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Examining stakeholder perceptions of oyster ecosystem services using fuzzy cognitive mapping

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Abstract

Nature provides numerous ecosystem services to people, yet the prioritization of these services often depends on the goals of various stakeholder groups. The eastern oyster (*Crassostrea virginica*) is an ecologically important species along the Gulf and Atlantic coasts of the United States, where it provides essential fish habitat and may mitigate against climatic variations in urban areas. The eastern oyster also supports a multimillion dollar aquaculture industry in coastal communities. Recent declines in eastern oyster populations, however, have spurred widespread restoration activities. Here, we look at three expert stakeholder groups (academics, nongovernmental organizations, and governmental agencies) in Rhode Island (United States) to understand how stakeholder perceptions of oyster ecosystem services differ. Stakeholders' mental models showed differences among the groups' topologies and components, although the terms "Water Quality" and "Habitat/Structural Complexity" were prioritized in all the groups. Our results suggest that there is substantial intergroup variation, but that there are common threads around which future oyster restoration and management programs can be designed. By making these mental models of ecosystem services explicit, we illuminate tacit assumptions held by different stakeholders of the oyster stakeholder community in Rhode Island. In doing so, we highlight opportunities for more efficient collaboration around commonly shared goals for sustainable social and ecological management.

KEYWORDS

coastal management, coastal resilience, restorative aquaculture, stakeholder conflict, stakeholder engagement

1 | INTRODUCTION

Decisions around optimizing ecosystem services are often highlighted when incorporating the desires, needs, and ecosystem visions of various stakeholder groups (Menzel & Teng, 2010). Furthermore, management actions will be based on the values and priorities held by decision-makers and those communicated by other stakeholders. For example, farmers may want to manage an area to optimize crops, while land managers may want to diversify the suite of plants grown on a plot as a way to mitigate against climate uncertainty (Knoke et al., 2014), or stakeholders may differ on ways to reallocate the expenditure of public funds among different management options (Palacios-Agundez et al., 2014). When those priorities differ along stakeholder lines, internal conflict or management inefficiencies can emerge (St. John et al., 2019). These challenges can be further exaggerated when incompatible, or even contradictory, policy mandates exist (Kellner, 2011). However, by examining the tacit assumptions and value statements of various stakeholders, we can gain insight into the ways that miscommunication across stakeholder groups may be leading to a breakdown in the effective management of natural resources (Harrison, Kochalski, Arlinghaus, & Aas, 2019).

Our research explores this theoretical framework in the context of a commercially, ecologically, and culturally important shellfish, the eastern oyster (*Crassostrea virginica*) in Rhode Island, USA. Our goal is to provide a proof of concept by surveyying several key management stakeholders and describe the way they perceive how oyster ecosystems are constructed and interact. Because of its importance across multiple axes, oyster management involves multiple stakeholders—each of which have their own prioritizations and perceptions of how these "oystersystems" are constructed.

While managing areas for biodiversity can simultaneously provide numerous ecosystem services (Palumbi et al., 2008), it may be challenging to craft practices that concurrently provide other, particularly extractive, goals. The eastern oyster allows us to explore these challenges as it plays multiple complex and instrumental roles in coastal ecosystems and communities along the Northwest Atlantic Ocean. These bivalves provide critical ecosystem functions such as water quality improvements (Coen et al., 2007; Newell & Koch, 2004), coastal protection (La Peyre, Serra, Joyner, & Humphries, 2015), and nutrient cycling (Humphries et al., 2016; Kellogg, Cornwell, Owens, & Paynter, 2013; Pollack, Yoskowitz, Kim, & Montagna, 2013). When oysters aggregate together over multiple generations, the reefs they form also provide habitat for numerous other species (Humphries & La Peyre, 2015; Peterson, Grabowski, & Powers, 2003). In addition, oysters have been utilized as an economically and culturally important fishery since human settlement began on the U.S. East Coast. Oysters were an important fishery for numerous Native American people throughout the east coast of the North America where they provided both food and material culture (Kurlansky, 2007; Thompson et al., 2020). Today their value is still evident with, the oyster fishery being valued at approximately USD 197 million in 2015 (National Oceanic and Atmospheric Administration 2018). In Rhode Island, wild caught oysters were a major component of the economy from the 17th through early 20th centuries (Figure 1) but today are no longer a major fishery. However, today commercially raised oysters are a 6 million dollar per year aquaculture industry, with over 8 million oysters per year sold (Rhode Island Coastal Resources Management Council, 2018). A variety of associated industries, such as gear manufacturers and food-based tourism, are also predicated on healthy and marketable oysters. In addition, oyster reef restoration has become a priority for protecting developed areas along the Atlantic coast (Rodriguez et al., 2014). This is especially true in urban areas that have witnessed the rise of extreme storms like Sandy (2012) and Florence (2018) (Steiner, Simmons, Gallagher, Ranganathan, & Robertson, 2013).

