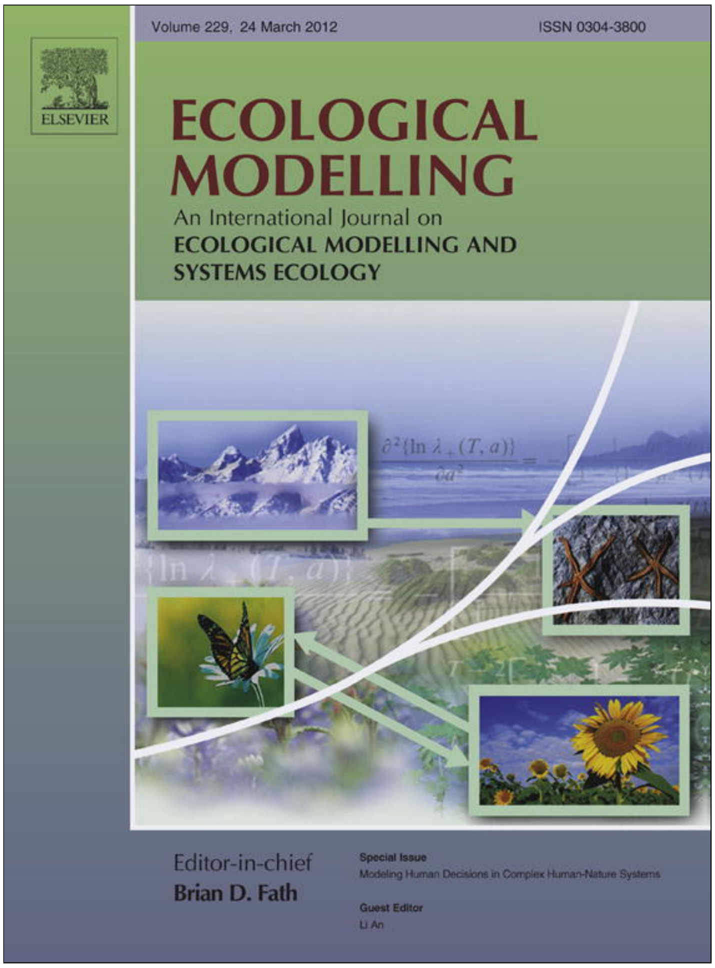
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Modeling the integration of stakeholder knowledge in social–ecological decision-making: Benefits and limitations to knowledge diversity

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ABSTRACT

Integrating stakeholder knowledge into natural resource governance is considered to add flexibility to social–ecological systems (SES) because knowledge diversity reduces rigidity, represents multiple perspectives, and promotes adaptability in decision-making. Characterizing the differences between knowledge systems, however, is not easily accomplished. There are few metrics readily available to compare one knowledge system to another. This paper characterizes knowledge about a model SES, the summer flounder fishery in the mid-Atlantic, to evaluate differences and similarities in the structural and functional characteristics of stakeholder mental models. To measure these differences, we collected Fuzzy-Logic Cognitive Maps (FCM) from several stakeholder groups (managers, scientists, harvesters, pre and post harvest sectors, and environmental NGOs) which comprise social agents within the SES. We then compared stakeholder groups' maps using graph theory indices to characterize the structure and function of the model system. We then combined stakeholder FCM to generate a community map which represents a theoretical model of the combination of stakeholder knowledge. Our study indicates that while there may be benefits to integrating knowledge in resource decision-making, it also has costs associated with it. Although integrating knowledge may increase structural knowledge, it may also decrease precision in understanding of how a system functions and be overly focused on driving components which would reduce the ability of decision-makers to predict system reaction to a decision or policy plan.

1. Introduction

As a way to manage and organize the complexity found in social–ecological systems (SES), many researchers have highlighted the benefits of integrating diverse types of knowledge systems. A knowledge system refers to a coherent set of mental constructs, cognitions, and practices held by individuals within a particular community (Richards, 1985). This knowledge can be internal representations of the external world (e.g. mental models) or can be a series of beliefs about the external world or components within it. The ways in which different knowledge systems are organized, socially influenced and useful for institutional resource management have seen increasing attention in recent years (Kellert et al., 2000; Gadgil et al., 2000; Armitage, 2003; Brown, 2003; Davis and Wagner, 2003). Promoting diversity in the types of knowledge considered in management is thought to lead to more resilient outcomes in SES because it makes knowledge structures less rigid and more adaptive to change (McLain and Lee, 1996; Johannes, 1998; Folke, 2004; Ludwig et al., 2001).

The most common way natural resource managers have to promote knowledge integration is to include the public in decision-making. The term public participation refers to a number of activities and ranges from after-the-fact education programs to environments in which decision-making power resides solely with stakeholders (Arnstein, 1969; Berkes, 1992; NRC, 2008a,b). The benefits of integrating stakeholder knowledge into resource management have inspired a number of management strategies which are aimed at reducing traditional boundaries between knowledge sources (Berkes, 2004) and highlighting the importance of two-way learning between participants (Chase et al., 2004; Johnson et al., 2004; Lynam et al., 2007). When different types of knowledge are included in resource management, reliance on experts and elites is decreased, making the system more adaptable (Agrawal, 1995). Knowledge integration allows the local context and behaviors of individuals to be better understood so that uncertainty can be reduced (NRC, 2008b). Since ecosystems are complex, diverse, and adaptive, it has been suggested that the knowledge used to

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guide management decisions should also be complex, diverse, and adaptive (Berkes et al., 2000; Dietz et al., 2003; Folke, 2004).

