Supplementary Material for: The 18 benefits of using an ecosystem services classification system

A. Case study on how using ES-CS can improve metrics

To highlight how the use of ES-CS can encourage consistent definition and measurement of FES, consider Liss 2013 (Liss et al., 2013). From 121 studies on the ES of pollination, Liss 2013 identified 5 definitions of the ES, 12 metrics [measures], and 62 unique combination of those measures. Comparing Liss 2013's definitions and measures to how NESCS Plus and CICES would organize them, illustrates the consistency that the use of ES-CS can engender. Liss 2013 also made 6 key recommendations that are all addressed by ES-CS. Moreover, Bartholomée and Lavorel 2019 conduct a similar assessment that also called for guidance on measures. If this guidance is provided without ES-CS, some 18 benefits will not be realized.

A.1 Defining pollination

An FES is the point where an ecological product transitions from becoming primarily ecological to becoming primarily economic (Boyd and Banzhaf, 2007). The transition point—termed ecological end-product in NESCS Plus or class type in CICES—for pollination occurs the moment pollen is transferred to a crop (white arrow in Figure 1A). This is impractical to measure, so CICES defines the class type "pollination by amount or pollinator" (Haines-Young and Potschin, 2018). NESCS Plus has "fauna" [the presence of pollinators] for the ecological end-product and "the… support of plant... cultivation" as the use (EPA, 2015).

About 30 percent of the studies in Liss 2013 had a similar definition—either "pollinator abundance" or "pollinator diversity" (yellow box Figure 1A). Nearly 40 percent of the studies used "crop yield" (orange box in Figure 1A) that is a benefit, or a result of pollination, which is not identified by ES-CS. The definitions "pollen transfer" and "pollinator visitation" represent 21 and 13 percent of the studies, respectively (white boxes in Figure 1A). They are accurate definitions of the FES, the flow of pollen from the ecosystem to the economic use, plant cultivation. The final definition in Liss 2013, "plant fitness," was found in approximately 10 percent of studies. It represents a range of measures from species abundance to seed production and is difficult to place in Figure 1A.

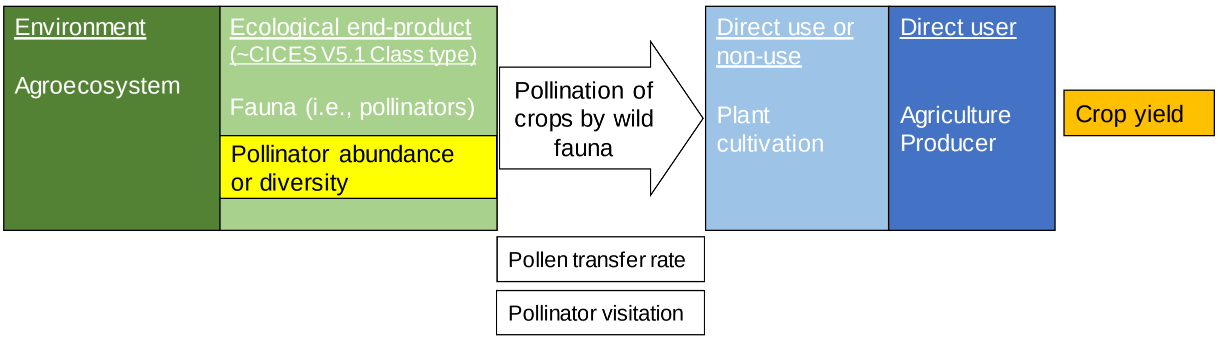

Figure 1A Matching definitions of pollination from Liss 2013 to the NESCS Plus structure

Using ES-CS helps standardize definitions, creating efficiencies in research design and data interoperability (Table 2, a, j, l, m, f, p, q, r). In addition, ES-CS help guide the selection of measures (Table 2, e, i). With a unified definition, more researchers would seek to measure the number and diversity of pollinators. Those unable to do so, perhaps because of data or time constraints, could relate available measures to ES-CS structure, easing the discovery, interpretation, and reuse of that research. For example, “crop yield” is an economic definition of pollination, measuring the results of pollination in combination with other factors affecting yield. A study may have attempted to control for other factors by comparing crop yields before and after the rehabilitation of natural areas near crops to attract native pollinators. Proper identification of this increased crop yield as a benefit, builds credibility in the study (Table 2, k), speeds the discovery of the data by other researchers (Table 2, b), and eases its reuse (Table 2, n). This same process carries to measures of all elements of an ES-CS (Table 1).

