Journal of Environmental Management 166 (2016) 348–356

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Fuzzy cognitive mapping in support of integrated ecosystem assessments: Developing a shared conceptual model among stakeholders

James M. Vasslides [a, *], Olaf P. Jensen [b]

[a] Graduate Program in Ecology & Evolution, and Department of Marine and Coastal Sciences Rutgers University, 14 College Farm Road, New Brunswick, NJ, 08901, USA
[b] Department of Marine and Coastal Sciences, Rutgers University, 71 Dudley Road, New Brunswick, NJ, 08901, USA

ARTICLE INFO

Article history:
Received 11 April 2014
Received in revised form
15 April 2015
Accepted 21 October 2015
Available online xxx

Keywords:
Ecosystem based management
Barnegat bay
Fuzzy logic cognitive mapping
FCM

ABSTRACT

Ecosystem-based approaches, including integrated ecosystem assessments, are a popular methodology being used to holistically address management issues in social–ecological systems worldwide. In this study we utilized fuzzy logic cognitive mapping to develop conceptual models of a complex estuarine system among four stakeholder groups. The average number of categories in an individual map was not significantly different among groups, and there were no significant differences between the groups in the average complexity or density indices of the individual maps. When ordered by their complexity scores, eight categories contributed to the top four rankings of the stakeholder groups, with six of the categories shared by at least half of the groups. While non-metric multidimensional scaling (nMDS) analysis displayed a high degree of overlap between the individual models across groups, there was also diversity within each stakeholder group. These findings suggest that while all of the stakeholders interviewed perceive the subject ecosystem as a complex series of social and ecological interconnections, there are a core set of components that are present in most of the groups' models that are crucial in managing the system towards some desired outcome. However, the variability in the connections between these core components and the rest of the categories influences the exact nature of these outcomes. Understanding the reasons behind these differences will be critical to developing a shared conceptual model that will be acceptable to all stakeholder groups and can serve as the basis for an integrated ecosystem assessment.

1. Introduction

It is widely accepted that the sustainable management of natural resources must include consideration of human interactions with the environment, not only from a unidirectional perspective (humans impacting natural systems or vice-versa), but with the understanding that these coupled socio–ecological systems are dynamic and have a variety of two-way interactions and feedbacks (An and Lopez-Carr, 2012; Liu et al. 2007). The realization that the use of natural resources is inextricably interwoven with the social, political, and economic complexities of human systems has led to these management challenges being called "wicked problems" (Xiang, 2013), *i.e.* "problems which are ill-formulated, where the available information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing" (Churchman, 1967). With an ever increasing number of wicked problems recognized in social–ecological systems throughout the globe (Sayer et al. 2013; Jentoft and Chuenpagdee, 2009; Ludwig, 2001) the idea of ecosystem-based management has gained traction, particularly in marine policy in the United States (NOAA, 2006). Ecosystem-based management (EBM) attempts to look at a defined geographic area in a holistic manner, defining management strategies for an entire system rather than individual components (Levin et al. 2009).

To successfully manage resources from an ecosystem-wide perspective it is necessary to gather pertinent information on all of the system components, but by definition the data available in instances of wicked problems are confusing, as no clear patterns are

* Corresponding author. Permanent address: Barnegat Bay Partnership, PO Box 2001, Toms River, NJ, 08754-2001, USA.
E-mail addresses: jvasslides@ocean.edu (J.M. Vasslides), olaf.p.jensen@gmail.com (O.P. Jensen).

http://dx.doi.org/10.1016/j.jenvman.2015.10.038
0301-4797/

readily emergent, or if there are patterns they are often contradictory. One organizing framework to synthesize and analyze large amounts of confusing data to support EBM is the Integrated Ecosystem Assessment, or IEA (Levin et al. 2009). The IEA approach is a series of formal processes during which relevant stakeholder groups (including public representatives, scientists, managers and policy makers) synthesize existing knowledge regarding the ecosystem in question, set ecosystem management objectives, select management options, and then adjust future management actions based on feedback from continuing monitoring. The initial activity in the IEA process is the scoping step, during which stakeholder groups define the ecosystem to be addressed, review existing information, construct a conceptual ecological model that identifies ecosystem attributes of concern and relevant stressors, and develop appropriate management objectives (Levin et al. 2008). Generally, this step is conducted during one or more workshops (Hobbs et al. 2002; McClure and Ruckelshaus, 2007) where participants interact in a facilitated format designed to generate consensus on the ecosystem attributes and management objectives. However, there are concerns with the quality of both the process and the outcome when public participation is included in solving environmental issues (Gray et al. 2014; NRC, 2008). In particular, prior studies have shown that groups tend to converge on majority views, that powerful or influential individuals or groups may attempt to dominate or unduly influence the proceedings, and that quality processes and outcomes, especially those related to consensus building, can be cost prohibitive (NRC, 2008).