Although integrating knowledge through participation has been reported to create higher quality and more durable decisions (Reed, 2008), it does present some difficulties. National Research Council (NRC) (2008) summarize three basic arguments that critics of public participation cite: (1) the costs are not justified by the benefits, (2) the public is ill-equipped to deal with the complex nature of analyses, and (3) participation processes seldom achieve equity in process (NRC, 2008a). These criticisms highlight that knowledge systems are neither easily reconciled nor integrated. Knowledge systems are unique to communities and often develop historically and independently from one another (Folke, 2004; Banjade et al., 2006; Ojha et al., 2007). The costs of knowledge sharing are in terms of potential conflict and management resources because it may take considerable time to build common understandings between disparate stakeholder groups and institutions (Renn et al., 1995).

Understanding the benefits and limitations of knowledge-sharing is not easily accomplished (Raymond et al., 2010). Questions about the types of knowledge and the degree to which they are complimentary or incongruent are not easily answered. Although knowledge integration through participation has become standard in environmental policy, there are concerns about the biases (NRC, 2008a,b) and lack of empirical evidence which support some of the beneficial claims (Reed, 2008). In a comparative study of knowledge integration in three environmental management contexts, Raymond et al. (2010) found that knowledge integration is inherently complex, classification of knowledge is arbitrary and perspectives on the process are qualitatively very different. Additionally, categorizing what constitutes different types of knowledge has led to additional confusion (Fazey et al., 2006). Most often, knowledge systems are coarsely defined and can be placed into two main bins: local knowledge and scientific knowledge. Local knowledge reflects individual experiences (Fazey et al., 2008) or non-expert or localized information (Jones, 1995). Local knowledge includes traditional, indigenous and lay knowledge, each describing a particular point on a continuum of knowledge mediated by personal or cultural experiences. Scientific knowledge refers to knowledge created by more systematic means. Scientific knowledge utilizes agreed principles and a process of study, including reliability and validity to generate new information (Turnbull, 1997; Gunderson and Holling, 2002).

These knowledge categories, however, have been criticized for being overly simplistic since they do not account for the way in which people process different types of information or the role that social contexts may play in influencing knowledge development (Raymond et al., 2010). Further, knowledge classification does not inform the way in which stakeholders view important structural and functional aspects of the social–ecological system of which they are a part. Additionally, it is likely that all stakeholders hold varying degrees of both local knowledge and scientific knowledge concurrently. These categories alone do little to explain how or why individuals or groups may anticipate environmental or social change. In this paper, we investigate the differences in knowledge systems by analyzing representations of mental models from stakeholders involved in the management of a model SES, the summer flounder fishery in the mid-Atlantic. We begin by characterizing the structure and function of stakeholder group knowledge. Next, we compare knowledge by stakeholder group to uncover differences and similarities. We then combine stakeholder knowledge into a community knowledge system which represents the integration of different stakeholder perspectives. Finally, we compare the community knowledge system to individual stakeholder knowledge systems to better understand the theoretical benefits and limitations of integrating knowledge in a natural resource management context.

1.1. Model system: mid-Atlantic summer flounder fishery

Marine fisheries offer an ideal opportunity to evaluate stakeholder knowledge in the context of a resource management debate. Fisheries management in the United States is a hybrid of federal and state-level management, guided by legislation, which integrates various aspects of stakeholder participation throughout the decision-making process. Since many fishery decisions are designed to be made in open and transparent forums, understanding differences in mental representations about the system may give insight into the way discourse develops as stakeholder knowledge is integrated through participation.

The summer flounder fishery in the mid-Atlantic was chosen as a model system for multiple reasons. Summer flounder is a highly valuable resource to the region and debates about how to best manage ecological and social aspects of the fishery vary considerably. Over the last several years, the stock has been in recovery or "rebuilding" which has placed strict annual limitations on its harvest. Further, management decisions which determine these harvest levels, affect a range of stakeholder groups which include harvesters, coastal communities, and environmental NGO representatives. These stakeholders meet routinely throughout the year with fishery managers and fishery scientists to discuss the scientific assessment of the stock and potential management strategies meant to sustain both the social communities which rely on fishing and the summer flounder population.

2. Materials and methods

2.1. Structure and function of systems

To understand how knowledge may vary, it is important to examine how individuals internally organize knowledge about the external world. To accomplish this, we sought to collect explicit representations of stakeholder mental models of the SES. Since SESs are complex systems, we wanted to understand the structure and function of individual and group mental models. In our study, the structure and function of mental models correspond to the structure and function of the SES.

Structures are the parts that define a system. The observational and conceptual recognition of structures has been linked to nearly every mode of inquiry and discovery in science, philosophy, and art (Pullan, 2000). The relationships between structures are what give a system its shape which can be hierarchical or networked. Understanding structures is analogous to the "whats" of the system and have been shown to be the foundation of observational learning about complex systems (Hmelo-Silver and Pfeffer, 2004). In ecological systems, structures exist across varying scales of organization, from molecular to ecosystems, in a hierarchy. In social systems, structures refer to organizations which are networked by connections between groups of individuals. Functions are the outcomes of the system. The functions of complex systems have been defined in value-laden terms to indicate the purpose of the system. In biological terms, function has been referred to as the purpose of a chain of causal reactions (Dusenbery, 1992) such as adaptations which aid in a species survival. In social terms, the function of ecosystems has been defined in terms of ecosystem services, or what human societies ultimately derive from ecosystem operation. Understanding structure and function is important to understanding systems since these aspects define the form and the outcome of system operation.

