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Human Dimensions of a Participatory, Collaborative Modeling Process - Oysterfutures

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This thesis is dedicated to the stakeholders of OysterFutures. Without you, none of this would have been possible.

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For Troy – for picking me

For my committee and VIMS friends – for allowing me to pick them

For my family – who had no choice in the matter, but have loved my anyways

And for Charlie – who will always be my number one pick

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ABSTRACT

Participatory, collaborative modeling processes represent a unique decision-making technique within natural resources management that allows for the combination of stakeholder involvement with the analytical and predictive power of scientific models. The continued use of participatory modeling within decision-making processes depends in part upon the willingness of stakeholders to participate. Continued participation of stakeholders is key to the persistence and overall success of these processes, and yet limited information exists concerning the impacts of these processes on participants. The consideration of human dimensions advances our understanding of the design and function of participatory modeling processes, including their ability to create consensus outcomes, their capacity to integrate natural and social sciences, and their capability to advance sustainable natural resources policy and management. Within this thesis, I analyzed stakeholders' advice and communication social networks and their attitudes towards scientific models to better understand the impact of these participatory modeling processes on participants.

I found that the development of group cohesion was more heterogeneous than previously thought. While there was a significant increase in advice ties between OysterFutures members, silos of advice within stakeholder groups remained. There was also a high level of between-stakeholder group advice ties that existed prior to the OysterFutures process. This history between stakeholders and stakeholder groups is also thought to have impacted the development of advice ties. Lastly, the transition of the advice network structure

over time supports arguments in the literature that suggest that different network structures are necessary at certain time points during participatory processes.

Stakeholder group silos also persisted within the communication network. These silos are thought to have helped stakeholder groups develop their own attitude towards scientific models based on their unique “way of knowing”. As a result, attitudes towards models were significantly different between stakeholder groups. This strength of stakeholder group impact on attitudes likely limited overall changes in attitudes towards models over the course of OysterFutures. The importance of considering social network structure of participatory modeling processes was demonstrated through results that certain brokering network positions significantly impacted attitudes towards models. Methods to facilitate more between group communications during participatory modeling processes could help mitigate the strong impact of stakeholder group membership on attitudes. Overall, results for attitudes towards models support the idea that models are acting as “boundary objects” that help facilitate discussion during these processes.

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CHAPTER 1 - INTRODUCTION – OYSTERS IN THE CHESAPEAKE BAY – CONTEXT FOR OYSTERFUTURES

The Eastern oyster, *Crassostrea virginica,* plays an important ecological, economic, and cultural role within the Chesapeake Bay. Oysters provide ecological benefits to the Chesapeake Bay estuary through the addition of hard bottom habitat, enhanced water filtration, and shoreline stabilization (Piazza et al. 2005, Beck et al. 2011, Wilberg et al. 2017). These ecological benefits overlap with oyster's economic benefits, which include providing habitat for commercially valuable finfish or invertebrate species and supporting an active commercial fishery (Grabowski and Peterson 2007, Beck et al. 2011). The cultural benefits of oysters to the Chesapeake Bay include supporting a traditional way of life for watermen (Chesapeake Bay fishermen) and providing an important connection to the Chesapeake Bay to those living within or visiting (Ishikawa and Kennedy 2014, Freitag et al. 2017).

The noted reduction in oyster populations within the Chesapeake Bay since the late 1800's has threatened the ability of oysters to provide these benefits (Kennedy and Breisch 1983, Keiner 2009, Wilberg et al. 2011). The decline in oysters within the Bay has been attributed to a combination of high harvesting, reduced water quality and disease (Kennedy and Breisch 1983). Since the first noted decline in oyster harvest after an 1885 peak of 15 million bushels (Keiner 2009), managers and policy makers within Maryland and Virginia have used a variety of legislative, management, and policy actions to bolster the ecologic, economic, and cultural benefits associated with large oyster populations. Determining how to manage the oyster population to achieve these goals has historically been a point of contention. As early as the 1900's, Maryland conservation commissioner Swepson Earle equated oyster's "political entanglements" within the region to the "havoc" reeked by Helen of Troy in starting the Trojan War (Keiner 2009). The diversity of inputs and the history of disputes between different stakeholder groups, most notably and violently, the "Oyster Wars" of the 1940's and 1950's where watermen and law enforcement exchanged gun fire, have led to the common perception of division within the community over how oysters should be managed (Wennersten 2011, Freitag et al. 2018).

Evidence of this division exists within the management of oysters today. In the late 1990's, after oyster diseases MSX (*Haplosporidum nelsoni*) and Dermo (*Perkinsus marinus*) further reduced oyster populations, Virginia and Maryland considered, but ultimately rejected, the introduction of a nonnative oyster species, *Crassostrea ariakensis*, into the Chesapeake Bay as a replacement for the native oyster (National Academies of Science 2004, Paolisso and Dery 2010). The rejection was praised by environmental groups, but some watermen expressed frustration over the decision, especially when the native oyster populations were then at an all-time low (Blankenship 2009). Since then, both Virginia and Maryland have become more proactive in managing oysters towards the goal of increasing the overall number of oysters in the Bay. Virginia has enacted policies that have made the Commonwealth a leader in oyster aquaculture and oyster seed production from hatcheries (Schulte 2017, Hudson 2018). The Commonwealth's rotational harvest practice (i.e., where regions are closed for a set amount of time to let public grounds recover from harvest pressure) and shell-planting program have created a “put-and-take fishery” that is supported by the state (Schulte 2017, p. 13). Within Maryland, new oyster policies represent a change in management strategy. The transformation of Maryland’s aquaculture policies, following the lead of Virginia, provide an example of this strategy change (Ishikawa and Kennedy 2014).

The history of oysters within Maryland is one focused on public oyster grounds. Early advocates for privatization of oyster beds within the state were confronted with heavy pushback from watermen working on the water who were concerned about large industries taking ownership of the Bay (Keiner 2009). The desire for access to public fishery grounds, which some watermen considered their God-given right (Keiner 2009), is still a driving force behind much of the conflict surrounding oyster management and policies today. Access and availability of oyster grounds are driving unease surrounding changes in oyster aquaculture laws and large-scale oyster restoration operations in Maryland.

Updates to Maryland aquaculture laws since 2005 have eased historic restrictions on the private cultivation of oysters on public bottom. The combination of streamlined leasing applications and state financial and logistical support has led to a boom in aquaculture oyster production (Green et al. 2013, Kobell 2017). Despite the economic benefits, conflict has arisen between commercial watermen, waterfront landowners, Maryland recreationists and private aquaculture harvesters over aquaculture’s increasing use of public bottom (Wheeler 2018). Watermen voiced concern over the potential interference of leases with crabbing and fishing, reducing their profits, and recreationists and homeowners have expressed issue with oyster cages impeding navigation and diminishing water views (Wheeler 2018). These concerns have led to individual counties in Maryland attempting to limit the growth of aquaculture (Wheeler 2018).

In 2014, the Chesapeake Bay Watershed Agreement, a joint multi-state and federal effort, outlined efforts toward native oyster habitat and population restoration in 10 Bay tributaries by 2025 (Chesapeake Watershed Agreement 2014). Enacting the agreement within Maryland has consisted of extensive oyster reef building and oyster seed distribution in five tributaries, four on the Eastern Shore divided between the Choptank River Complex (Harris Creek, Little Choptank, and Tred Avon River) and the Manokin River, and one within the Potomac River on the Western Shore (St. Mary's River) (Wheeler 2018, WBOC 2018). Restoration in these tributaries includes creating no-harvest sanctuaries which allows oysters to grow uninterrupted, a management strategy favored by environmental groups who have called sanctuaries an "insurance policy for the survival of oysters in the Chesapeake" (Wheeler 2018). Watermen have criticized the loss of access to some of the historically-best oyster harvesting grounds and the high price tag of restoration (Wheeler 2018). Objection from watermen groups to the head of Maryland's Department of Natural Resources (DNR) and the Governor's office led to the temporary halting of restoration efforts within the Tred Avon in early 2016 (Wheeler and Kobell 2016). Restoration efforts were stagnant until August 2016 when the Oyster Advisory Commission (OAC), a multi-stakeholder group charged with advising DNR on all matters relating to oysters, recommended efforts be restarted (Turque 2016, HB 133 2007).

Further conflict occurred in early 2017 when a draft DNR plan that would open 11% of state sanctuaries to rotational harvest (i.e., where areas are opened at different schedules to allow time for oysters to recover after harvest pressure) was proposed at an OAC meeting (DNR 2017, Dance 2017). Watermen praised the move that would increase their access to harvestable bottom whereas environmental groups said opening sanctuary grounds lacked any scientific justification (Dance 2017). Although DNR called the proposal a working draft, Maryland lawmakers quickly passed legislation that barred any changes in sanctuaries until a joint state-University of Maryland Center for Environmental Science stock assessment on the oyster population was complete (Wheeler 2017, HB 924 2017). Released in November 2017, the stock assessment reported that Maryland's overall adult oyster population has reduced by 50% in the last 18 years (Wheeler 2018).

The conflict in managing oysters within Maryland is not due to different goals amongst the stakeholder groups. Paolisso and Dery (2010) found that stakeholder groups who have a stake in the management of oysters within the Chesapeake Bay have similar goals of a larger oyster population and cleaner water. Differences exist in the manner in which these goals are accomplished, the specific management steps.

Part of the contention over management options is related to the way in which management decisions are made. Maryland DNR possess authority for oyster management within the state. When developing management options and approaches, DNR consults relevant stakeholders. DNR then develops fishing regulations and policies which are subsequently subject to public comment. Final regulations and policies are then selected and implemented by DNR. This style of decision-making is characterized by top-down decisions. These decision-making approaches place the "best available science" at the center of the decision (Reed et al. 2018). Although efforts are made to solicit stakeholders' point of view into recommendations, like through the Oyster Advisory Commission, this style of decision making would not traditionally be considered "participatory", although this is debated in the literature (Rowe and Frewer 2000).

Recognition of the importance of increasing stakeholder involvement in the decision-making process has existed since the 1960's (Chase et al. 2004, Stanghellini 2010). Participation has been recognized as especially important when addressing natural resource management issues, which are increasingly characterized as "complex, unpredictable, open ended or intractable" (Head and Alford 2015, p. 712). By involving stakeholders more in the decision-making process for natural resource management issues, participatory, collaborative processes are enhancing procedural justice. Procedural justice is the perceived fairness of the way in which decisions are made (McFarlin and Sweeney 1992). Including stakeholders in the decision-making process makes them more committed; they understand how and why certain decisions are made and how the process works to incorporate and include their insights (Konovsky et al. 1987). Due to enhanced procedural justice, collaborative, participatory processes are theorized to have increased capacity to reduce between-stakeholder conflict, build trust, facilitate learning, and lead to management or policies decisions that are more likely to be implemented and supported in the long term (Reed 2008, de Vente et al. 2016, Reed et al. 2018).

Overview of Participatory, Collaborative Modeling

The benefits associated with collaborative, participatory approaches led to interest among a group of academics to apply a similar process to the management of oysters within the Chesapeake Bay. OysterFutures, a collaborative, participatory modeling process, was created with an overall goal to improve the sustainability of natural resource management. To accomplish this goal, OysterFutures developed a quantitative description of a natural system (the Choptank River Complex referred to as “the Choptank”) that sought to integrate stakeholder objectives and values into a set of consensus management recommendations. The setting of the Choptank was selected due to the high concentration of state and federal restoration efforts, the presence of which has resulted in stakeholder conflicts. The impact and relevance of participatory processes are enhanced if they can be integrated into a “broader political and social process or agenda” (Röckmann et al. 2012, p. 1075). The Choptank, therefore, offered a unique opportunity to introduce an enhanced participatory tactic of decision making that could incorporate a range of stakeholder points of view through quantifying the oyster’s complex ecological, economic, and cultural dynamics.

Collaborative, participatory modeling represents an extension of traditional participatory approaches where stakeholders' information, knowledge and values are incorporated "into an otherwise purely analytic modeling process" (Voinov and Gaddis 2008, p. 197). These processes use a scientific model to help facilitate and format discussions between scientists and stakeholders regarding management and policy areas of interest (Wondolleck and Yaffee 2000, Röckmann et al. 2012, Voinov and Gaddis 2008). The ability of these processes to provide scientific information and support in investigating and evaluating stakeholder management and policy inputs has led to their increased use (Schmitt Olabisi et al. 2014). The flexibility of these processes regarding how and how often they involve stakeholders has also furthered their increasing usage. The variety in the level of stakeholder involvement during modeling stages and the inclusion of stakeholder groups allows for specification in problem definition (Hare et al. 2011, Voinov and Gaddis 2008, Basco-Carrera et al. 2017). In the best-case scenario, the literature emphasizes the importance of stakeholder direct involvement in the model building, the formulation of modeling scenarios and options, and the assessment of the efficacy of these options (Basco-Carrera et al. 2017).

<u>OysterFutures</u>

The OysterFutures participatory, collaborative modeling approach was based on a similar project that took place on the Gulf Coast of the United States. FishSmart brought together a group of stakeholders with interest in the recreational King mackerel fishery to develop objectives for the fishery, options for how those objectives could be met, and performance measure to assess success (Wilberg et al. 2009, Miller et al. 2010). From this process, OysterFutures embraced FishSmart's careful selection of stakeholders, their use of neutral facilitators, the consensus-based decision-making process and definition, and the use of facilitated, closed workshops in order to solicit information, suggestions, and feedback on the quantitative model (Wilberg et al. 2009, Miller et al. 2010, Ihde et al. 2011).

Selection of stakeholders was one of the preliminary steps in the OysterFutures process. Full involvement and commitment of stakeholders is essential in providing consistent representation of views for model building and evaluation (Voinov and Gaddis 2008). Due to the level of importance, selection of appropriate stakeholders is difficult and requires significant resources, time, consideration of local norms, use of local recruiters, and focus on an issue that has widespread interest (Mikalsen and Jentoft 2003, Wondolleck and Yaffee 2000). A similar selection process to FishSmart was used which evaluated the "history, perspectives and relationships" of the stakeholders to the oyster fishing community in the Choptank (Miller et al. 2010, p. 427).

The oyster fishery "community" in the Choptank is a "multidimensional, cross-scale, social-political…network" (Carlsson 2000). The close-knit community of the Choptank oyster fishery made the recognition and selection of leaders and potential representatives within each stakeholder group less challenging. Individual participants were selected by either reputation (i.e., known opinion leaders, agency representatives, organizational leaders) or snowballing (i.e., reference by another stakeholder based on their having a different perspective) (Sabatier et al. 2005). To start the process, lead Principal Investigator (PI) Elizabeth North personally called, emailed or visited 30 watermen, 2 aquaculturists, and 2 state or federal agency representative (34 stakeholders out of the total 60 stakeholders interviewed) to gain recommendations and gauge interest in participation in the workshop group. The PI lives in the fishing community, was formerly married to a waterman, and remains a familiar name and individual within the watermen community. The PI created a large master list of potential representatives of the stakeholder groups to be included in the OysterFutures process. To be considered, individuals had to reflect the community they were chosen to represent; they had to be individuals who others looked to and listened to and would be seen as valid representatives of the broader stakeholder groups' interests. Individuals also had to be willing to listen and cooperate during the process. This master list was then discussed by the co-PIs (scientists and facilitators) until a final list and alternate list was created based upon the best judgement of the co-PIs. Representatives from all participating stakeholder groups (commercial watermen, aquaculturists, recreational fishermen, environmental groups, government and management, seafood buyers, scientists) resulted in twenty-nine different participants over the course of OysterFutures (new members added due to turnover) and scientists.

Even though stakeholders committed to the entire OysterFutures process, some ***turnover and absences*** were expected, although strongly discouraged by the facilitators. The turnover or introduction of new stakeholders can hinder “the development of positive working relationships between stakeholder groups” (Ihde et al. 2011). Stakeholders from the alternate list were selected if a participant who was a member in their stakeholder group left the process. Additionally, some stakeholders designated an alternate to attend in their absence, leading to the inclusion of both stakeholders’ input in the model. By a lesson learned from FishSmart, compensation was provided for stakeholders who missed work to participate in the meetings to lessen the financial burden of meeting attendance (Miller et al. 2010).

The selection of ***neutral facilitators*** was another aspect of the collaborative modeling process that was emphasized in the literature and incorporated into the OysterFutures process. Voinov and Gaddis (2008) and others have emphasized the importance of an independent facilitator as a way to reduce bias in the process and create an even playing field from which all stakeholders have equal opportunities to participate (Wondolleck and Yaffee 2000, Sabatier and Zafonte 2001, Levine et al. 2005). Gleason et al. (2010, p. 57) said “engaging a neutral third party can help introduce a system of checks and balances” into the system and ensure that all the thoughts and feelings of a diverse group are heard. The same facilitators from the FishSmart project from the Florida State University's Florida Conflict Resolution Consortium (FCRC) were chosen for OysterFutures because of their experience with participatory modeling facilitation and their lack of history with the oyster fishery of the Choptank.

The facilitation method used by the FCRC and applied to the OysterFutures process is ***consensus-based*** and emphasizes that no ranking during the process is final until the end. Unlike other consensus-based approaches that require full agreement on any options or recommendations, the minimum threshold was support from 75% of OysterFutures members. This threshold consensus definition was unanimously accepted by the stakeholders in the OysterFutures process during the first workshop. This approach to consensus ensures that the process continues to move forward and avoids some of the stalemates that could occur if a 100% acceptability was required where "no decision would be taken if any member disagreed" (Wilson 1989, p.269). This 75% minimum was applied to all model option rankings (as the quantitative model was being built) and to the final recommendations. Miller et al. (2010) emphasized the importance of stakeholders not being locked into any votes until the final meeting. By allowing stakeholders to change their rankings based on discussions and new information, the facilitators helped ensure that stakeholders were not locked into their preliminary positions.

Stakeholders and scientists together crafted the model objectives, model components and performance measures to assess model options during nine workshops that took place over twenty-five months from 2016 to 2018. Crafting the model included determining what information is used to create the model, how and where this information was produced, determining what results the model can and cannot produce, and why those results are useful for the stakeholders in making recommendations and fulfilling their objectives (Voinov and Bousquet 2010, Podestá et al. 2013, Henly-Shepard et al. 2015). Evaluating model inputs and outputs required extensive interaction between the scientists and stakeholders, allowing modelers to take advantage of the experts in the room for data collection and validation (Schmitt Olabisi et al. 2014, Reed 2008, Voinov and Gaddis 2008). The development of the models during workshops was an iterative process, with necessary revisiting of model specifications and outcomes (Sampedro et al. 2017). This process has been shown to result in increased communication between stakeholders and the opportunity for collective learning through shared framing of the problems (Hajer 1995, Röckmann et al. 2012,).

In between meetings, scientists worked on incorporating specific options into the model for evaluation and additional input from stakeholders during the following meeting. The original topics considered within the model included larval dispersal, oyster abundance, biomass, harvest and egg production, availability of substrate, ecosystem services such as nitrogen removal, and economic costs and benefits of harvest.

Through the iterative discussion and deliberation process, additional topics of interest were incorporated into the model and existing topics were altered to better address stakeholder's interests. For example, the availability of substrate was expanded to also consider the quality of substrate. The water quality model became more narrowly focused throughout the process, concentrating on nitrogen levels as a performance metric. Most significantly, the economic element of the model was changed due to stakeholder input. When scientists presented previous work on profits in the public oyster fishery, the results were called into question by industry due to concerns over the representativeness and accuracy of the information. For example, the previous economic study took place before power dredging was permitted in Maryland. As power dredging is now a major form of harvesting, industry felt that the previous numbers weren't representative of the economic costs of the fishery today. Entire analyses related to the profits related to oyster harvesting had to be re-run and newly incorporated into the model. Lastly, a series of "what-if" scenarios were developed to predict outcomes of management or policy changes (e.g., the economic and ecological outcome of increasing or decreasing the area of sanctuaries).

Care was taken to ensure the openness, transparency, and accessibility of models during the entire process, as emphasized in the literature (Voinov and Bousquet 2010, Schmitt Olabisi et al. 2014). Performance measures and visualizations were utilized to help summarize findings of the model in ways that were salient and helpful to the stakeholders (Barnaud et al. 2013, Voinov et al. 2016).

After nine meetings, the OysterFutures stakeholder group was able to come to consensus on a set thirty recommendations for the oyster fishery within the Choptank (OysterFutures Stakeholder Workgroup 2018). Recommendations encompassed the topics of limited entry, rotational harvest, habitat modification and restoration, planting hatchery-reared spat, utilization of the shell resource, use of the consensus solutions process, business practices and marketing, taxes and fees, education and training, and areas for future research. The set of recommendations was delivered to Maryland DNR in May 2018. Any decisions on whether to implement any of the recommended changes are in the hands of Maryland DNR. Although commitment to consider the recommendations carefully was regularly communicated by the DNR leadership participating in OysterFutures, they have no obligations to implement any of the groups' recommendations.

<u>Human Dimensions of OysterFutures</u>

An objective of the NSF-funded OysterFutures project to improve the integration of natural systems models and stakeholder objectives to enhance the sustainability of natural resource policy ensured that there was accompanying social science research. The participating stakeholder's attitudes towards science, models, and local ecological knowledge and social networks were evaluated over the course of the workshops. Participatory, collaborative modeling processes have been noted for their potential to facilitate and structure deliberations among scientists and stakeholders surrounding scientific uncertainties and information (Röckmann et al. 2012). Other projected benefits of these processes include collective learning, increased legitimacy, and improved scientific understanding (Hare et al. 2011, Henly-Shepard et al. 2015). It is through processes like OysterFutures, which allow repeated opportunities for quality discourse to occur, that true learning, understanding, and formulation of common views can be produced (Calhoun 1992). By fostering increased understanding, learning, and formation of common views, participatory, collaborative processes can help address some of the challenges in the science-to-policy integration process. OysterFutures presented a unique opportunity to quantitatively measure the human dimensions of a collaborative, participatory modeling process.

Challenges of scale, lack of trust, lack of understanding, and deficient communication networks all play a role in hindering the ability of information to be included in management (Leonard et al. 2011, Weiss et al. 2012, Hoefnagel et al. 2013). Cash et al. (2003) identified three criteria (salience, credibility, and legitimacy - SCL) that impact the use and adoption of information into management. Specifically, the salience of the information as applied to the policy problem, the credibility of the information, and the perceived legitimacy of the way in which the information was developed have been recognized as perceived characteristics of information that help link “knowledge and action for environmental decision-making” (Wilson 2009, White et al. 2010, p. 222). The application of a SCL analytical framework to a participatory, collaborative process can help us understand how and to what degree these processes are creating knowledge that can be linked to action for environmental decision making (Cash et al. 2003, White et al. 2010).

In addition to assessing the evolution in stakeholders' attitudes, we used a social network analysis framework to assess the changes in the stakeholder's communication, mutual understanding, and advice networks. As fisheries management is increasingly understood as an example of governance networks, understanding the structure and functions of these networks can provide information on the functionality of management (Gibbs 2008, Hartley 2010, Leonard et al. 2011). In particular, the longitudinal element of our research, studying the changes in network structure and function over the course of OysterFutures, is a unique research opportunity and will contribute to the literature. By studying the evolution of these stakeholder networks, we can better understand how and if networks drive mutual understanding, trust-building, influence, and SCL of information.

Within this thesis, I will address questions using both data on stakeholders' attitudes and their social networks. Specifically, Chapter 2 will use the social network theory of bridging and bonding ties to understand changes in OysterFutures advice network cohesion on two levels - advice ties (i.e., who individuals consult with to formulate their opinions) internal and external to the OysterFutures membership, and advice ties within the OysterFutures membership that are between or within stakeholder group. Chapter 3 will continue to use social network metrics in addition to elements of participation in OysterFutures (e.g., meeting attendance) and stakeholder demographic characteristics (e.g., year of experience) to understand how stakeholders formed their attitudes towards scientific models over the course of the OysterFutures process. Chapter 4 will present a summary of the results, dive into overall conclusions, and present areas for future work.

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CHAPTER 2:
Network Perspective on Natural Resources Governance: Longitudinal Evolution of Bridging and Bonding Ties within a Participatory Modeling Process

ABSTRACT

Many “wicked” natural resources management problems today are utilizing more collaborative methods of decision making. Through involving stakeholders in decision-making, resource managers can induce buy-in and support for final decisions, reduce enforcement needs and prevent future conflict. These results are possible through the impact of participation on the stakeholders themselves. Participation is thought to yield increased group cohesion, where stakeholders better understand others’ perspectives. This understanding allows for social learning and the pursuit of common goals. However, participation-induced changes in cohesion have not been quantitatively determined during these processes. Using longitudinal social network analysis and quantitative modeling, we demonstrate changes in cohesion during OysterFutures, a participatory modeling process in the Chesapeake Bay. Results showed changes in cohesion were not linearly homogeneous. This article ends with a discussion on the value of using a social network approach for analysis of the human dimensions of participatory processes and areas for future research.

INTRODUCTION

The process of managing fisheries and coastal systems has been called "intrinsically diverse, complex and dynamic" (Jentoft and Chuenpagdee 2009, p. 553), all elements that contribute to the designation of these management scenarios as "wicked" (Rittel and Webber 1973). Wicked problems are ones that are difficult to define. Solutions to such problems are not straightforward; they are "inherently resistant to a clear definition" due to the multitude of involved stakeholder groups and interests (Head and Alford 2015, p. 714). The lack of a clear path forward can result in solutions relying more so on political judgements than scientific certainties (Rittel and Webber 1973, Head and Alford 2015). The application of the idea of "wicked problems" extends beyond fisheries; many natural resource governance challenges are described as "wicked", from disaster preparedness (Kettl 2009), to land management (Barkemeyer et al. 2015), forestry (Allen and Gould 1986), and water resources (Freeman 2000). In many situations, the existence of wicked problems has been attributed to differences among stakeholders, which can result in conflict (Turnbull 2006).

Due to the complex nature of these problems and the enhanced possibility of conflict, traditional techniques of government are seen as incapable of addressing and detangling "wicked" issues (Kettl 2009). Instead, more collaborative, participatory and dialogue-focused governance efforts have been proposed as a pathway forward to include stakeholders from different backgrounds and points of view (Weber & Khademian 2008, Wondolleck and Yaffee 2000, Heikkila and Gerlak 2016). Collaborative decision-making processes can take many forms and vary in the degree to which stakeholders are involved. Participatory modeling is one approach that is used to “facilitate and structure discussions between scientists and stakeholders” through including outside stakeholders in the process of scientific modeling (Wondolleck and Yaffee 2000, Voinov and Gaddis 2008, Röckmann et al. 2012, p. 1072).

The importance of these collaborative decision-making processes, including participatory modeling, comes from the inherent dialogue and deliberation fostered during the processes (Walker 2007). Dialogue refers to any communication between stakeholders that promotes discovery, learning, and understanding as primary goals (Walker and Daniels 2004). Dialogue in collaborative processes represents a form of communication that creates a shared understanding of the problem at hand from the diverse insights of those participating (Daniels and Walker 2001, Pahl-Wostl and Hare 2004). Dialogue evolves into deliberation, opening a path for communication that can critically examine ideas and discuss policy feasibility, soundness and roads towards implementation (Daniels and Walker 2001, Walker and Daniels 2004, Walker 2007).

The benefits of collaborative, participatory processes are fostered through dialogue and deliberation. Participatory modeling engages stakeholders in dialogue and deliberation through focus on a scientific model and the modeling process. By involving stakeholders in the modeling process, they are provided the opportunity to better understand the formation of the model and have the chance to include their own sources of knowledge into model formation (Voinov and Bouquet 2010, Röckmann et al. 2012). The inclusion of a diverse set of stakeholders is a cornerstone of participatory, collaborative processes (Conley and Moote 2003). Through the incorporation of a wider network of individuals in the modeling process, the literature suggests that there is an increased likelihood that solutions to the problem being addressed can be found (Aanesen et al. 2014). In addition to finding a solution, the inclusion of stakeholders into the management of their resources of interest can create more buy-in and support of the final decision, easing enforcement and preventing conflict further down the line, and helping to ensure sustainable management of the resource (Allen et al. 2013, Ostrom et al. 1999, Voinov and Gaddis 2008, Voinov and Bousquet 2010, Allen et al. 2013). The more sources of knowledge that are included, the more information stakeholders have to work towards the creation a shared definition of the issues at hand (Voinov and Bousquet 2010, Haapasaari et al. 2012, Head and Alford 2015).

