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A framework towards a composite indicator for urban ecosystem services

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ABSTRACT

This article describes a composite indicator for ecosystem services. This composite is composed of several sub-indices, each representing either land use types or ecosystem services. While the overall composite indicates a general overview of the performance of a system in terms of ecosystem services provision, the sub-indices provide sources of variation. Taking into consideration potential trade-offs between making the framework complex and keeping it simple, the composite was developed on two levels. The first level, a simpler one, requires few indicators and therefore needs less data as inputs. The second level, in contrast, is more complex requiring more indicators, involving more detailed measurements, and therefore can be applied with more confidence.

1. Introduction

Ecosystem services (ES) is a multi-dimensional concept that combines a large number of ecological, biophysical and social values (MEA, 2005). There is an increasing demand for a comprehensive composite indicator for measuring and evaluating ES, since the high degree of information needed for traditional measurements are often not available and collection of biophysical and economic data is often resource intensive. In view of this growing demand, a new composite indicator – Ecosystem Services Composite (ESC) – is proposed and described in this article.

The use of indicators for environmental monitoring is not new and they have been successfully utilized for environmental policy and planning for some time (de Sherbinin et al., 2013). A composite indicator (often called an "index") is formed by combining together a few or many individual indicators. It is then used to understand the dynamics of a system in a single numerical value. Among numerous successful composite indicators are Environmental Performance Index (Hsu et al., 2013), Ocean Health Index (Halpern et al., 2012) and Human Development Index (UNDP, 2014), each being applied at different scales targeting different sectors. Whatever their scale or the sector of application, their underlying structure, methodology and theoretical considerations have certain similarities.

The aim of this article is to present a newly developed ecosystem services composite, to describe its various components and to show an application using a prototype. The article begins with a discussion on the need for a composite of ES and its potential applications in research and policy making. Next, we provide a broad conceptual framework followed with a description of five major methodological steps. We then present a case study of a Canadian city where this tool is being tested. Finally, we discuss some of the pros and cons as well as on the opportunities for improvements in a more complex situation.

2. Why a composite indicator for ecosystem services?

One of the outstanding research questions in ecology and ecological economics today is the relationship between ecosystem structure, processes and ecosystem services (Daily et al., 2009; Kandziora et al., 2013; Mitchell et al., 2013). How can the provision of ES be linked to biodiversity and ecosystem dynamics? How a marginal change in forest area may change ES and how these marginal values are to be quantified in a meaningful way?

There is a large body of literature on economic valuation from across the continents (TEEB, 2010). While economic value generates useful information regarding the extent and magnitude of many ES, it has limitations in 'aggregation' of a bundle of services. This is partly because of the issues related to valuation of cultural services (e.g. recreational, religious and educational services), since

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they have no market in conventional sense (Daniel et al., 2012). There are arguments that cultural ES are non-material in nature, therefore cannot be aggregated or traded-off with material services. Contrary to this, Satz et al. (2013) argue that despite the incommensurability between material and non-material services, it may be possible to compare them and even make trade-offs. Such incommensurability can be dissolved either by expressing them in the same units (e.g. monetary value) or transforming them into dimensionless values. A composite indicator works to resolve such issues arising from multiple dimensions of different variables (de Sherbinin et al., 2013; Nardo et al., 2005).

Other potential applications of the composite can be achieved by integrating it into spatial analyses. Although widely used in spatial modelling, land use and land cover (LULC) is probably a poor proxy of ES supply (Eigenbrod et al., 2010). The composite can overcome this shortcoming. Mapping ESC values can reveal important information regarding supply and use of ES. Such spatially explicit information may also help mainstream ES framework into long-term planning and policy processes (Maes et al., 2012). These mapping exercises will also lead to answering outstanding research questions such as: biodiversity-ES spatial congruence (Anderson et al., 2009), trade-offs (Mace et al., 2012) and demand-supply gap analysis (Burkhard et al., 2012).

3. Conceptual framework

The multivariate concept of ES is often explained in terms of ecological, physical, social and economic indicators. These indicators individually do not convey meaningful information until they are analyzed altogether. The idea behind the composite is to combine those multi-dimensional concepts and variables into a single value. Mathematically it can be represented as:

$$\sum_{i=1}^{n} w_i = 1; \quad 0 \le w_i \le 1$$

where X_i, normalized variables, w_i, weight of X_i, and N, number of sub-indices

The theoretical foundation of the composite is similar to that of existing environmental indices such as City Biodiversity Index (Chan et al., 2014). However, like any other indices the ESC has strengths in some areas and weaknesses in others; Table 1 lists some of them.

Taking into consideration the potential trade-offs between making the framework complex and keeping it simple, the ESC was developed at 2 levels. Level-1 framework is simpler, requires few indicators, and therefore needs less data as inputs. Level-2, on the other hand, is a more complex one, needs more indicators, involves more measurements, and therefore can be applied in real world with more confidence. Examples of level-1 indicators for air quality regulation in an urban setting are area of forest, street density and vehicle load; whereas, level-2 indicators include leaf area index (LAI), weather data, pollutant particle concentration and so on (Table 2).

The ESC is composed of several sub-indices, each representing either a land use type or an ecosystem service. While the composite provides an indication of the overall performance of the system, the sub-indices are aimed at a more detailed understanding of the sources of variation within the ESC. Ideally a set of indicators would have to be selected for each ecosystem services right at the beginning. Those indicators will vary depending on land cover characteristics, therefore, sub-indices are to be constructed for each land cover classes where the ecosystem services originate. Those sub-indices are finally aggregated to arrive at a final index to represent the whole political or policy boundary (Fig. 1).

Table 1
A SWOT analysis of the proposed ESC.

Strengths	Weaknesses	Opportunities	Threats
A wide range of environmental indicators are available which could be used within ES framework	The underlying relationship between ecosystem structure-processes-services is poorly understood	Develop composite for various ecosystems as well as for various spatial scales	Political misuse through inputs manipulation to support desired policy
Reduces data dimensionality and facilitate communication between science and policy	There is an inherent weakness in construction of a composite (e.g. subjectivity in weighting)	Apply in local, regional and national policy decisions	Can be challenged by users for subjectivity
	Indicators can over-simplify the complex interactions in the system	Integration of different models (e.g. i-Tree) for indicator development	

Table 2
A list of indicators needed for construction of ESC.

Ecosystem services	Indicator types	
	Direct indicators (Level-2)	Proxy indicators (Level-1)
Air quality	SO_X, NO_X concentration in the air	Area of mitigation source (e.g. forest)
	Number of people exposed	Street density
		Vehicle loads
Biodiversity conservation	Plant diversity	Area of habitats
	Bird diversity	Threats density (e.g. roads, infrastructure)
	Diversity of endangered/rare plants and animals	Fragmentation
	Proportion of native and invasive species	Connectivity measures
		Protection status
Climate regulation	Carbon sequestration rates	Land use classes
	Air temperature	Carbon sequestration capacity
Storm protection	Historical storm data	Area of tree cover
	Damage data	Vegetation density

4. Construction of the composite

There are five major steps involved in construction of the composite. We briefly discuss them below, but more details can be found in the cited literature.

4.1. Scoping

The structure of the ESC depends largely on the study objectives, its geographical focus as well as on the ES of interest. Therefore, the initial steps involve delineating the study or policy area, mapping landscape composition and configuration and identify the ES which are relevant and important. The next decision concerns the level of analyses to be performed given the resource constraint. The number of sub-indices also has to be determined at