Mediated modeling lessons for stakeholder engagement with science-based management: case study focused on Texas Gulf Coast (USA) estuaries

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Abstract

In this paper, we illustrate the use of mediated modeling and collaborative learning as a framework for good modeling practice. We describe facilitatation of local stakeholder involvement in developing policy recommendations for managing important estuaries along the Texas Gulf Coast. We designed a shared system of learning among local stakeholders and scientists, and via a series of workshops integrated that shared learning into a quantitative computer model. The quantitative model that emerged focused on estuary components of greatest interest to participants. Workshop participants initially developed a conceptual model of two adjacent Texas Gulf Coast (USA) estuaries, which are part of the Mission Aransas National Estuarine Reserve. We then formalized the conceptual model into a quantitative model representing the spatial-temporal dynamics of one of the estuaries. Engagement in this collaborative modeling process enabled workshop participants to understand more fully what is known, suggest ways to fill important knowledge gaps, and to experiment with the quantitative model to project possible futures for the selected estuary.

Keywords

adaptive natural resource management; estuarine dynamics; public engagement; quantitative modeling; social learning

1. Introduction

Mediated modeling refers to model building *with* stakeholders rather than *for* stakeholders, and although a variety of specific methodologies exist, all share a common emphasis on enabling collaborative learning and decision support (van den Belt, 2004; Zellner, 2008; Metcalf et al., 2010; Hovmand, 2013; Hall et al., 2019; Elsawah et al., 2019; Sterling et al., 2019). The importance of incorporating stakeholder knowledge into decision-making affecting complex socio-ecological systems is well established (e.g., see Hall et al., 2019 and references therein). And a variety of specific methodologies for eliciting, representing, and analyzing stakeholder knowledge exists (Elsawah et al., 2015; Iwanaga et al., 2021). Mediated modeling as a participatory modeling approach has been applied within a variety of socio-ecological contexts; for example, floodplain management

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(Metcalf et al., 2010); marine fisheries (Gray et al., 2012); and involvement of indigenous stakeholders (van den Belt, 2013). The extensive literature associated with good modeling practice within the context of science-based management emphasizes mediated modeling (implicitly) via highlighting the various roles of stakeholders in problem scoping and conceptual model formulation (Ford, 2010; Wang et al., 2023; Jakeman et al., 2024).

In this paper, we describe a case study related to development of an adaptive natural resource management plan for two adjacent Texas Gulf Coast (USA) estuaries, which are part of the Mission Aransas National Estuarine Reserve. In this case study we examined stakeholder engagement in problem scoping, conceptual model formulation, and use of a resulting quantitative computer model. Our mediated modeling work was part of a larger adaptive management plan designed to provide information for Texas Senate Bill 3 (SB3), which was a formal political process aimed at addressing the effects of land use and climate change on freshwater inflows to the Texas Gulf Coast estuaries, and the effects of freshwater inflows on commercially and biologically important estuarine organisms (https://www.twdb.texas.gov/surfacewater/ flows/environmental/index.asp). We focused specifically on facilitating shared systems learning about estuaries among the local stakeholders and scientists, and integrating that shared learning to construct a quantitative computer model. We do not describe details of the quantitative model here, a detailed quantitative model description inavailable in Wang et al. (2025). Thus, the purpose of the modeling exercise was social learning (*sensu* Edmonds et al., 2019) to facilitate stakeholder engagement with science-based natural resource management.

2. Study area and stakeholder recruitment

The mediated modeling process focused on the adjacent Guadalupe-San Antonio and Mission-Aransas estuaries in Texas (Figure 1). Upstream freshwater demands include the metropolitan areas of San Antonio and Austin as well as agricultural and recreational users. Rivers supply freshwater to these productive estuaries, which support recreational piscine and crab fisheries, the world's second largest chemical industry, energy extraction, the Gulf Intracoastal Waterway, and the Aransas National Wildlife Refuge, which is notable as habitat for several rare species including the federally endangered whooping crane, *Grus Americana* (USFWS, 2009).