The ability to create this shared definition is possible through the increased cohesion that is suggested to result among participants in collaborative processes. The act of participating in collaborative, participatory processes and taking part in the dialogue and deliberation is suggested to enhance cohesiveness among diverse individuals through increased communication and opportunity for collective learning. This is accomplished through joint problem framing over the course of iterative collaborative processes. Throughout these collaborative, participatory processes, group members begin to see each other as “us” and people outside the process as “them” (Feld 1981, Hajer 1995, Voinov and Gaddis 2008, Röckmann et al. 2012, Schmitt Olabisi et al. 2014). This cohesiveness allows the stakeholders to develop and work off a common platform to integrate multiple sources of knowledge to work towards an acceptable solution (Costanza and Ruth 1998, Roberts 2004, Habron et al. 2004, Gaddis et al. 2010, Voinov and Bousquet, 2010).

The benefits of participatory, collaborative processes have led to their increasing use to address "wicked" problems in natural resource policy. Limited work, however, has been done that quantitatively validates these benefits. In particular, the increase in cohesion between participants in participatory, collaborative processes has been presumed, but not demonstrated (Voinov and Gaddis 2008, Schmitt Olabisi et al. 2014). To examine the theorized increase in group cohesion among participants during participatory, collaborative processes, the human dimensions aspect of these processes must be studied. Determining the relationships between individuals and how they work together and rely upon each other during these participatory, collaborative processes can be accomplished by considering these stakeholders as members of a social network.

Applying a Social Network Analysis Framework to Participatory, Collaborative Processes

The field of social network analysis sees individuals as innately connected and operates under the assumption that relationships matter (Krackhardt and Stern 1988). Social network analysis looks to measure relationships (ties) among different individuals (actors or nodes). The network structure, "the sustained pattern of interaction" that results from the ties between actors, can then be measured and analyzed to better understand the nature of the relationship in question, such as friendship, advice, or communication (Wasserman and Faust 1994, Ernston et al. 2008). The prominence of the discussion of group cohesion that results from collaborative, participatory processes fits well within a social network framework. The "network" of stakeholders participating in these processes and the relationships between them can be studied through analysis of changes in the network structure. The presumed changes in the relationships between the involved stakeholders – their network structure – can be examined using the social network concepts of bridging and bonding ties. The ability to examine changes in the tie formation over time allows for a better understanding of the impact of participatory, collaborative processes on stakeholder relationships and network cohesion.

Within social network analysis, bonding ties are links between individuals in defined groups who see each other as alike (Coleman 1988, Alexander 2015). Because of the role bonding ties play within networks, they are characterized as cohesive ties. Common understanding, cooperation, and trust are necessary foundations that allow for the creation of bonding ties; it is through bonding ties that individuals receive most of their social support (Hurlbert et al. 2000, Putnam and Cross 2002, Marshall and Stolle 2004, Newman and Dale 2004). This trust and shared understanding can create a common language, a set of common rules or ways of operating that act as a solid foundation from which to engage in dialogue and deliberation (Krackhardt 1992, Newman and Dale 2004). While bonding ties are useful to create group cohesion, there is the possibility of too much cohesion. Excess cohesion has been shown to create conformity pressures, making it difficult for new ideas to be introduced (Newell et al. 2004, Coffe and Geys 2007). This excess cohesion can result in groupthink, a mode of thinking in a cohesive group when a desire for unanimity overrides any motivation to realistically appraise other course of action (Janis 1972). The acceptability of decisions from highly-cohesive groups to those outside the process may be hampered (Nelson 1989, Janis 1991).

Bridging ties play an opposite, but complementary role. Network theory classifies bridging ties as relationships that exist between individuals of different sub-groups, ties or connections between dissimilar others (Tiwana 2008). Individuals who facilitate these bridging ties are called brokers, individuals who, because of their position in the network, can aid interactions and transactions between other disconnected actors (Marsden 1982, Obstfeld 2005). Broker's network positions come with significant power; they can act as bridges or bottlenecks for the spread of information or advice throughout the network and between network sub-groups (Bodin et al. 2006). While bridging ties lack the strength and trust building present in bonding ties, they enable actors to access novel sources of information, providing a 'bridge' across divided communities or between disconnected groups (Granovetter 1973, Burt 1992, Hansen 1999).

A network characterized with many disconnected groups is said to possess high modularity. High modularity within a network can lead to the development of distinct group-specific knowledge, which can be beneficial to the overall network if these distinct knowledge sub-groups can connect (Crona and Bodin 2006). The ability to access resources and information from dissimilar individuals increases the overall resources available to the network, which can help prevent instances of groupthink, and promote innovation (Granovetter 1973, Arrow et al. 2000, Reagans and McEvily 2003, Tiwana 2008). Therefore, networks characterized by bridging connections are said to be “more likely to generate positive externalities”, what Putnam (2000) distinguishes as the differences between “getting by” (building relationships with only those individuals similar to you – bonding ties) and “getting ahead” (building relationships with individuals different from you – bridging ties) (Coffe and Geys 2007, p. 124). However, lack of connection between silos can limit innovation due to reduced access to novel sources of knowledge and a hindered ability to create common understanding (Cross et al. 2009, Bevc et al. 2015, Sayles and Baggio 2017).

The balance of bridging and bonding ties, the “favorable level and mix of different network characteristics”, within a network structure has been suggested to impact functionality of the network (Bodin and Crona 2009, p.366). This suggests that a misbalance, a network structure with too many bridging or too many bonding ties, can hinder the ability of the network to reach certain outcomes. Networks with too many bonding ties are limited in their ability to be introduced to new ideas. Networks characterized by too many bridging ties will have difficulties creating common language, assumptions and ways of operating that are necessary to build a stable foundation of trust and understanding from which to work (Newman and Dale 2007, Bodin and Crona 2009, Stein et al. 2011).

There is no one recognized optimal network structure (Bodin et al. 2014). However, social network literature has suggested that different network structures may be more beneficial within certain contexts (Reagans and McEvily 2003, Crowe 2007, Sandström and Carlsson 2008). The change in cohesiveness presumed to occur during participatory, collaborative processes suggests that the network structure of these processes will change over time. Longitudinal studies that capture a network at more than one period are rare but are necessary to study and better understand the determinants of network changes (Nestler et al. 2015). Capturing the longitudinal aspect of these collaborative processes through measuring their social networks throughout the process will enable us to understand the *evolution* of these processes and their networks. Through examining the network structure through changes in bridging and bonding ties during a participatory, collaborative process, we can better understand the presumed link between participation in these processes and increased group cohesion (Sandström and Lundmark 2016, Zheng et al. 2016, Groce et al. 2018). Within the realm of natural resource governance, a social network framework has been utilized to examine the connection between network structure and stakeholder learning, information sharing, the development of social capital, and outcomes (Floress et al. 2011, Weiss et al. 2012, Kittredge et al. 2013, Barnes et al. 2015, Bodin et al. 2017, Groce et al. 2018,). Social network analysis, however, has not been used to study changes and evolutions in stakeholder relationships and network cohesion with a collaborative, participatory process.

To study the evolution of bridging and bonding ties during a collaborative, participatory process, we examined stakeholders' advice networks. Seeking out an individual for advice suggests that the seeking actor have "some perception of the relevance of the other person's knowledge, skills and abilities in relation to the current problem" and that the named individual is seen as a legitimate source to either gain or validate information (Cross et al. 2000). Advice networks were used because they are conduits for the exchange of work-relevant information and knowledge (Wong 2007). A reduction in advice path barriers over time, as seen through increased group cohesion, could imply that previous costs stakeholders associated with seeking advice from their fellow stakeholders are reduced (Nebus 2006). Through the study of advice networks, we can better understand what knowledge and whose knowledge individual stakeholders are relying upon, and thus what knowledge the group overall has access to (Sparrowe et al. 2001, Reagans and McEvily 2003, Wong 2007). The longitudinal analysis of changes in bonding and bridging ties within the advice network allows us to understand how changes in stakeholder's reliance on each other for information changes and understand these changes relative to their participation in participatory, collaborative processes.

Participatory, Collaborative Processes – OysterFutures

The setting for our longitudinal study of collaborative, participatory processes is OysterFutures, a participatory modeling project in the Choptank

River Complex in the Maryland portion of the Chesapeake Bay. The oyster fishery “community” in the Choptank is a “multidimensional, cross-scale, social-political…network” with a history of tension between stakeholder groups on oyster management options (Carlsson 2000, Berkes 2004, p. 623). Recently tensions have been focused on the creation of three federal sanctuaries and active oyster restoration operations within three tributaries in the Choptank River Complex, Harris Creek, the Little Choptank, and the Tred Avon Rivers (2016 Maryland Oyster Restoration Update). Despite common interests in enhancing the oyster population, improving water quality and promoting economic advancement of industry members, conflict has persisted, with stakeholder groups expressing different preferences for managing the resource or what “success” would look like (Paolisso and Dery 2010). These differences are demonstrated in results from Paolisso and Dery (2010) where the authors found that acceptability of oyster restoration techniques and goals varied based on stakeholder group membership. For example, 81.8% of scientists agree that oyster harvesting should cease if it would help native oyster restoration, whereas just 11.2% of watermen (Chesapeake Bay fishermen) agreed with the same statement. One of the goals of OysterFutures was to use collaborative, participatory methods to better incorporate these different viewpoints into recommendations for the management of the oyster fishery.

The OysterFutures project consisted of nine facilitated workshops over the course of 25 months. With a mission statement of “develop[ing] recommendations for oyster policies and management that meet the needs of industry, citizen, and government stakeholders in the Choptank and Little Choptank Rivers", the OysterFutures workshops brought stakeholders together from several different stakeholder groups (watermen, aquaculturists, recreational fishers, environmental groups, and members of state and federal government agencies) to develop consensus recommendations for oyster management in the Choptank River Complex (see Figure 1) to deliver to the Maryland Department of Natural Resources (MDNR), the agency in charge of Maryland fisheries management (OysterFutures website). The inclusion of this diverse group of stakeholders was done to bolster the legitimacy of the process and any recommendations that would come from it (Kallis 2006, Krueger et al. 2012, Colvin et al. 2016).

Outside facilitators from Florida State University led the workshops. Other participatory processes have emphasized the importance of a neutral, independent facilitator to reduce bias in the process and create an even playing field for stakeholder participation during meetings (Wondolleck and Yaffee 2000, Voinov and Gaddis 2008). It is important for stakeholders to feel like they have an opportunity to contribute and be heard and a neutral facilitator can "introduce a system of checks and balances" to accomplish this (Gleason et al. 2010, p. 57). These facilitators were chosen because of their previous experience with facilitating a fisheries participatory modeling process (Miller et al. 2010) and their lack of history with the oyster fishery in the Choptank River which enhanced their perceived neutrality.

Individuals selected to participate in OysterFutures had to reflect the community they were chosen to represent, had to be individuals who others looked to and listened to, and had to be valid representatives of the broader stakeholder groups' interests (Miller et al. 2010, Irwin et al. 2011, Colvin et al. 2016). Ensuring the appropriate balance of individuals was considered essential by the OysterFutures primary investigators. Studies have shown that group composition, the distribution and diversity of appropriate knowledge, skills and expertise can contribute to the successful completion of prescribed activities (Newell et al. 2004). The diversity of individuals within the waterman community who needed to be represented and the efforts of OysterFutures primary investigators to ensure industry cooperation resulted in around 60% of the workshop group being compromised of industry individuals (n = 9 industry representatives comprised of watermen, a seafood buyer, and aquaculturists). The remaining seven stakeholder spots were filled with representatives from other stakeholder groups, although no other group was as large as the waterman group. Figure 2 shows the setup of the room during the process that ensured that stakeholders from different groups sat next to each other, something which was done to help promote communication between groups.

Even though stakeholders committed to the entire OysterFutures process, some turnover and absences were expected and occurred. The turnover or introduction of new stakeholders during participatory processes has the potential to hinder "the development of positive working relationships between stakeholder groups" (Ihde et al. 2011, p. 80). Participatory processes can create their own sort of organizational culture, a “pattern of shared basic assumptions that the group learned as it solved problems” which reflect a belief in how the participatory process should operate (Schein 1992, p.12, Moynihan 2012). The introduction of new members can be difficult on current members as they try to integrate and for the group as they try to bring the new member(s) up to speed. However, familiarity, like connections between OysterFutures stakeholders before the process, has been suggested to ease difficulties of onboarding (Van Maanen and Schein 1979, Burt 2005, Slaughter and Greguras 2009).

OysterFutures was run as a consensus-based process with a minimum threshold of 75% of participants or greater needed to approve a recommendation. Since no individual stakeholder group represented 75% of the workshop, this necessitated compromise and recommendations that could be acceptable to more than one group. This definition of consensus helps ensure that an outcome can be reached and avoids potential stalemates that could occur if a 100% acceptability was required where “no decision would be taken if any member disagreed” (Wilson 1989, p.269).

METHODS

Data Collection

We examined the advice networks among individuals participating in the OysterFutures participatory, collaborative modeling process. Twenty-nine total stakeholders participated in OysterFutures over the course of 25 months. To assess the social networks of the stakeholders participating in OysterFutures, we developed a questionnaire that was distributed at the beginning of each meeting.

Timing of the questionnaires immediately before a workshop captured changes in stakeholders' network structure and function since the previous workshop. Questionnaire completion time ranged between 15 and 20 minutes.

Stakeholders were asked who among their professional contacts they would consult before making a statement or formal testimony to a management body concerning oyster management in Maryland. The links between the actors represent directed paths of advice seeking between stakeholders. The free response through recall allowed stakeholders to name any individual, both internal and external to the OysterFutures process, as a source of advice. In addition to providing names, OysterFutures stakeholders were asked to provide stakeholder group membership (i.e., watermen, seafood buyer, scientists, journalist, etc.) of their chosen actor. Of the named individuals who were external to the OysterFutures process, if their stakeholder group was left off, researchers determined the stakeholder group of the individual via online searches. Groups were consolidated into ten categories (Aquaculturist, Seafood Buyer, Environmental Group, Facilitator, Government Official, Journalist, Recreational Fishing, Scientist, US Army Corps of Engineers (USACE), and Waterman).

The question on stakeholders' sources of advice was repeated at the beginning of each workshop which allowed us to assess changes to individual's advice networks over time. An average of twenty-one stakeholders responded to the survey at each workshop, with the range of respondents varying from nineteen to twenty-four Response rate varied across the meetings due to both variation in attendance rates and stakeholders not filling out the survey, but remained high (Response Rates: Workshop 1 – 92%, Workshop 2 – 95%, Workshop 3 – 95%, Workshop 4 – 91%, Workshop 5 – 84%, Workshop 6 – 95%, Workshop 7 – 95%, Workshop 8 – 95%, Average - 93%).

Stakeholders' advice networks were assessed at each workshop except Workshop 8. The small gap in time between Workshop 7 and Workshop 8 (see Table 1 for Workshop Dates and time lapses between them) limited potential contact between stakeholders; data gathered from this period would not have been informative of overall advice trends.

Data form a matrix in which rows are i and columns are k. Each cell (j) reflects whether Stakeholder i nominated Stakeholder k as someone they turn to for advice. Cell values of 1 indicate that Stakeholder i sought advice from Stakeholder k; values of 0 indicate no tie. These matrices are then repeated over time (t) to account for the longitudinal nature of the analyses. All stakeholders were assigned numbers to protect their identities.

After each workshop, data was imported into UCINet, a social network analysis software (Borgatti et al. 2002). The advice network was examined on two levels – the Whole Network (including OysterFutures workshop participants and people they nominated who did not participate in the workshops) and the Workshop Network (which includes only OysterFutures workshop participants). Examining the advice network on these two levels allowed for a more complete understanding of changes in cohesion. A combination of social network analysis statistical and visualization methods and generalized linear mixed modeling (discussed below) were used to test hypotheses that:

- H1 – At the Whole Network level, the network structure will grow more internally cohesive over time – resulting in more internal advice ties.
- H2 – At the Workshop level, the relative number of ties between OysterFutures stakeholder groups will increase over time – resulting in more between-stakeholder group advice ties.

E-I Index and Network Measures

Methods from social network analysis were used to quantitatively assess advice network structural aspects (Crona and Bodin 2006, Scott 2017). To investigate and describe longitudinal changes in bonding and bridging ties on two levels – Whole Network and Workshop Network levels – two E-I indices were created using UCInet software.

The E-I (external-internal) Index is used to determine the connectivity within and between selected subgroups of a network and was used as an indicator of cohesion within the advice network (Krackhardt and Stern 1988). The E-I Index subtracts the proportion of internal ties (i.e., ties between individuals in the same subgroup) from the proportion of external ties (i.e., ties to an individual in a different subgroup) and produces a value ranging from -1 to 1. A score of 1 indicates that all ties are external to the subgroup of question. Similarly, a score of -1 indicates all the ties are internal to a subgroup (Parise 2007).

Two E-I indices were created using UCINet software (Borgatti et al. 2002) to investigate and describe changes in longitudinal bonding and bridging tie formation at two levels – the Whole Network and the Workshop level. At the

Whole Network level, an E-I index was calculated to reflect the proportion of total ties, across all individuals within OysterFutures workshop participants and between OysterFutures workshop participants and non-workshop individuals. At the Workshop Network level, an E-I index was calculated to reflect the proportion of ties within and between members of different stakeholder groups.

E-I indices were primarily used to describe longitudinal changes. A Wilcoxon test for paired samples comparing the same individuals in Workshop 1 and Workshop 9 was used to determine if there were significant changes in E-I Indices at both levels.

In addition to E-I Indices, we calculated a series of general network measures on both the overall network and individual node levels of the advice networks using the UCINet software (Borgatti et al. 2002) to better understand changes in the network structure over time. Density of a binary network is the total number of ties divided by the total number of possible ties (Scott 2017). The percentage of internal network ties is more explicitly stating the E-I Index score – the number of ties internal to a group divided by the total number of ties. Isolates are nodes not connected to any other node in the network (Scott 2017).

Binomial Model

Two binomial generalized linear mixed models were created to understand how elements of workshop participation and individual stakeholder attributes impacted tie formation in the advice network. Fixed and random variables capturing changes over the course of the workshops, the time lapse between workshops, stakeholder group membership, number of advice ties listed (outdegree), and individual-level stakeholder differences were included. Results from these models provided further support to the E-I Index results from the Whole Network and the Workshop Network level. Table 2 further explains model variables. For more information on the models, see the supplementary material.

For the Workshop Network and Whole Network level, individual-level E-I indices were calculated for each stakeholder to form the dependent variable (DV). A “1” was assigned to all indices above 0 and a “0” was assigned otherwise. At the Whole Network level, a value of “1” indicated more ties to non-participants. At the Workshop Network level, a value of “1” indicated more between stakeholder group ties. Instances where the number of external and internal ties was the same were uncommon; in these instances, the binary dependent variable was coded as a “1”. Several independent variables (IV) were included to help better explain longitudinal trends in advice network tie formation on the Whole Network and Workshop Network levels.

The Workshop variable was an integer variable that represented each workshop meeting, allowing us to understand if there was a significant change in the relative number of reported internal/external advice ties over the course of the workshops. As the workshops progressed, we hypothesized that more of the stakeholder’s ties would be internal to OysterFutures and there would be an increase in the relative number of ties between stakeholder groups. The Time Lapse between Workshops variable represented the different amount of time (in days) between each workshop meeting. This variable was included to account for the different lengths of time between OysterFutures meetings. Due to circumstances beyond the control of OysterFutures organizers, the length of time between each meeting was not uniform. The literature acknowledges that participatory processes take time (Buchy and Hoverman 2000), but little is discussed about the time differences between meetings (Kallis 2006). Accounting for the non-uniform time gaps between meetings allowed us to better understand the degree of impact of participation in OysterFutures on tie formation (Conley and Moote 2003).

The last fixed variable included in both models captured individual-level differences in the number of ties reported. Stakeholders participating in OysterFutures who took the questionnaires self-reported ties. This resulted in stakeholders listing varying numbers of advice network contacts, ranging from zero to seven. Within the realm of social network analysis, this is called the outdegree, the total number of links that originate at an actor's node and is a measure of the expansiveness of the actor (Martinez et al. 2003). The outdegree captures the extent to which an actor is a "crucial cog" within the network and acts as a major channel of communication (Russo and Koesten 2004). Outdegree was included to account for any variance in the dependent variable explained by different individual-level network sizes.

An individual Stakeholder variable was included as a random effect within both models to control for individual differences in tie formation. The inclusion of the individual Stakeholder variable as random allowed us to account for the variation in individuals' tie formation, as we were not interested in the individual level differences in tie formation (Bolker et al. 2009). In addition, the inclusion of the Stakeholder variable accounted for variable participation rates (i.e., not all individuals attended all workshops).

Evidence concerning the importance of group membership in tie formation (Yuan and Gay 2006) and documented group differences in opinions on management options for oysters within the Chesapeake Bay (Paolisso and Dery 2010) guided the inclusion of a variable to account for stakeholders' group membership. Stakeholder group was only included as a variable Whole Network level model, to see if internal/external tie formation was homogeneous between stakeholder groups. Stakeholder group variables were not included in the Workshop level model due to the inclusion of a group size variable (see below), which was strongly correlated with stakeholder group fixed effects. Significant findings for this variable would suggest an individuals' stakeholder group membership significantly impacts the relative proportion of internal or external stakeholder group ties.

For the model predicting the formation of in/out ties at the Workshop level, an additional variable and interaction were added. The Group Size variable was added to account for the unbalanced membership of stakeholder groups around the table during the OysterFutures process. The design of OysterFutures purposefully gave more seats at the table to industry representatives, thus resulting in uneven group sizes. Blau (1975) and others have noted that the relative sizes of sub-groups within networks can have significant consequences for the number of internal versus external ties. Within the Workshop level model, differences in sub-group size were accounted for. Lastly, an interaction variable was added for Number of Ties Reported and Group Size, since both involved effects due to the number of potential ties.

Generalized linear mixed models were run in R using the glmer function, accounting for the binomial distribution of the response variable and the random and fixed variables (R Core Team 2015, Bates et al. 2015). Collinearity issues (where predictor variables are correlated, which can confound model interpretations and conclusions – Mason and Perreault Jr. 1991) with some of the factor levels of the Stakeholder Group variable necessitated running the Whole Network model with a subsetted Stakeholder Group factor variable. The subsetted Stakeholder Group factor variable excluded observations from individuals whose group had fewer than three members, following methods used by Crona and Bodin (2006). Collinearity issues with the Stakeholder Group variable on the Workshop level necessitated dropping this variable from consideration altogether. Results for the Whole Network level and Workshop level models are presented. Table 3 presents summary statistics for the non-factor variables in the Whole Network and Workshop Network models.

Two pseudo R^2 values were calculated to provide an estimate of the goodness of fit of the model. Pseudo R^2 values were used due to the inability to obtain appropriate estimates of residual variance from traditional R^2 methods for non-Gaussian response variables (Nakagawa and Schielzeth 2013). R^2 values were reported in two categories (Vonesh et al. 1996). Marginal R^2 accounts for the variance explained only by the fixed effects. Conditional R^2 accounts for the variance from both the fixed and the random model effects (Nakagawa and Schielzeth 2013).

RESULTS

Advice Network - Network Maps for Whole Network and Workshop Network Levels

Network maps showing both levels of the advice network – Whole Network and Workshop Network levels – from Workshop 1, Workshop 4 and Workshop 9 reflect snapshots of the OysterFutures advice network structure at the beginning, middle and end of the process (Figures 3-8). Network maps for additional workshops at the Whole Network and Workshop level are included in supplementary material (Figures 9-18).

Whole Network Level

One hundred-five individuals were named overall on the open-ended questionnaire, consisting of members of state agencies in Maryland and Virginia, federal agencies, environmental nonprofits, universities in Maryland and Virginia, Chesapeake Bay journalists, and several industry sectors (e.g. watermen, aquaculturists, seafood buyers, and recreational fishermen). The network maps indicate who the stakeholders would go to for advice on oyster related issues. In Workshop 1, the 25 OysterFutures participants (square nodes) had ties to 42 different individuals external to the OysterFutures process (circle nodes) (Figure 3). By Workshop 4, the 26 participants in this workshop had ties to 25 individuals outside the OysterFutures network (Figure 4) and by Workshop 9; the 23 participants in that workshop had ties to only 16 individuals outside the

OysterFutures network (Figure 5). This downward trend in the total number of external nodes named in the network suggests a decreasing reliance on stakeholders external to the OysterFutures process for advice as the workshops progressed.

The decrease in reliance on external OysterFutures members occurred alongside an increase in the reliance on internal OysterFutures members, suggesting growing internal cohesion of the advice network. This shift in advice reliance is demonstrated through the increased isolation of external nodes and the increased relative number of ties between internal nodes. Circle nodes (individuals external to the OysterFutures process) transitioned from playing broker roles in Workshop 1, sometimes representing the only advice path for two square nodes (Figure 3), to occupying less central positions by Workshop 9 (Figure 5). This is also demonstrated through the number of circle isolate nodes. The number of circle nodes that appear as isolates – those nodes on the side of Figure 3 that are not tied to any other node – are lowest in Workshop 1, with 34 circle node isolates. By Workshop 4 (Figure 4), the circle nodes are less central to the network, occurring more so on the periphery. The number of isolate circle nodes also has increased to 48, meaning OysterFutures stakeholders are relying less on external nodes for advice. By Workshop 9 (Figure 5), the advice network is characterized by internal OysterFutures advice ties, with 60 isolate circle nodes representing external individuals who are not a part of the advice network.

Workshop Network Level

Twenty-nine nodes made up the Workshop Network. The network maps indicate who the stakeholders would go to for advice on oyster related issues within the OysterFutures process. From Workshop 1 to Workshop 9 (Figures 6-8), we see an overall increase in the number of ties for the Workshop advice network (Workshop 1 = 36 ties, Workshop 4 = 49 ties, Workshop 9 = 56 ties), indicating that more stakeholders are turning to other members of the OysterFutures workgroup for advice. The density of Workshop level network, representing the extent to which actors are connected, also increased from Workshop 1 to Workshop 9 (Workshop 1 = 0.039, Workshop 4 = 0.055, Workshop 9 = 0.070). These results follow those suggested at the Whole Network level that stakeholders relied on other internal actors for advice more so as the workshops progressed.

The decreasing prevalence of brokers within the Workshop network suggests that this increased reliance on internal actors was occurring between stakeholder groups. Brokers were determined by locating nodes that connected individuals who would become disconnected components if either one node or one relation were removed. In Workshop 1, there were nine total brokers (square nodes) who played the role of bridges, serving as the only connection between two otherwise unconnected actors (Figure 6). By Workshop 4, only two brokers existed (Figure 7). Two brokers still existed in Workshop 9, but the increase in the total number of ties and the network density suggest that the brokers did not play as essential of a role by this final workshop (Figure 8). The decreased prevalence of brokers demonstrates that these roles are less necessary as the workgroups progress due to the increase in ties formed between stakeholder groups within the OysterFutures process.

Advice Network - E-I Index

Changes observed in the Advice network visually and through social network measures are also reflected in the two E-I Indices. Looking from Workshop 1 to Workshop 9, there is a transition at the Whole Network level from a network comprised of more external (Workshop 1 E-I = 0.364), to more internal ties (Workshop 9 E-I = -0.229) (Table 4). A paired Wilcoxon test at the Whole Network level found that the shift from Workshop 1 to Workshop 9 was significant ($p < 0.05$).

The E-I Indices for the Workshop advice network indicate that the majority of stakeholder group ties are external, meaning most ties exist between stakeholder groups (Table 4). There is a limited temporal change at the Workshop level, in the relative number of internal versus external stakeholder group ties, with ties becoming slightly more external – more between group ties (Workshop 1 E-I Index = 0.625, Workshop 9 E-I Index = 0.686). A paired Wilcoxon test at the Workshop Network level found no significant shift in the E-I values from Workshop 1 to Workshop 9 ($p > 0.05$). For the Workshop level, the E-I Index values increase until Workshop 4 where it reaches a maximum value of 0.830. The value then drops down in Workshop 5 where it rises again until Workshop 9 where it drops.

The E-I Index at the Whole Network level suggests that the network became more cohesive, with a significant increase in the relative number of internal ties. The results for the Workshop Level E-I Index are less clear. The constant positive value of the E-I Index shows that between stakeholder group ties existed all throughout the OysterFutures process, with a relatively high level of between group ties from the start. The oscillation in terms of the values of the E-I Index suggests a dynamic nature of tie formation and possible impacts of workshop participation or outside events on tie formation.

Advice Network - Binomial Generalized Linear Models

Whole Network Level

Model results show that the Workshop (-0.22, $p = 0.02$) variable was significant and negative (Table 5). For each additional Workshop, there was a significant decrease in the relative number of external ties. Since the dependent variable is binary, the independent variables are predicting which of the two categories the binary dependent variable fall into. Odds ratios tell you how likely something is (e.g., more internal ties) relative to something else (e.g., more external ties), and logistic regressions allow you to see how predictor variables change these (log) odds. The odds of having more external ties compared to internal ties changed by 0.80 for each increase in workshop. In terms of percentage, these results suggest that each additional meeting increased the odds an individual will have more internal ties by 20%.