As a direct reflection of oysters' multifaceted ecological utility, multiple stakeholders are involved in management efforts. Engineers, marine scientists, educators, governmental bodies, nongovernmental organizations (NGOs), coastal residents, aquaculture farmers, and many others have added their voices to the growing conversation around oyster restoration and aquaculture. In general, opinions on both aquaculture and oyster restoration are mostly positive (Dalton & Jin, 2018; La Peyre, Nix, Laborde, & Piazza, 2012). However, there appears to be little agreement or coordination in terms of priorities, management strategies, and implementation. As these internal differences can lead to explicit and implicit variations in how ecosystem services are perceived (Ban et al., 2013; Hicks, Cinner, Stoeckl, & McClanahan, 2015), effective communication and priority-sharing between stakeholders is necessary to foster restoration activities and policymaking (La Peyre et al., 2012). Variations among different groups' construction of oysters' ecosystem services can result in the potential for miscommunication and inefficiency in multistakeholder restoration projects ultimately impacting policies that support oyster management. By extension, examining expert stakeholder opinions on the components of an oyster ecosystem and the topology of the connections among those components could help identify areas of potential overlap and identify areas of collaboration.

Cash et al.'s (2003) systems of knowledge theory suggests that information about ecosystem services, which is salient, credible, and legitimate, has the power to engage policy holders. Furthermore, when seeking to affect policy change, especially in systems that are complex with multiple stakeholders, the apparent legitimacy of the scientific finding—a finding that the research presented to managers was unbiased and considered multiple stakeholders' views within its conclusions—is a strong predictor of the impact of that research (Posner, McKenzie, & Ricketts, 2016). Research that is inclusive of multiple viewpoints, and

FIGURE 1 The oyster fishery in Rhode Island during the late 19th century was an important part of the state's economy. In 1880, it was valued at $680,500 dollars which has a value in 2020 of $16,700,000 (Ingersoll, 1881). Narragansett Bay Oyster Co. photograph, circa 1908. VM013_WC0362, RI General Photograph Collection, Providence Public Library

decisions made with clear and explicit representation, can, therefore, provide this legitimacy to policymakers, and ultimately help create more efficient management practices.

1.1 | Our approach

Here, we assess the different views stakeholder groups hold regarding the ecosystem services oysters provide using mental modeling, a technique that has been widely applied in social science contexts, including conservation biology (Stier et al., 2017). Mental models are simple yet powerful tools that center around small-scale representations of how participants view a system being structured (Moon et al., 2019). When constructed, they give insight into both the presence of key concepts (model components) and the interrelationships among those concepts (model topology). And while there are numerous kinds of mental models which have been used in a variety of fields from geography (Reinfried, 2006) to psychology (Johnson-Laird, 2004), here we use fuzzy cognitive mapping (FCM)—a technique that is being rapidly adopted in conservation biology (Gray, Gray, Cox, & Henly-Shepard, 2013; van Velden, Moyo, Ross, & Biggs, 2020). FCM is an analysis methodology for creating quantitative mental models and analyzing them using graph theory (Gray et al., 2013, 2014). This methodology can be applied across several groups to elucidate the differences and similarities among stakeholder groups. For example, Bosma et al. (2017) used FCM to highlight the different ecosystem services that stakeholder groups prioritized when viewing a wetland in Uganda. While some groups (government and farmers) prioritized the land for agricultural support, a unique assemblage of stakeholders (papyrus collectors, beekeepers, hunters, and fishers) all valued the wetland as a conservation area. Through using FCM, the authors were able to identify disparate stakeholder groups that can form collaborations around shared ecosystem service priorities. Mental modeling has emerged as a powerful tool for visualizing stakeholder conceptions and has been used in numerous contexts including wild meat harvesting (Nyaki, Gray, Lepczyk, Skibins, & Rentsch, 2014), First Nation/governmental coupled marine ecosystem planning (Stier et al., 2017), international freshwater management plans (Hobbs et al., 2002), and climate change resilience among coastal Pacific Islanders (Chandra & Gaganis, 2016).

