169] This relies on the organization and storage of data in human and machine readable formats, such as the Open Geospatial Consortium (OGC) standards.[170]

Such a transformation to FAIR standards could begin with encoding of existing datasets, adding tags for the data concepts and FES and their elements.[171] Databases of research such as the Environmental Valuation Reference Inventory,[172] the Natural Capital Hub,[173] the Ecosystem Valuation Toolkit,[174] and the anticipated Ecosystem Services Valuation Database[175] could be tagged with FES codes. Next, more complex tools such as the Integrated Biodiversity Assessment Tool (IBAT),[176] US EPA's EnviroAtlas,[177] the US EPA's EcoService Tools Library[178] InVEST, MIMES, among others,[179] could not only add tags to the data, but also provide outputs aligned with ES-CS while implementing full FAIR Data Principles for the data and models. Finally, using these data and models could be integrated into ecological-economic models, analysis of the environmental impacts of trade flows, and other more complex modeling to yield additional benefits (m. and n. Figure 4).

Business environmental accounting systems

Adopting an ES-CS is critical to expanding business environmental accounting. It would support the integration of ES in both management and financial accounting frameworks and systems. Historically, environmental management and financial accounting has focused on the physical and monetary dimensions of negative environmental impacts (e.g., solid waste, air, water emissions) and non-product outputs (e.g., replacement costs of wasted raw materials).[180, 181] Using ES-CS from the outset, there is an opportunity to save time and costs in exploring the ES dependencies of companies, their suppliers, and clients. Notably, through the development of integrated FES–financial accounts[182], the ES intensity of specific business accounts and associated transactions could be modelled, accounted for, and disclosed to shareholders, and other stakeholders (m and n. in Figure 4). This would, among other items, allow for easier benchmarking of a businesses' impacts and risks.

Scaling

Implicit in many of the techniques described above is the ability of ES-CS to ease 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.

Scaling is critical because ES are produced, consumed, and managed at different scales and rigorous analysis is not always possible where these three converge. Drinking water is often produced at a watershed scale, it may be consumed at a single location, but a farmer and utility may make management decisions at a local or watershed scale, depending on the regulatory context and other factors. Moreover, the understanding of the watershed—or any ecosystem—is directly influenced by the scale of analysis.[183] Because analysis is more difficult at coarser scales where the interactions among species, ecological processes, and human uses can be overwhelming, studies at more manageable scales can be aggregated or otherwise scaled-up, to predict how these geographically larger systems enable ES production and consumption. In addition, analysis at multiple scales can uncover unique information missing from a study at a single scale.[184] For example, a largescale study can define the myriad of ecosystem characteristics and processes necessary for anadromous salmon to live, and a small scale study the specific locations along a river where First Nations people hold Salmon Ceremonies.

ES-CS were developed with the challenges of scaling in mind.[185] Their hierarchal levels (see Table 1) organize ES information in ways that support scaling. Some ecological organizations (e.g., individual-population-community-ecosystem-landscape-biome-biosphere) are helpful in defining terms, but can create difficulties (e.g., loosely defined metrics, double counting, lack of system wide knowledge). In short, they do not simplify the body of knowledge in ways that support rigorous analysis. ES-CS hierarchal levels, on the other hand, support scaling by:

1. *Driving greater accuracy in scaling analysis* because the overall data are more accurate and decomposable, or modular. Discussed above and detailed in the *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 to apply to scaling exercises.
2. *Informing the selection of scales* by directing users to locate ES production and consumption—effectively defining the FES. [186] These boundaries are likely to define a study's focal scale. Down scaling may simplify analysis that is not feasible at the focal scale, and up scaling may inform management decisions made at this coarser scale.
3. *Encouraging greater consistency in defining the appropriate scales for analysis over time.* With more unified FES and metrics, over time there is likely to be more consistent definition of scales. The "breaking points" where spikes or rapid increases in scale analysis (e.g., scale variance, hierarchical partitioning, spatial statistics) should be consistent among FES within similar ecological systems (e.g., temperate coastal marsh, boreal forest). Hence, the effort necessary to define scales should decrease.
4. *Helping ensure that FES are not "lost" in scaling*. Cultural FES, for example, can be non-existent at coarser scales but can be the strongest FES at smaller ones (e.g., popular picnic spot near a village, small grazing area for goats). With a local FES defined, practitioners are guided to conduct an analysis at this scale.
5. *Improving 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.[187]

This improved ease of scaling (m. and n. in Figure 4) is likely to increase the quality and quantity of scaling analysis among practitioners and institutions.