The highly positive, slightly significant ($p < 0.10$) variable for the Environmental Group stakeholder group implies that members of this group had significantly more external Whole Network ties than other groups; they were 8.55 times more likely to have more external than internal Whole Network ties. This suggests the relative number of internal versus external advice ties depends in part upon group membership. Results from the pseudo R^2 show that the inclusion of individual stakeholder differences in tie formation provided a better goodness of fit and that a large amount of variance remained unexplained.

Workshop Level

Consistent with results from the E-I index, which showed oscillation in values during the process, but no significant change from Workshop 1 to Workshop 9, model results showed that Workshop was not a significant variable (Table 6). This indicates that unlike on the Whole Network level, the relative number of ties between and within stakeholder group did not change linearly, like in the Whole Network level, as the workshops of OysterFutures progressed. The only slightly significant variable was the Number of Total Ties, the outdegree, which was negative and significant at the 0.10 level. This suggests that as the number of ties reported increases, the ties are significantly more within stakeholder group. The odds of having an internal tie changed by 0.73, or 27%. The slight propensity to go to others from your own stakeholder group for advice follows the network concept of homophily, the idea that nodes will seek out relationships with other like-nodes (McPherson et al. 2001). Results from the pseudo R^2 again show that accounting for individual stakeholder differences in tie formation led to a higher goodness of fit for the model (Nakagawa and Schielzeth 2013). This suggests a considerable among of variation in tie formation is due to individual factors.

DISCUSSION

The objectives of this work were to analyze longitudinal changes in stakeholders' advice network structure to examine changes in group cohesion due to participation in a participatory, collaborative process. Network structure was examined through the changes in bonding and bridging ties. Results from the advice network illustrate the unique complementary roles of bridging and bonding ties on two levels in the OysterFutures network – the Whole Network and the Workshop levels. The increase of bonding ties at the Whole Network level demonstrates increased group cohesion. The evolution from bridging to bonding ties at the Whole Network level speaks to literature suggesting the importance of different network structures during different phases of natural resource governance processes (Crona and Bodin 2006). At the Workshop Network level, while there was no significant change in number of between/within stakeholder group ties due to workshop participation, the reduction in significance of brokers in the network maps suggests a similar shift from bridging to bonding ties and increased group cohesion over the course of OysterFutures.

Evolution of Bridging and Bonding Ties at the Whole Network Level

Our results show that the stakeholder's advice network at the Whole Network level became more internal, with stakeholders relying more on each other for advice within the OysterFutures participatory modeling process by the end. The prominence of bridging ties early on at the Whole Network level suggests stakeholders were seeking advice primarily from external-OysterFutures sources; a minority of the ties (37%) were to their fellow stakeholders participating in OysterFutures. The transition from a network comprised mainly of bridging ties to a network of more bonding ties shows a shift in the relationships that OysterFutures stakeholders had towards each other and towards external individuals. The increase in bonding ties within the advice network suggests that stakeholders recognized that their fellow internal stakeholders could best understand the relevant needs and demands to provide advice. The closed nature of the OysterFutures meetings contributed to this recognition, providing the opportunity for stakeholders to discuss and learn from each other which then could contribute to the creation of an OysterFutures network-level organizational culture (Kaufman 1960, Schein 1992). Over the course of OysterFutures, members began to see themselves and their co-participants as individuals in a defined group who were creating this shared culture classified by a common identity, shared language and norms or ways of operating (Coleman 1988, Krackhardt 1992).

This sense of “us” and the increase in bonding ties continued during OysterFutures despite turnover and on-boarding of new members. The history between all the stakeholders, their levels of familiarity with each other from interactions preceding OysterFutures, likely helped ease the transition. Evidence of this sense of “us” between stakeholders was present during discussions on the final recommendations in Workshop 9. Multiple stakeholders advocated for including a recommendation to use an OysterFutures-like process in the future. Advocating for this recommendation, one stakeholder said that applauding the process was like applauding “all of us”, showing recognition of their fellow participants as members of the same OysterFutures team.

This transition from a network comprised primarily of bridging ties to significantly more bonding ties, indicating an increase of group cohesion, was found to be significantly impacted by participation in the participatory, collaborative process OysterFutures. The result also controls for attendance at the workshops. Despite importance of the individuals sitting at the table in tie creation and network structure, coming to the workshops and participating significantly increased the cohesion of the group (Newig and Fritsch 2009). The substantial increase of the model pseudo R^2 with addition of random effects to control for individual stakeholder’s further supports that attendance matters. Participation has this positive impact because it creates the opportunities for discussion, shared framing of problems, and the opportunity to partake in mutual learning (Hajer 1995, Voinov and Gaddis 2008, Videira et al. 2010, Röckmann et al. 2012, Schmitt Olabisi et al. 2014). Stakeholders recognized the important role of participation, and attendance, during the OysterFutures process. When low participation rates occurred during Workshop 3, stakeholders agreed to make calls to other participants to encourage attendance. Stakeholders continued to show up and participate because they said this process was “unique” in what it could achieve due to the wide representation.

Although participation in OysterFutures had a significant impact on the transition of the network structure, the workshops were not the only significant factor. The results from the model also suggested that stakeholder group membership could have a significant impact on Whole Network tie formation. The suggestion of significance of stakeholder group membership for the formation of advice ties supports findings in the literature on the importance of group association for who individuals reach out to (Reagans and McEvily 2003, Yuan and Gay 2006, Crona and Bodin 2006). Individuals within OysterFutures were always heavily associated with the stakeholder group that they were chosen to represent. Therefore, it is not surprising to see that stakeholder group membership could be significant in determining how individuals formed ties. The stakeholder group that was significant (Environmental Group) had significantly more external OysterFutures ties, meaning that they relied on external sources for advice significantly more than stakeholders in other groups. This suggests that the cohesion created at the Whole Network was not homogeneous; there is evidence for some heterogeneity in the effect of participation in participatory, collaborative process on bridging and bonding tie formation.

Evolution of Bridging and Bonding Ties at the Workshop Network Level

Although there was not statistically significant change in the relative number of between or within stakeholder group ties at the Workshop Network level, there is evidence that this level of the network experienced a transition like at the Whole Network level, with a shifting network structure from bridging to bonding ties. This shift, however, cannot be directly attributed to OysterFutures participation.

The slight increase in the E-I index and the increase in the number of ties between stakeholders seen in the network maps suggests that bridging ties became more prolific over the course of OysterFutures, with stakeholders reaching out to more individuals from different stakeholder groups (Figures 6, 7, and 8). The high, positive values for the E-I Index from the start of OysterFutures show that there was already a high relative number of between stakeholder group connections within the advice network. This is evidence of familiarity among the stakeholders prior to the OysterFutures workshops. These individual stakeholders were not selected at random; they were selected because they were prominent within the oyster community in the Choptank region in Maryland and most already had relationships to each other before OysterFutures, either via other ties like professional relationships or from past oyster management discussions. The familiarity of stakeholders has been shown to foster increased trust within a social network context, suggesting that a level of trust and cohesion existed between the stakeholders prior to participation in OysterFutures (Gulati and Sytch 2008).

Despite the pre-existing familiarity, there were changes to the number of between group ties in each workshop. Through the E-I Index, we saw an increase in the relative number of external ties from Workshop 1 to Workshop 4. The number of external ties dropped in Workshop 5, and then steadily rose again until dropping in Workshop 9 where it evened out at a level slightly higher than Workshop 1. This suggests that despite the stakeholders having previous relationships with each other, there was a change in the relative number of internal and external ties. The lack of linearity and timing of these changes suggests possible impacts of OysterFutures participation and events external to

OysterFutures contributing to tie formation. Within the OysterFutures context, participating stakeholders continued to interact with each other outside of the workshops through events in the Maryland oyster world (e.g., new legislation, hearings, and changes in Maryland DNR policy). The changes in the number of bridging ties could reflect the specific needs of the stakeholders during a certain point in time in the OysterFutures process; participating in OysterFutures at different points necessitated different levels of between group interactions.

For example, the period during the process where stakeholders developed model options necessitated a high level of intergroup cooperation and discussion. The developing of model options occurred during the period of the highest relative number of external ties on the E-I Index (Workshop 4 = 0.830, reflects advice ties in the period between Workshop 3 and Workshop 4). The discussion over the limited entry system for the oyster fishery reflects the enhanced between-group interactions. During the conversation in which the stakeholders determined what elements they wanted included for the limited entry option, individuals from the aquaculture, environmental nonprofit, government, recreational fishing, seafood buyer, scientist, and watermen stakeholder groups were involved in outlining what a “good” limited entry system would look like to them. During the discussion, individuals not only offered their own suggestions, but inquired about other group’s statements to try to understand what limited entry meant to them. The increase in the E-I Index value during this time could reflect the increased need on the part of the group for between-group advice during these discussions.

The drops in the E-I Index value from Workshop 4 to Workshop 5 could reflect the influence of events external to OysterFutures in the Maryland oyster world on tie formation. The OysterFutures process did not occur within in vacuum. Network maps represent snapshots in time. Changes between these snapshots, including changes related to external events, cannot fully be captured but can potentially explain shifts in structure of the advice network (Folke et al. 2005). Within the OysterFutures context, participating stakeholders continued to interact with each other outside of the workshops through events in the Maryland oyster world (e.g., new legislation, hearings, changes in Maryland DNR policy). These outside-OysterFutures interactions could explain changes in tie formation. In between Workshop 4 and Workshop 5 (E-I Index drop from 0.830 to 0.538), the Maryland legislature passed a bill that protected oyster sanctuaries from any alternation until 2019 (HB 924), a move in response to a Maryland DNR straw plan that proposed reducing the size of sanctuaries in the state by 11% (Wheeler 2017). These actions saw stakeholder groups, especially environmental groups and watermen, on opposite sides. The conflict from these discussions on oyster sanctuaries could have influenced the reduction in between group advice ties within OysterFutures.

The flexibility of the advice network structure reflects the nature of the OysterFutures process. The pulse in external stakeholder group advice ties and the overall ebb and flow of the number of between and within stakeholder group ties demonstrates that the individuals within the process were able to adapt the network structure of OysterFutures during different periods of the process

(Larson 1992, Provan and Kenis 2008, Daly and Finnigan 2011). This is typical of forms of decision making that utilize network governance structure, where a “select, persistent, and structured set of autonomous [individuals] engaged in creating products or services based on implicit and open-ended contracts to adapt to environmental contingencies and to coordinate and safeguard exchanges” (Jones et al. 1997, p. 914). Unlike hierarchical structures where individuals have some sort of long-term tie or connections to each other, network governance structures are able to accomplish tasks by involving the appropriate, necessary people for the period of time it takes to complete a task; after the task is complete, the network no longer needs to exist (Provan and Kenis 2008).The reduction in the relative number of external stakeholder group advice ties at the end of the OysterFutures process demonstrates this return to the status quo after a task has been completed.

The overall lack of change in between stakeholder group tie formation over the course of the process suggests a limited long-term effect of participation in OysterFutures; stakeholders returned to similar levels of between and within advice tie levels. The lack of long term change speaks to the necessary balance in network governance settings between flexibility and stability. The flexibility of the network governance structure allowed the group to respond quickly to any opportunities or challenges, like the need to solicit more external stakeholder group advice during model formation (Provan and Kenis 2008). The short-term nature of OysterFutures, with a single goal of creating a set of consensus recommendations, did not need to focus on building long-term stability; the flexibility allowed the group to accomplish their goal. Moving forward, if Maryland wanted to continue to use this approach to manage oysters, they would need to find the appropriate balance between a flexible versus more stable network structure, which has been linked to increased process legitimacy (Provan and Kenis 2008).

Despite the ebb and flows of between stakeholder group ties and lack of overall significant change, there was a consistently high level of between group advice ties throughout OysterFutures. The high amount of these “bridging” ties along with the reduced role of brokers representing the only advice path suggests that there was an overall change at the Workshop Network level. The ties between stakeholder groups were characterized as bridging ties because they provided the network access to diverse sources of knowledge and information. Schneider et al. (2003) and others have theorized that more frequent interactions among these “weak” bridging ties can “cement relationships between individuals and actually increase the flow of highly specialized information” (p.154). This suggests that a transition can occur in the nature of existing ties and that the presence of bridging ties in a network does not mean that cohesion does not exist (Provan and Milward 1995). Through our longitudinal analysis of the Workshop level of the advice network, we can see that this theorized transition is occurring. The increase of the number of ties at the Workshop level and the persistence of those ties that “bridge” stakeholder groups suggests that these ties are no longer acting in a bridging way to connect stakeholder groups. Instead, the ties are acting as bonding ties that are connecting stakeholders within the OysterFutures process and creating more internal cohesion, as was suggested from the network maps at the Whole Network level.

Simply looking at the E-I index or the modeling results for the Workshop Network level to determine the evolution of network structure is deceiving; only through the analysis of the network maps and the shifting roles of brokers was the longitudinal shift on this level able to be detected. Although we cannot directly attribute the shift in the network structure to participation, there is evidence that the structure changed over the course of OysterFutures. Although these stakeholders did have relationships and advice paths prior to OysterFutures, the creation of new advice paths both between and within groups occurred during the process.

The significance of the outdegree variable within the model suggests a tendency towards internalization in terms of tie formation. Outdegree measures the expansiveness of an actor, but it does not necessarily mean that the higher number of ties will be to a diverse group of individuals. Even though the advice network at the Workshop Network level saw a transition from bridging to bonding ties and an overall increase in the number of advice ties, network literature demonstrates a propensity for individual nodes to create ties with individuals like themselves, in this case, within the same stakeholder group (McPherson et al. 2001, Daly and Finnigan 2011). A longitudinal network study by Daly and Finnigan (2011) demonstrated a similar trend, with the number of advice ties between individuals in their network increasing, but at the same time, the advice ties were more likely to be between colleagues who were similar in terms of work setting. This highlights the persistent strength of stakeholder group membership on tie formation which could limit the ability of collaborative, participatory processes to create overall cohesion.

CONCLUSION

The rise in prominence of both participatory processes (in particular, participatory modeling, Schmitt Olabisi et al. 2014) and social network analysis for studying natural resource governance scenarios (Hartley 2010, Hartley and Glass 2010, Hartley 2016, Groce et al. 2018) lends to combining these approaches. The ability to focus on the human dimensions of participatory processes will help us better understand how these processes work, including what elements of these processes contribute to their success.

Through a mixed-methodology approach of social network measures and binomial models, we found evidence of a longitudinal shift in the advice network on both levels from a network comprised of bridging ties to bonding ties. The changing nature of ties between stakeholders was noted by an OysterFutures stakeholder during the final meeting. When asked if OysterFutures built new connections, the stakeholder answered that the process did not create new ties, they were already aware of “all these guys” before the process, but impacted the nature of these ties, indicating that they were using existing ties in different ways. In examining overall network cohesiveness and the road to creating a cohesive network, the roles that both bridging and bonding ties play need to be considered. The ability to analyze a network longitudinally allows us to consider bonding and bridging ties together within the same network, just at different points in time.

The transition of the network structure fits the nature of participatory, collaborative processes and the efforts of these processes to create cohesion amongst participants. Results support suggestions in the literature that participatory, collaborative processes increase cohesion among participants (Bayley and French 2008, Basco-Carrera et al. 2017, Falconi and Palmer 2017). However, within both models, the fit of the model was improved when accounting for the random effects of individual stakeholder. In addition to group-wide factors, who sits at the table impacts tie creation and network structure and function (Newig and Fritsch 2009).

OysterFutures represents a single occasion of applying new methods and this theoretical perspective to the study of collaborative, participatory processes. Our results are some of the first to analyze a collaborative natural resource management process over time and can provide a framework for future studies of these processes. Recent work has emphasized the importance of the longitudinal study of these processes to help link network structure to specific social and environmental outcomes (Crona and Hubacek 2010, Bodin and Prell 2011, Groce et al. 2018). Future research looks to explore these connections between longitudinal trends in collaborative processes and process “success”, (e.g., the group reaching consensus), the relation of individual role and position in a network, and the influence of their impact on the final decision. In the case of OysterFutures, the process did end in a set of consensus recommendations

(OysterFutures Stakeholder Workgroup 2018). In addition, our results suggest that cohesion and what factors lead to cohesion within a collaborative process is more complicated and nuanced than previously reported; internal silos still existed on the Workshop level and the formation of ties was suggested to be influenced by stakeholder group association. OysterFutures led to a change in network structure and function. Strong bridging and bonding ties developed between stakeholders within the process; simultaneously, ties to external experts weakened. This combination drove the creation of group cohesion, with stakeholders relying on each other more. At the same time, networks are dynamic and flexible. We saw ebb and flow adjustments in network structure that mobilized individuals and their knowledge to address key issues under consideration at the time.

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TABLES

Table 1: OysterFutures Workshop Dates including the Time Difference between subsequent workshops

Workshop Meeting	First Day of Workshop	Time Lapse Between Workshops (Days)
1	02/26/2016	0
2	04/30/2016	64
3	11/15/2016	199
4	03/25/2017	130
5	07/22/2017	119
6	11/10/2017	111
7	01/06/2018	57
8	02/04/2018	29
9	03/23/2018	47

Table 2: Binomial Model Variables

Variable	Included in one or both models?	Variable Characteristics
Stakeholder Level Tie Formation - DV	Both	• Binomial variable • Variable measures if there are more relative internal or external ties
Workshop - IV	Both	• Integer variable • Same across all individuals • This variable corresponded to the workshop number
Time Lapse between Workshops – IV	Both	• Entered as the number of days between the first date of the current workshop and the first date of the workshop previous • Same across all individuals
Stakeholder Group - IV	Whole Network	• Factor variable with 5 levels representing all stakeholder groups with 3 or more individuals • Unique to individual • This variable captured group membership of stakeholders
Stakeholder - IV	Both	• Included as a random variable • Different across all individuals • Variable captured differences due to individual stakeholder
Number of Ties Reported (Outdegree) – IV	Both	• Integer variable • Different across all individuals • Variable accounted for different reported number of ties by stakeholders – each individuals' personal outdegree
Group Size – IV	Workshop Level	• Integer variable • Same value for individuals in the same group; different between stakeholder groups • Variable accounted for the different size of stakeholder groups within the OysterFutures process
Number of Ties Reported (Outdegree) x Group Size - IV	Workshop Level	• Integer, interaction variable • Different across all individuals • This interaction variable captured differences in stakeholder group tie formation due to interaction between number of total ties reported and group size

Table 3: Summary Statistics Whole and Workshop Network Model Variables

Variable	N – Whole Network	Mean – Whole Network	Standard Deviation – Whole Network	N – Workshop Network	Mean – Workshop Network	Standard Deviation – Workshop Network
Stakeholder Level Tie Formation	138	0.43	0.50	138	0.74	0.44
Workshop	138	4.58	2.58	138	4.5	2.58
Time Lapse Between Workshops	138	87.7	58.8	138	88.4	59.5
Total Ties - Outdegree	138	3.81	1.19	138	2.27	1.46
Group Size				138	5.45	1.86
Group Size x Outdegree Interaction				138	12.1	9.24

Table 4: E-I Index results for relative number of internal versus external ties at the Whole and Workshop network level for each workshop. Scores range from 1, where positive scores indicate the number of ties is more external at the workgroup (or workshop) level, to -1, where negative scores indicate the number of ties is more internal at the workgroup (or workshop) level

Workshop	E-I Observation – Whole Network Level	E-I Observation – Workshop Network Level
1	0.364	0.625
2	-0.099	0.625
3	0.053	0.778
4	-0.132	0.830
5	-0.031	0.538
6	-0.027	0.660
7	-0.25	0.708
9	-0.229	0.686

Table 5: Binomial Model Results for the Whole Network Level

Number of Internal/External Advice Ties at the Whole Network Level	
	Dependent variable:
	Number of External/Internal Whole Network Ties
Constant	-0.47 (p = 0.75)
Workshop	-0.22** (p = 0.02)
Dates Between Meetings (days)	-0.004 (p = 0.26)
Total Number of Ties - Outdegree	0.17 (p = 0.50)
Stakeholder Group - Environmental Group	2.15* (p = 0.07)
Stakeholder Group - Government	1.20 (p = 0.33)
Stakeholder Group - Scientist	0.15 (p = 0.89)
Stakeholder Group - Watermen	0.92 (p = 0.41)
Pseudo R^2 – Marginal	0.17
Pseudo R^2 - Conditional	0.35
Observations	134
Log Likelihood	-78.20
Note:	*p<0.1; **p<0.05

Table 6: Binomial Model Results for the Workshop Level

Number of Internal/External Advice Ties at the Workshop Level	
	Dependent variable:
	Internal/External Stakeholder Group Ties
Constant	4.07* (p = 0.10)
Workshop	0.01 (p = 0.94)
Difference Between Meetings (days)	-0.003 (p = 0.53)
Group Size	-0.30 (p = 0.42)
Group Size x Outdegree	1.36 (p = 0.14)
Total Number of Ties - Outdegree	-0.26* (p = 0.07)
Pseudo R^2 – Marginal	0.27
Pseudo R^2 - Conditional	0.59
Observations	138
Log Likelihood	-56.72
Note:	*p<0.1

FIGURES

Figure 1: Image of the Choptank River Complex, setting for OysterFutures, a facilitated collaborative, participatory modeling process to help create consensus management recommendations for oyster management within this region. Image reproduced from the Integration & Application Network (IAN) at the University of Maryland Center for Environmental Science

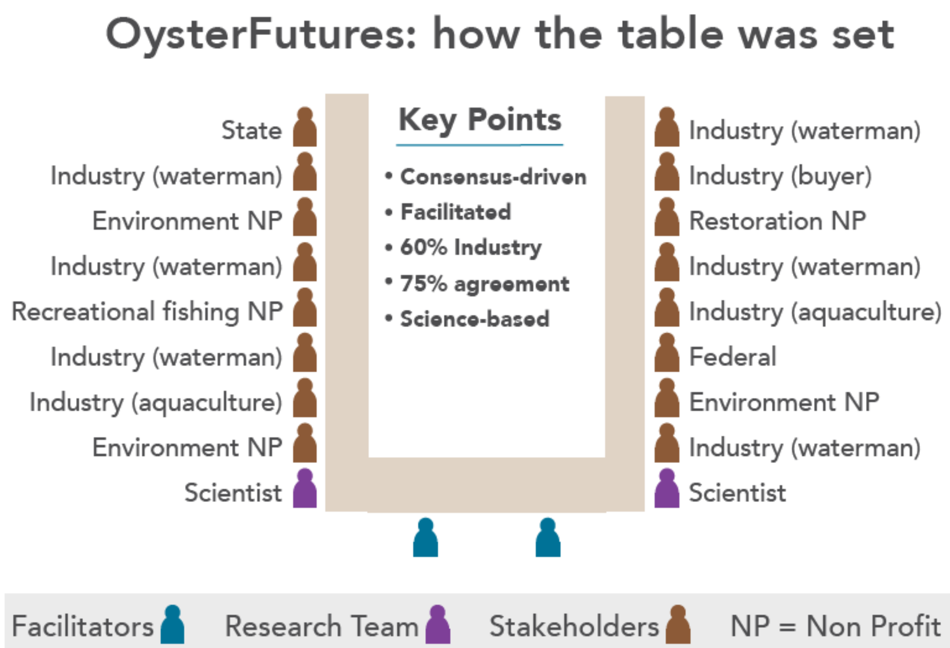

Figure 2: Visualization of the full OysterFutures participants. Image reproduced from the OysterFutures final report, OysterFutures Stakeholder Workshop, 2018

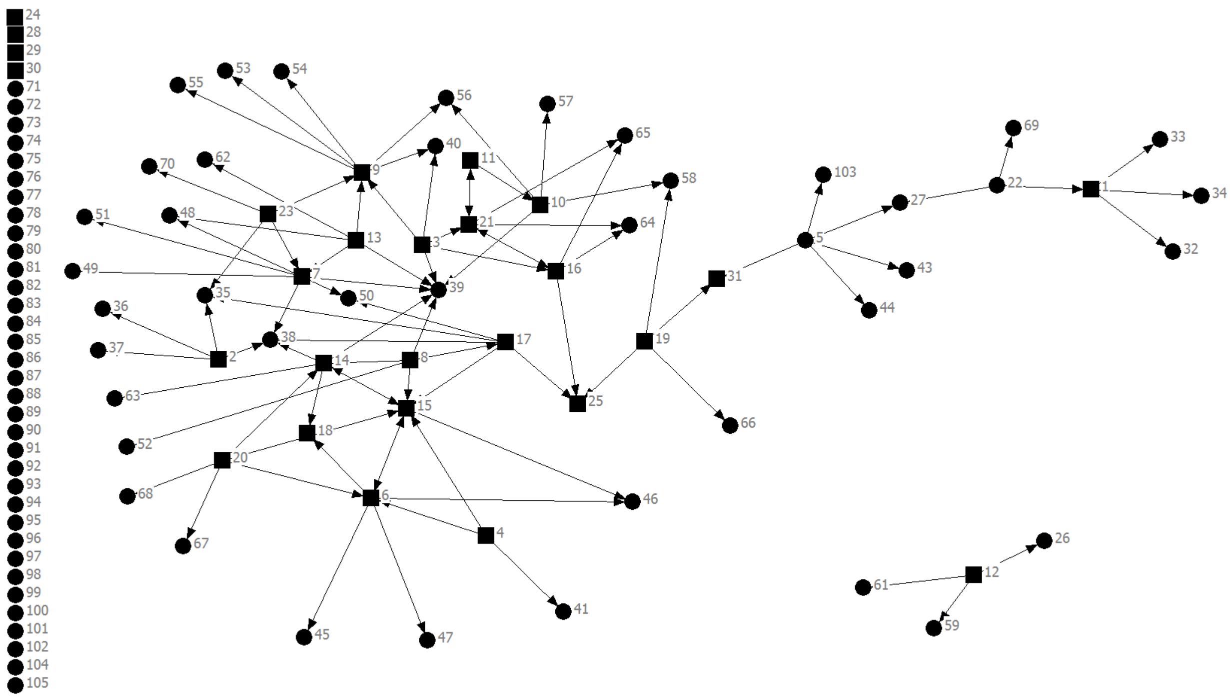

Figure 3: Advice Network – Whole Network - Workshop 1 with square nodes indicating stakeholders who were OysterFutures participants and circle nodes indicating individuals who did not participate in OysterFutures. Arrow heads represent the direction of the advice tie

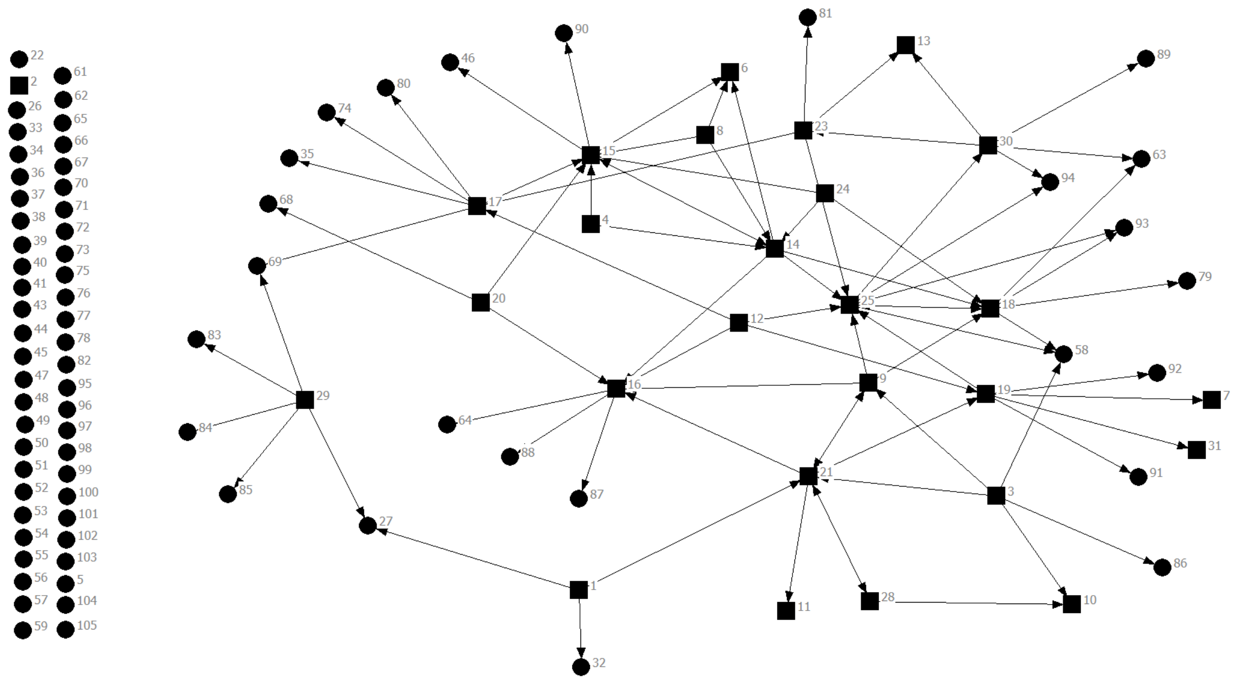

Figure 4: Advice Network – Whole Network - Workshop 4 with square nodes indicating stakeholders who were OysterFutures participants and circle nodes indicating individuals who did not participate in OysterFutures. Arrow heads represent the direction of the advice tie