Our study examines how a subset of key stakeholders perceive and organize the ecosystem services provided by oysters. In this paper, we examined stakeholder groups in Rhode Island, a place where oysters are a critical economic and social component of the community (Dalton & Jin, 2018). As a proof of concept, we examined three expert stakeholder groups that were active in oyster science and management: academics, nongovernmental conservation organizations, and state-level management agencies. We aimed to tease apart how perceptions of oyster ecosystem services differ among these groups. We also wanted to demonstrate how understanding stakeholder groups' perceptions might be translated into more efficient, legitimate, and effective management practices, and to provide a framework for a more inclusive sampling in the future.

2 | METHODS

2.1 | Study design

Our study consisted of interviews with stakeholder groups in Rhode Island, USA. Three expert stakeholder types were targeted to obtain group-level opinions about oysters and the stakeholders' inputs in active management: nongovernmental conservation organizations (NGOs), academic groups, and governmental bodies. We initially contacted oyster aquaculture farmers as a fourth stakeholder group, but due to the considerable time constraints in their growing season, we were unable to coordinate interviews. Thus, while we endeavored to include a richer representation of stakeholder diversity, logistical constraints limited stakeholder participation. Thus, our results should be viewed as less of an accurate reflection of the diversity of views held by those involved with oyster aquaculture and restoration in The Ocean State, but rather a proof of concept for the use of this technique, and a touchstone for further investigations, especially for areas north of Maryland where there has been relatively less intense research focus on oyster fisheries.

The authors initially contacted individual members of each group through emails or professional opportunities. These initial contacts were then asked to name other individuals who would be able and interested in participating (e.g., snowball sampling). These sampled groups represented stakeholders with different objectives: restoration/outreach and environmental advocacy (NGOs), research (academic groups), and regulatory management (government groups). Group sizes ranged from 11 to 16 participants (Table 1). Group members differed in experience, from those relatively new to the field to lifelong career workers. Our research compared perceptions from stakeholder groups, and therefore multiple individuals from each stakeholder group were present at each interview.

For each organization, we held workshops ranging from 90 to 120 min in which we introduced FCM by building an example model with participants for reference. Following this orientation, the group of participants worked together to develop a mental model for the ecosystem services created by oysters. The group was provided with a list of initial potential terms, processes, or actors within the mental model ("components"), which served to start the conversation and to provide a common comparative framework (Table 2). These components were derived from initial conversations with oyster stakeholders in a neighboring region (New York), the literature, and informal conversations with Rhode Island stakeholders prior to interviews. To assess the willingness of groups to toss out terms they felt were inappropriate, we also included one dummy component ("pearls"), as these oysters rarely produce pearls and pearling is not a focus of oyster aquaculture or restoration.

To begin participants were prompted to choose a term from the suggested component list of key species, processes, and stakeholders and build onto it as necessary. Importantly, as the model grew, participants were encouraged to add any new autochthonous components and connections that they felt were important, including those that were not included in the initial list. In doing so, the interviewees expressed a graphic representation of their own visions of oyster ecosystems and their goods and services and were not simply responding to the existing choices. As these new terms were added, there was often vigorous debate about their placement within the model.