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. This both reduces the learning curve for new employees who have fewer internal systems to learn and the cost to the organization of departures of employees.[188, 189]

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 (p., q., and r. in Figure 4).

Cost and benefits of an ad-hoc versus an ES-CS approach

Each of the five functional benefits can be matched to generic benefits of defining data, discovering data, and avoiding the recreation of CS, yielding eighteen benefits specific to ES-CS (see Figure 4). Moreover, CS makes topics easier to teach. Teenagers use the Linnaean and periodic tables as principal means of understanding how to organize concepts and data in a field new to them. Collectively, these eighteen benefits will expand the quality and quantity of existing ES research, enabling new entrants to the field, while easing the risk to organizations taking similar steps.

There are also costs associated with breaking from using an ad-hoc approach. The drive toward standardization could fail, even if in negotiation among standard setters. Officials in North America have been unable to develop a North American Product Classification System that compliments NAICS—Canada uses a different system than the United States. Successful adoption of a CS by a community of practitioners—rather than an organization—likely rests on there being clear demand from users and an influential champion of the system such as a government agency or coalition.[s, 190, 191] There are also real costs to adopting a CS. These include:

1. *Developing* the CS
2. *Promoting* use of the CS
3. *Updating* of research structure, models, data sets and other tools to match the CS by:[192]
    a. *Implementation* of the CS onto specific data sets and tools (e.g., tagging data, defining ecological end products)[193]
    b. *Building and using the search systems* to share and retrieve the data and outputs[194]

There are sunken costs[t, 195] in development of ES-CS borne by the EEA, US EPA, SEEA, and select members of the natural capital accounting community. Because of stakeholder involvement in the development of these ES-CS, the costs of promotion are lower than they otherwise would be. In addition, ES-CS is already being promoted in key journals, international leadership institutions, and forums for discussion (e.g., ACES, ESP), though data and modeling has been a limited part of these conversations. The primary cost—professional judgement suggests more than 90 percent—lies in updating ongoing research, models, tools, datasets, and related ES infrastructure (see Table 2).

There will also be costs to updating the ES-CS over time. However, experience shows that benefits from updating CS generally outweigh the costs (e.g., recoding data tables to reflect data splits created by the new classification system).[196] Regardless of the length of time ES-CS versions developed today last, the cost of transition will be easier with an ES-CS in place than without because the majority of knowledge will already be organized.

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[s] The Department of Labor developed and promoted use of the North American Industrial Classification System in concert with their counterparts from Mexico and Canada.

[t] Best practices in cost-benefit analysis encourage removing sunken costs.

There are cultural, identity, and social issues—costs—related to the choices made in developing the CS. For example, the International Statistical Classification of Diseases and Related Health Problems (ICD) was written to strip away the cultural and contextual information related to diseases. Miscarriage is categorized differently from abortions because of the specific medical intervention, making either term readily understood across cultures.[197]

These issues exist with ES-CS, especially with regard to cultural ES.[198] For example, does the cultural FES of "viewing salmon," as defined by ES practitioners, truly approximate the values a member of Canada's first nations has when seeing a salmon?" While not explored in this paper, the flexibility offered in ES-CS should provide a means for accommodating these complex cultural FES. It may require more sophistication in ES analytics. Researchers may want to crosswalk the FES to the specific cultural context of the beneficiary and note the deconstructive nature of the exercise and how the discrete parts of this are to be used in the study and how they may be incorporated into decision making. Likewise, experts aggregating these values, perhaps into a regional natural capital account, need to consider the weaknesses inherent in the ES-CS. These weaknesses parallel those with CS used in economics, health, and other fields.

Moreover, CS tend to embody the biases of the groups that developed them.[199] Taxonomy can use monophyletic, paraphyletic, and polyphyletic means to classify organisms.[200] The EEA and US EPA's ES-CS may reflect institutionally unique perspectives. In turn, these ES-CS help shape practitioners' understanding of what an ES actually is and how their research is conducted.