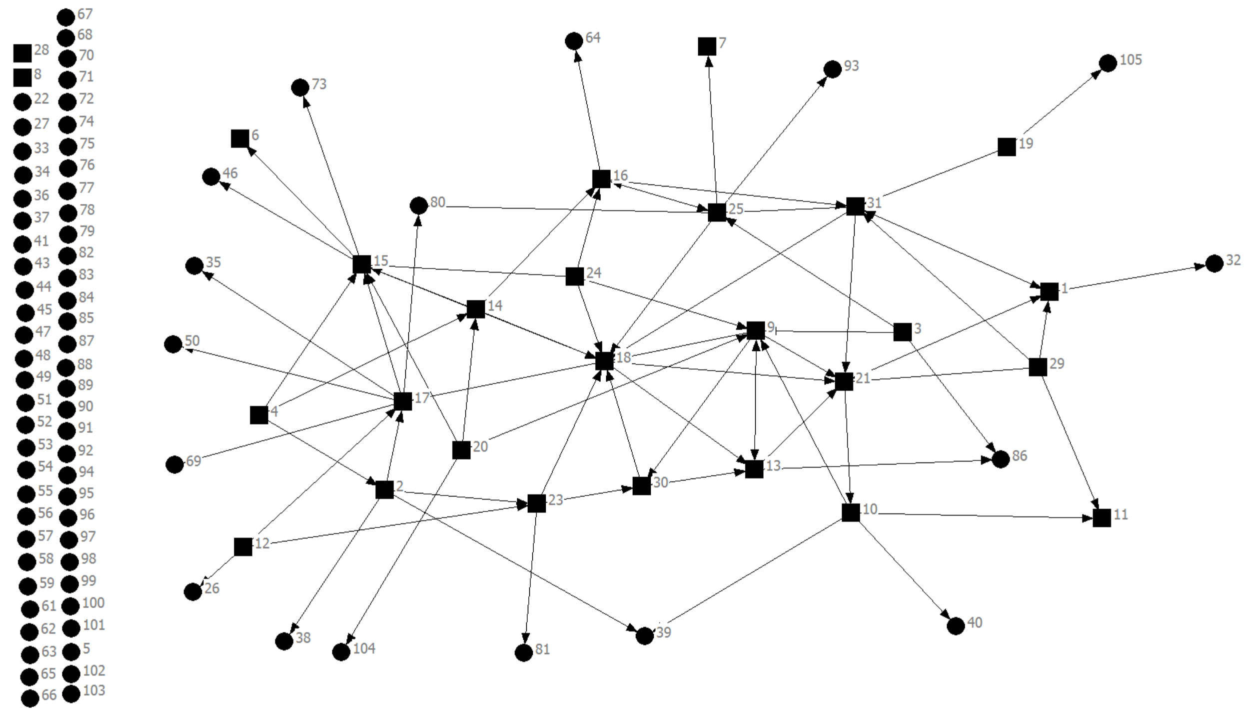

Figure 5: Advice Network – Whole Network - Workshop 9 with square nodes indicating stakeholders who were OysterFutures participants and circle nodes indicating individuals who did not participate in OysterFutures. Arrow heads represent the direction of the advice tie

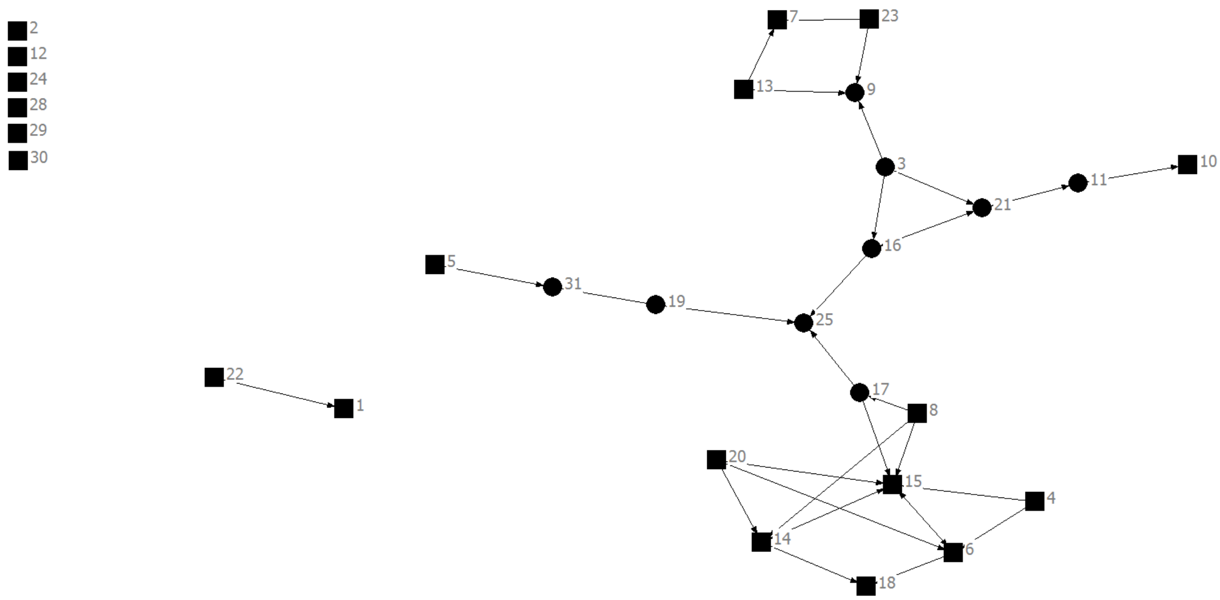

Figure 6: Advice Network – Workshop Network level - Workshop 1 with circle nodes indicating stakeholders who are playing a brokering role in the internal advice network and square nodes indicating stakeholders who are not playing a brokering role. Stakeholder groups are not labeled to protect the identity of individual stakeholders

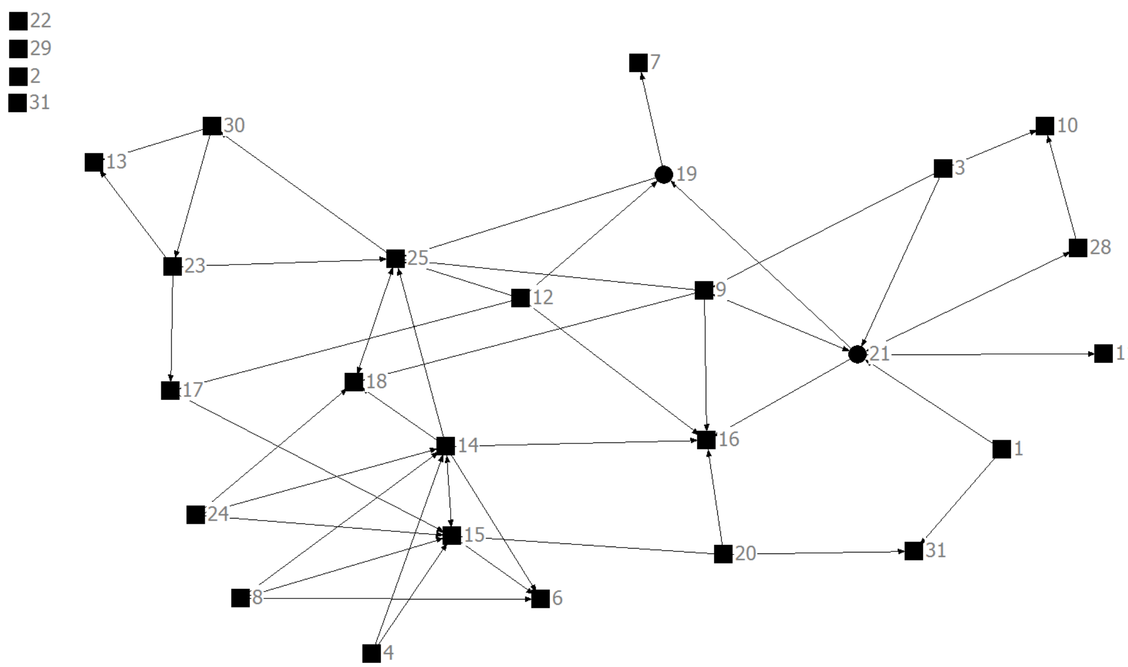

Figure 7: Advice Network – Workshop Network level - Workshop 4 with circle nodes indicating stakeholders who are playing a brokering role in the internal advice network and square nodes indicating stakeholders who are not playing a brokering role. Stakeholder groups are not labeled to protect the identity of individual stakeholders

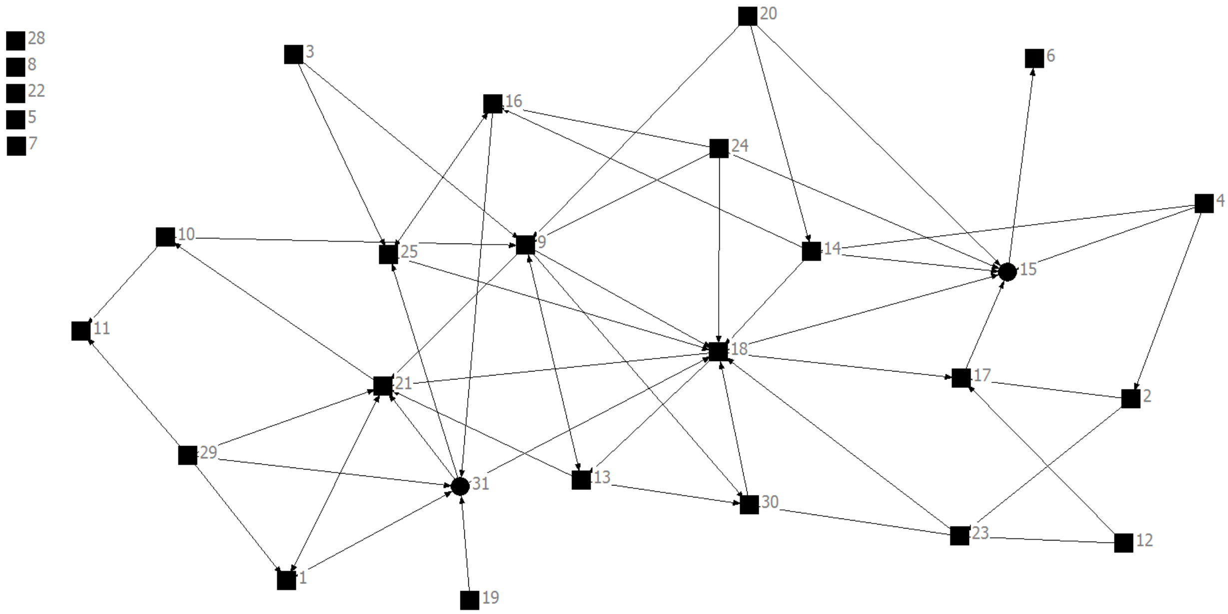

Figure 8: Advice Network – Workshop Network level - Workshop 9 with circle nodes indicating stakeholders who are playing a brokering role in the internal advice network and square nodes indicating stakeholders who are not playing a brokering role. Stakeholder groups are not labeled to protect the identity of individual stakeholders

The generalized linear mixed model incorporates both fixed and random effects to evaluate the conditional mean of the response variable (Barr et al. 2013, Bates et al. 2015). Both models follow a similar equation

$$Y_{si}=\beta_0+S_{0s}+\beta_1X_i+e_{si},$$

$$S_{0s} \sim N(0, \tau_{00}^2),$$
$$e_{si} \sim N(0, \sigma^2)$$

Where response Y_{si} for subject *s* and item *i* to a baseline level via fixed-effect β_0 (intercept), a treatment effect via fixed-effect $\beta 1$ (slope), S_{0s}, a random-effect that accounts for deviation from β_0 for subject $_s$, and observation-level error e_{si} with a variance of σ^2.

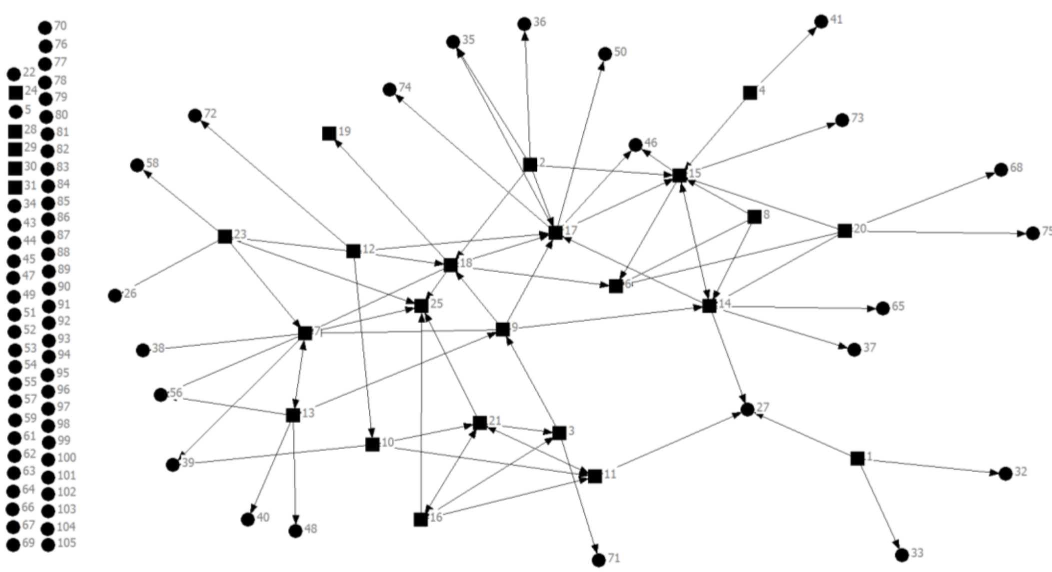

Figure 9: Advice Network – Whole Network - Workshop 2 with square nodes indicating stakeholders who were OysterFutures participants and circle nodes indicating individuals who did not participate in OysterFutures. Arrow heads represent the direction of the advice tie

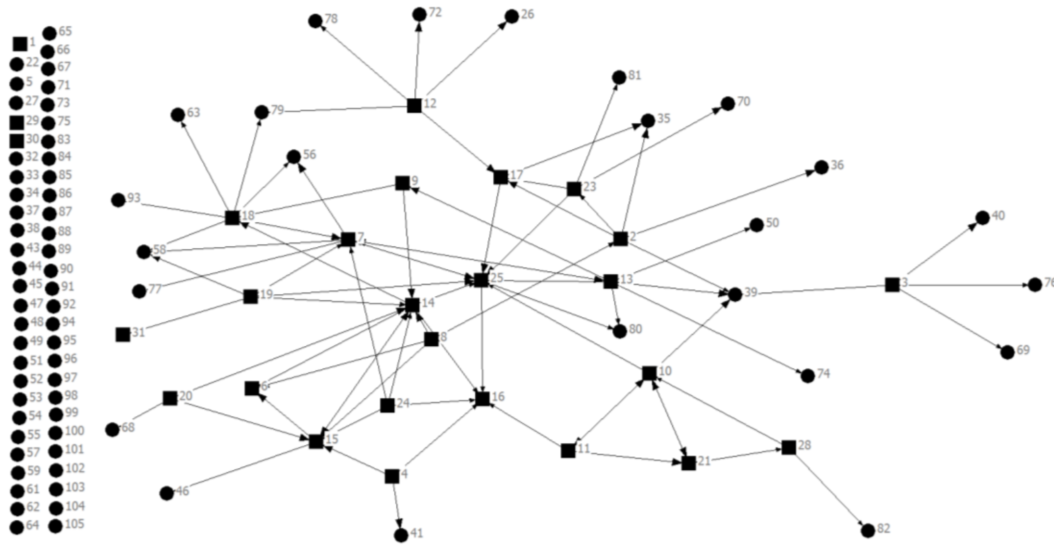

Figure 10: Advice Network – Whole Network - Workshop 3 with square nodes indicating stakeholders who were OysterFutures participants and circle nodes indicating individuals who did not participate in OysterFutures. Arrow heads represent the direction of the advice tie

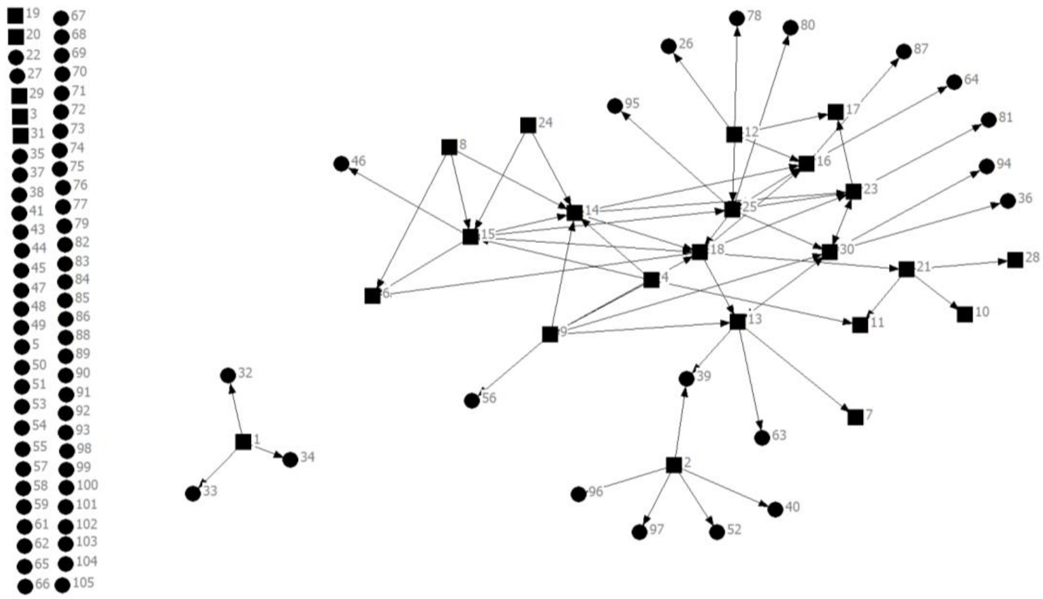

Figure 11: Advice Network – Whole Network - Workshop 5 with square nodes indicating stakeholders who were OysterFutures participants and circle nodes indicating individuals who did not participate in OysterFutures. Arrow heads represent the direction of the advice tie

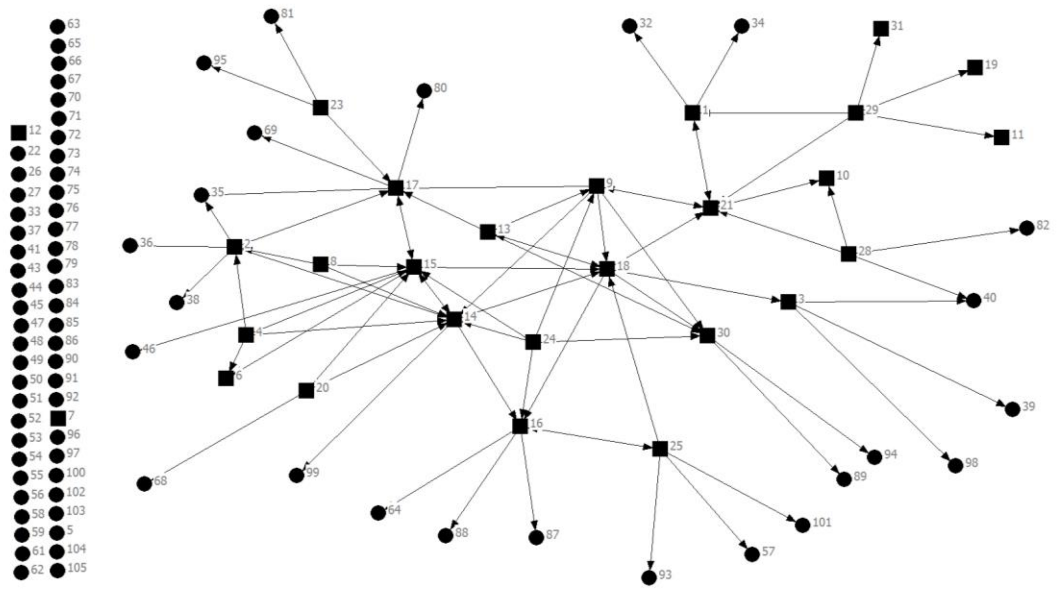

Figure 12: Advice Network – Whole Network - Workshop 6 with square nodes indicating stakeholders who were OysterFutures participants and circle nodes indicating individuals who did not participate in OysterFutures. Arrow heads represent the direction of the advice tie

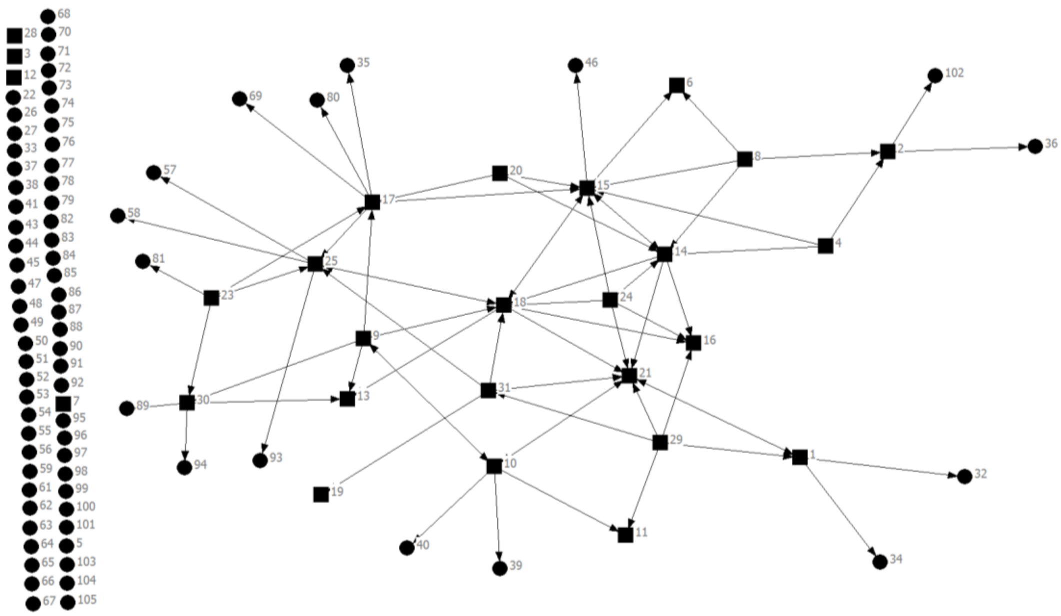

Figure 13: Advice Network – Whole Network - Workshop 7 with square nodes indicating stakeholders who were OysterFutures participants and circle nodes indicating individuals who did not participate in OysterFutures. Arrow heads represent the direction of the advice tie

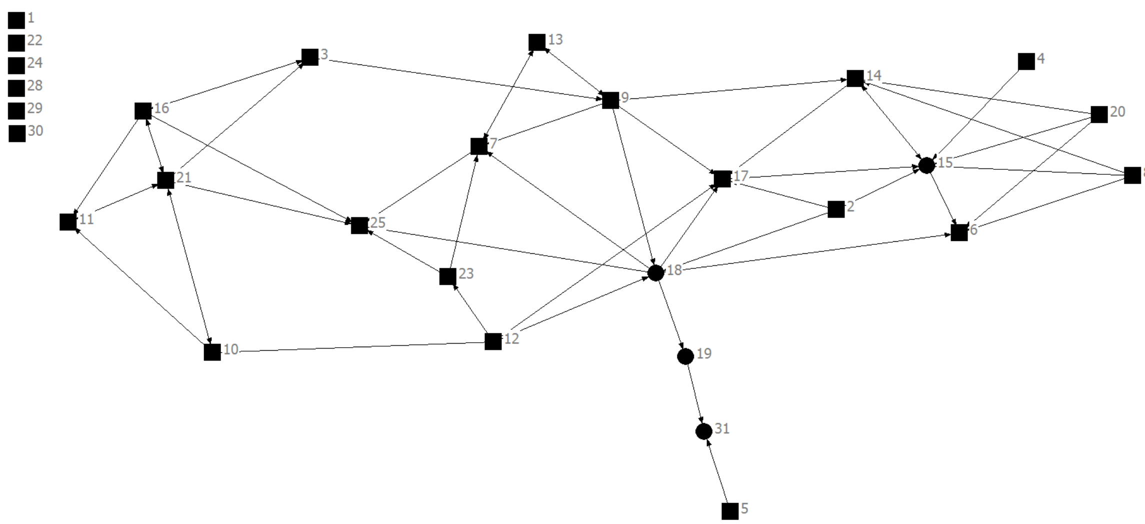

Figure 14: Advice Network – Workshop Network level - Workshop 2 with circle nodes indicating stakeholders who are playing a brokering role in the internal advice network and square nodes indicating stakeholders who are not playing a brokering role. Stakeholder groups are not labeled to protect the identity of individual stakeholders

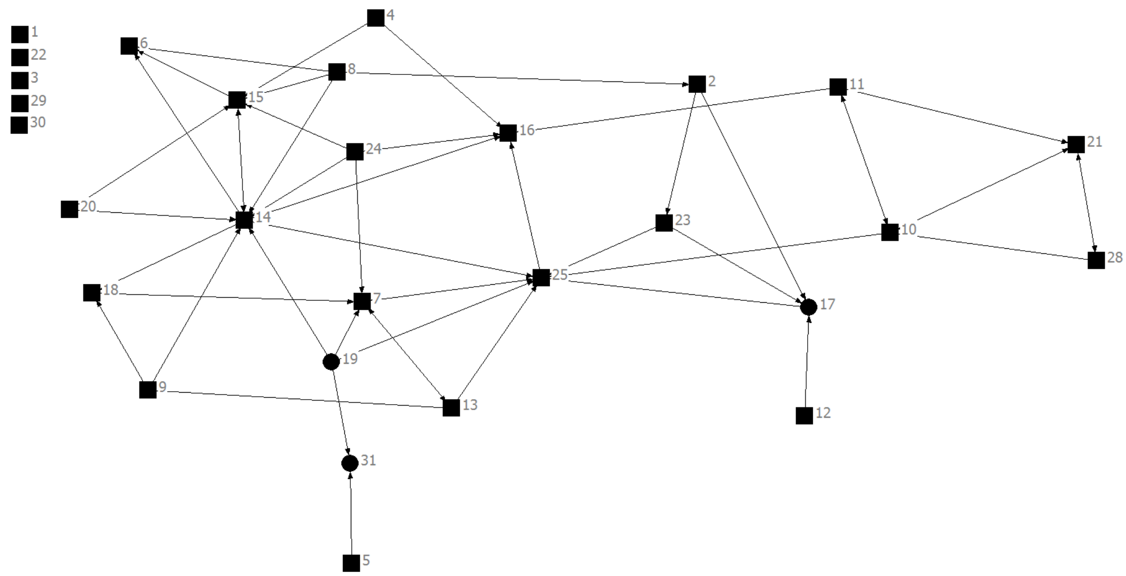

Figure 15: Advice Network – Workshop Network level - Workshop 3 with circle nodes indicating stakeholders who are playing a brokering role in the internal advice network and square nodes indicating stakeholders who are not playing a brokering role. Stakeholder groups are not labeled to protect the identity of individual stakeholders