Once the components (which represent nodes in a graph theory approach) had been decided upon by participants, they then assigned subjective measures of importance by estimating the strength and confidence of the relationships (similar to edges in a graph theory approach) among those components, using a positive or negative rating scale (using +, ++, and +++ for positive relationships, and −, −−, and −−− for negative relationships) to quantify relationship strength. Confidence in each edge was provided on a scale of 0.25 for "unsure," 0.5 for "weakly confident," 0.75 for "somewhat confident," and 1 as "fully confident" (Gray et al., 2013). This measure of ambiguity about the effect of an impact

TABLE 1 Number of participants, terms, centrality scores, and similarity indices for stakeholder groups

	Academic	NGO	Government
Number of participants in each group	11	12	16
Components	24	22	21
Total connections	71	46	44
Density	0.129	0.100	0.105
Connections per component	2.958	2.090	2.095
Number of driver components	5	4	3
Number of receiver components	0	0	3
Number of ordinary components	19	18	15
Complexity score	0	0	1

Abbreviation: NGO, nongovernmental organization.

provides the "fuzzy" in FCM and allows for more nuanced models (Gray et al., 2013). The model was drawn on a whiteboard by the workshop facilitator, while another researcher simultaneously inputted connections into the Mental Modeler software (Figure 2).

TABLE 2 : A list of oyster ecosystem services used to seed the conversation

Initial terms
Storm surge protection
Biodiversity
Nutrient cycling
Water quality
Food and fisheries
Economy and job creation
Habitat and structural complexity
Luxury items (ex. pearls)
Oyster farmers
Coastal residents
Engineers
Educators
Restaurant establishments
Shell donation programs
Local government
City and municipal beach management
Spat recruitment and settlement
Seed stock
Fish recruitment and larval settlement
Sedimentation

2.2 | Data analysis

The FCM software Mental Modeler (http://www.mentalmodeler.com; Gray et al., 2013) was used to create the constructed model and output summary statistics. These data included the number of elements, the centrality of each individual component, and the role of each component in the model (i.e., driver components, ordinary components, receiver components). The models and their associated summary statistics were then used to compare differences and similarities among groups. Specifically, for each mental model, we calculated mean complexity, mean number of drivers, and mean number of components. We also calculated the density of the model, the connections per model component, the complexity of the model, the number of components in the model, the number of connections within the model, and the number of each component type.

A model's complexity is expressed by the ratio of receiving variables compared to transmitting variables. When a model is complex, it has a high number of receiving variables, indicating that the model is subject to external influences (e.g., the number of components influencing the system is greater than the number of components the system influences). The reverse, when there are a greater number of transmitting variables than receiving variables indicates a unidirectional flow of