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.[201] Updates to the ES-CS are supported because ES-CS were designed to allow for flexible use. It may also be beneficial to have more than one ES-CS to accommodate for multiple perspectives and reconcile them with "concept matching" methods.[202, 203, 204] It should also be noted that one of the largest differences among ES-CS is the level of specificity in defining ES consumption. Other differences are important, but the most dramatic difference is confined to this area.

Finally, in some instances, CS have encouraged specialists to communicate among themselves rather than with other specialists in a given field.[205] This appears to be more relevant to systems like the ICD, where specializations form around specific diseases. At present, discussions in the ES community are more difficult to enter because of the sparse use of ES-CS.[206]

Table 2 Costs and benefits of transitioning from an ad-hoc approach to ES-CS

Costs	Benefits
• Promotion through existing ES networks and institutions (ongoing) • Updating ongoing research, tools, and databases over time • Building search systems for ES-CS elements and FES (ongoing) • Managing cultural, identity, and bias issues (e.g., ISO process) • Updating the ES-CS over time	• Eighteen ES-CS benefits (see Figure 4) ⬇ • ES easier to teach (outside of ES practitioners)

Conclusions

The dictum from Delphi Group "Our ability to create information has substantially outpaced our ability to retrieve relevant information"[207] applies to ES. The field is still developing a vernacular for use among ecologists, economists, accountants, and decision makers. Biophysical models and ecological analyses are often not clearly linked to human use of the environment,[208] and the reuse of past knowledge in new studies is often limited. Economic models and valuation techniques are rarely well linked to ecological analysis.[209, 210] ES analyses often fail to directly inform the pragmatic choices that governments and businesses face.[211] As a result, consideration of the ecological functions that underpin the human benefits from the natural world is largely absent from many policy discussions.

ES-CS provide a language and structure to link ecological and economic frames of reference, advancing ES research and its application to decision making. With a unifying language and metrics, researchers will be more able to share research, develop interoperable datasets and tools, and improve institutional knowledge. Moreover, by making data, models, and tools using FAIR Data Principles and semantic annotation, the data discovery benefits will multiply in ways that are hard to predict. As a result, decision makers will have access to more comparable sets of data and the field at large will more quickly develop evidence linking public and private sector decision making to ecosystem change, and on through to human wellbeing.

These steps are encouraged:

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.*

   The sustainability of natural systems depends on beneficiaries understanding the utility of these natural systems.[212] Stakeholders need to understand the benefits derived from ecosystems from their own perspectives.[213] In addition, some stakeholders resist analysis that refers to the value of nature when it is divorced from its cultural context.[214]

   Stakeholder understanding of the benefits of nature can be linked or cross-walked to ES-CS.[215] 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 necessary for a healthy biotic system to enable that specific ecological end-product. The classification can also exist in a study's technical appendices, for use in stakeholder engagement or policy discussion, when appropriate.

2. *When not using an ES-CS, clearly define the ecosystem, ecological end product (or CICES equivalent), the use and users*.[216] This will help nurture the transition to ES-CS. It will facilitate more modular data development for use across ecology, economics, and policy making.

3. *Where practical, use an ES-CS.* Referencing an ES-CS is often a quick process that yields benefits to the researcher and to the broader community of practitioners.

4. *Promote the adoption of ES-CS* among colleagues and leadership organizations (e.g., UNSD SEEA, ESP, UNEP, World Bank, IUCN, scientific journals). Adoption by these groups will build momentum.

Regardless of the speed with which practitioners adopt ES-CS, the movement toward a common understanding of FES is underway. This movement has been instilling precision in the distinction among biodiversity, ecological processes, ecological end-products, and the benefits associated with ecosystem services. Ultimately, simplified and more unified classification systems and related tools for data management, modeling, and valuation will lead to a larger ES practitioner community. This broader field of practitioners will help ES analysis influence policies.