Diverse stakeholder representation is critical to social learning as a source of new ideas and social resources Brunie, 2009; Daums et al., 2020), and necessarily is the first step in the collaborative modeling process (Figure 2). We define stakeholders as people who have an interest or stake in a place and its future (Banerjee et al., 2020). To expand stakeholder involvement beyond that required by the Texas SB3 process, we identified over 500 people who had been active in coastal issues during the previous five years, targeting potential participants with high influence and interest. We used public print and web-based media to advertise workshops and garner participation of anyone not included in our list. Workshops were open to the public, and invitations encouraged participation of stakeholders from agriculture, commercial fishing, and recreation industries; local government; water resource agencies; scientists; and citizens. We used attendance records (names and self-identified affiliation) to categorize participants into stakeholder categories based on their functional roles in natural resource management (Gray et al., 2012; Prell et al., 2009).

We labeled the stakeholder categories as scientists, environmental NGO representatives, citizens, municipal/county government officials, natural resource managers (state and federal), other state agency personnel, regional water authority representatives, industry representatives, reporters, and primary resource users (such as agriculturalists, ranchers, boat captains, commercial and recreational fishers). These categories, which are neither independent nor mutually exclusive, illustrate the diverse stakes held by local residents. We further illuminated the diversity of perspectives by encouraging participants to self-identify their primary affiliations and perspectives while exploring the affiliations and perspectives of other attendees. Our overall approach to facilitation was designed around best practices for enhancing both quantity and quality of public participation in natural resource management Daums et al., 2020) (Supplementary Material).

To facilitate social learning in the workshops, which were several months apart, we always summarized results of prior workshops and displayed conceptual models in the workshop room. We also gauged institutional knowledge carryover from repeat attendance and self-perceived learning. As expected, attendance began with 62 curious participants at the first workshop, then gradually dropped over time, with 28 participants attending the final workshop. At the same time, the rate of repeat attendance increased from 45% at the second workshop to 100 and 82% at the final two workshops. In order to gauge attitudes toward social learning throughout the