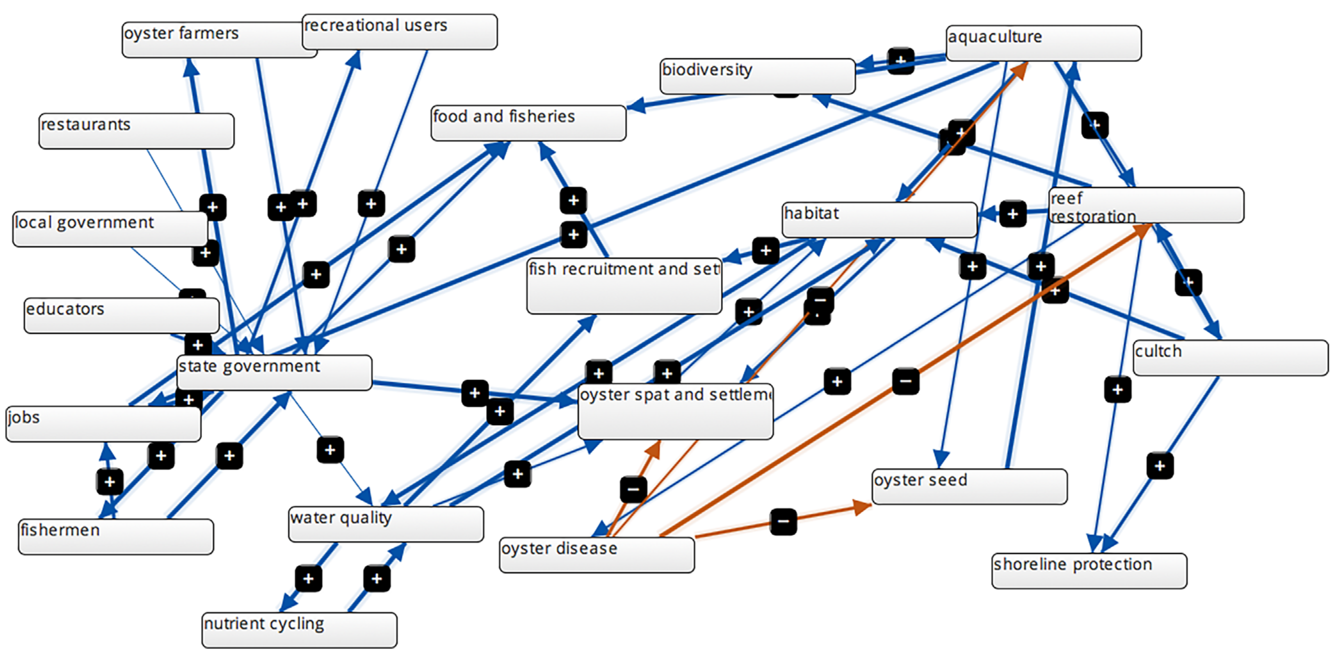

FIGURE 2 An example of a raw mental model from this study. This model was generated from a session with the Government Group

TABLE 3 : List of top 10 ecosystem services by centrality value per stakeholder group

Academic		NGO		Government	
Term	**Centrality score**	**Term**	**Centrality score**	**Term**	**Centrality score**
Oyster farms	9.83	Habitat structural complexity	6.45	State government	7.91
Restaurant	9.39	NGO	4.99	Habitat	6.83
Food and fish	9.06	Water quality	4.81	Aquaculture	6.32
Coastal residents	8.59	Aquaculture	4.79	Water quality	5.37
Habitat	7.06	Coastal residents	3.65	Reef restoration	5.24
Local government	5.36	State government	3.49	Jobs	3.65
Predators and pests	5.23	Fish recruitment and larval settlement	2.65	Food and fisheries	3.6
Jobs	5	Biodiversity	2.65	Fish recruitment and settlement	3
Water quality	4.7	Nutrient cycling	2.5	Oyster disease	2.99
Disease	4	Researcher	2.34	Cultch	2.99

Abbreviation: NGO, nongovernmental organization.

TABLE 4 : Novel and endemic components added to models by a group

Organization type	Academic	NGO	Government
Total terms added	Restaurant, predators and pests, jobs, disease	NGOs, aquaculture, state government, researchers	State government, reef restoration, jobs, oyster disease, clutch
"Endemic" terms added	Restaurant, predators and pests	Researchers	Oyster disease, clutch, reef restoration

Abbreviation: NGO, nongovernmental organization.

information out of the system and a hierarchical knowledge structure (Özesmi & Özesmi, 2004; Williams et al., 2020). The connections score is the total number of edges between nodes. By definition, the more edges, the higher the amount of interaction there is between the components of the model (Özesmi & Özesmi, 2004). The model density refers to the number of edges within the model (the connections score) compared to the number of all possible potential connections among nodes, and some studies have suggested productive management strategies are found within groups with a higher density score (Hage & Harary, 1983; Özesmi & Özesmi, 2004).

We also focused on components' centrality score. Centrality is the absolute value of the influence of variables for each component and is a key measure to indicate not only the connections among components, but the weights of those connections (Özesmi & Özesmi, 2004). The higher the degree of centrality, the greater the influence of the component on the dynamic behavior of the model (Williams et al., 2020). We recorded the 10 most central components for each model, as well as the number of times a component appears in the top 10 centrality list of any model.

Using the list of the top 10 central components, we calculated both Jaccard's similarity index and the Bray-Curtis dissimilarity indices for all pairwise comparisons using the R package SpadeR (Chao & Shen, 2010; Supplement 1). We used two similarity indices: Jaccard's, which utilizes the presence–absence of shared terms between different stakeholder groups, and the Bray-Curtis dissimilarity index, which leverages a term's centrality score within a stakeholder group's ranking (in effect being analogous to the abundance of a species within a community, Gardener, 2017). Additionally, we calculated the "N-community" similarity indices for the entire community data set using both the N-community Jaccard similarity index (presence/absence data) and the N-community Bray-Curtis index (using absolute abundances), because these matrices can reveal patterns of similarity not evident within pairwise comparisons (Chao & Shen, 2010).