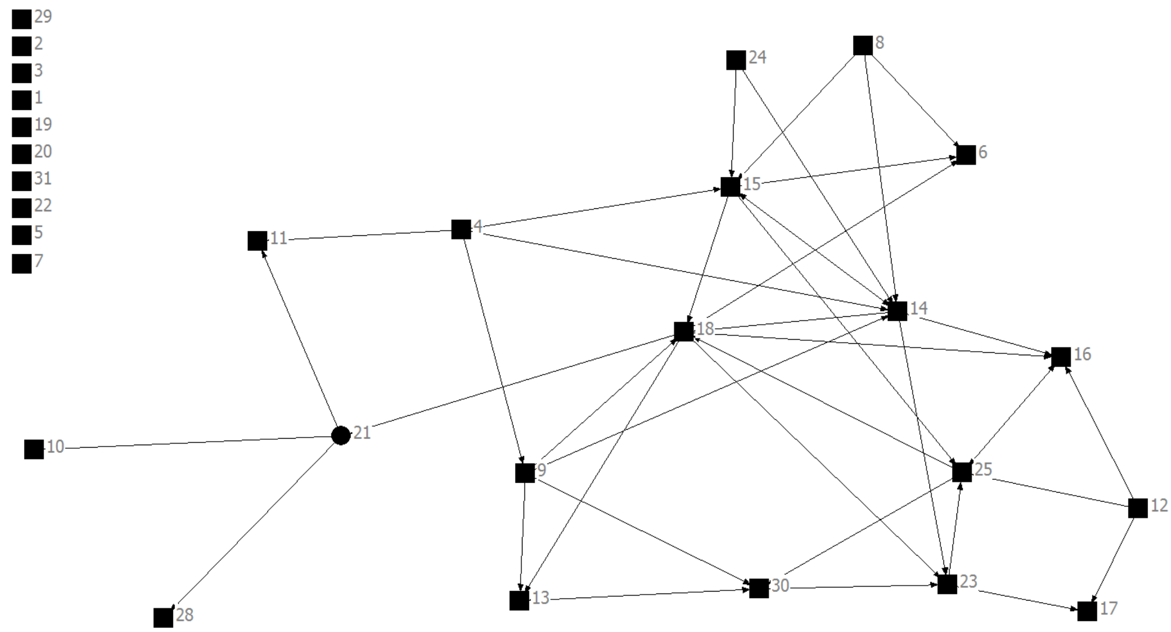

Figure 16: Advice Network – Workshop Network level - Workshop 5 with circle nodes indicating stakeholders who are playing a brokering role in the internal advice network and square nodes indicating stakeholders who are not playing a brokering role. Stakeholder groups are not labeled to protect the identity of individual stakeholders

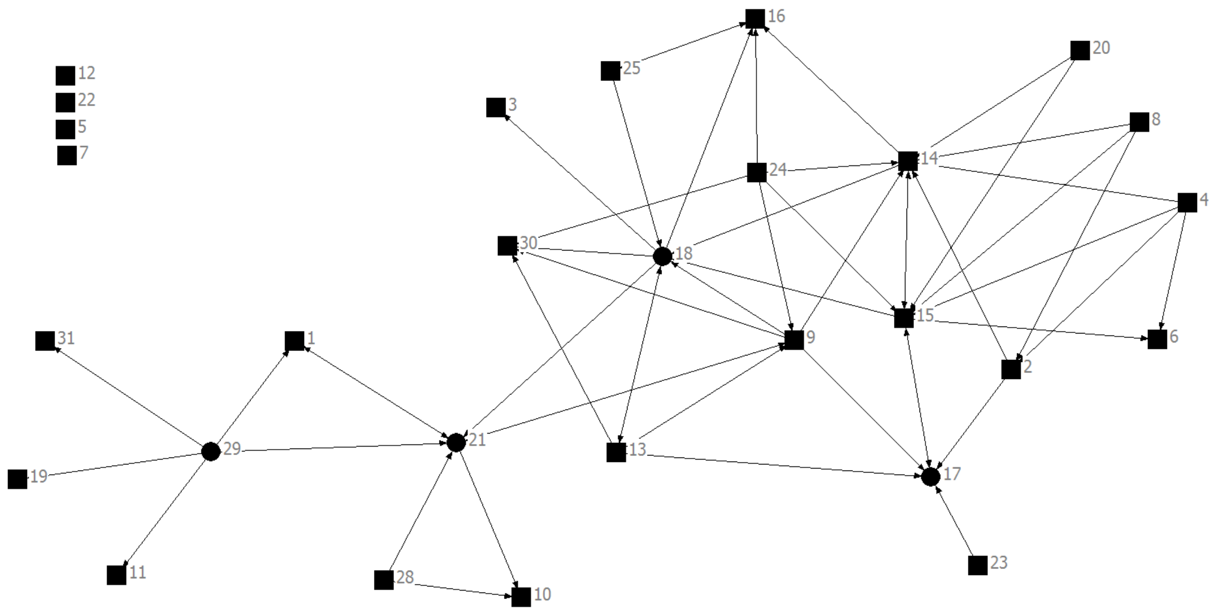

Figure 17: Advice Network – Workshop Network level - Workshop 6 with circle nodes indicating stakeholders who are playing a brokering role in the internal advice network and square nodes indicating stakeholders who are not playing a brokering role. Stakeholder groups are not labeled to protect the identity of individual stakeholders

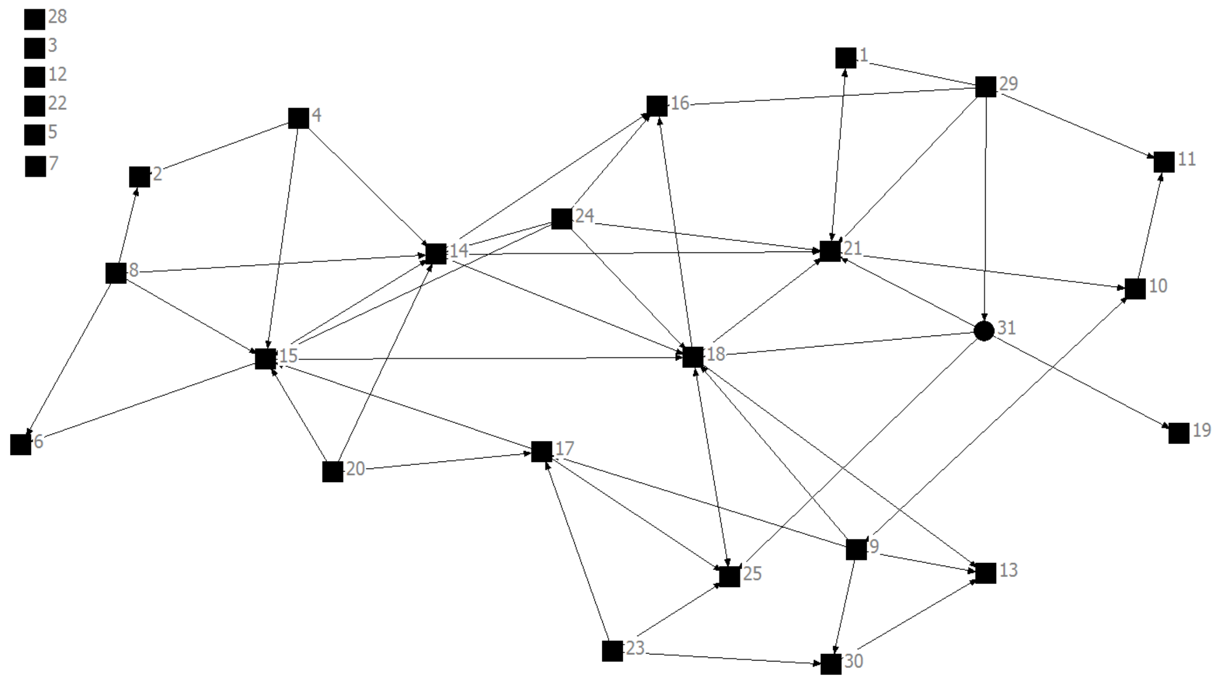

Figure 18: Advice Network – Workshop Network level - Workshop 7 with circle nodes indicating stakeholders who are playing a brokering role in the internal advice network and square nodes indicating stakeholders who are not playing a brokering role. Stakeholder groups are not labeled to protect the identity of individual stakeholders

CHAPTER 3:
The Development of Attitudes Towards Scientific Models during a Participatory Modeling Process – The Impact of Participation and Social Network Structure

ABSTRACT

Scientific models have increasingly been utilized in natural resources management. Specifically, models are being used to help facilitate participatory decision making processes. The linking of scientific models to some form of stakeholder participation is called “participatory modeling”. Within these participatory modeling processes, a variety of stakeholders and stakeholder groups are expected to interact with and use models to aid decision making. However, despite the emphasis of stakeholder interaction with the model, no work has previously measured stakeholder’s perceptions or attitudes towards models during a participatory modeling process. Using a mixed-methods approach, we longitudinally measured stakeholders’ attitudes towards scientific models during OysterFutures, a participatory modeling process in the Chesapeake Bay. Results showed that attitudes were primarily driven by stakeholder group membership and their associated ways of knowing. Additionally, social network structure was found to significantly impact model credibility. This article ends with a discussion on the unique “boundary object” role of models during these processes and recommendations on how to better facilitate exchange of knowledge between stakeholder groups.

INTRODUCTION

The growing complexity of natural resources management problems has necessitated the involvement of a wider scope and variety of knowledge in decision-making processes. This bypasses the narrower focus utilized in more "traditional" decision making (Rouwette et al. 2011). Obtaining a wider scope of knowledge is accomplished through the involvement of a range of stakeholders into decision-making processes (Armitage et al. 2008, Seidl 2015). The diversity of knowledge and values that stakeholders bring to the table has been suggested to led to more effective, higher quality, more inclusive, and longer lasting policies (Newig 2007, Reed 2008, Allen et al. 2013).

The manner in which stakeholders participate in the decision-making process varies. Recently, scientific models have been increasingly used to facilitate participation in decision-making processes. Modeling in this context, where scientific modeling is linked with some form of stakeholder participation is called "participatory modeling" (Dreyer and Renn 2011). Decision-making processes incorporate models into their process because of the theorized enhanced ability of scientific models to conceptualize "the inherent complexity of natural systems" (Robles-Morua et al. 2014 p. 274). This is especially important as problems in natural resources management today are increasingly "wicked"; they are more complex, have high levels of uncertainty, lack structure and have ambiguous solutions (Rittel and Weber 1973).

Participatory modeling processes have advantages when addressing wicked problems because are flexible instruments that can help "facilitate and structure discussions between scientists and stakeholders" concerning uncertainty and different sources of knowledge (White et al. 2010, Röckmann et al. 2012, p. 1072). The ability of participatory modeling processes to help stakeholders and scientists address complex natural resources questions has led to its growing application in natural resource management contexts, ranging from farming and agriculture (Podestá et al. 2013), to watershed management (Voinov and Gaddis 2008) to fisheries (Haapasaari et al. 2009).

In addition to management and system-wide impacts, participatory modeling processes are suggested to influence the participating stakeholders. Through the act of model building and discussions, participatory modeling processes can facilitate social learning, form or strengthen stakeholder connections and create similar attitudes through consensus-building (Reed et al. 2010, Rodela 2011, Gray et al. 2014, Henly-Shepard et al. 2015). However, the unique benefits of participatory modeling processes are contingent upon stakeholders understanding of, engagement with, and willingness to use the scientific models as sources of knowledge and information. Liu et al. (2008) argue that knowledge sources, like scientific models, must meet various stakeholder expectations for the model to be utilized. Cash et al. (2003) framed these knowledge (and therefore model) expectations into three categories, salience, credibility, and legitimacy (SCL). Stakeholders will see models as more effective and will be more likely to use models, if models meet their expectations for salience, credibility and legitimacy.

Salience of a model is multi-faceted. Elements of salience are derived from model relevance (i.e., is the information useful for responding to the problem) (Wilson 2009). Further, the context of knowledge is key in determining model salience; if stakeholders don't see the model as important for "understanding and solving the policy issue at hand" (i.e., they have to know that it is relevant), then the model lacks salience (van Voorn et al. 2016 p. 225). The credibility of the model concerns the logic and soundness of the model's construction and output (van Voorn et al. 2016). When considering model credibility, stakeholders will evaluate if the model concepts and processes are technically adequate and meet their standards for a reliable representation of the system. Lastly, the legitimacy of the model stems from the stakeholders' perception of the model fairness and its use in decision making; was the model unbiased towards any groups' views or interest? Was the model respectful of divergent stakeholder values? (Cash et al. 2003, Wilson 2009, White et al. 2010). Legitimacy of the model will be determined by each stakeholder's belief about what constitutes fairness (Wilson 2009).

Using this SCL analytical framework, we can measure stakeholder's attitudes towards models during a participatory modeling process. This work looks to address a knowledge gap in the literature concerning the impacts of participatory modeling processes on participants, focusing on changes in attitudes towards models. Some work has been done to understand process impacts on participants (Pahl-Wostl 2002, Rouwette et al. 2002, 2011). Even more limited has been attempts to understand longitudinal changes in stakeholders due to these processes (Rouwette et al. 2002, 2011). Measuring stakeholder's attitudes throughout a participatory modeling process, not just at the beginning and end, is crucial due to the dynamic nature of these processes (Seidl 2015, Sarkki et al 2015). Assessing attitudes over time allows us to better understand the nature of attitude formation and better attribute any attitude changes to the participatory modeling process itself. We are examining longitudinal changes in stakeholder's attitudes towards models due to factors related to participation in participatory modeling processes, stakeholder characteristics, and elements of social network structure.

Factors Impacting the Formation of Attitudes - The Role of Participatory Process and Social Network factors

Research into how individuals form their attitudes spans many disciplines, ranging from marketing (Bottomley and Doyle 1996), to psychology (Addison and Thorpe 2004), education (Stenseth et al. 2016), and issues of climate change and individuals' connection to nature (Happer and Philo 2016). Within participatory modeling processes, Rouwette et al. (2011) linked attitude changes to stakeholders' exposure to relevant ideas, either from other stakeholders or the model itself, during a group-modeling activity (Petty and Cacioppo 1986, Petty and Wegener 1998, Rouwette et al. 2011). No work, however, has examined attitude formation in relation to the models themselves. To determine what impacts changes in attitudes towards models, we focused on factors related to the participatory process itself and the stakeholders' social network.

Participatory Modeling Process Design and Stakeholder Characteristics – Impact on Attitudes Towards Models

The form and function of participatory modeling processes varies. Some processes utilize pre-built models to solicit stakeholder understanding concerning existing policy options (Voinov and Gaddis 2008) while others involve stakeholders in the creation and running of model scenarios to explore potential novel solutions to existing problems (Falconi and Palmer 2017). In past studies, these differences have been suggested to influence both the type and quality of decisions and how the stakeholders interact with each other and the overall process (Reed 2008). Despite the diversity in participatory modeling processes, there exist some universal factors that can be used to broadly understand the impact of these processes on stakeholders' attitudes towards models. By investigating what factors of participatory modeling practices influence stakeholder's attitudes towards models and *how*, we can better understand the role that the scientific models play during participatory modeling processes.

The selection of stakeholders and the representativeness of different stakeholder groups is a critical element of participatory modeling processes. The literature emphasizes the importance of who sits around the table, suggesting that individual characteristics and overall group composition can have a meaningful influence on group dynamics, model goals, formation and presentation, and the individuals themselves (Hare et al. 2003, Reed 2008, Voinov et al. 2014). The group of participating stakeholders dictates the knowledge sources available to the process. However, within the larger group, there exist natural sub-groups representing the different stakeholder groups within the process. These sub-groups represent pockets of knowledge and information. The availability of this group-specific information to the overall group has been suggested to foster innovation in decision-making processes (Fischer and Jasny 2017). In terms of the model, increasing the diversity of knowledge sources could enhance the ability of the model to represent the system in question by accounting for multiple perspectives (Duncan 2016).

However, these sub-groups can turn into echo chambers. Individuals within the same stakeholder sub-group have similar life experiences that facilitate increased communication and ease the development of trust (Yuan and Gay 2006). Oftentimes this results in individuals reflecting and reinforcing the views of their sub-group, leading to the creation and reinforcement of group-specific attitudes (Long et al. 2013). Paolisso and Dery (2010) noted differences in opinions on management options for oysters within the Chesapeake Bay based on stakeholder group affiliation. The increased level of familiarity and understanding with those in the same stakeholder sub-group can influence attitude formation.

Individual-level stakeholder characteristics other than stakeholder sub-group membership can also have an impact on attitude formation. Along with ones' sub-group association, level of education and years of experience speak to different ways of knowing among stakeholders (Lejano and Ingram 2009). Different levels of education or years of experience in one's field influence how stakeholders see and experience the world, including their assessment of the validity of knowledge, how knowledge is produced, and the assumptions inherent in the production of knowledge (Miller et al. 2008). Higher levels of education have been linked with enhanced thinking and reasoning skills, enabling stakeholders to better understand and utilize the model, which then aids the development of more positive attitudes towards models (Glaser 1984, Vila 2000).

Years of Experience speaks to a different manifestation of ways of knowing; learning and understanding begins with what individuals “already know and have experienced in everyday life” (Barnhardt and Kawagley 2005 p. 12). Since the early 2000’s in particular, scientific models have become much more common in natural resource management (Shenk and Franklin 2001). Thus, stakeholders who have more experience are likely more familiar with the benefits and limitations of models within natural resources management (e.g., when it is or is not appropriate to use models). However, the different ways of knowing inherent within different stakeholder sub-groups (e.g., watermen’s experiential way of knowing versus scientists’ more standardized, quantifiable way of knowing) could lead to differences between stakeholder groups in terms of attitudes towards models (Berkes 2009, Duncan 2016).

The literature also emphasizes the impact of participation on stakeholders during the participatory modeling processes. Different levels or degrees of participation, whether through process design or stakeholder attendance, has been cited as influencing the process itself and the results (Reed 2008). Literature on participatory processes has emphasized how enhanced participation can create the development of shared concepts and ideas through social learning and lead to increased likelihood of actors continuing to work together (Reed 2008, Scholz et al. 2014, Scott and Thomas 2015). The inclusion of models in the participatory process is thought to enhance these positive results even further. Participation in participatory modeling processes takes place through in model building. The model acts as a boundary object (White et al. 2010, Henly-Shepard et al. 2015), helping to facilitate the discussion between stakeholders, allowing them to better recognize their own implicit assumptions (Andersen et al. 1997), refine and alter their own mental models (Rouwette et al. 2011), and generalize knowledge that can be used or applied later or in a different scenario (Lane 1994).

However, the theorized positive impacts from participation and engagement in participatory processes aren't universal (Layzer 2008, Newig and Fritsch 2009). For participatory modeling processes, their ability to deliver on these results rests on stakeholder's willingness to use and engage with the model. This willingness can be examined through the salience, credibility, and legitimacy framework (van Voorn et al. 2016). Understanding how SCL attitudes towards models are impacted through elements of participation and stakeholder characteristics can help us improve how participatory modeling processes organization and use of models.

A Social Network Approach to Attitude Formation

In addition to the impact of a participatory modeling process on the formation of attitudes, we examined attitude formation from a social network approach. Using a network-perspective to examine attitudes is not new

(Festinger 1954). Network literature has long argued that “attitudes are made, maintained, or modified” through interpersonal relationships and communication (Visser and Mirabile 2004, Erickson 1988, p. 99). Thus, to understand and describe how attitudes are formed, social networks are the “natural units of analysis” (Erickson 1988, p. 99). The relationships and interactions between the stakeholders involved in participatory modeling processes represent “networks” that can be formalized through a social network analysis approach (van der Hulst 2009). The application of a social network analysis framework to study participatory processes has been limited (Prell et al. 2009) and hasn’t been applied to a participatory modeling process or longitudinally. Through the analysis of overall network structure and specific stakeholder roles during participatory modeling processes, we can better understand how the connections between actors during this process could impact the formation of their attitudes towards models. Specifically, brokerage roles within networks and overall levels of connectivity are examined to understand the impact of social network structure on attitude formation.

Brokerage in Communication Networks

Brokers are individuals in a network that facilitate a transaction between two otherwise unconnected actors (Marsden 1982). This position is seen as powerful; brokers can control how information flows within a network, facilitating opportunities for interaction, or inhibiting the spread of knowledge and resources (Cvitanovic et al. 2017). The role brokers play is considered especially advantageous in networks with many isolated clusters or sub-groups, like participatory modeling processes that involve multiple stakeholder sub-groups. Sub-groups in networks represent silos of knowledge and information that, if left unconnected, cannot benefit the overall network (Long et al. 2013). In these settings, brokers have the unique ability to create connections to these divergent sources of knowledge, breaking down silos and opening room for greater collaboration, innovation and understanding (Padula 2008, Bercovitz and Feldman 2011, Long et al. 2013). All brokers, however, are not made the same. Gould and Fernandez (1989) used an ego-centric (an individual-focused) approach to divide the concept of brokerage into five distinct roles based on *who* the individual is brokering communication between. Two roles, gatekeeper and liaison, could impact attitude formation towards scientific models.

Breaking Down Brokerage: Gatekeepers and Liaisons

A gatekeeper is an individual who, in an un-directed network, acts as the access point to their sub-group. These brokers represent the only path of connection in a network between their sub-group and an individual in a different sub-group (Figure 1). From this intermediary position, gatekeepers can selectively grant access to and from their group, acting as a gate that either permits or hinders the spreading of information (Gould and Fernandez 1989). Limitations in awareness and availability of information has been noted as an important factor in attitude formation (Upham et al. 2009). By controlling this flow, gatekeepers can influence attitude development. A liaison represents a brokerage role where an actor links two different sub-groups, neither of which they are a member (Figure 2, Gould and Fernandez 1989). The liaison mediates and coordinates transactions, playing a key role in connecting otherwise disconnected groups. This type of brokering creates more points of access to different sources of information and individuals, again potentially impacting attitude formation.

While there are potential attitude impacts, network-wide or within a specific sub-group from these positions, brokers themselves can be impacted by their roles. Valente and Fujimoto (2010) suggested that individuals in these brokering roles are more receptive to attitude changes as they are the recipient of targeted communication; individuals are specifically seeking out these brokers to communicate with them, which can have more influence on attitude formation than passively receiving information. Brokers also have access to an expanded range of ways of knowing. Through connections beyond one stakeholder sub-group, brokers' attitudes towards models may be influenced, depending on the nature of their connections (Beach 1997, Hargadon 2002). The extent to which an individual plays the role of a gatekeeper or liaison influences their access to and level of receptiveness to new information, which can then impact attitudes.

Degree Centrality

The theory of brokerage theorizes that actors are influenced by the specific nature of their connections and relationships; it's not just how many people you know, but *who* you know. Conversely, the idea of degree centrality focuses on that concept of 'how many' people you know. The degree measure is the total number of nodes that an actor is connected to (Opsahl et al. 2010). While the degree measure doesn't consider overall network structure, it does represent the level of connectivity of an actor, suggesting their level of influence. Individuals with high degree scores are in prominent and visible positions within the network. Rogers (2003) found these high degree individuals to be opinion leaders. The nature of this leadership position can come with an expectation to uphold the status quo, limiting any changes in these actors' attitudes (Becker 1970, Valente and Fujimoto 2010).

The OysterFutures Case

OysterFutures was the participatory modeling setting in which we studied the longitudinal changes in stakeholders' salience, credibility, and legitimacy attitudes towards scientific models. The goal of OysterFutures was to "develop recommendations for oyster policies and management that meet the needs of industry, citizen, and government stakeholders in the Choptank and Little Choptank Rivers", located within the Choptank River Complex in the Maryland portion of the Chesapeake Bay (OysterFutures website). Recommendations were developed for the Maryland Department of Natural Resources (DNR), the agency in charge of Maryland fisheries management. The OysterFutures project consisted of nine facilitated closed workshops over the course of twenty-five months from 2016 to 2018. The process used a diverse group of stakeholders from multiple sub-groups (watermen, aquaculturists, recreational fishers, environmental groups, and members of state and federal government agencies) to iteratively develop a scientific model to forecast the effects of different management options on outcomes related to oyster abundance, harvest, and environmental performance measures. Stakeholder input into the model and model guidance occurred throughout the process to develop a model that fit the needs and interests of the participating stakeholders. Continued communication and interaction has been noted as important for maintaining the salience, credibility and legitimacy of knowledge and model options (Galford et al. 2016, van Voorn et al. 2016). Using the model, stakeholders considered a variety of oyster management and policy options, including enforcement, rotational harvest, habitat modification and restoration, and combinations of options that included multiple management options in a single model run.

The model creation and building during OysterFutures was complemented by professional facilitation from Florida State University's Florida Conflict Resolution Consortium (FCRC). Previous literature on participatory processes have emphasized the importance of neutral, independent facilitators to reduce process bias (Wondolleck and Yaffee 2000). Facilitation creates an even playing field to promote equal stakeholder participation, and discussion of the scientific model, during meetings (Voinov and Gaddis 2008). These facilitators were chosen due to their previous experience facilitating a fisheries-focused participatory modeling process and their origin outside the Choptank River, which enhanced their perceived neutrality (Miller et al. 2010). During the OysterFutures process, the facilitators emphasized that the scientific model was a tool to help stakeholders make decisions and was not the sole guiding force. The model was acting as a boundary object that aided facilitation; it was used to create linkages between environmental science and policy and between different stakeholder sub-group knowledge (White et al. 2008, Lejano and Ingram 2009, White et al.

2010). While boundary objects like scientific models can “foster integrative deliberation” (Lejano and Ingram 2009, p. 653), they are sometimes associated with “mutual misunderstanding”, where different stakeholder sub-groups don’t see the model in the same way (Borowski and Hare 2007 p. 1049). This can result in different attitudes towards models by different stakeholder groups, and therefore different levels of willingness to use the model to inform decision-making. Thus, the facilitators encouraged stakeholders consider all sources of knowledge, including government data, scientific reports and local ecological knowledge, along with the model when ranking and voting on recommendations.

Voting on recommendations during OysterFutures was consensus-based with a minimum threshold of 75% of participants needed to approve a recommendation. No individual stakeholder group represented 75% of the workshop (60% of stakeholders represented industry groups - watermen, seafood buyer, aquaculturist, n = 9). Thus, stakeholder groups had to cooperate and compromise during recommendation formation. Defining consensus at 75%, not 100%, helped ensure an outcome could be reached, avoiding any stalemate where “no decision would be taken if any member disagreed” (Wilson 1989 p. 269).

A combination of social network analysis statistical methods and ordered logistic regression modeling were used to test hypotheses related to how stakeholders formed their attitudes towards models during OysterFutures. The hypotheses can be divided into those concerning the participatory modeling process and stakeholder characteristics and those concerning the impact of social network factors.

Participatory Modeling Process Hypotheses

- PMH1 - Stakeholder group membership (sub-groups) in OysterFutures will impact SCL attitudes towards models and
    - PMH1b - Not all Stakeholder Groups will have the same attitudes towards models.
- PMH2 - Increased attendance and participation in the workshops over time (participation level) will positively impact stakeholders' SCL attitudes towards models.
- PMH3 – Higher levels of education and more years of experience will increase attitudes towards models and
    - PMH3b – Differences in Stakeholder Groups ways of knowing will result in different impacts of levels of education and years of experience.

Social Network Hypotheses

- SNH1 - An actor's type and extent of brokerage function in the social network (gatekeeper and liaison) will positively relate to attitudes towards models - the more of a broker an actor is, the higher SCL attitudes towards models will be.
- SNH2 – Lower degree centrality scores will result in lower SCL attitudes; the less connected an individual is in the network, the more capable they

are of being influenced to change their attitudes towards models because the pull of group norms is weaker.

METHODS

Data Collection

We used survey instruments, observations and interviews to examine changes in stakeholders' attitudes towards scientific models over the course of the OysterFutures participatory modeling process. Twenty-nine stakeholders representing eight stakeholder sub-groups (scientists, facilitators, seafood buyers, aquaculturists, watermen, environmental groups, recreational fishers, and state and federal government officials) participated. A questionnaire distributed at the beginning of each of the nine workshops was used to gather data on stakeholders' communication networks and their attitudes towards models. Timing of the questionnaires immediately before a workshop captured changes in networks since the previous workshop, acting as a lagged response. The questionnaire took between 15 and 30 minutes to complete.

The communication social network question examined the frequency of communication between the stakeholders participating in the OysterFutures process. The stakeholder communication network was examined because of the role of communication in creating motivations and influencing attitudes (Putnam 2000, Hartley 2010). The influence of interpersonal relationships in social networks on attitude formation has been built on the idea of communication (Rantala et al. 2017). Networks were measured over time to examine changes in network structure. In addition to detecting changes, longitudinal analysis of networks allows any changes to be assessed “as a consequence of...certain [network] structures and not others” (Berardo 2014 p. 218).

Stakeholders were presented with a roster of the other participants and asked how often they communicated with everyone (excluding themselves) since the previous OysterFutures workshop. For this study, any form of information or resources exchange within and beyond the scope of the OysterFutures process were considered equal instances of communication. Choices for communication frequency ranged from “Never” to “1 or more times per day”, creating a 0-5 Likert scale. Instances where no level of communication frequency was reported were recorded as 0, no communication existing between the stakeholders during that period. The frequency of communication for Workshop 1 acted as a baseline, providing the initial level of communication between stakeholders before the OysterFutures process.

