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Developing scientific information to support decisions for sustainable coral reef ecosystem services

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) has recently realigned its research enterprise around the concept of sustainability, including improving understanding of benefits derived from ecosystems. We provide an example of how EPA is applying structured decision-making (SDM) as a framework for guiding development of scientific information, data, and models to support watershed and marine-based management in coastal communities. In particular, we have been using the Driver–Pressure–State–Impact–Response (DPSIR) model as a tool in the SDM process to identify and assemble a broadly applicable suite of information with relevancy for coastal management, including 1) development of conceptual models to clarify the decision context, 2) identification of measurements of ecosystem attributes, ecosystem goods and services, and their connection to stakeholder objectives, 3) elaboration of potential decision alternatives, and 4) identification of ecosystem production and valuation functions for modeling consequences of decision alternatives on benefits derived from coral reefs. Finally, we overview how this information is being applied for two case studies: development of water quality criteria and watershed management to protect coastal resources. We posit that applying a systems thinking framework, such as DPSIR, within a structured decision-making approach will better enable marine ecosystem managers to utilize scientific information toward more sustainable decision-making.

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1. Introduction

Despite growing recognition that human well-being is inextricably linked to sustainable use of environmental resources, ecosystem function and services are often overlooked or taken for granted in social and economic decision-making (MEA, 2005; NRC, 2005). A key challenge is that environmental assessments typically focus on ecological endpoints, yet decisions can also cause changes to social and economic variables that are important to stakeholders. The U.S. Environmental Protection Agency (EPA) and other federal agencies have been criticized in the past for relying too heavily on technical-based assessments, and failing to adequately consider stakeholder values in decisions (Arvai and Gregory, 2003; EPA SAB, 2001). Integrating stakeholder values with scientific information can ensure that future research, data gathering, and model development better support the decision making process (Maguire, 2003).

Applying the concepts from value-based decision-making to complex environmental management problems requires a formalized process to ensure that decisions are consistent with stakeholder values, cognizant of tradeoffs among alternatives, and account for uncertainties and risks. The structured decision-making (SDM) approach can be described as an iterative process that uses principles from decision analysis to integrate fact-based and value-based thinking (Failing et al., 2007; Gregory et al., 2012). The first step consists of understanding the context for decisions, which will frame the focus of the problem and the subsequent analysis (Fig. 1). The next step requires characterizing what is valuable to stakeholders through objectives and identifying evaluation measures to define what is valued in the decision context. Once alternatives for achieving objectives are identified, technical analyses can be done to compare the potential outcomes from decisions and explore tradeoffs that stakeholders and/or decision makers are willing to make. The final step is selecting and implementing strategies for achieving objectives that are consistent with values and preferences of stakeholders, and monitoring the success of the decision.

The EPA has recently realigned its research enterprise around the concept of sustainability (Anastas, 2012), including the sustainable delivery of social and economic benefits derived from ecosystems. For research to be effective, it must include consideration of whole systems thinking, long-term consequences, and stakeholder involvement (NRC, 2011). In this paper, we describe how our EPA research team is applying the Driver–Pressure–State–Impact–Response (DPSIR) framework (EEA, 2005) in conjunction with the SDM approach (Fig. 1) as a tool to link ecological science with stakeholder values toward development of scientific information in support of watershed and coastal management decisions.

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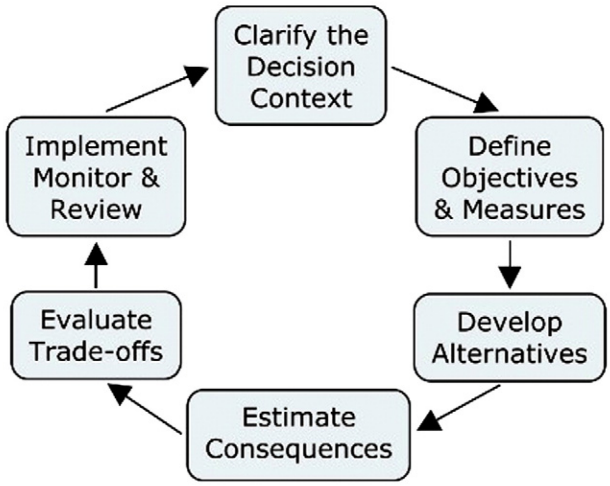

Fig. 1. Generic steps in a structured decision making process. (Modified from Gregory et al., 2012).

Coral reef ecosystems, in particular, support multibillion dollar reef fishing and tourism industries vital to the sustainability of regional economies (Burke and Maidens, 2004; Cesar, 2000; CI, 2008; Pendleton, 2008), but are threatened by a rapidly growing regional human population, climate change, and serial over-exploitation (Waddell and Clarke, 2008; Wilkinson, 2008). Policies to protect coastal resources will be more effective when they account for the social and economic concerns of stakeholders in the watershed, and are responsive to potential tradeoffs with, for example, agriculture or industry (Productivity Commission, 2003; Roebeling, 2006). SDM provides an approach to build a common understanding of the problem, identify key objectives and creative solutions, and tackle key tradeoffs (Gregory et al., 2012).