2.2. Fuzzy logic cognitive mapping

To better understand the structural and functional aspects of knowledge systems, we collected Fuzzy Logic Cognitive Maps

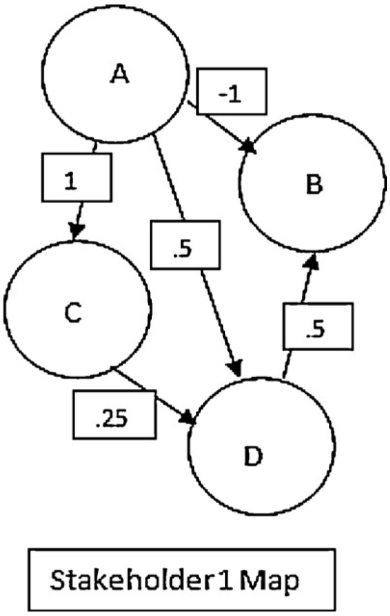

Fig. 1. Example of a FCM.

(FCM) from stakeholder groups involved in the summer flounder fishery. FCM have been called simplified mathematical models of belief systems (Wei et al., 2008) and have been used to represent individual (Axelrod, 1976) and group (Özesmi and Özesmi, 2004) knowledge systems. Cognitive maps have been used in a number of disciplines to indicate relationships among variables as well as to understand system dynamics. Anthropologists have used signed digraphs to represent different social structure in human societies and systems of operation (Bauer, 1975; Malone, 1975; Bougon et al., 1977; Klein and Cooper, 1982; Hage and Harary, 1983; Carley, 1990; Palmquist et al., 1997) and ecologists have used them to understand relationships between organisms and their biotic and abiotic environment (Puccia, 1983; Radomski and Goeman, 1996; Özesmi and Özesmi, 1999; Hobbs et al., 2002). Here we use FCM to develop individual representations of the concepts and causal relationships in social and ecological systems. FCM are models of how a system operates based on defined components and the causal links between these components. These components can be quantifiable constructs like temperature or abstract constructs such as satisfaction. The individual participating in developing a FCM decides what the important components are that comprise the system in question (see A–D in Fig. 1) and then draws causal relationships among the components with numbers between −1 and +1. These numbers indicate the amount of positive or negative influence one component has on another (see directional arrows and numerical influence Fig. 1).

2.3. Data collection

For this case study, five stakeholder groups from the summer flounder fishery created FCM of the fishery system following best practices as outlined by Özesmi and Özesmi (2004). These groups include harvesters (commercial and recreational fishermen), members of the pre and post harvest sectors (members of coastal communities which indirectly rely on the fishery for income), fishery managers (state and federal-level), fishery scientists (state, federal and academic), and representatives of environmental non-government organizations (ENGOs). These groups were chosen a priori since they represent the social actors routinely included at fishery management meetings. In total, 35 individuals engaged in drawing FCM. Participants included ten harvesters, seven members of the pre and post-harvest sectors, seven state and federal fishery managers, seven scientists and four individuals employed by a national ENGO. In total, 27 maps were generated for analysis (Table 1).

As methodological papers have suggested, map collection took between 45 and 180 min, averaged about one hour and included individuals and groups of individuals in map construction (Özesmi and Özesmi, 2004). Participants were shown an unrelated example of a FCM and then asked to list the important components within summer flounder SES. After an initial list was developed, they were asked to organize the components within the system by drawing relationships between the components. Finally, participants were asked to provide quantitative values on the causal links between components (between −1 for strong negative relationship to +1 for strong positive relationship). All maps were completed to the satisfaction of the participant.

3. Theory and calculation

FCM are subject to a range of analytical techniques (Eden et al., 1979; Kosko, 1991; Özesmi and Özesmi, 2004). Maps can be analyzed to represent individual knowledge or aggregated to represent stakeholder groups or entire community knowledge (Özesmi and Özesmi, 2004). In this study, we analyzed FCM to examine knowledge about the structure and function of a model SES. First, we present structural measurements of the FCM. The structure of individual maps were determined by developing adjacency matrices, determining the types of components included in the maps, and developing indices which indicate the amount of adaptability and complexity each stakeholder represented in their map. Second, we present functional measurements of the FCM which offer insight into how these models may react to change given a change to the system. Perceived function can be measured by running model scenarios on stakeholders' models to determine how they see the system reacting to change when components included in the model are artificially increased or decreased (Kosko, 1991). The function of the maps was analyzed in two ways: (1) by aggregating individual maps to examine stakeholder group function and (2) aggregating stakeholder groups maps to examine function of the entire community map. The differences in these measurements were then compared to draw conclusions about the differences between stakeholder knowledge systems and to compare the benefits and limitations of integrating knowledge systems.

Table 1
Stakeholder groups involved in summer flounder fishery in the mid-Atlantic.