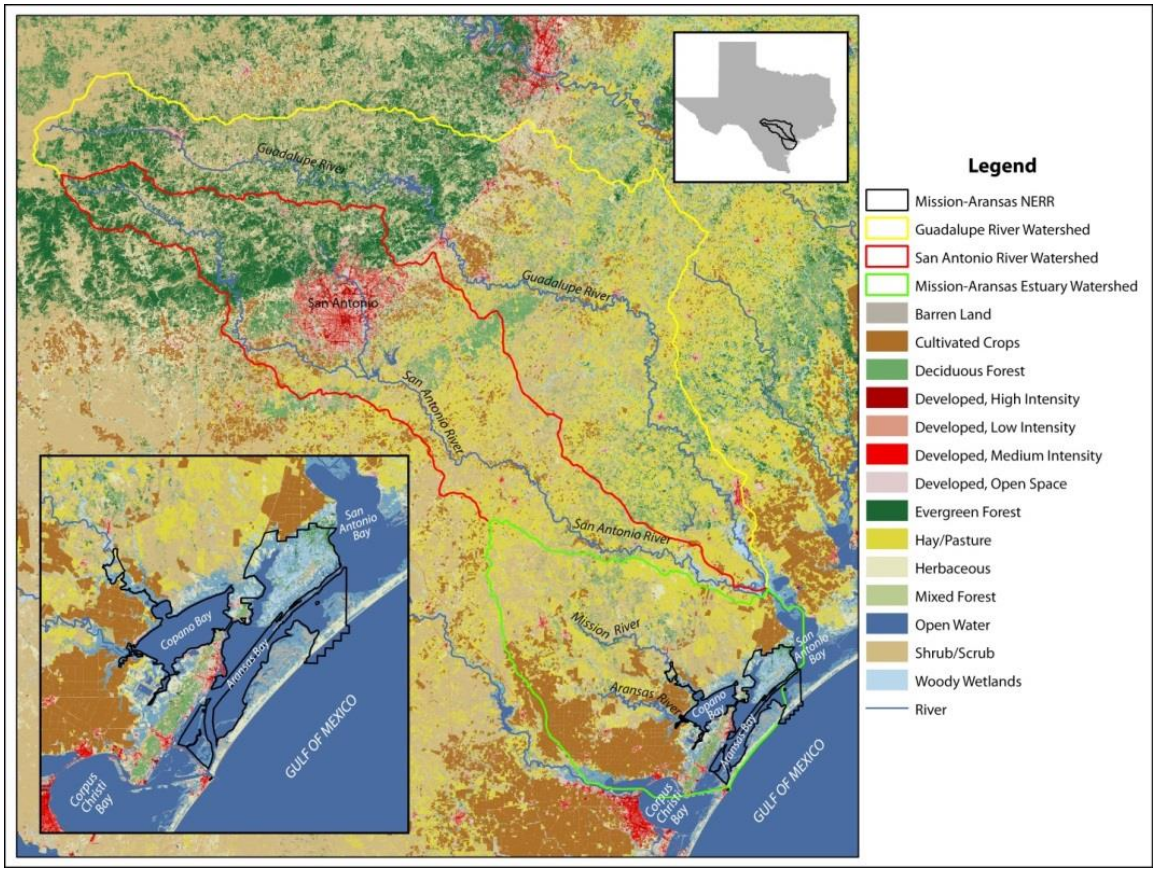

Figure 1: Map of the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays watershed, Region N water planning area, and Aransas National Wildlife Refuge. Inset shows the estuarine area along the Texas Gulf Coast that was the focus of the mediated modeling process.

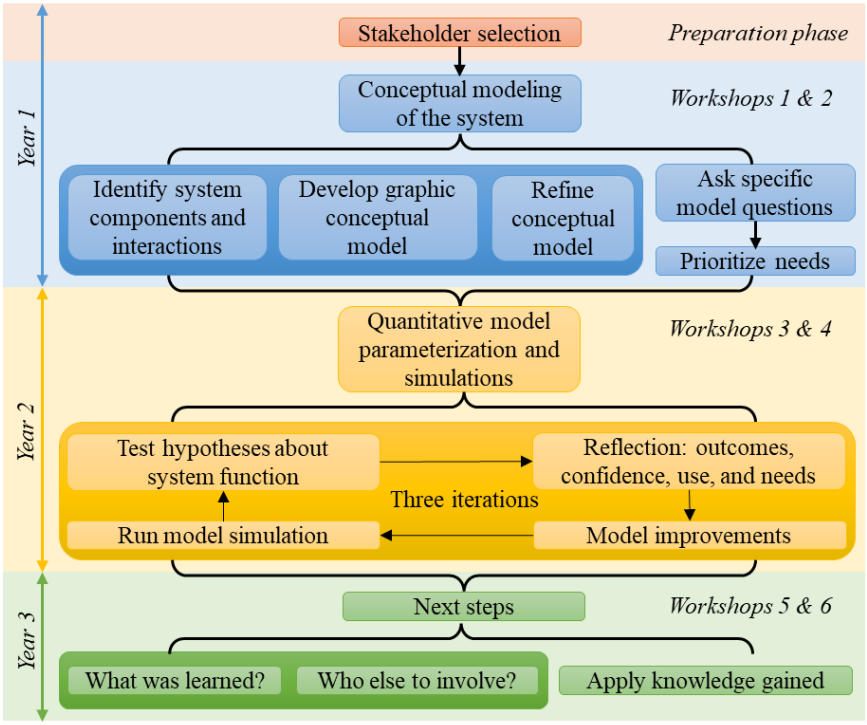

Figure 2: Flow chart describing the collaborative modeling process that emerged as we developed a quantitative computer model of the Guadalupe-San Antonio and Mission-Aransas estuaries. The three iterations indicated during year 2 represent the input of "expert opinion" provided by workshop participants (Horn, 2015; Ragland, 2015).

entire project, we asked participants to complete evaluations at the close of each session. Unlike attendance, the number of completed evaluations remained relatively stable throughout the project, beginning with 27 (of 62 attendees) and ending with 22 (of 28 attendees).