Appendix 1 Transitioning from ad-hoc groupings to ES-CS

The process of adopting an ES-CS may be gradual, allowing practitioners time to update their knowledge, tools, and systems. Moving too quickly risks leaving practitioners behind and may arguably jeopardize the transition to an ES-CS. However fraught with risk such predictions are, some foresight about the transition can help avoid the worst errors when adopting ES-CS.

A stepwise transition might involve three stages over a period of a few years each (Figure 6). The pace of change could be driven by institutional opportunities such as revenue growth or planned improvements to organizational systems and processes. Alternatively, individual ambition could speed progress. Organizations and groups of ES specialists (e.g., environmental accounting specialists, land managers, policy makers, life cycle assessment experts) are likely to proceed at different paces, while still informing one another.

Stage 1: Adopt ES-CS principles

A conscious effort is required to move from an ad-hoc approach to adopting ES-CS. This does not mean dropping work in progress or distancing oneself from previous endeavors. Rather, the deliberate recognition of the benefits from adopting an ES-CS should be acknowledged. Organizational policies, guidance documents, or operating procedures should reflect ES-CS principles. A national statistical office may add ES-CS principles to a technical document, a research institution may offer ES-CS principles as guidance to staff, and journals may call for contributions that are based on ES-CS principles.

Stage 2: Apply principles

With a commitment to the transition, practitioners can turn to application. Effectively, this means (1) properly labeling every ES with the ES-CS structure and (2) using the metrics associated with the elements in the ES-CS.

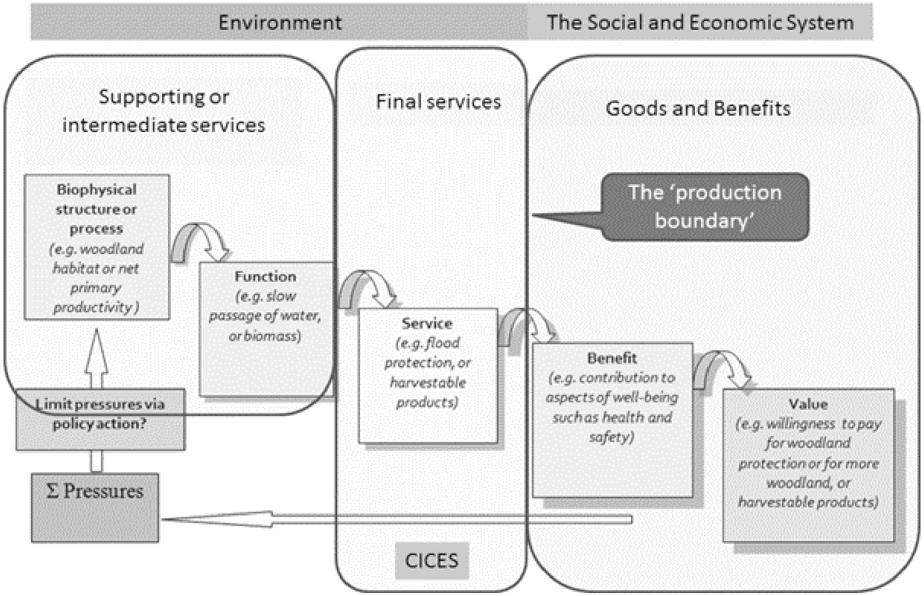

Figure 5 The cascade model [217]

ES defined by practitioners are already an FES, or if they are not an FES, they are likely an element of an FES within a hierarchical level (Tables 3, 4). Those not in a hierarchical level generally exist in the cascade model as biophysical structures, processes, functions, or benefits or values (Figure 5 above).

Table 3 Applying ad-hoc definitions of ES to CICES

	Ad-hoc ES	FES[*]	Element (s)	Element's hierarchal level (s)
1	Carbon sequestration	Regulation of chemical composition of atmosphere and oceans	Regulation & Maintenance (Biotic), Regulation of chemical conditions, atmospheric composition, regulation of chemical composition of atmosphere and oceans	Section, Division, Group, Class
2	Water	Water	Provisioning (Abiotic), Water	Section, Division
3	Municipal drinking water	Surface water used for drinking	Provisioning (Abiotic), Water, Surface water used for nutrition and materials	Section, Division, Group, Class
4	Coastal storm protection	Regulating the flows of water in our environment	Regulation & Maintenance (Abiotic), Regulations of physical conditions, regulation of extreme baseline and extreme events, hydrological cycle and water flow regulation for coastal protection	Section, Division, Group, Class
5	Recreation	Using the environment for sport and recreation	Cultural (Biotic), Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting, Physical and experiential interactions with natural environment, Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions, By type of living system or environmental setting	Section, Division, Group, Class, Class type
6	Mangrove habitat for fish breeding	-	-	None (intermediate service, physical structure)

