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An evolving role for ecological indicators: From documenting ecological conditions to monitoring drivers and policy responses

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ABSTRACT

Monitoring the health of ecosystems is imperative to achieve sustainability. In this, ecological indicators have a crucial and evolving role to play. Although indicators are vital to monitoring the state and trends of ecosystems and the consequences of anthropogenic pressures, they may not lead to necessary action unless they are coupled with identification and monitoring of drivers. This will provide a basis for evaluating the effectiveness of policy responses, thus providing information that is actionable by policy makers and the public. We argue that expanding the role of indicators will render them far more effective as a resource for combating ecosystem degradation. Using the Baltic Sea as an example we analyse the nature of this challenge and provide concrete solutions to problems hindering the effectiveness of ecological indicator use in restoring health to large-scale ecosystems.

1. Introduction

Over the past half century, it has become increasingly evident that not only are the earth's ecosystems "human dominated" (Vitousek et al., 1997), but that human activities have led to marked degradation. (Rapport and Whitford, 1999; Rapport, 2007a,b; MEa, 2005; UNEP, 2007; CBD, 2010). In documenting the changes, the role of ecological indicators has evolved considerably from a primary focus on environmental quality (air and water) to a more holistic description of ecosystem characteristics. These include indictors of biotic community structure, primary productivity, biological diversity, size spectra, and other measures that track changes in the organization, vitality, and resilience of ecosystems. Ecological indicators thus have provided the big picture of the cumulative and synergistic impacts of a variety of anthropogenic stresses, and have served to raise awareness of the consequences of ecosystem degradation for sustaining human well-being (Niemi and McDonald, 2004; Rapport et al., 1985, 1998; Rapport, 1992; Rapport and Singh, 2006).

However, one of the paradoxes of our time is that, while we are getting better at assessing the state of ecosystems, the health of ecosystems continues to plummet. At the global scale, the rate of biodiversity loss is estimated to be at least several orders of magnitude above historic (pre-industrial) levels (Pimm et al., 1995; Pereira et al., 2010). Much of this is due to the loss of vital habitats that support biological diversity. Global forest cover has declined at least 40% over the past several centuries. Losses in the world's wetlands are likely to have been even greater, perhaps as much as 50% over the same period. Overall, more than half of the world's major watersheds has been compromised by human activity (Foley et al., 2005).

Ecological indicators ought to play a key role here. We already have ample and convincing evidence pointing to anthropogenic stress as the root cause of ecosystem and biosphere degradation. Further, we have long identified the main categories of pressures that human activities generate (Rapport and Friend, 1979): e.g., release of waste residuals (pollutants, ranging from toxic substances to excess nutrients), physical restructuring of the environment (such as dams, roads, clearing of forests for expansion of agriculture and draining of wetlands.), introduction of invasive species (whether accidentally, or by intent), and over-harvesting of renewable resources (both biotic and abiotic). To this we can add the overarching pressures of climate warming as a result of the build-up of greenhouse gases as well as human-enhanced natural disasters.

Thus, one might well argue that there is sufficient knowledge at the local, regional, and global scales to identify the nature of the major pressures on the earth's ecosystems. Further, in a great many cases, there is an abundance of information relating anthropogenic stress to ecological consequences, thereby pointing the way to actions that need to be taken in order to prevent further degradation. But the reality is that actions to combat degradation are generally insufficient or lacking altogether. Partly, this conundrum arises owing to the prevailing political stance, whereby short

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term economic growth is consistently favored over environmental protection, regardless of the ultimate economic consequences of environmental degradation. But perhaps, too, ecological indicators have failed to be as persuasive as they might be. There has in fact been too much emphasis on tracking the state of the environment along with the general pressures on ecosystems, and far less attention given to the specific types of economic activities (drivers) that generate the pressures, and even less attention to the effectiveness of policies in confronting the drivers.

2. Functions of ecological indicators

One may distinguish between three general functions of ecological indicators: conceptual, legitimizing, and instrumental (Amara et al., 2004; Beyer, 1997). "Conceptual" refers to information that strengthens the cognitive basis for decisions; "legitimizing" refers to information used in arguments without actually influencing relevant decisions; and "instrumental" refers to information that might directly impact decisions. This begs the question, when proposing ecological indicators: what will they contribute to policy development? Are they primarily for the purpose of increasing knowledge of ecological processes ("conceptual")? Are they pedagogical devices for environmental education, for example in state of environment reporting ("legitimizing")? Or are they designed as policy-relevant information in order to head off further damage to ecosystems ("instrumental")? We argue that, thus far, ecological indicator development has largely focused the conceptual and legitimizing aspects, and far less on instrumental aspects. Clearly, the law of diminishing returns suggests that adding more indicators pertaining to the conceptual and legitimizing aspects (e.g. another indicator for tracking biodiversity) offers less value added than focusing on indicators that can be used instrumentally, i.e., those that lead to decisions directly affecting the state of the environment (Rosenström, 2009). This is not to suggest that one could or should do away with ecological indicators that enhance our understanding of relevant ecological processes, but rather that these classes of indicators ought to be complemented by an equally strong set of measures that are designed to be policy relevant. We illustrate this challenge by reviewing the role of ecological indicators in the concerted effort made by Baltic coastal states, under the egis of the Helsinki Commission (HELCOM), to restore health to the Baltic Sea.