3. Mediated modeling

We facilitated mediated modeling activities at six workshops (Figure 2). The overall goal of these activities was to integrate knowledge and interests from all stakeholder groups into a collaboratively developed conceptual model of the Guadalupe-San Antonio and Mission-Aransas estuaries. The conceptual model that emerged from these activities focused on estuary components of greatest interest to participating stakeholders. Workshop participants initially developed the conceptual model, which we then formalized into a quantitative computer model of one of the estuaries (the Mission-Aransas Estuary). Workshop participants then used the resulting quantitative model to experiment with (i.e., simulate) various scenarios they envisioned for the Mission-Aransas Estuary. Participants also were surveyed to enable us to learn which workshop activities had contributed more and less to their motivation for continued participation in this, and other collaborative conservation efforts (Tunnell et al., 2015).

Workshop participants followed a standard protocol (van den Belt, 2004) to construct the conceptual model of the two estuaries. Working together in small groups, participants attempted to 1) tell the story of the estuaries as a system, 2) ask three basic questions about the system, 3) translate the questions into modeling language, 4) retell the story, using formal modeling language, and 5) revise the model to tell a more persuasive story. We used the conceptual model developed by participants as the basis for developing the formal quantitative model. Over the next several workshops, workshop participants then experimented with the formal model, critiqued the results, and suggested additional changes each time they met (Thompson et al., 2010).

3.1 Conceptual modeling

In May 2012, workshop participants begin designing conceptual models of the estuary by asking basic questions about estuary components, actions that affect these components and issues that affect estuarine function. We first asked each participant to reflect on these questions individually, and note components, actions, and issues they believed to be important. We then asked participants to share their individual reflections in small group discussions. Participants worked in small groups (ranging from 4 to 6 members/group). We attempted to maximize intra-group diversity by suggesting that participants partner with those who claimed affiliations different from their own, but we did not insist that they do so. As participants progressed from reporting their individual thoughts to connecting those thoughts with ideas suggested by other group members, we invited the participants to draw conceptual diagrams of the estuary. We provided central guidance by displaying and briefly explaining examples of diagrams drawn of other ecosystems, and then shifted to roving facilitation, wherein we circulated throughout the room, responding to participant requests for assistance as groups drew their own diagrams We provided a tentative composite of these diagrams as the basis for the next workshop, when workshop participants further examined component relationships and prioritized questions about system function that addressed their needs and concerns. We also invited each group of participants to critique our composite diagram, and to suggest alterations. Suggested alterations were discussed, and depending on agreement among workshop participants, some were implemented. To guide the participants toward developing a quantitative model, we asked participants what they wanted or needed from the estuary, how the estuary currently satisfied those needs and how they hoped it would do so in the future. Our final request was for each group of participants to identify a central question about the estuary's ability to meet their needs that they would like a model to explore. We gathered both individual and group responses to these questions. Although each group of participants produced a slightly different diagram, all the diagrams included the same basic elements. The portion of p. 19 in Tunnell et al. (2015) titled "Balancing Freshwater Needs in the Mission Aransas Estuary" indicates where conceptual models developed by workshop participants contributed directly to the larger project (the Texas Senate Bill 3 (SB3) process). During the time between the first (May 2012) and second (September 2012) workshops, we synthesized the six small group diagrams into a single diagram. Using elements identified in the diagrams produced during the May 2012 workshop, we generated lists of 1) what workshop participants want/need from the system, and 2) what participants worry may interfere with the system's ability to satisfy their wants/needs.