[*] CICES defines FES contextually, allowing users to determine if an ES is an FES. In this table, the ES's description is the extent of context information available. As a result, some of the hierarchal levels associated with each element are not identified and ES number 6 is not an FES.

Table 4 Applying ad-hoc definitions of ES to NESCS

	Ad-hoc ES	FES[**]	Element (s)	Element's hierarchal level (s)
1	Carbon sequestration	-	-	NONE (Biophysical process)
2	Water	-	Water	Ecological end-product
3	Municipal drinking water	Water used by municipal water utility or households	River/water/water drinking, household use, light industrial use/water management industry or homeowners	Environment/Ecological end-product/Direct Use/Direct User
4	Coastal storm protection	Regulation from coastal storms from wetlands for homes	Wetland/storm regulation (combined end-products)/protection of property /homeowners	Environment/Ecological end-product/Direct Use/Direct User
5	Recreation	Forest habitat for recreational hiking	Forest/scapes (combined end-products including views, sounds, etc.)/recreation/hikers	Environment/Ecological end-product/Direct Use/Direct User
6	Mangrove habitat for fish breeding	-	Mangroves	Environment (ES also refers to the biophysical processes that enable breeding within the wetlands)

[**] NESCS defines FES as the point when an element of the environment enters the economy. An FES requires that the environment, end-product, use, and user be identified. Some of the ES in this table do not meet these requirements.

With the FES identified, metrics are needed. Teams dedicated to using ES-CS are rapidly developing lists of metrics associated with each element. Regardless of the state of these lists, ES-CS structures guide practitioners to identify better metrics (see functional benefit 3, Improved identification of elements, metrics, and analytical techniques).

Each group of ES specialists may want to consider this application of ES-CS principles separately. Each group may identify unique next steps that are explored below. Finally, properly considering the context is important for this application of ES-CS principles (Box 3).

Site management

Practitioners working at specific sites conducting mapping, modeling, valuation, or accounting can continue the transition with the proper identification of FES and their elements. This allows most of the benefits of ES-CS to be realized immediately, while allowing for more benefits to be gained as colleagues start the same transition, repurposing ES-CS based work.

Natural capital accounting

Leaders in natural capital or environmental accounting (public and private) may profit from starting with a "short list of ES."[218] This would build consensus among competing ES groupings and classification systems, focusing attention on the most commonly measured ES (whether these are the FES needed for accounting tables or not). If the ES-CS principles are applied when developing the short list, practitioners also realize many of the eighteen benefits (see Figure 4). Among these are reduced risk of double counting, improved identification of metrics, and quicker incorporation of new learning into the field. As practitioners add more FES to their site analysis, benefit transfers, natural capital accounts, etc.—effectively expanding the short list of ES—they can affirm that the EC-CS principles are not violated and that the magnitude of the eighteen benefits expands.

Accounting professionals could also identify "accounting exceptions" that do not technically match the definition of an FES, but warrant inclusion in natural capital accounts. Accountants may wish to include carbon sequestration—considered an ecological process and not an FES by some ES-CS—in their accounts, to help decision makers track the decarbonization of an economy. Crops—an economic commodity—or biodiversity—a concept often measured by the diversity of species that is somewhat akin to an ecosystem characteristic that reflects the health of ecological processes—may also be included in accounts to meet stakeholder interests. If these exceptions are clearly identified as not being FES, they should not be problematic. Failure to recognize them as such could lead to double counting or similar errors.

Databases, models and tools

Database, models, and tool developers can begin by tagging or otherwise marking existing data or tool outputs with appropriate FES, hierarchical levels, or elements (Tables 3 and 4). Semantic annotation of the data and models should allow FAIR type principles in model and data sharing. This will provide immediate support to researchers working with ES-CS. Should needs for ES-CS data and products be unclear, surveys of users and experts could reveal additional data products, tool outputs, etc. that could be developed.