3 | RESULTS

We found substantial variation in how stakeholder groups view oyster ecosystem services. The richest model in terms of density and number of components was made by the academic group. The NGO and the government groups had similar levels of model richness.

"Habitat Complexity" and "Water Quality" appeared as key model components, as they had high centrality scores and were in the top 10 centrality scores for all three stakeholder groups (Table 3). These components were followed by others related to biodiversity (e.g., reef restoration and "fish recruitment"), pointing to the influence of oysters on fish and invertebrates, and "Coastal Residents" signifying that oyster ecosystems exist as coupled social-ecological systems. Four major driver components were revealed: "Environmental NGOs," "Engineers," "Sedimentation," and "Local Government." Each of these terms was on the initial list of potential nodes. All groups rejected the component "Pearls," indicating that the interviewees were critically assessing the initial list of terms. In addition to these initial terms, each organization contributed its own set of novel or "endemic" components to the models, which were related to the group's particular interests (Table 4).

The pairwise diversity indices indicated relatively low levels of similarity across stakeholder prioritizations. The Jaccard coefficients, which are based on presence or absence of shared components, ranged from 0.31 to 0.33 (with 1 being total overlap). Using the Bray-Curtis analysis, which considers the centrality scores showed that the pair with the most overall was the NGO/Government couple with a dissimilarly index of 0.51 (Supplemental 1). The estimated N-community indices which measure diversity across the system as a whole resulted in similar levels of lower similarity using the Jaccard's (0.29 ± 0.01) than with the Bray-Curtis (0.43 ± 0.04).

4 | DISCUSSION

This study revealed that stakeholder groups perceive ecosystem services provided by oysters differently. These differences manifest themselves in three ways. First, stakeholders differ in the unique terms incorporated into their respective mental models. Second, the centrality scores ascribed to each component differed across stakeholder groups. Last, the arrangement of the terms, or the model topologies, differed. Together, these differences highlight how stakeholder groups, who all work with the same species, and in many cases closely collaborate in that species' management, retain fundamentally different mental organizations of the ecosystem services provided. However, despite these differences across terms and topologies, there are some similarities across stakeholders with the terms "water quality" and "habitat/structural complexity" emerging as components with consistently high centrality scores.

By using a mental modeling approach that included a quantitative and qualitative approach, we have gained insight into not only the species, processes, and stakeholders that interviewees find important, but also by putting them in a quantitative framework we are able to ascribe specific centrality scores and leverage analytical methods from community ecology to understand how related these ecosystems of ideas are. The 'fuzzy' in FCM allows us to evaluate the stakeholders' perceived strengths of connections. This makes explicit the conceptualization of flow within the system and by extension helps to highlight areas that small interventions may bring about large management impacts (Williams, 2020).

The novel components added often reflected the stakeholder groups' policy or institutional mandates. In doing so, they displayed a sense of stakeholder agency within the process by customizing the network to reflect their views of how various oyster ecosystems worked. For example, the government stakeholder group added "Seed," "Clutch," and "Spat Settlement" highlighting their keen interest in aquaculture, while the NGO added both "Researchers" and "State Government" indicating their position as a boundary spanning organization with active roles in both the research and the policy communities. These "endemic" terms show what is unique, what is special, and what is integrated into each stakeholder groups' oystersystem construction.

The four most important driver components across all of models were "NGOs," "Engineers," "Local Government," and "Sedimentation." The NGO employees we interviewed exercise influence on policy, monitoring, and outreach. Likewise, engineers are responsible both for the creation of reefs through restoration efforts and the destruction of reefs through dredging. In a similar vein, local governments are capable of being simultaneously responsible for policies that both enhance and reduce oyster populations, depending upon their priorities at a given time. This is by far the most compelling evidence of just how complex the issues are surrounding oyster ecosystems. The result of "Sedimentation" as a driver was somewhat surprising—it can represent an avenue of exposure of harmful pollutants to oysters (Gifford et al., 2004) and is driven mainly by land use and development (Squires, 1992). Ultimately, the inclusion of "Sedimentation" as a driver in models might be an artifact of the way we conducted our mental modeling exercise, as it was one of the terms introduced to participants (Table 2). Model density and complexity were largely inconclusive and of little use in making assumptions about the stakeholder groups themselves.