At the September 2012 workshop, we presented participants the diagram we had synthesized, and then asked participants to suggest any changes needed. Workshop participants stated that the synthesis diagram appropriately captured their ideas and incorporated all essential elements for a model of the system. Participants also suggested refinements, which were made during the September workshop. To further guide model development, workshop participants chose the most important item from both the list of what they wanted/needed from the system, and from the list of potential threats they feared could interfere with satisfaction of those wants/needs. After prioritizing these items, participants identified the most important components to include in a quantitative model of the estuary. At this point, participants chose to focus the model on the effects of freshwater inflows on crab populations in the Guadalupe-San Antonio and Mission-Aransas estuaries. Workshop participants then used the lists of important issues they had identified to generate questions they would like a quantitative computer model to help them answer. Participant questions took a variety of formats and ranged from very specific to highly generalizable. Examples of participant questions include:

1) How much freshwater inflow is needed to sustain estuarine species?
2) How many acre-feet of freshwater are needed for a healthy estuary?
3) How does freshwater inflow increase/decrease affect food web dynamics in the estuarine system?
4) What do we need to do to maintain estuary health?
5) How can we maintain estuarine function?
6) What are the significant physical and ecological interactions that determine the ecological health of the estuary?
7) What amount of human use/impact can the estuary incur without damage to fish and wildlife species?
8) Will future generations still enjoy fishing of similar quality as we have now?.

3.2 Quantitative modeling

We compiled all information generated by workshop participants during the first two workshops. Workshop participants used this information to guide development of a quantitative model that demonstrated possible effects of changes in salinity on the population dynamics of blue crabs in the Guadalupe-San Antonio and Mission-Aransas estuaries. At the third (January 2013) workshop, we presented the first iteration of the quantitative model to the workshop participants. During this workshop, we encouraged participants to experiment with the model, and to suggest ways to make it more useful. The participants provided feedback on ways to improve the model, ways they might use the model, and their confidence in the model. We cautioned the workshop participants that the quantitative model was not intended primarily as a tool for predicting the future so much as it was intended to be a learning tool (Grant & Swannack, 2008; Le Page & Perrotton, 2017; Edmonds et al., 2019).

Workshop participants spent most of the workshop learning to operate the model, and offering suggestions for changes that would make it more useful to them and to colleagues who were not participating in the workshops. The participants did this by exploring possible scenarios using the parameters specified in the model. Given that both the formal political context (Texas SB3) and needs/desires expressed by workshop participants focused on different ways freshwater flow affected salinity and temperature in the Guadalupe-San Antonio and Mission-Aransas estuaries, participants chose to spend most of their time testing scenarios centered on these relationships. Participants were surprised to discover that some system futures they had expected to be plausible seemed less so after modeling those scenarios.

Following the simulations, we used guided discussion, paper questionnaires, and keypad polling to determine the workshop participants' responses to the model. The guided discussion indicated widespread enthusiasm that participants had contributed directly to designing and building a tool that summarized important elements and interactions of the estuarine system. The workshop participants asked many questions about both the assumptions of the model, and the data that had been entered into the model. Participants were especially curious about how this information translated into crab population dynamics. Participants liked having a model that showed visual movement of crabs through various life stages as well as quantitative output regarding population fluctuations. Participants suggested several ways to make the model more useful, with some suggestions focused on model format (e.g., simplify and streamline the user interface), and others focused on model content (e.g., incorporate crab harvest data and add more detail on the relationship between salinity and freshwater inflow).

The paper questionnaire asked individual workshop participants to identify contexts where they thought engagement with the model could be most useful. The most frequently suggested uses were harvest fishery management and ecosystem health restoration. Participants also identified issues related to management of water flow and whooping cranes, as well as general outreach activities, as potentially useful reasons to engage with the model. We also used keypad polling to determine individual workshop participant responses to modeling activities and the model that had emerged from those activities. Specifically, we asked participants how closely the modeling experience had come to meeting their expectations, and how confident they were in the validity of the model itself. For both of these questions we offered participants a simple five-point scale, with "1" indicating "did not meet my expectations" or "no confidence", and "5" indicating, "completely met my expectations," or "total confidence." The majority of the participants indicated that the modeling process had met their expectations and that they had relatively high confidence in the model (selecting four or five on the questionnaire).

