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Developing integrated ecosystem indices

David K. Loomis[a,*], Peter B. Ortner[b], Christopher R. Kelble[c], Shona K. Paterson[a]

[a] Institute for Coastal Science and Policy, 250 Flanagan Building, East Carolina University, Greenville, NC 27858-4353, USA
[b] Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149, USA
[c] Atlantic Oceanographic & Meteorological Laboratory, 4301 Rickenbacker Causeway, Miami, FL 33149, USA

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ABSTRACT

Enabling ecosystem-based management requires, among other things, reaching a scientifically based consensus with respect to the key characteristics of a sustainable ecosystem capable of supporting those levels of key ecosystem services desired by society. To determine and convey whether an ecosystem is in fact approaching this goal implies developing indicators that capture the status of both the natural and societal aspects of the system. That said, developing consistent and useful indicators for both societal and natural system aspects of the ecosystem requires both resolving disparate perspectives and inconsistent terminology between human dimensions and natural system scientists and keeping the number of indicators manageably few, without oversimplifying a highly complex ecosystem. To accomplish this we employed a "recursive relationship" approach that defined (and redefined) variables, indicators, and indices along a sliding hierarchy from measurable parameters to highly aggregated indices. To illustrate this approach it is applied herein to both a human dimensions index (recreational quality), and a natural sciences index (water column). This "recursive relationship" approach facilitated development of a parsimonious set of high-level indices that together constitute an ecosystem report card integrating natural system status and related societal dimensions from an ecosystem services perspective, while maintaining all of the information at lower levels necessary to inform specific management decisions.

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1. Introduction

The goal of the MARine and EStuarine goal Setting for south Florida (MARES) project was "to reach a science-based consensus about the defining characteristics and fundamental regulating processes of a south Florida coastal marine ecosystem that is both sustainable and capable of providing the diverse ecosystem services upon which our society depends. To achieve this goal, it was necessary to consider regional, social, political, cultural, economic, and public health factors, in both a research and management context, along with ecological variables." (Kelble et al., 2013). The MARES process built consensus at workshops consisting of scientists, stakeholders, and resource managers. These workshops developed conceptual diagrams and integrated conceptual models using the EBM-DPSER (ecosystem based management-drivers, pressures, state, ecosystem services, response) framework to capture our consensus understanding of the ecosystem, including humans (Kelble et al., 2013, Fletcher et al., 2013). The EBM-DPSER is modified from the DPSIR (drivers, pressures, state, impacts, responses) framework which has proven useful for identifying focal ecosystem components and thus ecosystem "indicators" (Bowen and Riley, 2003; Levin et al., 2008, 2009); however, the EBM-DPSER model is more consistent with an ecosystem services approach that requires "indicators" not only for natural ecosystem status but also societal characteristics and the services derived from the ecosystem (Müller and Burkhard, 2012). The former may be biological, chemical or physical characteristics. The latter may be either economic or non-economic in character but in either case are the intellectual domain not of natural system scientists but of human dimensions scientists. These limitations of the DPSIR model are also addressed in the development of the DPSWR model that replaces impacts with welfare to accomplish similar goals to EBM-DPSER (Cooper, 2013). To develop consistent and useful sets of indicators of both human and natural dimensions with respect to a complex ecosystem that is sustainable and continues to provide desirable levels of valued ecosystem services, practitioners must overcome two inherent difficulties: (1) keeping the number of indicators manageable and (2) resolving differences in perspectives and terminology between human dimensions and natural system scientists.

* Corresponding author. Tel.: +1 252 737 4263.
E-mail addresses: loomisd@ecu.edu (D.K. Loomis), portner@rsmas.miami.edu (P.B. Ortner), chris.kelble@noaa.gov (C.R. Kelble).

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To comprehensively characterize this integrated ecosystem implies a prodigious number of indicators. However, to be useful a proposed set of indicators must efficiently communicate the ecosystem status relative to societal objectives and too large of a set makes it difficult to effectively communicate both with the public and with natural resource managers (Center, 2008; Doren et al., 2009). Thus, indicator assessments that seek to encompass the holistic, integrated natural and human ecosystem must develop methods yielding a parsimonious set of indicators that communicate the comprehensive status of the ecosystem.

MARES participants encountered another inherent difficulty regarding inconsistent terminology when human dimensions and natural scientists began trying to solve the aforementioned paradox. Human dimensions scientists and natural system scientists use much the same vocabulary ("indicators", "attributes"; "variables"; "indices" etc.) but often apply these terms in divergent manners. Given the growing emphasis upon ecosystem services, the necessity to seamlessly integrate these different disciplines and perspectives has been the focus of a number of recent publications (c.f., Ringold et al., 2013; Reyers et al., 2013; Knight et al., 2013), but none of these authors directly addresses the problems posed herein. In the paper that follows we first discuss how the two very different scientific communities use the same terminology to address the indicator "problem". Differences in approach become apparent. We then suggest the approach MARES adopted toward enabling a comprehensive integrated ecosystem assessment with a parsimonious set of integrated and consistent ecosystem "indicators". This framework, which we call a "recursive relationship" (by which we mean an iterative and hierarchical relationship), is usable by both human dimensions and natural systems scientists and allowed MARES to organize their contributions into a logically consistent framework.