Stakeholder group	Maps (*N*)	People (*N*)	Occupation/organization/social group
Harvesters	9	10	Commercial fishermen, charter boat captains, headboat captains, recreational fishermen
Post and pre harvest	4	7	Bait and tackle shop owners, fishery trade magazines, seafood wholesalers/retailers
Managers	5	7	State and federal fishery managers
Scientists	6	7	Academic scientists, federal management scientists and state management scientists
Environmental NGOs	3	4	National environmental non-profits
Total	27	35	

3.1. Analyzing structure

Since FCM are based in graph theory, the structure of FCM as a representation of a mental model is easy to determine. The structure of a FCM is determined by establishing a matrix. This allows the complexity in a hand-drawn map to be reduced, and system structure to become more apparent. The structure of an individual FCM is determined by listing the variables *vi* on the vertical axis and variables *vj* on the horizontal axis. The amount of influence one component has on another is then listed in the row and column in the matrix. All stakeholder maps were transcribed and examined for their structure.

3.1.1. Determining types of components

All components within a FCM were then categorized in one of three ways: transmitter, receiver, or ordinary. Transmitter variables are seen as having significant influence over system operation, receiver variables represent the end result of the system operation and ordinary variables are nodes in between. All components in an individual FCM were binned in one of these three groups (Eden et al., 1979). To accomplish this, we used the structural analysis matrix (Kosko, 1986; Özesmi and Özesmi, 2004). To determine the type of variable, the outdegree [$od(vi)$] and indegree [$id(vi)$] values for each variable is calculated. Outdegree is determined by the row sum of the absolute values of a variable. The indegree is determined by adding the column sum of absolute values of a variable. These values indicate the cumulative strength of the influence to other variables (outdegree) as well as the cumulative influence on a variable (indegree). To determine whether each variable is a transmitter, receiver, or ordinary variable, the outdegree and indegree variables are compared (Bougon et al., 1977). Transmitter variables have a positive outdegree and zero indegree. Receiver components have a zero outdegree and a positive indegree. Ordinary components (in terms of conceptual system function) have both positive outdegree and indegree (Bougon et al., 1977; Eden et al., 1979; Özesmi and Özesmi, 2004).

3.1.2. Amount of potential change and level of complexity

Density and complexity values were calculated for each individual stakeholder map and then averaged for each of the five stakeholder groups. To calculate the density, the number of components (N) and number of connections (C) in each individual map was determined. The density of a cognitive map (D) is an index of connectivity: $D = C/[N(N-1)]$ or $D = C/N^2$ if a variable can have a causal effect on itself (Hage and Harary, 1983). Density within a cognitive map indicates whether the system is hierarchical (some components are perceived to have more influence) or fully democratic (all system components are tightly linked) (Özesmi and Özesmi, 2004). Next, centrality for stakeholder group maps was calculated (Özesmi and Özesmi, 2004). Centrality is the ratio of receiver variables to transmitter variables (R:T). The higher the number of receiver variables, the more complex a map is considered to be since it considers many possible outcomes of a system, rather than fewer end points (Eden et al., 1979). Conversely, a larger number of transmitter variables has been said to indicate thinking in more top-down manner where there a map represents more forcing functions initially, but elaboration of the resulting consequences of these functions are not well articulated (Eden et al., 1979).

3.1.3. Stakeholder and community cognitive maps

All stakeholder groups' maps were weighted equally and combined by (1) individual maps within a stakeholder group to characterize each of the five stakeholder groups and (2) all five stakeholder groups to develop a large-scale community model of the SES. Combining stakeholder maps involves overlaying individual maps and averaging all influential connections between components. Summing relationships between components allows for repeating fuzzy logic understandings to be reinforced, where rarely mentioned components and influences identified by smaller contingencies are included, but not reinforced. For example, Fig. 2 shows a hypothetical example of the combination of two stakeholder group maps. Stakeholder Map 1 includes variables A, B, C, and D and Stakeholder Map 2 includes A, B, C, D, and E. For the combined map, these two individual maps are simply added together, holding equal weight in the final map. Notice, certain influences, for example $A \rightarrow C$, $A \rightarrow D$, and $A \rightarrow B$, are reinforced in combined map while others, for example $D \rightarrow E$, are included but are not reinforced since it was not mentioned by both participants. These summed values of reinforced influence values between components are then averaged to allow for fair comparison across groups.

3.1.4. Aggregating stakeholder maps

FCM were aggregated to ease analysis. Aggregation of stakeholder maps can be done qualitatively or quantitatively to reduce and standardize the dataset (Özesmi and Özesmi, 2004). After all maps were collected, variables included in all maps were listed by their frequency of mention to determine the most often reoccurring structures. Further, we subjectively combined similar variables into categories in order to standardize maps. To validate aggregation, subsuming variables were validated by at least one member