Within the same questionnaire, stakeholders were asked to rate their attitudes towards scientific models. Scientific models were defined as an approach commonly used in science to better understand and illustrate how the world works. Stakeholders’ attitudes towards the salience, credibility, and legitimacy of models were assessed with five questions examining the accuracy, reliability, fairness, and usefulness of models and if models made oyster management easier (termed easier management). Questions on easier management and usefulness measured salience, questions on accuracy and reliability measured credibility, and fairness measured legitimacy. For exact wording of the questions, see Table 1. Stakeholders were asked to rank their attitudes towards scientific models on a Likert scale from 1-5, with 1 representing the most negative attitude towards models, and 5 representing the most positive for each question. Stakeholders were also allowed to answer, “Do not know”, suggesting they do not have enough information to determine their attitude towards scientific modeling in that context.

Stakeholders’ attitudes towards models were assessed at each workshop. Their communication networks were assessed at all workshops except Workshop 8. The small gap in time between Workshop 7 and Workshop 8 (less than 4 weeks) limited variability in communication between stakeholders; data gathered from this period would not have been informative of overall communication trends. Response rates varied across meetings due to stakeholder absence or not completely filling out the survey but remained high (Response Rates: Workshop 1 - 100%, Workshop 2 - 92%, Workshop 3 - 81%, Workshop 4 - 85%, Workshop 5 - 73%, Workshop 6 - 81%, Workshop 7 - 77%, Workshop 8 - 81%, Workshop 9 - 92%, Average - 85%). Attitude towards Models data was compiled into a Workshop-specific document after each workshop with stakeholders’ other attitude questions (towards science and local ecological knowledge) and demographic information (e.g., years of experience, level of education). Attitude data was analyzed on its own to examine trends and as attribute data (data that describes the actors’ nodes in the social network) in examining the changes in the communication network.

After each workshop, communication network data was imported into UCINet, a social network analysis software (Borgatti et al. 2002). The communication network was symmetrized to account for different reported levels of communication. Between two individuals, there can only be one true frequency of communication number. However, at times, stakeholder pairs would report different levels of communication frequency. Symmetrizing the network selects one value of communication frequency to represent the level of communication between the pair. To not overestimate the frequency of communication, the communication network was symmetrized to the minimum reported value. That is, the lower communication frequency reported between node A and Node B was selected as the strength of the tie or link between them (Willging 2005). In the case of a missing value, the non-missing value was used to represent communication frequency.

Ordered Logistic Regression Model for Attitudes Towards Models

Five ordered logistic regression models (McCullagh 1980, Fullerton 2009) were constructed using the polr function in R (Venables and Ripley 2002, R Core Team 2015) to test the impact of social network measures, factors related to the participatory modeling process and stakeholder characteristics on stakeholders SCL attitudes towards models. The use of the polr function allowed the attitude responses to be represented as ordered categorical dependent variables, reflecting the nature of the Likert scale measurement tool. Each model's dependent variable captured a single dimension of stakeholders' attitudes towards models (two dimensions of both salience and credibility and one dimension of legitimacy). Examining each attitude question individually allowed us to understand more specifically if and how social network, participatory process, and stakeholder characteristics impact attitudes.

The same independent variables were used across all models for comparability. Table 2 reports the summary statistics for the five dependent variables and the non-factor independent variables. Collinearity issues involving correlation between predictor variables necessitated excluding participants from the model who were members of smaller stakeholder sub-groups ($n < 3$, facilitators, seafood buyers, and recreational fishers) (Mason and Perreault Jr. 1991, Crona and Bodin 2006). This also helped maintain the anonymity of individuals within these smaller stakeholder groups. As a result, twenty-five stakeholders representing five stakeholder groups (scientists, watermen, aquaculturists, environmental groups, and government officials) were included in the model. For further information on the model, see the supplementary material.

Participatory Modeling Process and Stakeholder Characteristic Variables

The Stakeholder Group, Workshop, Years of Experience, Number of Meetings Attended Until This Point, and Education variables all captured elements of the participatory modeling process and the OysterFutures stakeholders. The Workshop and Number of Meetings Attended variables allowed us to understand how the progression of the workshops and varying rates of participation impacted stakeholders’ attitudes towards models. The Workshop variable captured the progression of workshops, and a significant result for this variable suggests a temporal change in stakeholders’ attitudes. The Number of Meetings Attended variable captured how many meetings stakeholders attended until that point in the process. For example, during the Fourth Workshop, if a stakeholder had been present at all meetings, they were coded a four. However, if a stakeholder missed one meeting, they were coded as a three. To explore the impact of individual stakeholders on attitude formation, ordinal logistic regression models were also run with individual stakeholder as a fixed variable.

The Stakeholder Group, Years of Experience, and Education variables captured characteristics of the stakeholders participating in OysterFutures that could impact attitude formation. The Stakeholder Group variable captured the different group associations of stakeholders participating in OysterFutures. The Years of Experience and Education variables captured elements of stakeholders' training and knowledge. In the survey, education was recorded as an ordered factor variable. Based on the distribution of education amongst OysterFutures stakeholders and with the guidance of the literature, the education variable was transformed into a binary dummy variable for the model. 1 represented undergraduate and graduate (Masters or PhD) levels of education. 0 represented associates or high school levels of education. An undergraduate education level was chosen as the division point because it represented a natural even split in stakeholder education levels. The Years of Experience variable captured the varying lengths of time that stakeholders had been working in their respective fields.

Social Network Variables

The importance of networks in the formation of attitudes led to the inclusion of social network variables from a communication network. Social network measures related to brokerage (gatekeeper and liaison) and actor centrality (degree centrality) were used to understand the role that network position and structure plays in attitude formation. The sub-groups necessary to define the gatekeeper and liaison positions were the OysterFutures Stakeholder Groups. Focusing on these network positions allowed us to examine the communication flow and knowledge exchange between sub-groups within the network. To account for different sub-group sizes, the relative values of the gatekeeper and liaison variables were used (Everton 2012). The relative values normalize brokerage scores, dividing raw scores by the expected values given the number of groups and the size of each group. Expected brokerage assumes that brokerage is independent of which group a node occupies. Relative brokerage then allows us to understand how groups differ from this expectation, i.e., if brokerage is determined by group membership (Gould and Fernandez 1989). The network values represent stakeholders' role in the network since the previous workshop. The communication network question represents the frequency of communication between workshops; this makes the nature of these questions lagged. Lagged variables have been commonly used to investigate and attribute causation to economic, demographic or government policy variables (Bellemare et al. 2017). Consideration of the social network variables as lagged allows us to make causal inferences, e.g., a more central network position decreased attitudes towards models. However, we also ran the ordered logistic regression models with network variables altered to be lagged by one workshop to see if our assumptions about the lagged nature of the original question were valid. For further information, see the supplementary material.

McFadden's Pseudo R^2 values were calculated for each model to provide an estimate of goodness of fit (McFadden 1979). The categorical nature of the dependent variable did not allow us to obtain estimate of residual variance from traditional methods, and thus necessitated the use of a pseudo R^2 value.

RESULTS

Ordered Logistic Regression Model for Attitudes Towards Models

Results show that elements of the participatory modeling process and stakeholder characteristics significantly impacted stakeholders' attitudes towards the salience, credibility, and legitimacy of scientific models. Communication social network variables, on the other hand, only significantly impacted credibility attitudes towards models. This suggests different impacts of the OysterFutures process and communication network position on stakeholders' attitudes towards models.

Participatory Process and Stakeholder Characteristic Variables

Stakeholder Group membership was a significant predictor of all elements of the salience, credibility and legitimacy attitudes towards models. Membership in the Environmental Group resulted in significantly higher attitudes towards salience (usefulness: $p < 0.01$, easier management: $p < 0.01$), credibility (reliability: $p < 0.05$) and legitimacy (fairness: $p <0.05$) of models than membership in other stakeholder sub-groups. The coefficients of the polr model are scaled in terms of logs. These log odds can be converted into more easily-interpreted probabilities, or the likelihood that the variable significantly impacts attitudes towards models. For example, members of the Environmental Group stakeholder group has a 0.9 probability of viewing models as a legitimate way to make oyster management decisions compared to other stakeholder sub-groups. There was a 0.97 probability that Government stakeholders viewed the models as a salient way to manage oysters (usefulness: $p < 0.05$) and a 0.88 probability they viewed models as highly credible (accuracy: $p < 0.1$). Membership in the Scientist stakeholder group significantly impacted all elements of salience, credibility, and legitimacy attitudes towards models (Usefulness: $p < 0.01$, Easier Management: $p < 0.01$, Accuracy: $p < 0.01$, Reliability: $p < 0.05$, Fairness of models: $p < 0.1$). For example, there was a 0.97 probability that scientists viewed the models as a credible way to make oyster management decisions.

Lastly, being a member of the Watermen stakeholder group significantly impacted attitudes towards whether models make management easier ($p < 0.05$). When an individual is a Watermen stakeholder group member, the estimated probability of a higher attitude towards models decreases by 0.52. In other words, there is a significantly higher probability Watermen view models as making oyster management more difficult.

The Education variable closely followed the division between stakeholder groups. Members of the Government, Scientist, and Environmental Group stakeholders all had college degrees or above (see Figure 3). However, increased levels of education, when controlling for stakeholder group membership, led to significantly lower attitudes towards the salience (usefulness: $p < 0.01$, easier management: $p < 0.01$) and legitimacy (fairness: $p < 0.1$) of models. These, however, were accompanied by low probabilities. When examining the impact of higher education on attitudes, the estimated probability of lower attitudes towards the usefulness, easier management and fairness of models increased by 0.05, 0.01 and 0.01 respectively. Therefore, while education can significantly impact attitudes towards models, the probability of that impact is low.

The impact of Years of Experience was significant and negative for elements of model salience (usefulness: $p < 0.01$) and legitimacy (fairness: $p < 0.01$). There was a 0.5 probability more experienced stakeholders saw the models as both less useful and less fair for oyster management decisions. Despite the negative impacts of years of experience on the usefulness dimension of salience, there was a 0.5 probability that more experienced stakeholders saw the models as a significantly easier way to manage oysters (salience: $p < 0.01$). Thus, for more experienced stakeholders, models may make management easier, but they are not useful.

The Workshop variable was only a significant variable for determining attitudes towards the salience of models (easier management: $p < 0.05$). As the workshops progressed, there was a 0.63 probability that stakeholders overall saw the models as a significantly easier way to make oyster management decisions. Figure 4 shows this significant increase in easier management from models over the course of the OysterFutures workshops.

Results for the polr models accounting for the individual variation in stakeholder attitude formation demonstrate significant individual differences in attitude formation during OysterFutures. Adding a fixed variable accounting for individual stakeholders resulted in higher McFadden's pseudo R^2 values than the main model. The individual-stakeholder models resulted in more instances of significant changes over the course of the OysterFutures workshops (Workshop variable). Only the Workshop and individual stakeholder variables were significant in these model runs. (See supplementary material for Individual stakeholder model results).

Social Network Variables

The Gatekeeper variable was the only significant network variable for determining attitudes towards the salience, credibility and legitimacy of models; the liaison brokerage role and degree centrality were not significant. The more an individual played a gatekeeping role in the network, the estimated probability of a higher attitude towards the credibility (accuracy and reliability) of models decreased by 0.25 and 0.12 respectively (accuracy: $p < 0.01$, reliability: $p < 0.01$). By acting as more of a gatekeeper (i.e., by connecting members of your group to individuals in other stakeholder sub-groups), stakeholders had significant, but marginally lower probability of viewing the models as accurate or reliable.

Results from the Lagged models for communication social network variables did not drastically differ from the non-Lagged model results, although McFadden's pseudo R^2 values show the lagged model had a better fit. Results from these models reported less significant network and participatory modeling process variables, but none of the findings contradicted the non-lagged model findings. This supports our assumptions about the lagged nature of the original network question. The supplementary material shows model results and significant variables from these lagged models.

DISCUSSION

Findings from this work offer insights into factors that impact stakeholders' attitudes towards scientific models during a participatory modeling process, OysterFutures. Stakeholder group association had a strong, persistent impact on salience, credibility, and legitimacy attitude formation; individuals reflected and reinforced the views of their sub-group. In addition, by examining stakeholder's communication networks, we identified elements of network structure that influenced attitudes towards models. Acting in a gatekeeping capacity was connected to changes in perceived model credibility.

By better understanding what influences model attitude formation, participatory modeling processes can adjust their design and function to better take advantage of these models and practitioners can have more realistic expectations concerning the role of models participatory, collaborative natural resources decision-making processes.

Impact of Stakeholder Group Membership and Education: Indicators of the Impact of Divergent Ways of Knowing on Attitude Formation

The most prevalent factor influencing attitudes towards scientific models was Stakeholder Group membership. There were persistent differences in stakeholder sub-groups attitudes towards models throughout OysterFutures (Figure 5 presents legitimacy of models' attitudes as an example). Individuals consistently reflected and reinforced the views of their stakeholder sub-group and differences between stakeholder sub-groups weren't abated by the participatory process. Within collaborative processes like OysterFutures, shared ideology found through stakeholder group association can be a strong polarizing force (Calanni et al. 2014). A common ideology is built in stakeholder sub-groups because of shared beliefs (Yuan and Gay 2006, Henry et al. 2010). This foundation of similarity eases communication by reducing unknowns and lowering transaction costs, making it more likely that separate coalitions will form based on sub-group association. Communication within these groups can then influence the creation of similar group-wide attitudes, separate, distinctive framings of the problem at hand (Hovland et al. 1957, Sherif and Hovland 1961). Stern and Coleman (2015) refer to this as the reference group theory. People use reference groups of individuals they trust and feel have similar ideas to themselves to develop their own attitudes. While this increases intra-group reliance and trust, it can hinder the development of wider understanding, resulting in these persistent group differences in attitudes. The lack of group cohesion in terms of attitudes towards models could result in different levels of willingness to apply the model within the larger decision-making process.

The eased communication within stakeholder sub-groups created the opportunity to solidify like-attitudes (Gerber et al. 2013). However, it was the *strength* of these ties, the high frequency of communication, that was most influential, not simply the occurrence of communication. Within the whole OysterFutures network, we saw an overall increase in communication between all stakeholders, demonstrated through increases in network density and degree scores (the average frequency of communication) (Workshop 1 Density: 22.8%, Degree: 8.4, Workshop 9 Density: 38.9%, Degree: 11.67) (Opsahl et al. 2010). But the highest frequencies of communication were confined within sub-groups. Within the communication network, ties that represent more frequent communication are known as “strong ties” (Granovetter 1973). Strong ties are thought to have the most significant impact on actors. This suggests that attitude formation would most likely occur through strong tie connections (Visser and Mirabile 2004). Strong ties persisted throughout OysterFutures (Figures 6, 7 and 8). High-frequency communication remained within (solid lines) and between (dashed lines) likeminded individuals (individuals in the same stakeholder group and individuals in stakeholder groups who had similar attitudes according to model results, respectively). These results help explain why stakeholder group association was such a strong driver of attitudes towards models. Stakeholders stayed embedded in attitudinally congruent networks, which are more resistant to attitude change and exhibit more attitude stability (Levitan and Visser 2009).

The differences between the stakeholder sub-groups attitudes towards models was evident during the OysterFutures process. For example, watermen continually expressed concern that models made oyster management more difficult. In response to a scientist saying that watermen were “hard to model”, a waterman responded, “well I don’t know if we’re hard to model, or the model is hard to work”. Members of the environmental group, scientist, and government stakeholder groups, on the other hand, expressed that models made the oyster management process easier. They realized that the model “[was]n’t perfect” but that overall, it was an asset. A government member of OysterFutures spoke of how the models made it easier to defend positions. They said the ability to compare policy options using the model allowed for “a little bit better justification” for making decisions than “just…general sentiment” alone.

The divisions between stakeholder groups, with scientists, environmental groups and government having more positive attitudes towards models and watermen having more negative, suggests that the different attitudes stem from different ways of knowing. Duncan (2016) links different epistemologies (i.e., how we know) to different ontologies (i.e., what we know). The manner in which individuals frame and interpret the world impacts their levels of understanding and their ability to know and comprehend different pieces of knowledge (Ingram and Lejano 2009, Duncan 2016). Experiential-based knowledge, like watermen learning about Chesapeake Bay oysters based on years of direct observation out on the water, has often been termed local or traditional knowledge (Berkes 2009). Scientific “knowing practices”, on the other hand, are based on techniques that “standardize, aggregate, quantify” and give predictions about systems or areas of study (Duncan 2016, p. 153). The nature of scientific models stems from their ability to standardize, aggregate, quantify, and give predictions about systems, lining them up well with a more scientific way of knowing. The watermen stakeholder group was less captivated with models and their comments during OysterFutures illustrate that scientific models are not the way in which watermen come to “know” information; they are not how watermen typically formulate and acquire knowledge. Often during the process, watermen expressed concern over model results because the runs did not line up with what they knew from time on the water. Regarding the larval transport model, one older waterman said “what the model says is not what I see in the river. [I’m] not seeing [the larvae] land in all the places [the model] says it’s going.” To the watermen, the model was not a useful way to make decisions about oyster management because it did not reflect watermen’s knowledge and understanding.

Further, the decrease in perceived credibility of models speaks to an important distinction in the role of models in a participatory modeling process. The model is serving a fundamentally different role than it is in a scientific process; in participatory modeling the model is a tool of facilitation, to enable the exploration of ideas and the integration of diverse ways of knowing and not to illuminate understanding or be a dominant factor in decision-making.

The impact of different ways of knowing on attitudes towards models could also be seen in the Education variable results. The impacts of increased education towards the salience of the models seems counterintuitive. The pursuit of more education has been linked with enhanced thinking and reasoning skills (Glaser 1984). Vila (2000 p. 23-24) suggested that “more educated people have the knowledge, skill, and training required to search for, process, and use information more efficiently in decision-making processes.” Thus, it would seem likely that increasing education would increase attitudes towards the usefulness, ease, and fairness of models. The impact of the Education variable on attitudes towards models, however, is impacted by its connection with the Stakeholder Group variable. There was a division in terms of education levels of participating stakeholders, with roughly half of all participants having a college education or higher, and half not having a college degree. The stakeholder group and education variables captured similar individuals; most individuals who attended college or above were members of the scientist, environmental group, and government stakeholder groups. These sub-groups had significantly more positive attitudes towards models than other stakeholder groups. There were, however, a few members of the aquaculture and watermen stakeholder groups who attended college. The watermen sub-group in particular expressed instances of significantly negative attitudes towards models. Thus, when the model is run when controlling for stakeholder group association, the education variable is capturing the attitudes of these few individuals (watermen and aquaculturists, when consulting the raw data) who went to college and were not in the environmental group, scientist, or government stakeholder group. The negative education variable is speaking for these individuals and capturing the negative attitudes expressed by their stakeholder groups, *not* reflecting the impact of education on attitudes towards models. When the model is run without controlling for Stakeholder Group, the impacts of increased education on the salience and legitimacy of models all reverse. Instead we get positive impacts of education, though not all are significant (Salience: $p < 0.05$, Legitimacy: $p >$

0.05). This again highlights how the stakeholder group affiliation is acting as a strong indicator of different ways of knowing; the most educated stakeholders were all members of the scientific, government and NGO sub-groups and all had significantly more positive views towards models.

Multi-Faceted Nature of Salience

The stakeholders participating in OysterFutures were chosen because of their ability to represent and speak for their associated stakeholder groups. This is a common practice for participatory processes (Voinov and Gaddis 2008). The ability of a stakeholder to be seen as an opinion leader and accurately speak for their group is often associated with years of experience. As a result, stakeholders in participatory processes are usually older and have high levels of experience. Despite the efforts of OysterFutures to recruit both younger and older participants, especially within the watermen stakeholder group, the overall average experience was just over 24 years. Thus, based on our original hypotheses, since OysterFutures had more experienced stakeholders, their attitudes towards models would be higher given that they had worked with and seen models used for natural resources management in the past.

Years of Experience did significantly impact stakeholder's attitudes towards the salience and legitimacy of models. However, there was a conflicting impact of years of experience on the salience of the model. Across all stakeholder groups, the probability of stakeholders believing models made oyster management easier significantly increased with more years of experience. The impact of increasing years of experience on attitudes towards the usefulness of models, on the other hand, was negative – more experience led to a higher probability of stakeholders viewing the models as less useful. This implies that for individuals with more experience, the models made oyster management overall easier, but the models weren't perceived as relevant for the decisions at hand.

Instead of experience universally increasing attitudes towards models, experience resulted in stakeholders viewing the models more realistically, recognizing both their benefits and limitations. This difference in attitudes towards models could speak to more experienced stakeholders recognizing the difficult social and political context that the model simply could not represent. The setting of a scientific model, the larger context in which it is formed, can have an impact on model salience (Vader et al. 2004). The oyster fishery within Maryland presents a historically contentious setting that continues today (Kennedy and Breisch 1983). Many of the issues under discussion during OysterFutures have been frequently debated since the beginning of the public fishery. In the face of these long-standing issues, more experienced individuals doubted the relevance of the recommendations from the model. For example, when discussing shell availability, the topic of Man O' War Shoals, one of the largest remaining oyster shell deposits within the Chesapeake Bay, was raised (Cuthbertson 1988). Watermen and other industry groups have advocated harvesting shell from this deposit to supplement oyster bars in the public fishery. Many environmental groups oppose harvesting due to concerns over habitat degradation (Prost 2018). OysterFutures facilitators attempted to lead the group through discussions over these tensions, but these attempts resulted in overall discontent. More experienced stakeholders argued that this “20-year-old divisive issue” was “bigger than this room”, suggesting that they saw current discussions and modeling efforts as less useful, particularly regarding shell availability.

In addition, many experienced stakeholders noted that the limited geographic scope of the model also impacted its usefulness. The OysterFutures model was focused on the oyster fishery within the Choptank River Complex, not the overall fishery in Maryland. The limited geographic scope of the model frustrated many experienced stakeholders; they felt like any recommendations resulting from the model would not be useful in a statewide fishery. This was especially evident in the discussion surrounding limited entry options (i.e., a limited number of permits or licenses to harvest the resource are issued in order to reduce or maintain capacity and fishing effort). Most stakeholders, but especially more experienced watermen and aquaculturists, expressed an interest in a recommendation around limited entry. “We are a professional group and industry”, one member said, “we deserve an exclusive right - like a licensed electrician or plumber” or else the industry “cannot move forward”. The modeling team was able to model limited entry options recommended by the stakeholders, and a limited entry with rotational harvest option. The problems with the limited entry option wasn’t the modeling capability, but the *usefulness* of the modeling results to management, particularly regarding management strategies that have state-wide implications.

At the end of workshop 4, the idea of the mismatch of scales was first raised. Experienced watermen expressed that the “biggest problem” with the proposed recommendations was the regional focus of the model when the public fishery is a state license. The modelers had “no good answers” to address these concerns. The scope had such a strong limitation on the usefulness of the model, that no specific limited entry recommendations were included in the final report; the only mention of limited entry was a recommendation that Maryland Department of Natural Resources “evaluate” a limited entry system (OysterFutures Final Report 2018). The highly focused nature of the OysterFutures model made the model locally useful, but less relevant for state-wide management for more experienced stakeholders.

Salience, credibility, and legitimacy have the potential to counteract each other (Cash et al. 2003, van Voorn et al. 2016). Efforts to promote salience, credibility or legitimacy of a model can result in unavoidable tradeoffs during the modeling process where one criterion is given precedence (van Voorn et al. 2016). Ginger (2014) examined two dimensions of legitimacy to distinguish between internal (procedural based) and external (scientific expertise) sources of legitimacy during a participatory modeling process. Their results found evidence that these tradeoffs can also occur within a single criterion. Our results support this finding, demonstrating the difference between relevance and salience.

Both the complexity of the social and political reality of the Maryland oyster fishery and the limited geographic and socio-political scope of the scientific model contributed to more experienced stakeholders viewing the model and its outputs as significantly less useful. This finding suggests that participatory modeling processes should consider the broader geographic, social, economic and political context and limitations in which their model is based (Jones et al. 2009). While the process itself, the discussion and involvement of stakeholders, contributed to the model making management decisions easier, it was the larger political setting and history of the fishery that hindered the usefulness of the OysterFutures' model.

Limited Impact of Participation on Formation of Attitudes Towards Models

Van Voorn et al. (2016) hypothesized that stakeholders views on model salience, credibility and legitimacy could shift over the course of a participatory modeling process. Our results found limited evidence of this predicted shift (Figures 4, 9, 10, 11, 12). Only one of the dimensions of model salience (easier management) changed significantly over the course of the OysterFutures process; through participating in OysterFutures, stakeholders overall saw the model as a significantly easier way to manage oysters. The significance of the Workshop variable for attitude formation, but not the Number of Workshops Attended variable, suggests that meeting attendance alone does not shift attitudes towards models. Podestá et al. (2013) emphasized the importance of stakeholder's ownership and understanding of participatory modeling processes and the models themselves. For stakeholders to see the model as more useful (more salient), they need to actually use and engage with the model. Our results are along the same lines, suggesting that factors beyond attendance alone matter in the formation of attitudes towards models.

The impact of participation on model salience was evident during the OysterFutures Process. Stakeholders were actively engaged during the framing of the scientific model. Framing the model included elements of model design (e.g., spatial extent and time horizons), the intended role and expectations of the model, model inputs and scenarios, and model uncertainty (Liu et al. 2008, Girod et al. 2009, van Voorn et al. 2016). Engaging stakeholders in model framing occurred via iterative communication, which allowed modelers to hone in on stakeholders' ideas and suggestions, and a ranking system that permitted stakeholders to express their preferences for model scenarios. Van Voorn et al. (2016 p. 232) emphasized how "active dialogue reduces the risk of a loss of model salience" where stakeholders and modelers aren't on the same page. Discussion allowed for the establishment of common model perceptions by continually reviewing and revising model criteria. These specific elements of the OysterFutures process contributed to the increase in perceived salience of the scientific models (van Voorn et al. 2016). By emphasizing the role of stakeholders in determining model relevance and applicability, the modelers fostered this change in attitude. However, despite the benefits of dialogue and the impact of participation, there were still significant differences between stakeholder groups in terms of model salience. This demonstrates that the impact of participation and engagement in the model building process could not overcome the fundamental differences in ways of knowing between stakeholder groups.

Stakeholder Characteristics Impact on Credibility Attitudes

Stakeholder characteristics chiefly had significant impacts on the salience and legitimacy of the model. Credibility of the model was not significantly impacted by participation, years of experience, or education and only limitedly impacted by stakeholder group association. Credibility relates to belief in the modeling process (van Voorn et al. 2016). The lack of significance for credibility suggests that the scientists explained the model well; the stakeholders understood what the model was trying to do, even if they did not believe the model was salient or legitimate. The efforts taken by the scientists to communicate and explain the model scenarios and outputs contributed to its' credibility. As the workshops progressed and at the recommendation of stakeholders, scientists used more and alternative graphics and visualizations to represent the multitude of model outputs. Effective ways of presenting the model results included color coding the results to demonstrate changes in performance measures from the status quo and summarizing the estimated cost effectiveness of different model options. Stakeholders agreed that these visualizations were helpful for increasing understanding of the model results.

Social Network Variables

Results suggest that social network position played a significant role for gatekeepers in the determination of attitudes towards models. However, the direction of the network variable was opposite to what was hypothesized. The significant, negative Gatekeeper variable suggests that the more an individual plays a gatekeeping role, the probability of them viewing models as credible decreases ($p < 0.05$). Model credibility results from the scientific logic of the model and the perceived soundness of the knowledge and information used within the model (van Voorn et al. 2016). Assessing the credibility of the model is done, in large parts, through communication and discussion about the model (Girod et al. 2009, Schmolke et al. 2010). Communication with likeminded others is thought to have the greatest impact on attitude formation (Gerber et al. 2013). Thus, while both gatekeeper and liaison brokerage roles represent powerful positions of communication, only gatekeepers are in positions where they are communicating with those most like them, individuals in their own stakeholder group.

The communication within stakeholder groups acts as the foundation for the gatekeepers' attitudes towards models. However, the gatekeeper position is not built solely on these connections. Brokering considers the complex two-way relations that are necessary in the process of knowledge co-production (Turnhout et al. 2013). Gatekeeping provides access to multiple ways of knowing through connections to other stakeholder groups. Specifically, the impact of communication on gatekeepers is due to the targeted nature of the communication; individuals from other sub-groups are seeking out gatekeeping individuals (Valente and Fujimoto 2010). Through this targeted communication, gatekeepers learned about new sources of knowledge that could give additional meaning to their pre-existing knowledge, allowing gatekeepers to frame their attitudes towards models within a new context (Gick and Holyoak 1980, Reeves and Weisberg 1993, Beach 1997, Hargadon 2002).