2. The human dimensions science perspective

The human dimensions science of coastal resource management refers to the investigation of human thought and action toward natural environments (Manfredo et al., 1996). As Vaske (2008) points out, the notion of human dimensions in resource management as described above is not that new. However, the notion of human dimensions science is new to many, including our colleagues in the natural and physical sciences. This newness and unfamiliarity can create unnecessary confusion between the natural and human dimension science communities. Although the principles derived from the scientific method are the same for us all, we have in some cases developed different approaches and terminology while essentially doing the same thing. As noted earlier, one challenge in developing consistent integrated ecosystem indices is the use of too many indicators, and another is the inconsistent terms or vocabulary used by different disciplines. A basic understanding of human dimension science terms is provided here as a step toward developing a common vocabulary that can be applied in the "recursive relationship", as is a brief discussion of the use of indices in the human dimension sciences as a way of aggregating a larger number of measures down into a smaller set of indices. It should also be pointed out that the concepts referred to below, such as attitudes, norms, satisfaction, conflict, and crowding, have been heavily researched and have strong theoretical foundations. They are not opinions, philosophy, personal values or just subjective perspectives. They are the product of decades, or more, of the application of the scientific method and theory development. There are numerous examples of how the scientific method has been applied to specific theories in order to produce valid quantitative data and allow the use of accepted and rigorous statistical tools, some of which are described in texts such as Eagly and Chaiken (1993), Ewert (1996), Fishbein and Ajzen (1975), Manning et al. (2002), Vaske and Donnelly (2002), and Vaske (2008).

Much of what is studied through the human dimensions sciences is abstract, in that the subject or issue of interest does not physically exist in the usual sense (Babbie, 2013). The human dimension sciences in general focus on abstract concepts that typically can have multiple and ambiguous meanings; concepts such as attitudes, preferences, norms, conflict, satisfaction, crowding, power, and fairness are common (Babbie, 2013). While we individually might have some notion of what each of these concepts mean, it is doubtful that we would all agree on the meaning of any of them, at least initially. For example, we all have some sense of what is meant by the ecosystem service of recreation quality. We might think of, or have heard others say, things such as I'm happy, it isn't crowded, I'm having a good time, I spent time with my family, or I caught a lot of fish. These would all seem to speak to this thing we each call recreation quality. But it is a fuzzy thing, and our individual "definitions" of this fuzzy thing can differ greatly. As a result, this splintered notion/mental image does not have much tangible use or value to managers or stakeholders.

To advance these fuzzy notions toward a more precise and agreed upon idea, human dimension scientists move through a process known as conceptualization. The numerous individual and perhaps ill-defined notions are made more specific, with definitions articulated, until the agreed upon result is a "concept" (Babbie, 2013). At that point there is agreement within a scientific community on what is meant by a term (a concept), such as recreation quality. However, this does not mean that measuring this concept is straightforward. Concepts are very complex, requiring numerous measures which in themselves can be abstract. The measures of interest we often refer to as "indicators". We mean by this an observation that we wish to consider as a reflection of a variable we wish to study. As stated they would not yet be a variable and thus not yet directly measurable. Using the concept of a quality experience for saltwater recreational anglers, we would need to include measures of catch-related motives, non-catch motives, expectations, baselines, perceived conflict, crowding, and still others. An indicator of a catch related motive would be number of fish caught, or size of fish caught. It becomes apparent that developing and communicating a *complete* (ideographic) understanding of a quality angler experience would be extremely difficult, if not impossible. The list of indicators would be long, and could seem disorganized or even random to many. Conversely, this complexity renders single measures ineffective when seeking to understand the complex and dynamic nature of such concepts. However, having a comprehensive and extensive list of indicators is equally unworkable. Both extremes (single indicators, or complete inclusion of all indicators) are less than desirable. What must be sought is a compromise that focuses researchers on including only those indicators that provide sufficient information about a concept or phenomenon (i.e., multiple measures of high explanatory value), and are in a logical and organized fashion. The goal should be not too few indicators, but not too many either.

To avoid a seemingly random list of indicators, human dimension scientists will group individual indicators into meaningful groupings (Babbie, 2013). These groupings are called dimensions. A dimension can be defined as a specifiable aspect of a concept. For example, catch motives (or their indicators) would be one dimension of a quality recreational angling experience, and non-catch motives would be a second dimension of a quality recreational angling experience. Other dimensions would include expectations, baseline, conflict, etc. Dimensions are a way of making organized sense of larger numbers of indicators of a concept. The last step is to operationalize indicators into variables and their attributes.

To the human dimension scientist, a variable is a logical set of attributes that can be measured as stated, with the attribute being a characteristic or quality of that variable (Babbie, 2013). For example, "How important is it to you to catch a large fish on your