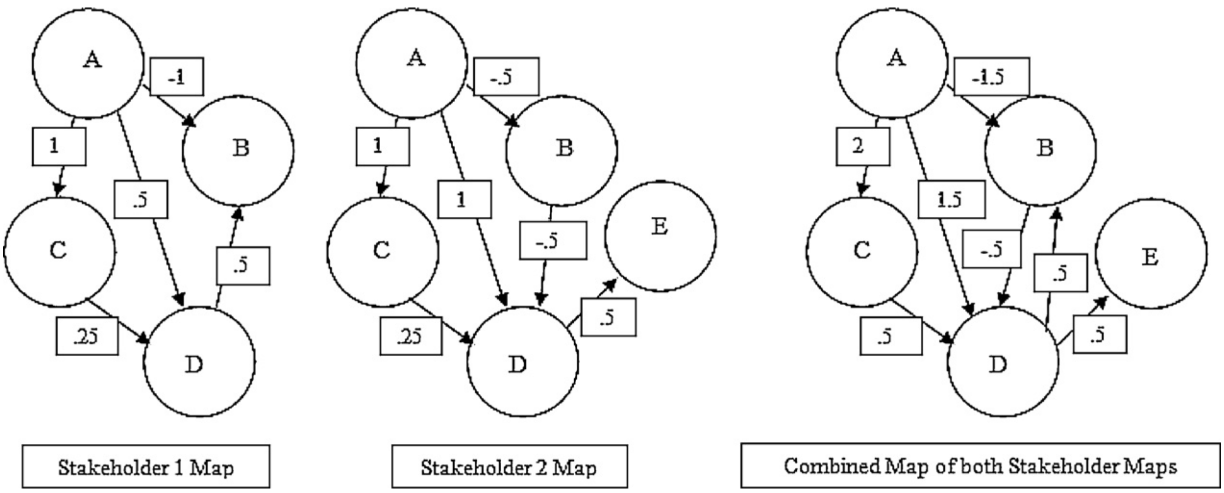

Fig. 2. Example of combining stakeholder maps were some components and relationships are reinforced while others are not.

of each stakeholder group. For example, different types of fishery regulations were mentioned by several harvesters such as "size limits", "bag limits", and "total allowable catch". These three variables were combined into one variable "management measures". After aggregation, follow-up conversations with stakeholder representatives verified new components. Aggregation of stakeholder maps reduced 124 variables into 27 final system components. Similar studies have reduced large amounts of variables into smaller and more manageable components (Özesmi and Özesmi, 2004).

3.2. Analyzing function through scenarios

After structural measurements and aggregation, the dynamics of stakeholder and community maps were determined using the matrix calculation for each stakeholder group and the community map. This allowed for the function of each map to become clear. Matrix calculation allows for artificial "what if" scenarios to be run to see how the system might change under a range of conditions (Özesmi and Özesmi, 2003, 2004). First, the steady state vector was developed by placing a value of 1 for each of the elements in the vector. Second, the steady state vector was then subject to matrix multiplication with the adjacency matrix of the desired cognitive map and a new vector was created. Third, each of the elements within this vector was subject to a logistic function ($f(x) = (1/(1 + e\hat{}(-x)))$ to keep the values in [0,1]. Fourth, the new vector was applied to matrix multiplication with the adjacency matrix and the elements were again subjected to a logistic function. Past studies have indicated that the resulting values can either go into a steady state, go into a limit cycle, or go into a chaotic pattern (Kosko, 1986). For our analyses, however, all of the calculations resulted in a steady state with less than 15 iterations.

The steady state of the stakeholder maps or community map was then used to test different SES scenarios to analyze differences in percieved function. Kosko (1985) first proposed a clamping method to measure functional outcomes under a given scenario by maintaining a variable's value between -1 and 1 in the steady vector at each time step during the matrix multiplication. Clamping a variable allows us to determine how the function of the system might change under certain conditions. While using the same cognitive map, this value remains clamped at each time iteration before the matrix multiplication step to achieve the next vector. The following iterations are then calculated using the same methods, but again the variable of interest in again set to a value between -1 and 1. The final vector of the clamp is then compared to the original steady state vector of the corresponding cognitive map by taking the difference between the clamped vector and the steady state vector. Thus, the resulting values for each variable show the amount of relative change given the SES operation under artificial conditions. These measurements offer insight into how stakeholder groups may anticipate changes to system functioning based on applying a scenario to their models.

Although researchers have written about the inherent limitations in predicting system states in SES (Walker et al., 2002; Folke, 2004), we developed a possible scenario for our stakeholder and community maps. The scenario was developed as a way to highlight differences between functional knowledge systems of stakeholder groups and create a theoretical model of the community SES knowledge system relative to individual knowledge systems. It was not developed as a way to predict specific structural and functional change in the SES in the real world but rather highlight differences in the conception of a system. The scenario chosen was to artificially increase the summer flounder population as continuously high which is presumably the desired state for this SES and the purpose of summer flounder management. Six models were run in total, one for each of the five stakeholder group maps and one for the community map.

4. Results

4.1. Differences in structure and function

When each stakeholder group's models were combined and compared, structural and functional measurements uncovered several differences in stakeholder knowledge systems (Table 2). Based on these measurements we summarize the knowledge which characterizes the summer flounder fishery for each of the five stakeholder groups and for the community as a whole. Functional values reported in the parentheses below indicate the amount of relative change under the model scenario which is an indication of how each stakeholder group anticipates components in their model to react relative to one another under a hypothetical scenario. These values reflect relative change in the models which allows differences between stakeholder groups to be compared. Although any variable in the models could have been increased or decreased as a potential model scenario to compare how stakeholder groups see the system reacting to dynamic changes, we chose to manipulate the summer flounder variable since it served as the conceptual center of the models. For graphs of functional response see Appendix 1.