Following the third (January 2013) workshop, we compiled the results of the guided discussion, paper questionnaires, and keypad polling to direct revisions of the quantitative model. Using these results, we revised the model for presentation at the fouth workshop (April 2013). At the fourth workshop, participants tested the revised model, and generated ideas about how the model might contribute to future management decisions regarding the estuaries. In response to participant requests, updates to the model included additional information on commercial and recreational harvest of blue crabs, increased options for model users to simulate freshwater inflow changes, and more detail on salinity changes over the course of a year.

Workshop participants spent much of the fourth workshop simulating different scenarios, evaluating their simulations, and discussing their results. Although some participants favored introducing additional variables, there was consensus that the model was sufficiently complex, and that the most important elements and interactions were already included. Most participants were fully engaged in these activities. During this workshop, one participant commented, "using the model is relatively easy, comprehending is harder." This was echoed by other participants. Upon discussion, the participants asked us to provide additional written documentation to further explain the assumptions and limitations of the model. The workshop participants agreed that this would enhance their understanding of the system, increase their confidence in the model's ability to simulate system processes, and facilitate their ability to explain critical system processes to others. Their request for and justification of the need for further documentation demonstrates how collaborative engagement in building a model to guide navigation of the complex relationships within these estuaries encouraged participants to assume greater responsibility for both their own understanding and for enhancing the understanding of others. We committed to adding this documentation before the fifth workshop, which was scheduled for September 2013.

At the fourth (April 2013) workshop, the most frequent frustration expressed by workshop participants was that, under no scenario did the model indicate that whooping crane predation had a measurable effect on crab populations. Participants had come into the process with a long-held belief that there was a strong relationship between robust crane and crab populations, and, despite the transparency of the modeling process, they found it difficult to accept this result. In an attempt to make sense of it, the participants discussed the possibility that the model may be demonstrating that, although crabs may be important to the health of the crane population, this may not be a reciprocal relationship: crabs are an important diet item for cranes but cranes are not numerous enough to have a significant impact on the crab population.

Following the scenario simulations and discussions, we repeated the keypad polling activity, asking individual workshop participants how much engagement in the process had increased their understanding of estuarine system dynamics, how closely it had met their expectations, and how confident they were in the validity of the model itself. Polling results indicated that 70% of participants thought engaging in the process had increased their understanding of freshwater inflows important in the estuary system and had met their expectations. Model confidence decreased however, with the majority of the workshop participants expressing moderate, rather than high, confidence in the model.

The loss of confidence in the model may reflect increased critical thinking as workshop participants continued to engage in the modeling process. Non-traditional experts rarely are expected to formally examine the validity of model outputs, and we saw this critical inquiry by workshop participants as a positive step in social learning

(Boschetti et al., 2012). Social learning focuses less on final outcomes of the learning (here, modeling) process than on urging citizens to dig more deeply into complex problems, discovering there is more to know, exploring next steps in communicating learning outcomes and identifying important research gaps (Radinsky et al., 2017).

Stakeholder engagement in modeling increases the likelihood that knowledge, even if not published, will transfer to those making management and policy decisions (Voinov & Bousquet, 2010). We also asked workshop participants how model results might be useful. The most frequent response was "for long term planning for drought and freshwater inflow changes." This response was consistent with concerns expressed by workshop participants about upstream freshwater release and timing as it affects the estuarine system, guiding water permits, and crab harvest.

At the September 2013 meeting, we provided the requested model documentation and offered workshop participants a further refined version of the model. Participants ran the further refined model under various environmental regimes of their choosing. After working with the model, participants again provided written feedback as to 1) confidence in the model, 2) how the model could be used, 3) expectations for the model, and 4) implications of model use for estuary management.

As in previous workshops, participant confidence levels for those who began with low confidence increased after simulations, while confidence levels for those who began with moderate to high confidence decreased after simulations. Participants said that they intended to share what they had learned from the modeling exercise directly with their peers, as well as through educational outreach. Participants expressed their belief that the model they had developed could be used to help others realize the important interconnections in the system. Participants also stated that the workshop series had stimulated ideas and raised new questions about knowledge gaps regarding the estuary system. Several participants also requested that future sessions would include greater integration of human influences on the system.