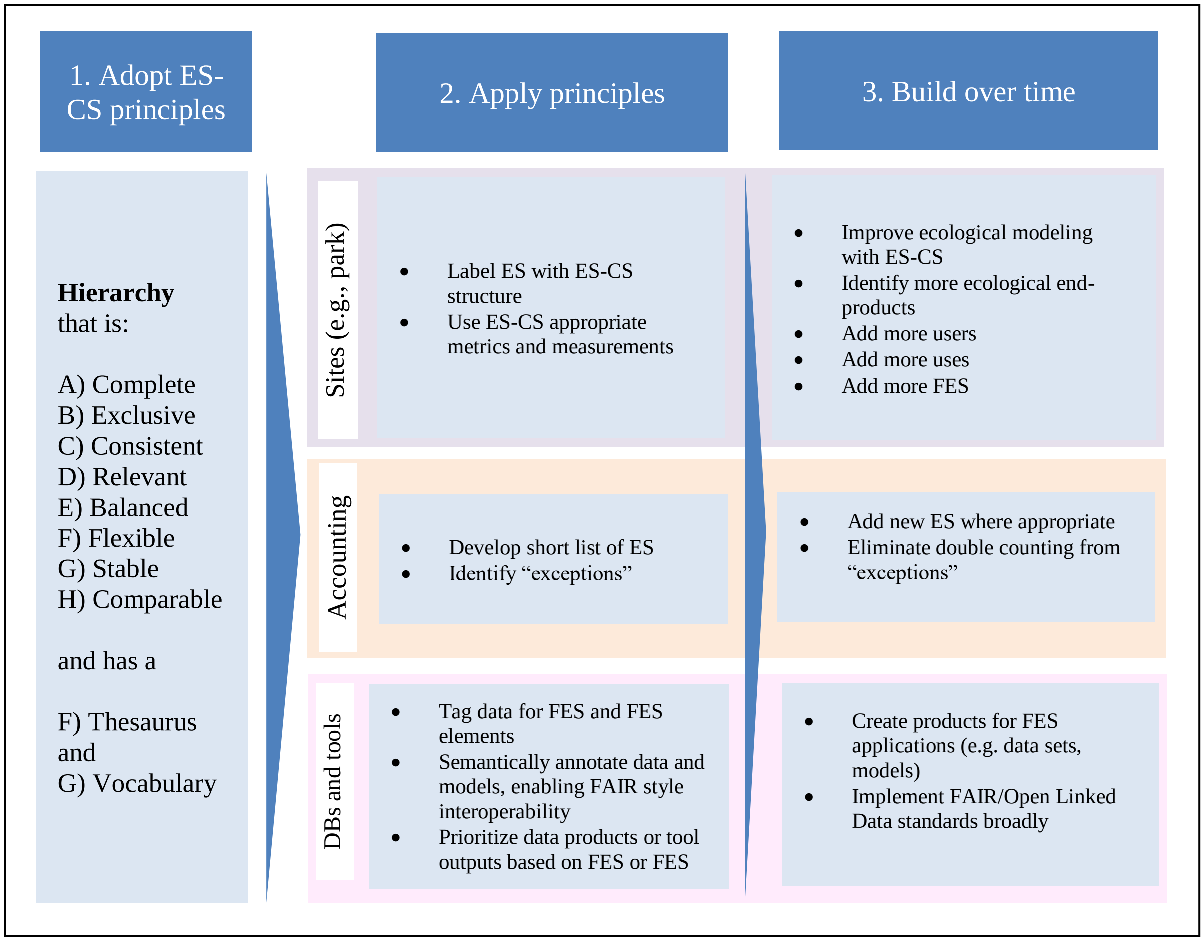

Figure 6 Stages of transition to ES-CS

Stage 3: Build over time

With the ES-CS in use, the gradual expansion of the eighteen benefits of ES-CS should be relatively intuitive. Site managers could begin transferring existing knowledge and research by adding more users, uses, and FES to their analysis, while using modeling, meta-analysis and benefit transfer to improve the accuracy of measurement. Natural capital accounts can also add new FES while refining methods to eliminate double accounting and related errors from "accounting exceptions" should any exist. Database, model, and tool developers should consider moving graph databases and adopting Linked Open Data (LOD) standards. These and other tools that support the vision of the semantic web would allow practitioners and computers to collaborate, share, reuse and combine data sets more fluidly, moving the field towards FAIR interoperability.[219] The standards even allow practitioners to reuse portions of data (e.g., FES element, sub-geography in a regional study) easily among different datasets.[220]