While some terms resonated among all stakeholder groups, there was substantial variation both within and among groups, and there were a large number of single-use components (10 out of 19 total components). The most frequently cited components were "Water Quality" and "Habitat/Structural Complexity" which appeared in all three lists. These findings suggest that while there is disparity in the conceptualization of ecosystem services among groups, those differential rankings do not mean that there is no common ground. Rather, by looking at how these terms appear in the conceptualizations of different stakeholders, we find that focusing only on stakeholder optima (e.g., the top ranked of each stakeholder group) we miss opportunities for collaboration along global (system wide) optima terms.

Throughout these analyses, we looked at how three different stakeholder groups contextualize the ecosystem services of oysters. While this is a critical way to assess efficiencies and linkages across these stakeholder groups, there are aspects of this work which must be treated with caution. There are multiple potential causes for unforeseen driver variables. One possible reason could come from the artificial aggregating of different components in a single term, such as "Local Governments." This potentially could contain both "Local Planning Boards" and "Local Conservation Officers" being responsible for the construction of buildings (i.e., aquaculture facilities) and oyster reefs, respectively. Another potential cause for unforeseen drivers could be interviewer fatigue, and that toward the end of the sometimes 2-hr session, the complexity of the model might lead interviewees to fail to critically examine all variables. Similarly, these interviews are dynamic, and often there is a vociferous and free-flowing stream of ideas. Within-group, power dynamics may lead to those with less social capital feeling unwilling or unable to challenge the proclamations made by their louder, senior (often white and male) colleagues (Femdal & Solbjør, 2018). Future research plans could better capture this by incorporating a larger group of researchers within groups to chronicle these ideas or use smaller interview groups. Additionally, and importantly, the temporal stability of these models remains to be tested. Finally, we recognize that the stakeholders included only represent a subset of the available members of the oyster system community. We therefore suggest that moving forward additional research be conducted to provide an avenue for these voices to be included in the modeling of the oystersystems.

One strength of FCM specifically, and mental modeling in general, is their ability to connect stakeholders together and to allow those conversations to influence conservation and management policies (Biedenweg, Trimbach, Delie, & Schwarz, 2020). For example, in Wade and Biedenweg (2019) used mental modeling to explore differences among fishers, NGOs, and policymakers, finding that there were significant differences among groups structured around specific goals and outcomes, suggesting the need for greater knowledge integration. Similarly, in the Philippines Horowitz, Pressey, Gurney, Wenger, and Pahang (2018) showed that mental models illustrated how different stakeholders' perceptions about declines in fish stocks were exacerbated through lack of knowledge sharing. Finally, Gray et al. (2014) examined local versus national perceptions of climate change finding that, again, there were challenges in integrating local values into national frameworks. While all three results indicate variation among stakeholders' perceptions, an optimistic reading of the papers also suggests that mental modeling lays explicit these mental conceptualizations and therefore offers an opportunity to find areas where small policy interventions at critical points in the models can have disproportionate, and positive, impacts on conservation and management outcomes (Williams et al., 2020).

While FCM and Mental Modeling are both powerful tools, they are based on individual perceptions. Thus, it is essential to include a discussion about their limitations and potential confounding factors. As each model was created through separate interviews, without a scripted narrative, it is difficult to lead them in the same standardized manner. All interviews were conducted by the same researchers (J. D. and A. H.), which decreases the variability among how each interview was structured. However, differences in how the conversations were moderated could influence the responses of the participants. Each of the participating stakeholders was recruited through similar forms of communication (i.e., email) and snowball sampling (e.g., respondents were asked who else should be in the room for these conversations), which reduces variation between groups and helps to ensure each started with the same amount of information. Finally, it is important to recognize that perceptions and values are not the same thing. For example, a group could perceive that a component was part of the system, yet not place a heavy value on that. For example, both NGOs and Academic stakeholders introduced the term "engineers" into their mental models; however, neither group's models gave that term a high centrality score (e.g., .15 for NGOs and .99 for Academics), suggesting that while both groups recognized that engineers needed to be included in how oystersystems work particularly as drivers, they both agreed that other components were more interconnected to the system.