A.2 Measuring pollination

The “matching concept” (Czúcz et al., 2018) can be used to sort ES measures identified from the studies in Liss 2013 into groups based on ES-CS elements. For example, the measure “captures of pollinators in field” is sorted into the CICES element “class type.” Measures are used in the matching concept because of the inconsistency of ES definitions and the variable pairing of measures with ES definitions. The matching concept reduces the effects interpretations through its focus on measures (Czúcz et al., 2018). Because the specific measures from the individual studies used for Liss 2013 were not available, their component groups were used in this case study. Liss 2013 used a data entry form to sort measures from the 121 studies into component groups (Table 1A)

Table 1A Components groups and example measures adopted from Liss 2013

Component group	Example measure
Species population measure - the abundance of a specific species	Number of pollinators
Ecosystem process/function - measure of an ecosystem flux through time	Pollen deposition
	Nutrient cycling, primary production, water flow
	Pollinator visitation rate, pollen transfer rate
	Fruit mortality rate
Ecosystem property - a measure of a static ecosystem property at a single point in time	Tree height, number of flowers, root mass
Biodiversity - the number or variety of species present	Species richness, functional diversity, evenness
	Species richness of species requiring pollination
	Number of pollinators, number of species of pollinators
Land cover - the spatial extent of different land covers	Forest, field, road, river cover
Abiotic variable - environmental or physical conditions	Temperature or precipitation; slope, soil type, or elevation
Economic value - a monetary valuation of the service provided, can be estimated using a variety of methods	Crop value, property value of cottages, replacement cost
Non-economic value - non-monetary valuation of the service provided	Human preference, intrinsic value
Human use - measurement of the human use or demand (actual or potential) on the ecosystem service	Amount of water used, number of park visitors
Human input - measurement of human inputs that have taken place or that need to take place for society to receive the benefits of the service	Cost of dam construction, number of marinas
Human decision/policy - measurement of human decisions or policies that affect provision of the service	Farm grants for native habitat restoration

The component groups are sufficiently distinct from one another to use the matching concept to link them to ES-CS elements (Tables 2A and 3A).

Some of the component groups, however, are not needed for identifying an FES. For example, a "human input" could change, for example, the extent and condition of pollinator nesting habitat. Likewise, an example of a "human decision/policy" could be to encourage planting of pollinator forage species in natural areas. Some component groups and their measures are worth linking to concepts and guidance documents that support ES-CS. For CICES this is the cascade model (Haines-Young and Potschin, 2018). NESCS Plus relies on definitions of "ecosystem characteristics and processes"—the range of functions of an ecosystem (United Nations, 2017)—and "benefits"—the social and economic result of an FES.

In addition, the linking is not always from one component group to one ES-CS element. For example, measures for the "biodiversity" and "species abundance" component groups link to either ecosystem characteristics and processes or the NESCS Plus element "ecological end-products" (Table 2A). "Ecosystem properties" can measure ecosystem characteristics and processes or the benefits from pollination (Table 2A). It is worth nothing that while ecosystem characteristics and processes are not used in identifying and naming an FES, they are often critical as proxy indicators, in an index, or in an ecological model.

The remaining component groups link to NESCS Plus elements (Table 2A). For example, the group "ecosystem function" is the flow of the FES itself, in some cases, and also measures akin with crop yield that are linked to benefits. Likewise, the component groups "ecosystem goods" and "human uses" are benefits. Measures in the component groups "land use/land cover" and "abiotic measures" are ecosystem conditions and processes. Finally, "valuation measures" are equivalent with benefits.

Table 2A Matching Liss 2013 component groups and measures with the NESCS Plus structure

		NESCS Plus structure					
Component group	**Ecosystem characteristics and processes**	**Environment** (Agroecosystems)	**Ecological end-product** (Pollinators)	Pollen transfer to crop	**Direct use or non-use** (Plant cultivation)	**Direct user** (Agricultural producer)	**Benefit**
Biodiversity	Species richness of species requiring pollination (non-crop only)		Pollinator species richness				
Species abundance	Beehive size (if naturally occurring)[1]		Pollinator abundance				
Ecosystem properties	Fruit or seed set (non-crops), seed or fruit mass (non-crops), flower corolla length, flower density, pollinator foraging and nesting resources						Fruit or seed set (crops), seed or fruit mass (crops)
Ecosystem functions				Pollinator visitation rate, pollen transfer rate			Fruit mortality rate
Ecosystem goods							Crop yield
Human uses	~~Number of managed beehives~~[2]						Amount of crop consumed
Land use/land cover	Isolation of crops from natural habitat, area of pollinator foraging and nesting habitat, Area of pollinated crop						
Abiotic measures	Sandy soil for pollinator nesting, elevation						
Valuation measures							Actual/perceived price/value of crops

The CICES matching is similar (Table 3A), but relies the external framework of the cascade model. The cascade model addresses ecosystem conditions and process with the categories “biophysical structures or processes” and “function” and addresses benefits with the category “benefits” and “values” (Haines-Young and Potschin, 2018).