Here, we provide an overview of our research process in which we have been applying the DPSIR framework as a tool to align scientific research through the SDM approach (Fig. 1) toward assembling a generic suite of information, tools, and models on reef ecosystem services with the potential for broad applicability to coral reef management. Then, we overview two specific decision scenarios for which this research is being applied and expanded: development of water quality criteria in the U.S. Virgin Islands and Puerto Rico, and watershed management to protect coastal resources in Guánica, Puerto Rico. Although a number of frameworks have been proposed for studying reef socio-ecological systems (Chang et al., 2008; Gordan, 2007; Thomas et al., 2012), the DPSIR framework, in particular, has been widely applied in environmental management, and is favored for its simplicity and transparency, focus on causal relationships, and ability to integrate socio-economic factors, biological and physical sciences with the decision making process (EEA, 2005; Maxim et al., 2009; OECD, 1994). The DPSIR framework has been increasingly applied in research with the aim of supporting decision-making (e.g., Helming et al., 2011; Svarstad et al., 2008). Because of its ability to integrate knowledge across different disciplines and visualize different decision alternatives, the application of the DPSIR framework in research studies has considerable potential for bridging the gap between scientific research and stakeholder concerns (Tscherning et al., 2012). Applying principles of the SDM approach through the use of a systems thinking framework, such as DPSIR, to organize research studies may improve the chances of linking scientific findings to "real world" issues.

2. Generic Research Framework

2.1. Using DPSIR to Clarify the Decision Context

The decision context encapsulates the decisions that are under consideration (Keeney, 1992). Establishing the decision context is a crucial step for subsequent analysis as it frames the problem, brings clarity to the scope and bounds of decision making capabilities and is the first step in structuring the decision evaluation process (Gregory et al., 2012). For decision contexts that include watershed and marine management, we have been applying the DPSIR framework to better characterize the influencing factors on reef ecosystem goods and services and management response capabilities (Bradley et al., 2014a; Rehr et al., 2012). Like causal mapping with influence diagrams, we have found the DPSIR framework to be useful for supporting "decision sketching", an important phase for establishing the decision context (Gregory et al., 2012). The framework has also helped us to structure later phases of the decision process, including guiding the development of information, data, and models that support decision-making.

The first step of our research program was to develop a comprehensive DPSIR conceptual framework to identify decisions and human activities likely to affect provisioning of reef ecosystem goods and services, and to delineate potential cause and effect relationships among key factors (EPA, 2012a; Yee et al., 2011). Within DPSIR, Drivers (D) are social and economic forces leading to human activities that create Pressure (P) on the State (S) of the environment, and Impact (I) the economic, physical, cultural, and social well-being of humans through a loss or gain in ecosystem goods and services. Decision-makers may enact a Response (R) to reduce the impacts on environmental resources through regulations, policies, and other decisions, which may alter Drivers (D) or Pressures (P), or directly affect the State (S) of the ecosystem (EEA, 2005; Maxim et al., 2009; OECD, 1994). We found that having rigorous definitions for each DPSIR category, for example defining Drivers explicitly as economic sectors, helps to reduce confusion during early discussions (Yee et al, 2012). In reality, any single category or concept may represent a complex suite of interacting ecological, social, or economic variables, and the derivation of objectives and performance measures that follows should reflect what is meaningful to stakeholders and the decision at hand.

Using earlier examples of DPSIR frameworks applied to marine resources (Mangi et al., 2007; Ojeda-Martinez et al., 2009), the conceptual systems model was developed through deliberations of focus groups consisting of federal, state, academic, and non-governmental coral reef experts and managers. Conceptual model development was further supplemented by discussions with participants at three decision workshops held in St. Croix, U.S. Virgin Islands (2007; Bradley et al., 2014b), Key West, Florida (2009; Rehr et al., 2012), and La Parguera, Puerto Rico (2010; Bradley et al., 2014a; Carriger et al., 2013). In the latter two workshops, participants, including academics, federal agencies, conservation groups, and local economic groups with an interest in reef management, were asked to identify priority issues through creation of their own DPSIR frameworks. Additionally, the focus groups recommended that available scientific literature be linked to each keyword in the DPSIR framework, as a coarse assessment of the state of knowledge (EPA, 2012a).

Key threats to reef ecosystems and benefits derived from reefs described by focus groups and workshop participants were captured in a generic coral reef DPSIR framework (Fig. 2; EPA, 2012a; Yee et al., 2011). Socio-economic Drivers, such as manufacturing, construction, energy, forestry, and agriculture, fulfill basic human needs in society for food, fuel, shelter, and culture. These Drivers might create Pressures on the reef environment through human activities in the watershed and coastal zone. In the watershed these can include atmospheric emissions, waterborne discharges, and runoff, and Pressures that alter the marine environment through sediment, nutrient, and contaminant pollution, ocean-acidification, and climate change. In the coastal zone and marine environment, Drivers such as the fishing, tourism, and shipping industries may directly impact reef biota through Pressures such as overfishing, harvesting, and physical damage from trampling or boating activities. When reef-building corals die, they are often overgrown and replaced by algae, with subsequent loss of complex reef architecture leading to a change in State (Alvarez-Filip et al., 2009)