4.1.1. Harvesters

Harvesters indicated a high number of transmitter variables, with a lower number of receiving variables. This is an indication that they consider many outside forces to affect the function of the system and articulate relatively fewer outcomes of those forcing functions. Transmitter variables seen as driving the system included *ENGOs*, *Fishing pressure*, *Compliance with regulations* and *Good weather* while the only receiver variable included in harvester's averaged map was *Satisfaction with catch*. This indicates that, when harvesters' knowledge is combined, these management variables were viewed as important to influencing ultimate system behavior, which harvesters see as their satisfaction in catch rates. Results of relative change revealed through the functional analyses indicated that an increase in the summer flounder population would result in increases in *Recreational fishing*, *Coastal community/Economic sectors*, *Summer flounder reproduction*, *Fishing pressure* and *Commercial fishing*.

Table 2
Mean and standard deviations by stakeholder group and community map.

Stakeholder group	Harvesters	Pre and post harvest	Managers	Scientists	Environmental NGO	Community map
Maps (N)	9	4	5	6	3	27
Number of variables	16.2(3.0)	12.8(2.1)	15.4(5.8)	19.2(1.71)	19.7(5.5)	27
Number of transmitter	6.33(3.08)	2.75(1.71)	5.8(3.27)	6.33(1.75)	7.67(3.51)	6
Number of receiver	1.44(0.88)	2(1.41)	0.8(0.45)	2.33(1.87)	1.67(0.58)	1
Number of ordinary	8.55(3.16)	8(3.47)	8.8(3.90)	10.33(3.72)	10.67(4.50)	20
Number of connections	26.22(7.70)	22.5(13.80)	25(13.80)	27.33(7.60)	40.67(19.00)	117
C/N	1.65(0.30)	1.66(1.24)	1.42(0.23)	1.41(0.30)	2.56(1.02)	4.34
Complexity (R:D)	0.34(0.40)	0.38(0.49)	0.27(0.22)	0.50(0.58)	0.17(0.29)	0.17
Density	0.11(0.02)	0.14(0.01)	0.11(0.04)	0.09(0.02)	0.12(0.08)	0.17

4.1.2. Pre and post-harvest

Analysis of pre and post harvesters sectors saw similar results to harvesters, however indicated far more room for change within the system relative to other groups. This was as evidenced by the group's high density score. Additionally when the models of the pre and post harvest sector models were averaged, *ENGOs* were seen as the only transmitting variable and *Fisheries management* was seen as the only receiving variable. Finally, on average this group identified the least amount of variables in the system, therefore designate the system to be comprised of the least amount of components. The functional analyses of increasing the summer flounder stock indicated the highest increase in the *Coastal community/Economic sectors*, followed by increases in *Recreational* and *Commercial fishing* and *Fishing pressure*.

4.1.3. Managers

Our results indicate that fishery managers fall in the middle of the range of stakeholders by most structural measures and indicated somewhat less diversity in their maps as indicated by their standard deviations relative to other groups. The amount of components designated to be in the system, their map density, complexity and numbers of connections included in their maps were all mid-range values relative to other groups. When averaged, managers indicated that *ENGOs,* and *Congress* were transmitting variables driving the system while *Coastal Communities/Economic sectors* and the *Summer flounder stocks* were the receiving variables. Anticipated change given an increase in summer flounder indicated the highest increase in *Recreational fishing* (0.03), *Coastal community/Economic sectors* and *Reproduction/spawn* with smaller increases in *Commercial fishing*, *Fishing pressure* and decrease in Prey.

4.1.4. Scientists

Scientists' maps viewed less room for change within the SES, yet represented the most complexity within their maps. This was indicated by two measures. First, scientists included more receiver variables than any other group, an indication that scientists may consider the results of a dynamic system more often than other groups. Second, scientists' density score was the lowest of those evaluated, an indication that scientists view the SES as more rigid than other groups with less opportunity for change within the system. Although individually, scientists included more receiver variables than any other group, when their models were combined only transmitting variables remained which included *ENGOs*, *Congress*, *Funding*, *Habitat*, and *Good weather*. Functional response to summer flounder population increase resulted in highest increases in *Reproduction/spawn Predators*, *Fishing pressure*, and decrease in Prey.

4.1.5. Environmental NGO

Members from environmental organizations had the least complex maps, however, included the highest number of variables and connections between variables. Additionally, ENGO representatives seemed to view more structures driving the system which was evident by the highest number of driving variables on average. The transmitter variables included in their combined model characterized *ENGOs*, *Congress*, *Coastal communities/Economic sectors*, *Good weather* and *Habitat* as driving the system with no receiving variables. This group also indicated the second highest score for density (or change) an indication they see the more room for potential changes to the system compared to all other groups, except the pre and post harvest sectors. Functional scenarios indicated decreases in *Fishing pressure*.

4.2. Community map

Compared to stakeholder group maps, the community map resulted in the highest number of variables, and connections between variables (Fig. 3). This included a high number of transmitter variables and a low number of receiver variables. This suggests the community map represents many outside forcing components and relatively fewer outputs of the system. Combing stakeholder maps also resulted in highest number of connections between components and therefore the highest indication of room for change in the system, however it also resulted in the lowest complexity score. Functional analyses resulted in highest positive response in *Recreational* and *Coastal community/Economic sectors*, *Reproduction/spawn*, *Commercial fishing*, *Fishing mortality*, *Fishing pressure*, *Predators*, and decreases in *Prey*.