The benefit of participatory modeling processes is in the discussions between individuals with diverse sets of knowledge. With gatekeepers, by comparing the knowledge of their group and the knowledge from outside their group, they were able to realize that models are “only one of several possible descriptions of any situation” (Hargadon 2002 p. 59). Exposure to other ways of knowing may have allowed gatekeepers to resist the “dogma” of any one way of knowing, lessening the overall credibility of any one technique or source of knowledge (Hargadon 2002 p.77).

Although gatekeepers’ attitudes towards models are influenced by their position within the network, they are not able to influence the attitudes of their fellow group members; stakeholder group remains a powerful driver of attitudes. Gatekeepers lack this influence because individuals who are gatekeepers are not necessarily the opinion leaders of stakeholder groups. Gatekeepers’ power comes from their access to and control over information, not their ability to influence and drive group attitudes’. Individuals with high degree centrality, high numbers of links or ties within a network or sub-group, are considered influential actors within a network (Rogers 2003). However contrary to our hypothesis, overall connectedness of actors did not impact their attitude formation. This suggests that who you know within these networks is more important than how many people you know. Everett and Borgatti (2005) have found similar results, suggesting that number of contacts within a network has less weight than other centrality measures. Individuals with high degree centrality are opinion leaders who are expected to uphold the status quo (Becker 1970, Rogers 2003, Valente and Fujimoto 2010). These are individuals who influence attitudes, not who are influenced by others’ attitudes. Network structure did influence attitude formation, but attitudes were primarily driven by individuals reflecting and reinforcing the views and ways of knowing of their stakeholder sub-group.

CONCLUSION

Participatory modeling has become an increasingly common technique in collaborative natural resources management decision-making processes (Barreteau et al. 2007, Jones et al. 2009). By engaging stakeholders in the modeling process, these processes are thought to be able to better address complex environmental policy questions (Hare et al. 2003). The foundation of these benefits is based on the scientific model used in these processes; for these processes to be able to address natural resource policy issues, stakeholders need to engage with and use the model. Measuring stakeholders' attitudes towards models can provide information on their willingness to use the information provided in the model, allowing us to better understand the role models play within the decision-making process (Cash et al. 2003). Stakeholder's attitudes were assessed during a participatory modeling process focused on oyster management in Maryland's Choptank River Complex, OysterFutures. This work addressed an existing knowledge gap concerning how stakeholders view scientific models used in participatory modeling processes. We hypothesized that elements of participation in OysterFutures, individual stakeholder characteristics, and communication network structure and position would impact stakeholders' attitudes towards models. Results have implications for how participatory modeling processes could better utilize models to enhance facilitation and guide and direct discussion between stakeholder sub-groups with diverse ways of knowing.

We found that stakeholder group association was a pervasive determinant of individuals' attitudes towards models. The impact of stakeholder group association was due to the frequency of communication between co-members, their common way of knowing, and their history with each other. The strength associated with stakeholder group affiliation on the formation of attitudes towards models is something that future participatory modeling processes should consider (e.g., dedicate time for stakeholders to share their way of knowing and how models do or do not reflect that way of knowing). Participation and communication did not erase the divide between stakeholder groups in terms of their attitudes towards models. Fundamental differences in ways of knowing, in particular between watermen (who's way of knowing is largely experiential and observational) and the other stakeholder groups (who's way of knowing is more analytical, focused on scientific assessment and quantification), led these groups to view the scientific model in significantly different ways. Going forward, participatory modeling processes should acknowledge that the integration of these divergent ways of knowing may not be possible (Turnhout 2013, Duncan 2016), and thus, focus on how models might help navigate these differences rather than seek to resolve them.

Instead of hoping knowledge integration and convergence of attitudes are the goals of participatory modeling processes, these processes should embrace the multiplicity of knowledge from different stakeholder groups and the co-production of knowledge and innovation that can emerge from diversity (Miller et al. 2008, Duncan 2016). In other words, can models help participatory modeling processes reach a level of co-production of knowledge and new, novel ideas rather than a consensus around a suite of existing ideas through trade-offs? Lejano and Ingram (2009 p. 656) emphasize the value in the exchange of knowledge versus simply bringing different "pearls of wisdom" to the table. Within a participatory modeling process, this could be done through allowing time and space for each stakeholder group to explain what they believe and why they believe it, giving them the chance to share how they see and understand the resource in question prior to model construction. Designing processes to allow for the sharing of diverse ways of knowing promotes access to resources needed for innovation, new and creative solutions to complex problems (Fischer and Jasny 2017). Participatory modeling processes can work towards innovative solutions by making sharing of diverse knowledge a priority.

The impact of access to diverse ways of knowing on attitudes towards models is evident through the social network results. Gatekeeping allowed stakeholders to understand the credibility of the model within a wider framework. The combination of inter and intra sub-group attitudes and knowledge allowed for a broadening of their attitudes towards models; gatekeepers were able to see the model in a more realistic light, better understanding its strengths but also its limitations (Hargadon 2002).

Wondolleck and Yaffee (2017) discuss the restrictions inherent in the application of scientific models for decision making. During a decision-making process, if your only tool to address policy issues is a hammer (a model), then all the problems begin to look like nails (issues that can be addressed using a model). Through discussion, problems begin to not all look like nails. Thus, models serve a fundamentally different role in a participatory modeling process than they do in a management or a scientific process. Here models are a tool of facilitation, directing and guiding discussions and negotiations, and a conceptual framework to integrate diverse ways of knowing to produce truly novel ideas. Models are not intended to be the arbitrators of disagreements or the decision-making tools. Disagreements persisted; we saw significantly different attitudes between stakeholder sub-groups. However, the model did work as a facilitation tool; the OysterFutures group was able to identify 30 consensus recommendations concerning the oyster fishery in the Choptank.

Using the OysterFutures case, we were able to understand the nature and factors impacting longitudinal changes to stakeholder's attitudes towards models over the course of a participatory modeling process. This represents the first application of a social network approach to study a participatory modeling process. Future work should analyze stakeholder's mutual understanding social networks to assess how understanding across stakeholder group divisions shifted over the course of the participatory modeling process. In addition, work will focus on stakeholder's attitudes towards science and local ecological knowledge to enhance our understanding of knowledge use and integration during a participatory modeling process. Last, we are examining the link between salience, credibility and legitimacy attitudes and network structure and function on one hand, and the consensus recommendations from OysterFutures (i.e., the outcomes) on the other.

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TABLES

Table 1: OysterFutures Questionnaire Attitude Questions

SCL Attitudes	Questionnaire Questions
SALIENCE	How ***useful*** are scientific models for oyster management? - extremely useful, somewhat useful, neither useful nor useless, somewhat useless, extremely useless
	Has scientific modeling made oyster management - much ***easier***, somewhat easier, not had much of an effect, somewhat difficult, much more difficult
CREDIBILITY	How ***accurate*** are scientific models in reflecting current conditions of oysters? - extremely accurate, somewhat accurate, neither accurate nor inaccurate, somewhat inaccurate, extremely inaccurate
	How ***reliable*** are scientific models in predicting future conditions of oysters? - extremely reliable, somewhat reliable, neither reliable nor unreliable, somewhat unreliable, extremely unreliable
LEGITIMACY	To what degree are scientific models a ***fair*** means of making oyster management recommendations? - extremely fair, somewhat fair, neither fair nor unfair, somewhat unfair, extremely unfair

Table 2: Summary Statistics for Ordered Logistic Regression Attitude Models

Model Variables	N	Mean	Standard Deviation
Usefulness of Models Factor (DV)	155	2.97	0.81
Easier Mgmt. of Models Factor (DV)	152	3.31	0.85
Accuracy of Models Factor (DV)	148	2.53	0.70
Reliability of Models Factor (DV)	152	3.39	0.80
Fairness of Models Factor (DV)	154	3.56	0.83
Stakeholder Group	225	N/A	N/A
Workshop	225	N/A	N/A
Years of Experience	216	24.33	11.05
Number of Meetings Attended Until This Point	225	2.85	2.32
Relative Degree Centrality	200	10.30	6.14
Relative Gatekeeper	200	1.25	1.00
Relative Liaison	200	0.63	0.63
Education Dummy Variable	207	0.7	0.46

Table 3: Summary of the Ordered Logistic Regression Model results for all Attitude Towards Models Questions

Ordered Logistic Regression Results

	Salience		**Credibility**		**Legitimacy**
	Usefulness of Models	Easier Mgmt. of Models	Accuracy of Models	Reliability of Models	Fairness of Models
Stakeholder Group - Environmental Group	4.13***	4.80***	1.59	2.50**	2.20**
	(1.08)	(1.07)	(1.04)	(1.06)	(0.95)
Stakeholder Group - Government	3.65***	2.57**	1.96*	0.84	1.24
	(1.15)	(1.02)	(1.13)	(1.04)	(0.99)
Stakeholder Group - Scientist	5.72***	3.52***	3.66***	2.43**	1.74*
	(1.17)	(1.09)	(1.20)	(1.13)	(0.98)
Stakeholder Group - Watermen	-1.06	-2.99***	0.70	0.55	-1.09
	(0.98)	(1.07)	(1.03)	(1.04)	(0.89)
Workshop	-0.08	0.55**	0.45	-0.04	-0.15
	(0.25)	(0.26)	(0.31)	(0.28)	(0.23)
Number of Meetings Attended	-0.19	-0.27	-0.41	0.20	0.25
	(0.29)	(0.29)	(0.34)	(0.32)	(0.27)
Years of Experience	-0.05***	0.03*	-0.01	-0.03	-0.06***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Network Metric - Degree	-0.003	-0.01	0.03	-0.03	-0.01
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Network Metric - Relative Gatekeeper	-0.08	-0.37	-1.24***	-0.83***	-0.28
	(0.27)	(0.30)	(0.38)	(0.32)	(0.27)
Network Metric - Relative Liaison	0.56	0.21	-0.41	0.47	-0.01
	(0.60)	(0.58)	(0.69)	(0.63)	(0.54)
College Education	-3.74***	-4.13***	-1.22	-0.76	-1.67*
	(1.07)	(1.10)	(1.01)	(0.97)	(0.95)
McFadden's Pseudo Rsquared	0.37	0.37	0.29	0.30	0.26
Observations	132	129	125	130	131

Note: *p<0.1; **p<0.05; ***p<0.01

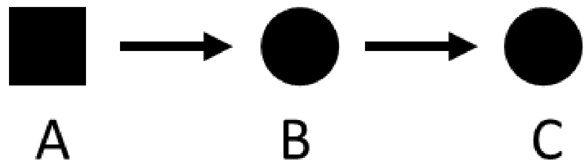

Figure 1: Representation of a Gatekeeper brokerage role (B), where B and C are members of the same sub-group, and B acts as the only path of communication between A and C. In this position, B can decide whether to grant access to the outside information into the sub-group

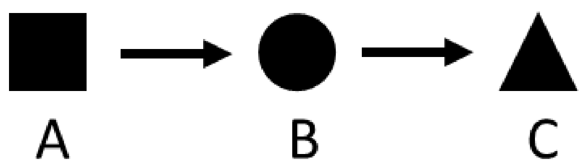

Figure 2: Representation of a Liaison brokerage role (B), where A, B, and C are all members of separate sub-groups. B's role here is to provide a link between individuals in two different sub-groups, while not being a member of either group

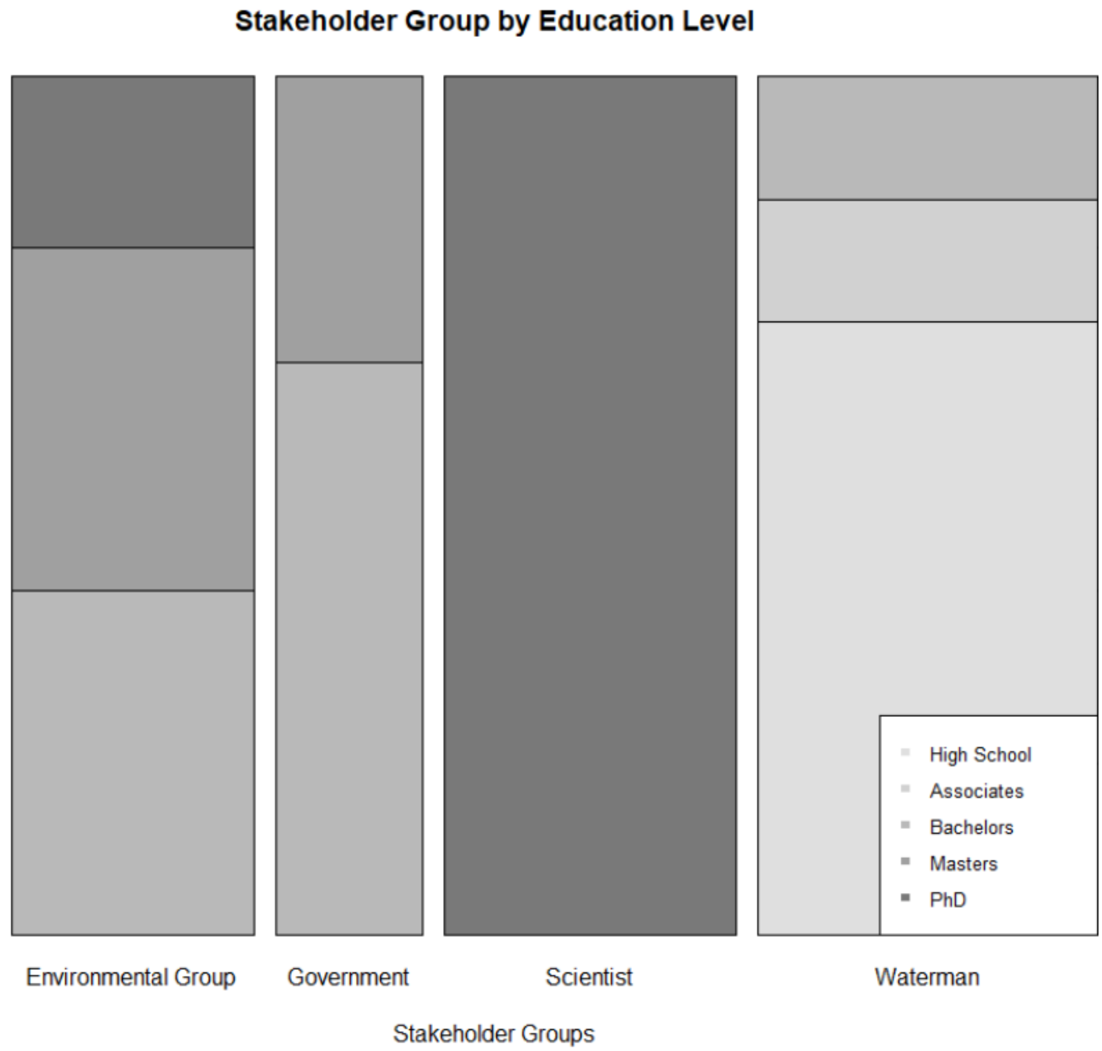

Figure 3: Levels of Education by Stakeholder Group

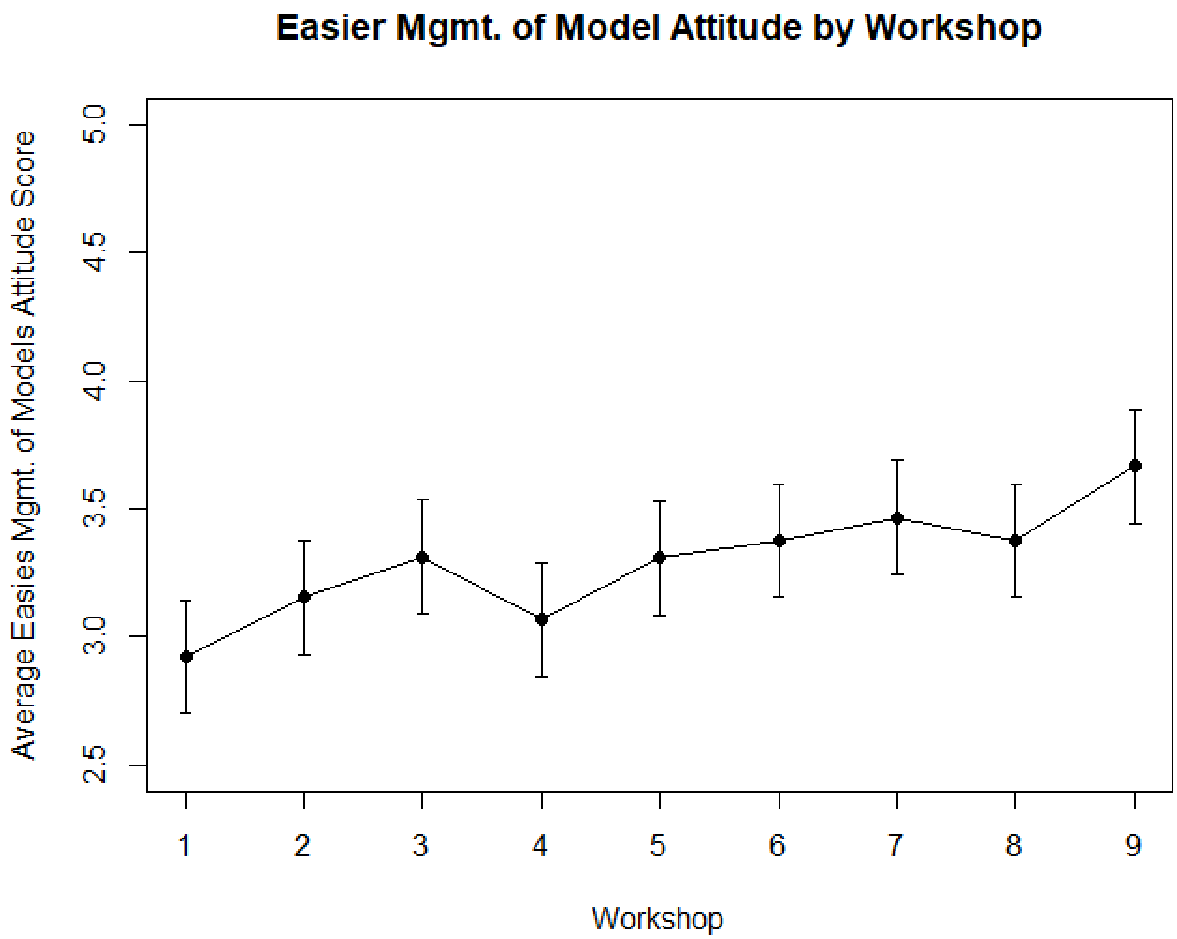

Figure 4: Average Ease of Models Attitude Score over the course of 9 OysterFutures Workshops with Standard Deviation

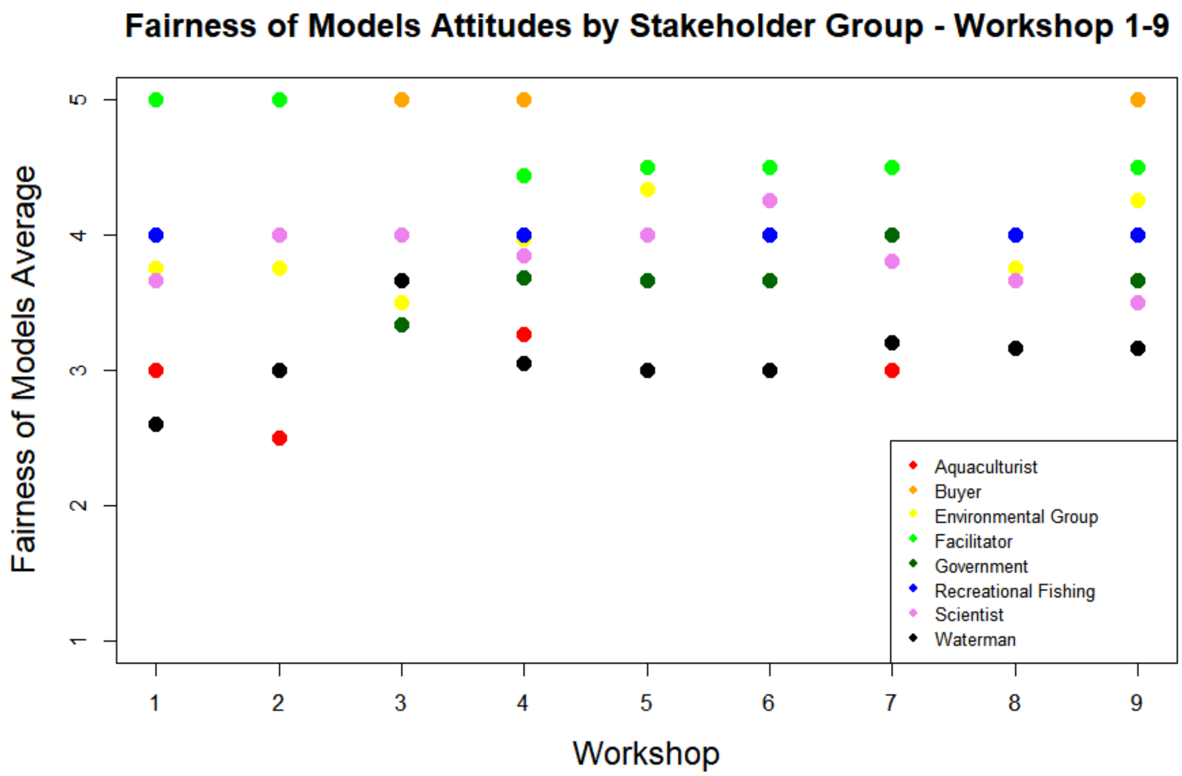

Figure 5: Example of the persistence of Stakeholder Groups' different attitudes towards models - here with the Fairness of Models - over the course of 9 OysterFutures Workshops

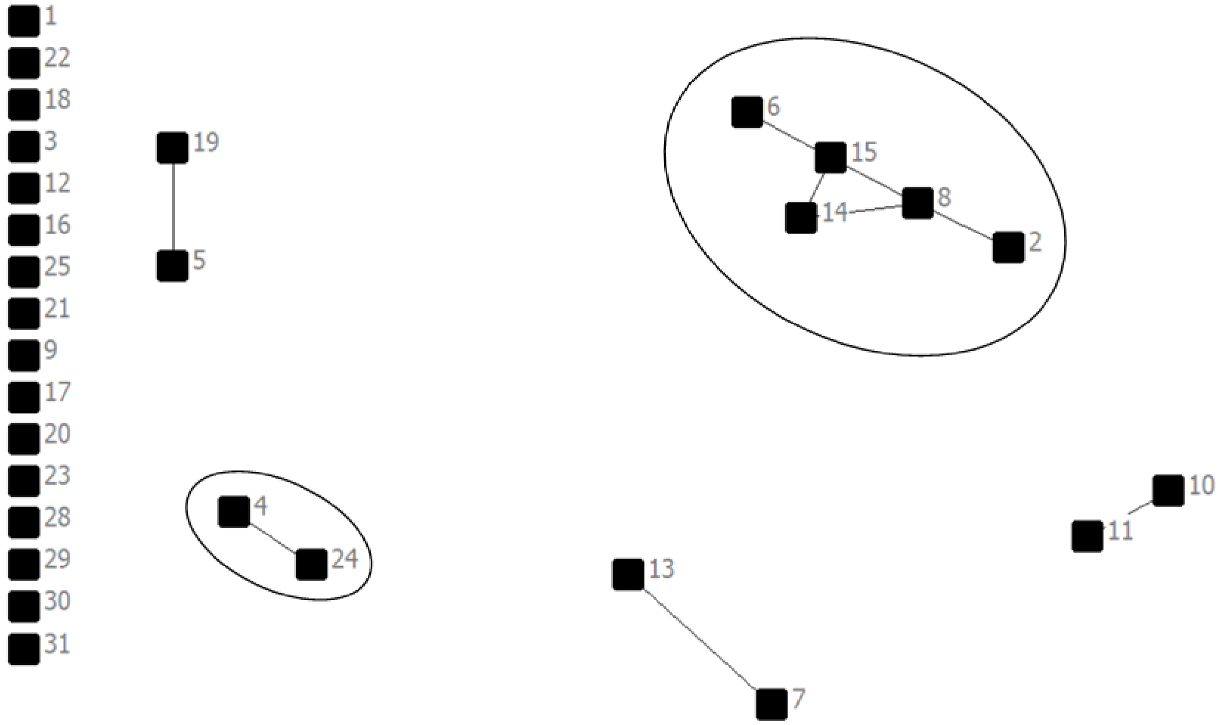

Figure 6: Workshop 1 High Frequency Communication Network - links representing communication paths with a strength of 4 or 5. Solid circles represent silos of communication between a single stakeholder group

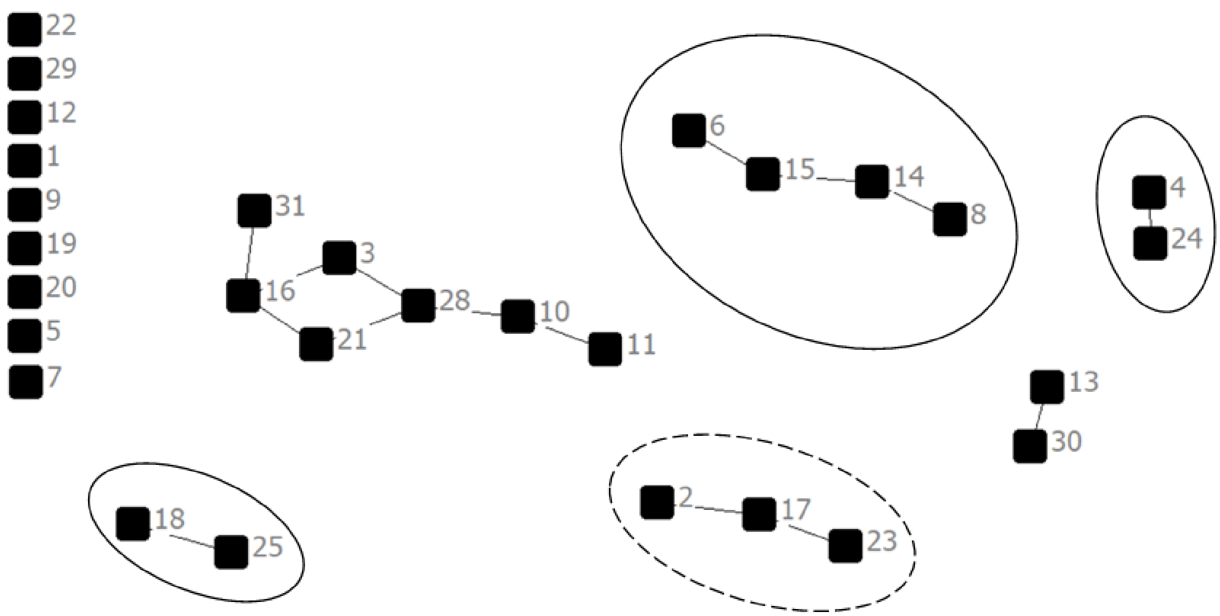

Figure 7: Workshop 4 High Frequency Communication Network - links representing communication paths with a strength of 4 or 5. Solid circles represent silos of communication between a single stakeholder group. Dashed circles represent silos of communication between two or more stakeholder groups with similar attitudes as described by the Ordered Logistic Regression Model

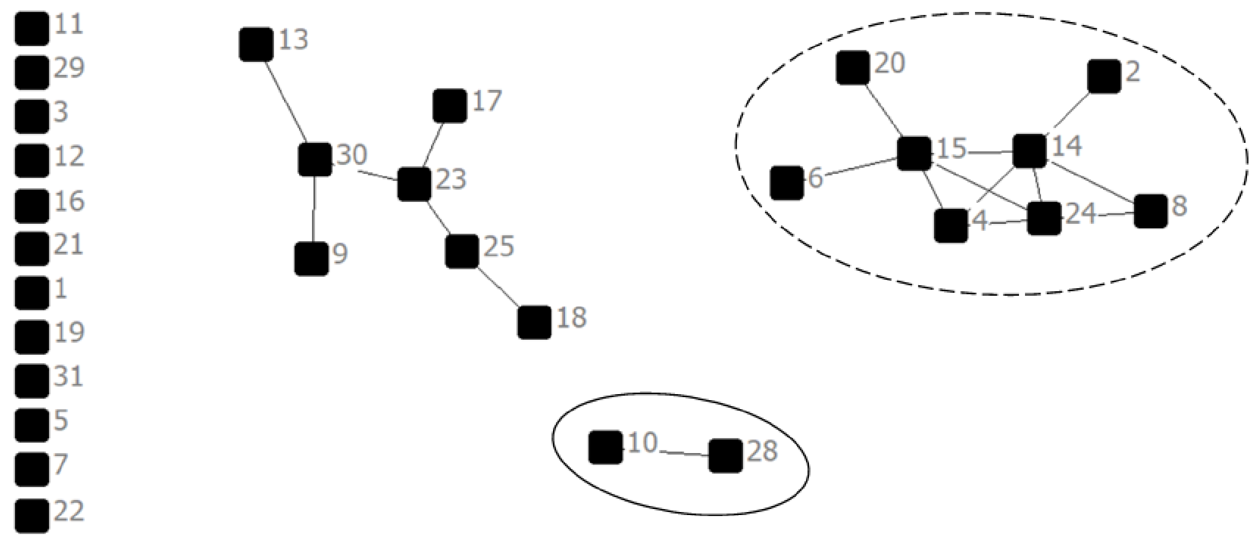

Figure 8: Workshop 9 High Frequency Communication Network - links representing communication paths with a strength of 4 or 5. Solid circles represent silos of communication between a single stakeholder group. Dashed circles represent silos of communication between two or more stakeholder groups with similar attitudes as described by the Ordered Logistic Regression Model