Appendix 2 Case example

Example 1: Commercial fishing versus SCUBA diving
The nonoverlapping nature of FES makes them amenable to trade off analyses involving competing uses and users. Leopard grouper (*Mycteroperca rosacea*) in the Gulf of California had been overfished, straining revenue from commercial fishing and SCUBA diving. Economic tradeoff analysis yielded conservation reserve options benefited the two uses (i.e. fishing, SCUBA) differently and that maximized the net benefits among users. This optimal reserve configuration would allow commercial fishing to co-occur with SCUBA diving.[221]

Example 2: Grupo Argos
The Colombian conglomerate, Grupo Argos, used the FEGS-CS in the environmental baseline assessment of its property on Barú Island near Cartagena. The assessment used FEGS as measurement points within the Corporate Ecosystem Services Review method.[222] It provided a basis for organizing all of the research, and yielded clear, compelling risks to Argos' development plans. The assessment lead, Ecoral S.A.S., found the method more effective than the MA-based ah-hoc alternatives.[223]

Example 3: Peru's Natural Capital Accounting
Conservation International has worked with Peru's Ministry of Environment to develop natural capital accounts for San Martin Peru, using FEGS-CS to identify the FES to be valued over time. In addition, they linked FES to the International Standard Industrial Classification System so that the values can be directly incorporated into national accounts. This should allow Peru to understand how ecological changes to the San Martin area will impact the broader economy.[224]

Appendix 3 Frequently Asked Questions

Drawing from experiences in other fields (e.g., health care, economic research, ecology) and the work of ES practitioners, this working paper describes 18 benefits of using ecosystem services classification systems (ES-CS). The responses offered to these frequently asked questions are illustrative and are underpinned by one or more of the18 benefits (benefits labeled a., b., etc. in Figure 4) detailed in the paper.

1. *Are ES-CS only for natural capital accounting?*
   ES-CS provide value to all ecosystem services practitioners. Knowledge workers can spend 30-40 percent of their time searching for information, with a 50 percent success rate. Environmental modelers can spend 50 percent of their time retrieving and preparing data. Use of ES-CS makes it easier to define and discover ecosystem services research and data. In addition, having ES-CS reduces the need to recreate these ES classification systems (all 18 benefits). UNSD SEEA discussion papers invite an analysis of the relative benefits of ES-CS beyond the accounting community and best practices in developing classification systems call for balance utility among all users.

2. *ES assessments typically analyze just a few ES; why do we need ES-CS that accommodate every possible ES?*
   With the capacity to address all potential ES, researchers can more easily build on existing knowledge, perhaps by analyzing new beneficiaries or new ES in a given geography (benefits e., f, and g.). A complete ES-CS also facilitates the interoperability of data (benefits k., l., m., and n.). Having ES-CS that meets the needs of all practitioners into the foreseeable future helps stabilize definitions of ES (benefits a., d., h., o., and r.).

3. *Are assessments that use ES-CS intended for economists and accountants, and analyses that use ad-hoc groupings intended for ecologists?*
   Use of ES-CS helps make connections among disciplines (benefit a.). Definitions offered by ES-CS guide studies of ecological conditions and functions to specific ecological end products that are directly used by humans. With the direct use and users identified, ecologists can better define the geographic and temporal scopes of their assessments, improve their selection of ecological indicators, and provide decision relevant studies and data for economists, accountants, and decision makers (benefits i., j.). This allows all disciplines to work independently, while creating shared value through the interoperability of research, data, and models (benefits l., m., n., o.).