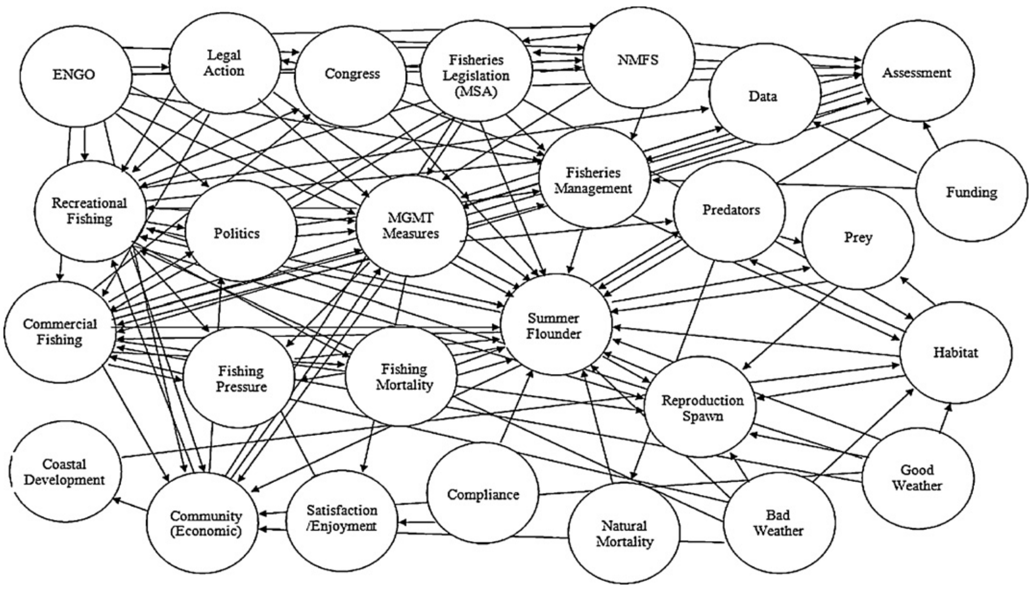

Fig. 3. Community FCM for summer flounder SES, including all negative and positive relationships between components.

5. Discussion

5.1. Differences between stakeholder knowledge

We attempted to compare standardized representations of stakeholder group mental models and community mental models to better understand how knowledge systems may vary and evaluate the beneficial claims about knowledge integration in natural resource management. In our study, harvesters' and the pre and post-harvest sectors' FCM indicated somewhat similar knowledge systems by our measures, while scientists and ENGO representatives seem to be divergent when compared to all groups. Managers' knowledge, on the other hand, seems to represent a mixture of other stakeholder groups' knowledge since managers' models were in the middle of all structural measures and their scenario analysis was similar to a combination of harvesters, the pre and post-harvest sector, and scientists' scenario analyses. This is an interesting finding since in U.S. fisheries management fisheries managers are both appointed officials which are meant to reflect the interests of fishery constituents (i.e. belonging to any of the other stakeholder groups) or, on the state-level, are career civil servants. Equity in fisheries management is expected to be enhanced when a range of stakeholder interests are represented in decision-making (Hanna, 1995). Therefore management knowledge should reflect a combination of fishery interests. Our results indicate that manager conceptions do represent the knowledge of other stakeholder groups since the results of the scenario analysis show that managers anticipated changes in focal subsystems closely matched harvesters and pre- and post-harvest sectors (e.g. fishing sectors and the coastal community) and also the scientist subsystems (e.g. increase in reproduction and decrease in prey). Additionally, since conflict in fisheries management has been characterized as the result of competing anthropocentric and biocentric worldviews (Varjopuroa et al., 2008) it seems appropriate that achieving equitable decision-making through participation would rely on the ability of managers to consider both socially-oriented and ecologically-oriented perspectives simultaneously.

The most divergent groups by comparison were scientists and representatives from ENGOs. Scientists see the summer flounder system as somewhat rigid with less opportunity for manipulation of the system compared to other stakeholder groups based on their low density score. This may be because scientists often focused on the ecological components of the fishery which were seen as less malleable than other social components. Scientists' maps were also shown to be the most complex since they represented both the forcing functions of the system and the end results of those processes. Further, scientists were the only group who considered *Funding* as a driving component to the system. Funding was seen as important since data collection and data analyses on which many fishery decisions are based, are reliant upon the ability of management institutions to decrease uncertainty by increasing data availability and analyses which are facilitated or limited by funding resources. The other more distinct group, ENGO representatives, identified the highest number of components within the system and the highest number of driving components, however, had the lowest complexity scores. Scenario results of anticipated change to the SES indicated that ENGO representatives see fishing pressure decreasing if there was a significant increase in the summer flounder population. At first a puzzling response, further evaluation of the structural model shows the underlying dynamics of this reaction. Their model indicated that increased stocks influence increase data availability and assessments. These increased assessments would decrease uncertainty about the population and increase management measures which would decrease fishing pressure. The perceived relationship that supports these relationships would be that if there are more fish to be assessed, uncertainty is decreased and management agencies would realize the low abundance of stocks thereby limiting resource harvest.