3. The Baltic Sea as patient – case history

Over the past half century, as the intensity of human activity in the basin greatly increased, it has become apparent that the health of the Baltic Sea has significantly deteriorated. Nutrients from sewage and from intensive agriculture have led to chronic algal blooms as well as widespread oxygen depletion in bottom waters and pockets of hypoxia in coastal waters (Conley et al., 2009). Baltic Commercial fisheries, particularly the Baltic cod and salmon, have declined considerably owing to both overharvesting and habitat degradation, which have adversely impacted the capacity for reproduction. Toxic loadings to the Baltic Sea, particularly from chemical agriculture, industry and shipping, have increased, impairing the health of marine mammals and avian fauna. Overall the Baltic Sea ranks as one of the most polluted of the world's seas, and among the most ecologically dysfunctional (Rapport, 1989a; Rapport and Whitford, 1999).

Recognizing the need to stem the degradation of the Baltic Sea, the Convention on the Protection of the Marine Environment of the Baltic Sea Area came into force in 1974.[1] All nine Baltic states are signatories to the Convention. The Helsinki Commission (HELCOM) was established as the governing body, and regularly publishes assessments and overviews on the state of the Baltic Sea (see www.helcom.fi). Its first retrospective holistic assessment of the Baltic appeared in 2010 under the title: "Ecosystem Health of the Baltic Sea" (HELCOM, 2010). The foundations for this landmark document are two-fold: the Pressure-State-Response (PSR) system, first developed by Statistics Canada (the national statistical agency of Canada) in the mid-1970s (Rapport and Friend, 1979), and soon after adopted by the OECD (Forget and Lebel, 2001); and the ecosystem health concept, which emerged in the late 1980s (Rapport, 1989b; Rapport and Maffi, 2011).

The PSR portrays the complex relationships between human activities, environmental transformation, and policy responses (Rapport and Singh, 2006), characterizing "drivers", "pressures", "state", "impacts" and "responses". For this reason the PSR system has also become known as "DPSIR". An important underpinning of the PSR is the recognition that human activities arise within ecosystems, have the potential to alter ecological structure and functions, and respond to changes in environmental conditions. The notion that "health" applies to the ecosystem level was suggested several decades ago (Rapport, 1989a), and subsequently has become a key goal of environmental management (Rapport et al., 2003) and sustainability (Rapport, 2007a,b; Rapport and Maffi, 2011). Today the goal of achieving healthy ecosystem as a precondition for human well-being is part of the mandate of a growing number of international agencies, including the International Union for the Conservation of Nature (IUCN), the United Nations Environment Programme (UNEP), and the World Health Organization (WHO).

4. Ecological indicators in assessments of the Baltic Sea

Concerns for the health of the Baltic Sea are centuries old. In the Kyrönjoki river and estuary (SW Finnish Coast), a decline in salmon runs was observed in the 18th century and attributed to tar production, which was claimed to foul the water and thus stop salmon migrations to tributaries where this production occurred (Hildén and Rapport, 1993). In the 19th century, in the same region, fish kills were observed and related to the draining of tributaries (and ensuing acidification of the waters). From the 19th century on, there have been concerns about water quality in the vicinity of towns that directly discharged wastewater to the sea (Laakkonen and Laurila, 2007).

One of the first uses of ecological indicators in assessing the Baltic Sea was the 1908 assessment of local marine waters in the vicinity of Helsinki, using chemical (ammonia, chemical oxygen demand), physical (secchi depth), hygienic (coli-bacteria), and biological (algae) analyses (Laakkonen, 2001). The confirmation of local pollution impacts in this region led to the first attempts to develop wastewater treatment, but the efforts were too limited to significantly improve even the state of the nearshore waters. In the latter half of the 20th century it also became clear that the whole Baltic Sea was suffering from anthropogenic impact. According to Thulin and Andrushaitis (2003), the input of nitrogen and phosphorus to the Baltic Sea is three to five times the 1940s levels. Similar increases can be documented for other pressures, including hazardous substances, intensification of fishing effort, shoreline restructuring, and shipping.

[1] The original signatories to the 1974 Convention were Denmark, Finland, German Democratic Republic, Federal Republic of Germany, Polish People's Republic, Sweden, and the Union of Socialist Republics. Currently all 9 coastal states are signatories to the Convention, which was renewed in 1992, i.e. Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The European Union is also a party to the Convention.