4.1 | Policy implications

Focusing on commonalities among these expert stakeholders provides insight into the development of robust and effective management plans (Bennett et al., 2017). Our results are qualitatively similar to other researchers working with oyster stakeholders who have described some of the complex and challenging dynamics underlying the management of these valuable bivalves. Looking at Chesapeake Bay (USA) oyster stakeholders, Freitag, Vogt, and Hartley (2018) found that despite differences in topology, there were similarities across stakeholder groups and that these similarities facilitated the transfer of knowledge across individual actors. While Holley, McComas, and Hare (2018) found variation within New York City area oyster stakeholders' values, there were themes that ran across groups around which restoration plans may coalesce. Similarly, a survey of Gulf Coast (USA) oyster stakeholders showed divergence among stakeholders among preferred oyster ecosystem services, yet those same stakeholders also expressed a core set of preferences centered around funding, enforcement, and appropriate site selection (La Peyre et al., 2012). More broadly, Vasslides and Jensen (2016) showed a similar phenomenon in estuarine stakeholder groups, where again, a limited number of consistent ecosystem services were retained across the system despite considerable variability in the individual stakeholder group's mental models.

This study highlights the importance of understanding different groups' perceptions of how systems are organized to improve the efficiency of management efforts. Our investigation of key stakeholders' views suggests that one potential avenue to explore is that collaborations should focus on global optima even if that involves emphasizing ecosystem services, which, at the stakeholder group level, are not most central. By extension, these shared ecosystem services may represent incipient points of collaboration for organizations and institutions interested in comanagement or prioritizing funding opportunities.

In the context of knowledge systems, our work presents a path forward that explicitly includes views from multiple stakeholders, which is a hallmark of "legitimate" knowledge being produced (Cash et al., 2003). This knowledge may ultimately reduce representational gaps within management and provide more cohesive management overall (Cronin & Weingart, 2019). Factoring in knowledge about shared concepts and organizations that were identified by all of our stakeholders (e.g., that water quality, and habitat complexity represent key components of oyster ecosystem functioning) may support management efforts that are likely to be more efficient and successful because stakeholders agree on their importance and will be willing to take action (Sterling et al., 2017). However, identifying that these gaps, or similarities, exist is the first step. To fully understand the motivations underlying the models' topologies will require more in-depth qualitative techniques such as further interviews, photo voice exercises (Michaelis, Walton, Webster, & Shaffer, 2020), or participant observational engagements out on the water.

Finally, our work, while situated within the context of eastern oysters in the Northeast of the United States and in Rhode Island specifically, speaks to a larger conversation about ecosystem services and stakeholder integration. An established theme in the literature is that conflict can arise when stakeholder groups hold strong opinions about resource management, and when those opinions are viewed as being oppositional (de Juan, Gelcich, & Fernandez, 2017; Harrison et al., 2019). Our work demonstrates a methodology that makes these opinions more explicit, and in theory, can illustrate areas where there is overlap among mental models. Understanding the kinds of ecosystem services that people expect out of the environment or a specific species such as water quality, as well as the topology of the relationships among those services, such as having habitat quality be connected to a variety of components, are critical early steps toward finding common ground and helping to speak clearly about what winners and losers in perceived conflicts might face (Daw et al., 2015), although additional research should be done as to highlight the motivations underlying those model topologies and similarities. Cultural ecosystem services, in particular, may offer shared ground around which management plans can be established (Darvill & Lindo, 2016) as they are difficult to quantify and therefore can reframe the conversation to include strong motivating forces such as a sense of place and identity (Hausemann et al., 2016).

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Research design: Joshua Drew; Data gathering: Joshua Drew, Austin Humphries; Data analysis: Joshua Drew, Beryl Kahn, Montana Airey, Nicolas Locatelli; Manuscript preparation: Joshua Drew, Austin Humphries, Beryl Kahn, Montana Airey, Nicolas Locatelli; all authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data will be archived at the SUNY College of Environmental Science and Forestry's Dataverse upon acceptance of the manuscript.

ETHICS STATEMENT

Interviews were conducted under the approval of the Institutional Review Board of Columbia University issued to JD Protocol Number: IRB-AAAR7058.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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