Even with these differences, some commonalities between groups did emerge. For example, all stakeholder groups indicated that ENGOs were drivers of SES operation, an acknowledgement of the increasing role that environmental groups have in directly or indirectly influencing natural resource management decisions. These reports from stakeholder have also been supported by recent studies. For example, in a historical analysis of the collapse and subsequent recovery of the groundfish fisheries in New England, Layzer (2006) argues that environmental groups, by way of lawsuits and threats to management autonomy, are the driving force behind the current a risk-averse framework adopted by fishery decision-makers. She cites two critical factors which enabled their influence to be productive: a compelling science-based argument about the relationship between fishing pressure and stock declines and explicit conservation in the laws used to guide fishery decision-making. Past studies have also indicated that eco-labeling (Jaffry et al., 2004; Iles, 2007) and other public campaigns (Jacquet and Pauly, 2007) initiated by environmental groups have led to changes in public perception of fisheries conservation issues which have influenced the way in which fisheries decisions, thereby changing the dynamics of fishery systems.

5.2. Benefits and limitations of knowledge integration

Although knowledge integration through participation has become standard in environmental policy, there are concerns about the biases (NRC, 2008a,b) and lack of empirical evidence which support some of the beneficial claims (Reed, 2008). Our data indicate that integrating diverse knowledge systems may better characterize the structural form of social–ecological systems, given that the varied perspectives of stakeholders within a SES help identify more details of the varied spaces within that system. A major strength of knowledge integration is combining separate foci on subsystems which inform more comprehensive understanding of the complexity of a system which a single perspective might overlook (Agrawal, 1995). For example in our study, scientists included more ecological components in their maps while harvesters focused more heavily on economic and social components. Both, however, articulated important shared links between these different subsystems which allows for conceptual bridges to be built, resulting in the opportunity to take advantage of both areas of expertise. When maps were combined, the community map density score was considerably higher than that of individual stakeholder groups, an indication that representing more opportunities in which desirable states can be promoted and undesirable states can be discouraged by way of a more comprehensive understanding of the system.

However, our results also indicated some limitations. Although integrating knowledge may increase structural knowledge, it may also decrease precision in understanding of how a system functions and be overly focused on driving components which would reduce the ability of decision-makers to predict system reaction to a decision or policy plan. This was evident in the low complexity score of the community map (.17) compared to the average complexity score of the individual stakeholder map (.33). Additionally, the community map indicated a low number of receiving variables (1.0) compared to the average for each stakeholder group (1.6). In practice this may make anticipating the results of a policy more difficult to characterize since more conceptual focus may be placed on transmitting variables at the cost of understanding the outcomes of these driving influences. Our study gives empirical support to some of the criticisms of including diverse knowledge in SES decision-making since outcomes are less understood given the increase in noise which may complicate management decision-making.

5.3. Decision-making under explicit knowledge representation

Although the goals of this study were to compare structural and functional differences in stakeholder knowledge systems and not to evaluate the applied benefits of making stakeholder knowledge systems explicit, it does have some implications for SES decision-making. Past research has indicated that challenges to move toward a more holistic approach to environmental decision-making should understand interaction between different knowledge systems (expert vs. lay; different sciences) and interaction between different value positions (Varjopuroa et al., 2008). Although data availability about these interactions are difficult to collect on the ecological and economic timescales needed to make fisheries management decisions, making stakeholder knowledge explicit through methods like the one described in this study could help resolve these issues by clearly articulating the relationship between social, ecological and physical components through methods of participatory modeling (Bousquet and Voinov, 2010). Making stakeholder knowledge explicit and standardized allows tacit knowledge to be deconstructed and reconstructed through collaborative learning which can show clear areas where there is consensus and community beliefs are supported by all groups. Additionally, and perhaps more importantly, it also allows for divergent beliefs to become known and provides an opportunity for incontinencies to be debated and reconciled.

6. Conclusions

Institutional and scientific knowledge on their own are inadequate guides to determining how SES should be managed and a range of stakeholder perspectives are needed to ensure that environmental policies are more fully informed. However, the methods needed to measure differences in the separate knowledge systems brought to participatory management forums are currently lacking. Additionally, empirical evidence which supports claims of the clear benefits or limitations of knowledge integration in participatory decision-making are sparse beyond qualitative case studies. To address these issues, an adapted a novel methodology, FCM, was applied to a case study to (1) compare structural and functional differences between stakeholder knowledge and (2) test theoretical questions about the utility and limitations of integrating knowledge systems in gaining understanding of a complex social–ecological system. Our study indicates that while there may be benefits to integrating knowledge in resource decision-making, it also has costs associated with it. Our analysis of the community map as a theoretical representation of knowledge integration indicates that including explicit stakeholder knowledge may lead to increased structural understanding of the system managed since it increases knowledge of components and the connections between them. However, integrating stakeholder knowledge in is not a panacea, and as the amount of complexity recognized within the system increases, the ability of decision-makers to understand the outcome of a proposed decision may decrease. Therefore, new analytical techniques that standardize and compare stakeholder knowledge in decision-making settings should be developed and tested in a variety of real-world contexts to more accurately measure the benefits and limitations of integrating diverse knowledge systems in participatory management.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ecolmodel.2011.09.011.

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