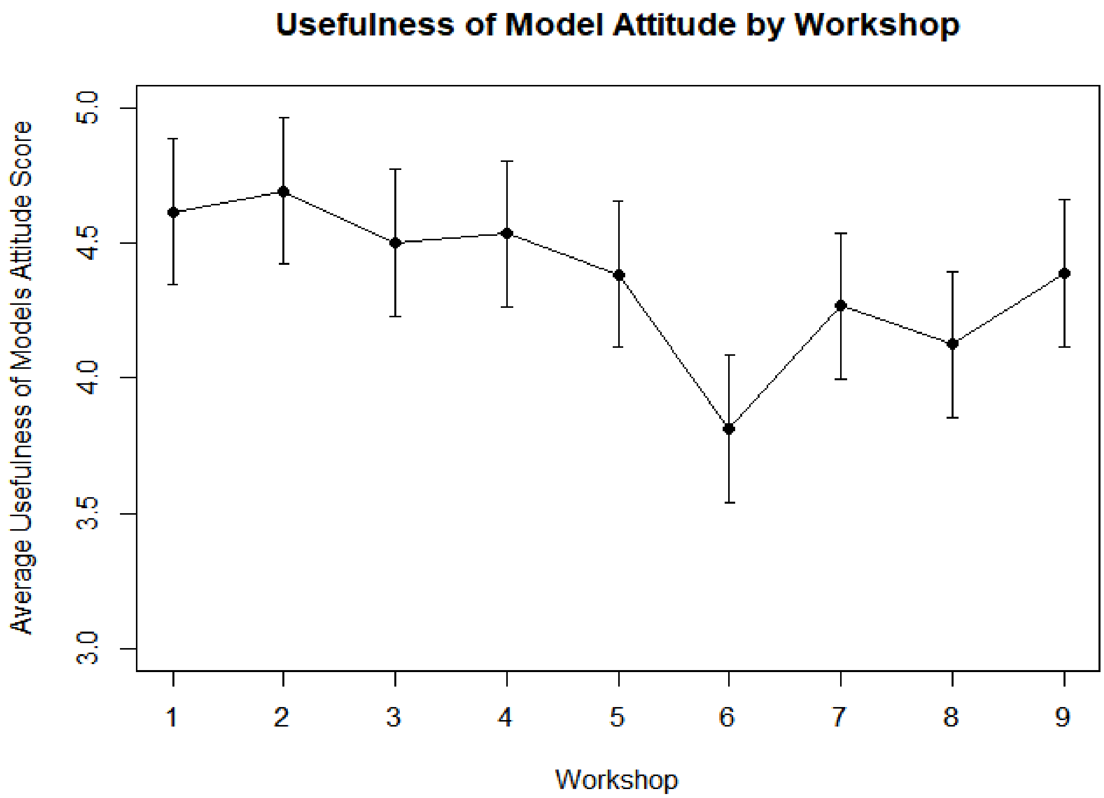

Figure 9: Average Usefulness of Models over the course of 9 OysterFutures Workshops with standard deviation

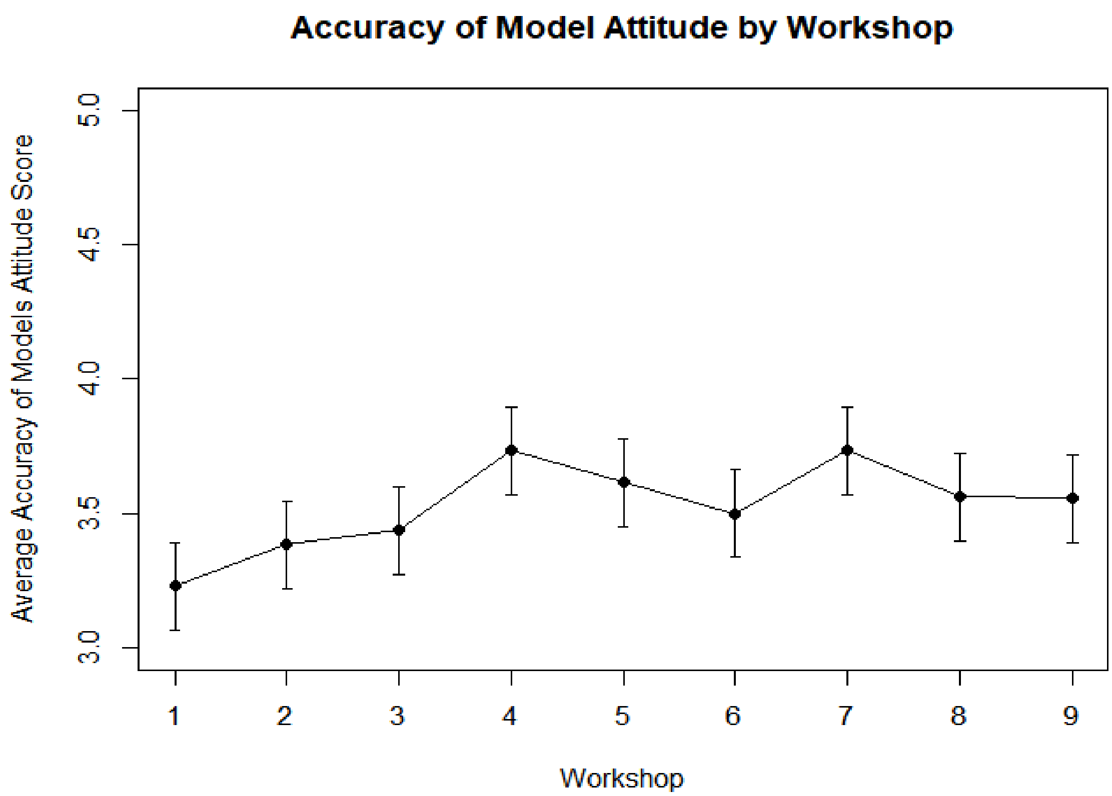

Figure 10: Average Accuracy of Models over the course of 9 OysterFutures workshops with standard deviation

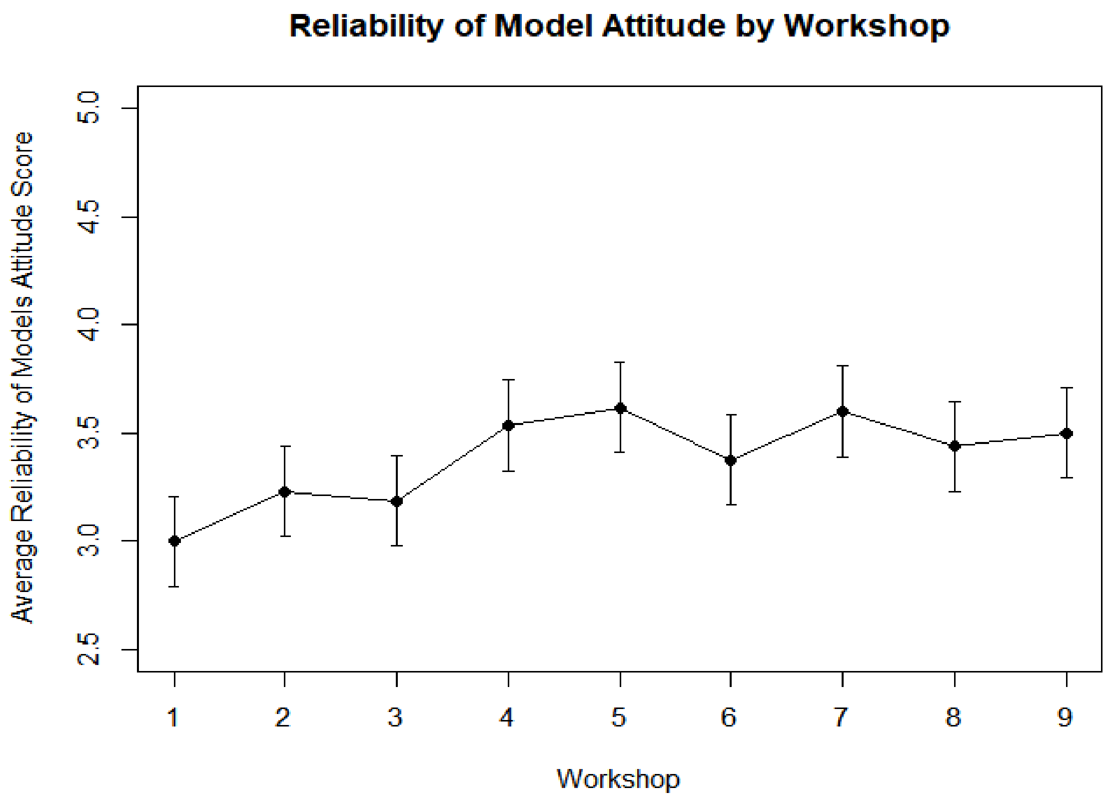

Figure 11: Average Reliability of Models over the course of 9 OysterFutures workshops with standard deviation

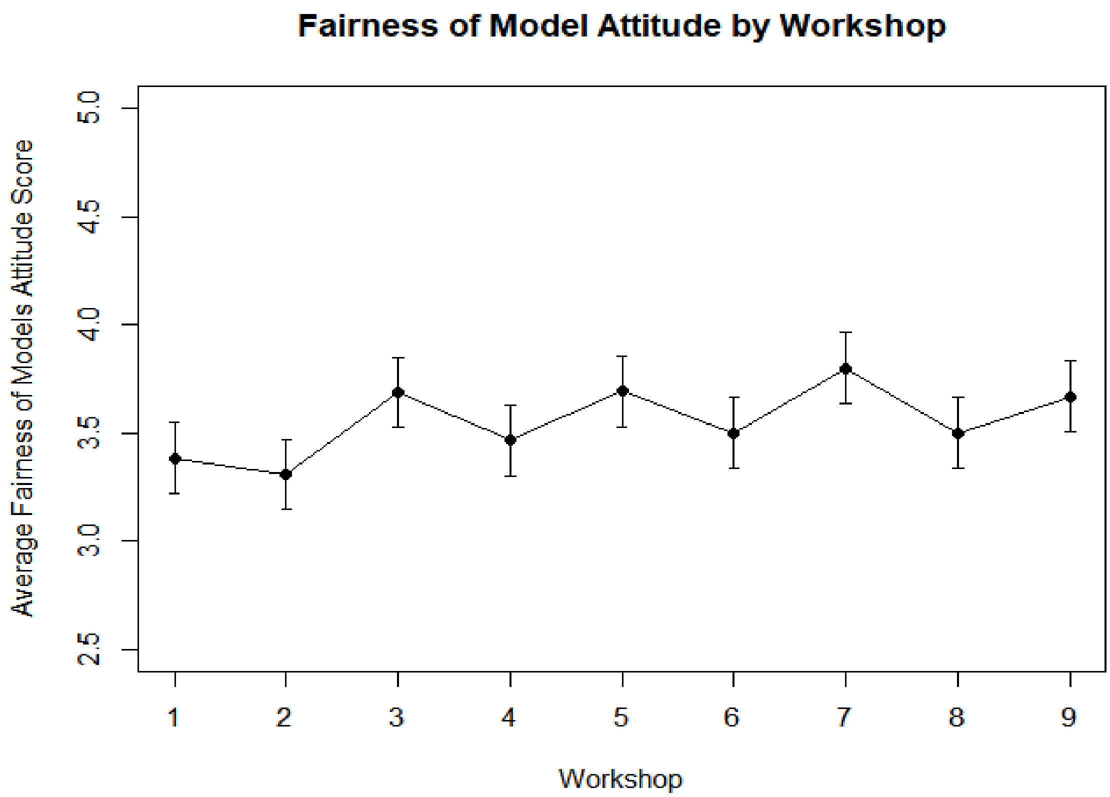

Figure 12: Average Fairness of Models over the course of 9 OysterFutures workshops with standard deviation

SUPPLEMENTARY MATERIAL

The models used to determine each of the Attitudes Towards models utilized proportional odds logistic regressions due to the natural ordering within the Likert scales used on questionnaire. Likert scales were developed in the early 1930's and are utilized as a way to measure character, personality traits and attitudes (Likert 1932, Boone and Boone 2012). This procedure for measuring attitudinal scales is necessarily ordered. For this study, the alternative responses were ordered from strongly disagree (1) to strongly agree (5), where 5 is necessarily higher than 4, etc. Proportional odds logistic regression models can be stated by the following formula

$$\textit{logit}\,[P\,(Y \leq j \mid x)] = \alpha_j - \beta x, \; j = 1,\ldots, J-1$$

where β is the slope and α_j is an intercept that changes depending on *j*. *j* here is the level of an ordered categorical variable of interest with J levels that have a natural ordering, where $y_1 < y_2 < \ldots y_j$. The dependent variable is the log odds of category *j* or less. The log odds differ only by a constant for different *j*, thus the odds are proportional. Only fixed variables are included in these models.

Table 1a: Fixed Individual Stakeholder Attitude Models results

Fixed Individual Stakeholder Ordered Logistic Regression Results

	Dependent variable:				
	Usefulness of Models	Ease of Models	Accuracy of Models	Reliability of Models	Fairness of Models
	Salience		**Credibility**		**Legitimacy**
Stakeholder 2	4.28***	5.62***	2.80**	3.22***	7.67***
	(1.35)	(1.35)	(1.16)	(1.22)	(1.59)
Stakeholder 3	1.13	6.33***	0.87	4.96***	5.57***
	(1.44)	(1.65)	(1.41)	(1.55)	(1.53)
Stakeholder 5	22.75***	-11.90***	-63.52	0.63	0.61
	(0.0000)	(0.0004)		(2.03)	(1.89)
Stakeholder 6	22.16***	-0.31	-79.43***	1.42	8.14***
	(0.0000)	(2.35)	(0.00)	(2.05)	(2.98)
Stakeholder 7	4.66***	7.85***	19.97***	23.72***	3.78**
	(1.79)	(2.25)	(0.0001)	(0.0000)	(1.70)
Stakeholder 8	3.18**	8.76***	30.17***	17.02***	6.40***
	(1.61)	(2.07)	(0.01)	(0.0000)	(1.69)
Stakeholder 9	2.96*	9.39***	3.77**	4.97***	6.87***
	(1.65)	(2.04)	(1.80)	(1.69)	(1.73)
Stakeholder 10	-4.02**	0.70	0.07	0.90	1.30
	(1.62)	(1.39)	(1.31)	(1.56)	(1.28)
Stakeholder 11	-0.71	2.86**	2.86**	1.94*	2.73**
	(1.04)	(1.27)	(1.14)	(1.03)	(1.16)
Stakeholder 12	2.96*	6.96***	2.74	5.44***	10.84***
	(1.56)	(1.86)	(1.71)	(1.73)	(1.74)
Stakeholder 14	4.26***	3.67**	15.68***	7.82***	6.26***
	(1.54)	(1.48)	(0.01)	(1.82)	(1.52)
Stakeholder 15	6.44***	3.11**	5.37***	7.06***	9.43***
	(1.46)	(1.31)	(1.52)	(1.54)	(1.59)
Stakeholder 16	0.84	2.56*	3.44**	4.80***	5.55***
	(1.25)	(1.33)	(1.38)	(1.34)	(1.39)
Stakeholder 17	3.60**	5.72***	4.85***	6.82***	7.07***
	(1.56)	(1.54)	(1.69)	(1.78)	(1.62)
Stakeholder 18	0.75	5.28***	4.58**	4.84***	6.36***
	(1.65)	(1.62)	(1.82)	(1.73)	(1.67)
Stakeholder 20	7.24***	6.20***	16.00***	3.01**	4.52***
	(1.56)	(1.58)	(0.002)	(1.21)	(1.30)

Stakeholder 21	0.83	5.62***	3.23***	4.44***	6.23***
	(1.14)	(1.33)	(1.12)	(1.15)	(1.33)
Stakeholder 22	0.62	-40.12***	12.91***		
	(2.97)	(0.00)	(0.001)		
Stakeholder 23	5.42***	5.13***	13.15	21.63***	9.59***
	(1.65)	(1.55)	(74.75)	(0.0000)	(1.78)
Stakeholder 25	-0.20	4.18***	2.48	2.54	3.67**
	(1.48)	(1.58)	(1.54)	(1.61)	(1.55)
Stakeholder 28	-0.97	3.32**	0.28	2.66*	4.89***
	(1.50)	(1.68)	(1.53)	(1.54)	(1.71)
Stakeholder 29	-1.40	-0.22	2.56**	1.95	2.89**
	(1.28)	(1.44)	(1.24)	(1.22)	(1.47)
Stakeholder 30	5.45***	11.41***	17.97***	21.81***	11.89***
	(1.59)	(1.95)	(0.0001)	(0.0000)	(1.89)
Stakeholder 31	0.34	3.58	1.37	1.79	2.86
	(1.88)	(2.25)	(1.78)	(1.77)	(2.12)
Workshop	-0.25***		0.19*	0.32***	0.11
	(0.09)		(0.10)	(0.10)	(0.08)
Network Metric - Degree	0.02	0.07	-0.10	-0.15**	0.02
	(0.06)	(0.06)	(0.07)	(0.06)	(0.06)
Network Metric - Relative Gatekeeper	-0.58	0.11	-0.77	-0.63	-0.14
	(0.46)	(0.50)	(0.50)	(0.47)	(0.42)
Network Metric - Relative Liaison	-0.05	0.18	-0.25	-0.41	-0.62
	(0.71)	(0.72)	(0.86)	(0.81)	(0.66)
McFadden's Pseudo Rsquared	0.45	0.47	0.46	0.45	0.45
Observations	138	135	131	136	137
Note:					*p<0.1; **p<0.05; ***p<0.01

Table 2a: Lagged Communication Social Network Model results

Lagged Ordered Logistic Regression Results

	Dependent variable:				
	Usefulness of Models	Ease of Models	Accuracy of Models	Reliability of Models	Fairness of Models
	Salience		**Credibility**		**Legitimacy**
Stakeholder Group - Environmental Group	3.77***	5.15***	0.72	1.31	1.97*
	(1.19)	(1.25)	(1.11)	(1.15)	(1.12)
Stakeholder Group - Government	4.26***	2.69**	1.19	-0.35	1.37
	(1.27)	(1.18)	(1.18)	(1.19)	(1.11)
Stakeholder Group - Scientist	3.51***	3.35***	2.19*	1.84	1.52
	(1.30)	(1.26)	(1.27)	(1.27)	(1.27)
Stakeholder Group - Watermen	-1.26	-2.99***	0.65	0.58	-1.19
	(1.02)	(1.12)	(1.04)	(1.03)	(1.02)
Workshop	-0.26	0.30	0.14	-0.18	-0.40
	(0.27)	(0.28)	(0.29)	(0.28)	(0.26)
Number of Meetings Attended	0.0004	0.05	-0.12	0.35	0.53*
	(0.30)	(0.30)	(0.32)	(0.31)	(0.28)
Years of Experience	-0.06***	0.04*	-0.03	-0.05**	-0.07***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Lagged Network Metric - Degree	0.05	-0.06	0.06	0.01	-0.08
	(0.05)	(0.05)	(0.06)	(0.06)	(0.05)
Lagged Network Metric - Relative Gatekeeper	0.84***	-0.33	-0.25	-0.85***	0.10
	(0.30)	(0.29)	(0.31)	(0.30)	(0.27)
Lagged Network Metric - Relative Liaison	-0.94	0.09	0.18	0.72	0.12
	(0.59)	(0.58)	(0.61)	(0.64)	(0.55)
College Education	-2.25**	-3.80***	-0.51	-0.44	-1.53
	(1.08)	(1.20)	(1.08)	(1.06)	(1.04)
McFadden's Pseudo Rsquared	0.46	0.46	0.41	0.39	0.38
Observations	113	110	108	109	112
Note:					*p<0.1; **p<0.05; ***p<0.01

CHAPTER 4 – CONCLUSION

Participatory, collaborative modeling processes represent a unique decision-making technique that allows for the combination of stakeholder involvement with the analytical and predictive power of scientific models. Through the joint framing and building of scientific models, scientists and stakeholders are able to provide a more complete representation of the natural resource management system in question (Robles-Morua et al. 2014, Duncan 2016). The continued use of participatory modeling processes for decision-making within natural resource management depends in part upon the willingness of stakeholders to participate in these processes. The role of stakeholders is key within participatory modeling processes, and yet limited information exists concerning the impacts of these processes on participants.

Using surveys, observation, and interviews, I examined the human dimensions of a participatory, collaborative modeling process through OysterFutures, an oyster management-focused participatory modeling process within the Choptank River Complex in Maryland. Specifically, within my thesis, I analyzed stakeholders' advice and communication social networks and their attitudes towards scientific models to better understand the impact of participatory processes on participants. I examined the evolution of cohesion within the advice network, using the social network concepts of bridging and bonding ties and the impact of communication social network, participatory modeling process factors, and stakeholder characteristics on the development of stakeholders' attitudes towards scientific models.

Advantages of Longitudinal Analysis of Participatory Modeling Processes

Past studies of participatory decision-making processes have been restricted by limited temporal measurements. These processes are dynamic by nature, involving constantly changing interactions between science and policy (Sarkki et al. 2015). The impacts of this dynamic nature naturally extend to the process participants. Therefore, when studying the human dimensions of participatory processes, it is essential to have appropriate temporal measurements. Within OysterFutures, the longitudinal nature of the data collection was able to provide insight on stakeholders' attitudes and communication and advice network trends. For example, within the communication network, results demonstrated that there were not constant, positive changes in communication. The frequency of communication increased, but then plateaued, remaining the same for the remainder of the workshops. When restricting the examination to the communication networks for Workshop's 1 and 9, one could conclude only that there was a significant increase in communication. Therefore, measuring the communication network only once during OysterFutures or even twice (once before and after the workshop) would result in misleading conclusions concerning patterns of communication between stakeholders and thus could lead to incorrect conclusions concerning access to diverse ways of knowing, for example.

Not only were trends detected, but the longitudinal nature of the data provides better support for attributing causation to changes in the measures (Koontz and Thomas 2006). Increases in OysterFutures group-cohesion (Whole

Network Level) was able to be linked to participation in the workshops; participation in the workshops resulted in significantly more advice ties between OysterFutures stakeholders. The power of longitudinal analysis was enhanced by the use of social network analysis. However, this work was limited to analyzing longitudinal changes and drawing conclusions based on the consideration of each workshop as a separate network, a snapshot in time during a participatory modeling process. Advances in longitudinal social network analysis allow for more substantive hypothesis-testing using both social network structure changes (e.g., formation of a new communication tie) and changes in individual-level traits (e.g., changes in attitudes towards models) in a complete network (e.g., the OysterFutures participatory modeling process) (Snijders et al. 2010, Mercken et al. 2012). The power of longitudinal network analysis for hypothesis testing provides the opportunity for further support when considering participatory modeling processes from a social network perspective.

Benefit of Applying a Social Network Analysis Perspective

Results demonstrate that participation in OysterFutures significantly contributed to increasing cohesion within the advice network. Due to the participatory process, stakeholders began to go to each other for advice on oyster management related issues. These findings demonstrate the benefit of using a network perspective to analyze participatory, collaborative processes. Past work has hypothesized that through participation in these processes, the overall group would become more cohesive (Voinov and Gaddis 2008, Schmitt

Olabisi et al. 2014). However, with the application of social network analysis, this hypothesized cohesion was able to be visually and quantitatively demonstrated.

The benefits of a social network approach were also evident through the analysis of the communication network. Past work has suggested that increased communication occurred during participatory, collaborative processes, and that the communication facilitated social learning and the creation of similar attitudes (Yuan and Gay 2006, Long et al. 2013). While there was an overall increase in communication over the course of OysterFutures, the most frequent communication, the “strong ties”, remained within the confines of stakeholder groups. The impact of targeted communication for stakeholders’ attitudes towards models was also evident through the significance of the gatekeeper network position. The dialogue within a participatory modeling process has been deemed as important as the models themselves for finding relevant and significant solutions to natural resource management problems. Discussions within the group help find common ground from which solutions can be formed (Cabrera et al. 2008). Using a network approach, these nuances and patterns of communication were able to be detected. These results can then be applied to better our understanding of the role that models play within participatory modeling processes. These findings, then, have applications to participatory modeling process design.

Insights for Participatory Modeling Process Design

A primary benefit of participatory modeling processes is their flexibility; processes can be designed to fit the specific challenges and goals of each natural resource management situation. However, there are some universal characteristics of process design that are thought to be beneficial to facilitate desired outcomes (de Vente et al. 2016). For example, the literature has emphasized the importance of “win-win solutions”, resolving conflict, and finding consensus between groups (Pahl-Wostl 2002). However, results from the communication network and the attitudes towards models suggest that divisions persisted between stakeholder groups throughout the OysterFutures process; participation and enhanced communication did not erase these differences. Instead of exerting effort on trying to erase sub-group differences, participatory modeling processes could instead focus on allowing stakeholders time and space to explain their different ways of knowing. Embracing the multiplicity of knowledge will allow stakeholders the opportunity to feel heard and plays into the strength of models within these processes, providing guided facilitation and the opportunity for discussion.

Our results highlighted the different role that models play in participatory modeling processes versus in scientific endeavors. Models here are tools of facilitation, providing a conceptual framework from which a group can integrate diverse ways of knowing to come to consensus and perhaps even produce truly novel ideas; they are not vessels to arbitrate disagreements. While our results show persistent differences in stakeholder attitudes, the model *did* work as a facilitation tool that helped the OysterFutures group identify a set of 30 recommendations for oyster management within the Choptank for Maryland Department of Natural Resources. By homing in on the role that models play within these processes, i.e., what they can and cannot accomplish, both the design and expectations of participatory modeling processes can be enhanced. A next step is examining the idea that participatory modeling processes can result in the creation of new, novel management actions or policies, versus simply aiding in the development of consensus around a suite of existing ideas (Newig et al. 2018).

Looking Forward - Avenues for Future Research

The work from this thesis represents an initial dive into analysis of the human dimensions data collected during the OysterFutures participatory modeling process. These results demonstrate the diversity of research directions that can be taken and the number of conclusions that can be drawn concerning participatory processes by studying their participants. Pursuing further analysis will allow for a more complete picture of stakeholders within a participatory modeling process. In terms of social networks, stakeholders' mutual understanding networks from OysterFutures will be analyzed. The combination of information on stakeholders' advice, communication, and mutual understanding networks can provide a more complete picture of the changes in the overall group of participants during OysterFutures, especially in terms of overall cohesion. Increased communication combined with increased mutual understanding would strengthen the argument that the overall group was more cohesive; not only would there be more communication, but the stakeholders would feel like they understood each other and were understood in return. The power of more advanced longitudinal social network measures for studying this and similar processes can allow for more in-depth testing on hypotheses surrounding the impact of stakeholder tie formation on stakeholders' attitudes and the ability of the group to reach consensus.

Results on stakeholders' attitudes towards models highlighted the diversity in ways of knowing within participatory modeling processes. The analysis of data on stakeholders' attitudes towards science and local ecological knowledge will provide a better picture of how knowledge is viewed, and utilized, during participatory modeling processes. This is especially pertinent given our interest in analyzing the outcomes of OysterFutures. The diversity of stakeholders involved in natural resource management has led to the consideration of participatory, collaborative management processes as governance networks (Hartley and Glass 2010). Insights from the consideration of governance networks can provide information on science-to-management pathways and be used to evaluate "success" of participatory modeling processes, like through enhanced compliance or environmental protection or determining how stakeholders were able to reach consensus (Robins et al. 2011, Drazkiewicz et al. 2015). In the case of OysterFutures, by using social network and salience, credibility and legitimacy attitudes, we can explore how different ways of knowing were used in the network, and connect the network and attitudes to the resulting consensus recommendations; i.e., did attitudes and networks influence actual management outcomes?

Although the time, effort, and resources required to study the human dimensions of participatory modeling processes is substantial, it is essential that we have a better picture of these unique decision-making settings. Time spent studying these processes can directly impact their design and operation, making them more efficient and effective environments for addressing complex, “wicked” natural resource management issues.

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