4. *Can ES-CS improve valuations?*
   Through increased precision in identifying the elements of an FES (e.g., class, ecological end product), there will likely be improvements in the metrics, valuation techniques, and reduced risk of double counting. As a result, valuations should improve (benefits e., f., i., and j.). Over time, more benefits should be realized, as the speed and precision of data discovery advances along with overall data integration (benefits b., and n.).

5. *Do ES-CS address non market values?*
   While some accounting practices eschew use of non market values, by definition ES-CS strive to be complete, having the ability to incorporate all possible FES. The existence value of the Amazon, for example, is defined in CICES, FEGS-CS, NESCS, and NESCS Plus. ES-CS can even accommodate specific charismatic megafauna, endangered species, and beneficiaries across the globe (benefit a.) who value them. They do this in a way that should improve the precision of valuations and the interoperability of the data (benefits e., f., i., j., b., and n.).

6. *Should both intermediate ES and final ES be used to track the flow of ES through an economy?*
   ES-CS help structure and manage data on all the flows of ecological end products into formal and informal economies. This includes flows to primary industries, processors, governments, and households. Once they have entered the economy, these flows become economic flows can be tracked using standard economic tools (benefit a.). Some ES-CS accommodate for the inclusion of ecological characteristics and functions (an alternate term for intermediate ES) in accounting exercises by determining the percent of an economic activity that nature enables.

7. *Is it easy to incorporate any data about ES into an ES-CS based assessment?*
   Efforts to integrate and combine data collected at various spatial and temporal scales, using different definitions of ES, and a variety of metrics and valuation techniques, have proven challenging. Experiences with benefit transfers and interregional assessments are useful reference points. Fields that are using classification systems (e.g., economics, ecology, health) have demonstrated their efficacy over the alternative of avoiding raw data analyses (benefit n.).

8. *Because metrics for some FES are still being developed, should we defer the use of ES-CS?*
   ES-CS are relatively new, and many metrics for FES (i.e., production and demand) are in development. In the absence of an FES specific metric—biophysical measures with clear relevance to the beneficiary and of appropriate temporal and special attributes—proxies,

indicators, or indices that align with the rules and definitions of the ES-CS can be used (benefit i.).

9. *Can ES-CS be used for individual site based ES assessments, mapping, and valuation?*
   By correctly using ES-CS, practitioners are assured that every FES is unique and that the elements of FES are well defined (benefit a.). Well defined elements, in turn, guide practitioners to more relevant metrics and valuation techniques (benefits i. and j.). Over time this structure allows researchers to more readily build on existing research (benefits b., c. e., f., g., k., m., and n.). In addition, ES-CS provide a means for data integration from multiple studies (benefit n.) and support with stakeholder consultation and facilitation (benefit c.).

10. *Do ES-CS reflect the shift toward "nature's contributions to people" that is advocated by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and others?*
    ES-CS can be viewed as a component of the "nature's contribution to people" framework. NCP directly notes that the instrumental values that ES-CS help define are an important part of decision making. As NCP develops, methods for integrating these values into the local, cultural context should emerge (benefit a.).

11. *Most FES are produced by a mosaic of ecosystems, should we avoid naming the environment when defining an FES?*
    Naming the environment from which an ecological end product is used or appreciated is a component of natural capital accounting and guides ecological modeling, mapping, valuation, among other techniques.

    With regard to accounting, the SEEA EEA defines an environment as an "ecosystem asset," similar to a capital asset (e.g. factory, home). Different natural capital assets (e.g., grassland, estuary) produce different ecological end products. By employing some ES-CS, errors such as failure to define the environment are less likely (benefits i., j., k., and m.).

    Turning to other techniques, defining the environment helps practitioners identify complementary ecological end products, uses, and users to the ones they are focused on (benefits e. and g.) and therefore helps speeds identification of research needs (benefit f.).

12. *Which ES-CS offer the most benefits? Is one ES-CS most appropriate for a particular application?*

    UNSD SEEA is facilitating discussions on the relative advantages of different ES-CS for natural capital accounting. Participants stated their need for a clear understanding of the relative advantages of different ES-CS to other specialists (e.g., mapping, ecosystem modeling, valuation). Moreover, best practices in CS require a balance of utility among all users. It is also worth noting that other fields have benefited from having two or more CS, as every CS embodies unique perspectives of its developers.

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