In light of the potential problems described above, there is a clear need for a strategy that can combine traditional scientific knowledge with public local context, thereby reducing uncertainty and providing for a diversified and adaptable knowledge base (Raymond et al. 2010; Gray et al., 2014). One methodology to improve stakeholder involvement that has been suggested is Fuzzy Logic Cognitive Maps (FCMs) (Axelrod, 1976). FCM are a simplified way of mathematically modeling a complex system (Özesmi and Özesmi, 2004), and have been used to represent both individual and group knowledge (Papageorgiou and Kontogianni, 2012; Gray et al., 2012). This approach has been applied to processes and decisions in human social systems, the operation of electronic networks, and in the ecological realm to identify the interactions between social systems, biotic, and abiotic factors in lakes (Özesmi and Özesmi, 2003, Hobbs et al. 2002), coal mine environs (Zhang et al. 2013), farming systems (Vanwindekens et al. 2013), fisheries (Gray et al., 2012), and nearshore coastal zones (Meliadou et al. 2012; Kontogianni et al. 2012a), but applications in estuaries or as part of a formal assessment process have been rare.

The FCM approach has several advantages to encourage its use in environmental management (but see Kok, 2009 for general limitations). Recognizing how stakeholders perceive relationships between components and the chains of cause and effect related to anthropogenic perturbations allows for the development of policy prescriptions that can be broadly supported by the community (Kontogianni et al. 2012b). A shared understanding of the important components and processes of the ecosystem in question is also critical if stakeholder groups are to fully “buy-in” to future management decisions (Ogden et al. 2005). The FCM methodology ameliorates many of the challenges associated with integrating the different types of stakeholder knowledge (Gray et al. 2014), and the transparent nature of the model combination allows stakeholders to identify how each groups' model contributes to the overall understanding. We do not expect the different groups' conceptual models to share all of the components; rather we anticipate these differences to be highly informative. Indeed, understanding why these differences occur is likely to help us avoid misunderstandings and disagreements during future phases of the IEA process (Kontogianni et al. 2012b).

In this paper we utilize fuzzy logic cognitive mapping to investigate differences in stakeholders' perceptions of the relationships within an estuarine system and develop a shared conceptual ecosystem model that can serve as the basis for an integrated ecosystem assessment. We begin by constructing stakeholder group conceptual models and then compare their structure and components for similarities and differences. We then combine those models into a shared community conceptual model. The final step is to compare the community model to that of the stakeholder groups to understand how combining the models effects our understanding of the ecosystem.

2. Methodology

2.1. Study site

The social ecological system we have chosen to study is the Barnegat Bay, a 279 km^2 lagoonal estuary located in central New Jersey, USA (Fig. 1). The surrounding 1730 km^2 watershed is home to an estimated 580,000 year round residents (US Census Bureau 2012), with a summer population that swells to over 1 million with the influx of tourists. The physical setting of the watershed is well described by Kennish (2001), but points germane to our study are repeated here. Land use is a mix of urban and suburban uses in the northeast and along the barrier islands, grading to less sparsely populated forested areas to the south and west. Portions of the E.B. Forsythe National Wildlife Refuge and the Pinelands National Reserve are located along the eastern and western sides of the watershed, respectively. There is limited extractive and agricultural land use, and other than minor hard clam and blue crab fisheries, no real commercial fishing. The watershed is considered “highly eutrophic” (Bricker et al. 2007), mainly due to nutrient enrichment through non-point source pollution, and the nation's oldest continuously operating nuclear power plant, Oyster Creek Nuclear Generating Station, is located within the watershed. There is extensive recreational use of the bay's waters for fishing, boating, sailing, and to a lesser degree, bathing.

2.2. Data collection

FCMs are models of a how a system operates based on key components and their causal relationships. The components can be tangible aspects of the environment (a biotic feature such as fish or an abiotic factor such as salinity) or an abstract concept such as aesthetic value. The individual participants identify the components of the system that are important to them, and then link them with weighted, directional arrows. The weighting can range from −1 to +1 (Hobbs et al. 2002; Özesmi and Özesmi, 2004; Gray et al., 2012), and represents the amount of influence (positive or negative), that one component has on another.

To collect FCM from a wide variety of stakeholders with knowledge of the Barnegat Bay ecosystem we contacted the Barnegat Bay Partnership, a US Environmental Protection Agency National Estuary Program, to obtain a list of their management and science committee members, as well as a list of public citizens who have expressed long-term interest in the ecosystem. While the map of an individual stakeholder provides information regarding that particular individual's conception of the important components and linkages within the system, it can be combined with other individuals within the group to produce a more robust picture of the group's understanding of the system (Özesmi and Özesmi, 2004). In addition, all of the individual stakeholder maps can be combined into a single map depicting the collective understanding of the system. To this end, the individuals were divided into four