[1] Human managed beehives are human inputs, they are neither part of the ecosystem nor the NESCS Plus structure.
[2] Managed beehives are dependent on human intervention and therefore not part of the ecosystem.

Table 3A Matching Liss 2013 component groups with the CICES and cascade model structures

	Cascade model and CICES structures				
Component group	**Biophysical structure or process**	**Function**	**Class type** (from CICES)	**Benefit**	**Value**
Biodiversity	Species richness of species requiring pollination (crops and non-crops)		Pollinator species richness,		
Species abundance	Beehive size (if naturally occurring)[3]		Pollinator abundance, total number of pollinators visiting flowers		
Ecosystem properties	Fruit or seed set (non-crops), seed or fruit mass (non-crops), flower corolla length, flower density, pollinator foraging and nesting resources			Fruit or seed set (crops), seed or fruit mass (crops)	
Ecosystem functions			Pollinator visitation rate, pollen transfer rate[4]	Fruit mortality rate	
Ecosystem goods				Crop yield	
Human uses	~~Number of managed beehives~~[5]			Amount of crop consumed	
Land use/land cover	Area of pollinator foraging and nesting habitat, area of pollinated crop, isolation of fields from natural habitat				
Abiotic measures	Sandy soil for pollinator nesting, elevation				
Valuation measures					Actual/perceived price/value of crops

[3] Human managed beehives are human inputs, neither part of the ecosystem nor the CICES and cascade model structures.
[4] These flows of FES may rely on measures from of both the supply and use of pollination.
[5] Managed beehives are dependent on human intervention and therefore not part of the ecosystem.

A.3 Discussion and conclusion

Assuming some error in translating from measures in individual studies to component groups in Liss 2013 and then to ES-CS elements, about 50 percent of measures in Liss 2013 are ecological end-products or class types. Some 20 to 30 percent measure the benefits from pollination. Regardless, all of these measures can serve as direct or indirect measure of the FES, with varying degrees of accuracy. Further, they can be part of an index or model of the FES. Moreover, accurate tagging or coding of these measures with ES-CS elements, can improve data interoperability and the accuracy of models (Table 2, n), especially with use overtime.

Finally, Liss 2013 makes six recommendations to address inconsistency of measures. They are all addressed by ES-CS (Table 4A).

Table 4A Addressing recommendations from Liss 2013

	Recommendation from Liss 2013	ES-CS address
1	Clearly define or identify the ES	Requires users to select element terms or numeric codes
2	Use precise, consistent ES definitions that specifically match the effort's context	ES-CS have exact definitions for FES and can accommodate a theoretically unlimited number of FES without overlapping definitions
3	Choose best metrics to measure ES	ES-CS mutually exclusive elements suggest metrics
4	Develop tools to guide metric selection for individual studies	CICES has published a tool, NESCS Plus is developing guidance
5	Use caution when comparing ES within and among studies	Numeric codes of ES-CS warn practitioners where poor comparison is likely
6	Ensure decision making is based on relevant ES measures	ES-CS facilitate this by forcing researchers to be more specific in naming elements, terms, and codes

This case study demonstrates that practitioners have existing, low cost ways to address critical problems in defining ES and in selecting metrics by using ES-CS.

In contrast, a more recent survey of pollination measures seeks to address their diversity by focusing directly on ES measures themselves (Bartholomée and Lavorel, 2019). Even with broad use of ES-CS, additional guidance on the selection of measures and survey methods is necessary. But in the absence of ES-CS, more unified measures themselves will not deliver all 18 benefits. For example, the definitions of elements will remain unclear, as will relationships among them (Table 2, a, b, c, d, e, f, g, h). The knowledge transfer and management benefits are more likely to be confined to specialists such as pollination, freshwater delivery, and coral reef tourism experts (Table 2, l, m, n, o, p, q, r). As a result, creating mutually exclusive definitions to for all FES is likely to take more time in the absence of ES-CS.

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