In May 2014, we reviewed the development of the quantitative model, and workshop participants ran additional simulations with the model. Workshop discussions centered on potential uses and limitations of the model. Some participants were concerned because the model did not show the dramatic responses of crab populations to periods of higher salinity that they expected it to show. Despite learning that data to provide evidence of the expected response did not currently exist, several participants remained frustrated. However, other participants commented that this model presented an opportunity to learn what is known, what is not known, and then to suggest how to fill existing knowledge gaps.

3.3 Participant assessment of the mediated modeling process

During the final discussion of the May 2014 workshop, we reviewed the overall collaborative process and looked toward the future. To ground the discussion, we referred workshop participants to the concept diagram of the larger adaptive management plan of which our mediated modeling work was a part (Tunnell et al., 2015, p. 19), noting where the participants' role fit into the larger project (i.e., the Texas SB3 process). The participants suggested that what they had learned through their engagement in the modeling process should be communicated to a wider audience including, but not limited to, policy makers. For example, participants expressed hope that suggestions based on science conducted by project research teams would be incorporated by the Texas Commission on Environmental Quality into their standards.

To gain an understanding of the workshop participants' overall experience with this multi-year process, we developed a 12-question survey (Horn, 2015) asking participants to identify the initial influences that led them to begin participating in the collaborative process, to report on their goals and objectives for the process, and to identify and describe roles they believed were the most important to the success of the process. Finally, we asked participants to explain their overall rationale for continued engagement in such a demanding project. This gave participants an opportunity to expand on one of the topics we had identified, or to introduce topics we had not included. The survey took approximately 20 minutes to complete and included both multiple choice and open-ended questions.

We invited workshop participants to provide their contact information at the completion of the survey should they wish to participate in an in-depth interview to be scheduled at a later date. We conducted five follow up interviews, using the same basic questions, but taking an informant-directed approach so the workshop

participants who were interviewed could direct the conversation toward topics of greatest interest to them. This provided greater depth regarding participant motivations.

We transcribed completed surveys and interviews and then conducted qualitative textual analysis to identify emergent themes. To maintain workshop participant confidentiality and fulfill IRB requirements (IRB2012-0187D), we removed respondent names. We labeled each completed survey and interview with a number. Likewise, we numbered each survey and interview response. For example, the citation S1,R3 refers to the third response to the first Survey; the citation I2, R5 refers to the fifth response to the first interview (Horn, 2015, pgs. 9-10).

4. Discussion

Three themes emerged from this mediated modelling process. Information sharing was the most frequently mentioned motivation for workshop participation and was often introduced in connection with other themes. The second theme participants identified was enthusiasm for the opportunity to expand their role beyond that of a relatively passive audience member who receives information from technical experts. Participants reported this process inspired them to take on greater responsibility for estuary management, and to encourage fellow residents to do the same. The third theme identified by participants was a desire to contribute to closer connections between science and management of the estuarine system. Overall, participants were motivated by their hope of accomplishing three objectives through this collaborative process: 1) learning about estuaries and bays and gaining exposure to current scientific practices; 2) communicating what they learned with each other to those unable to participate in the workshops; and 3) using science to make informed management decisions. These three objectives were closely interrelated with each other and with the themes of information sharing, role playing, and connecting science with management (Tunnell et al., 2015).

4.1 Information sharing

The sense that participation in the collaborative process gave participants access to management decisions provided the strongest justification for continued participation. The hope that information sharing would provide them with access to the management process motivated people to begin participating and continue participating over the multi-year project. Some stated that information sharing was most valuable when people shared their personal experiences with the group because it provided opportunities to engage all participants, to offer multiple perspectives, and to provide insight beyond the published literature. Participants believed that everyone gained from having multiple opportunities to share his/her own knowledge, and to learn from other participants.

One participant claimed that one of the most valuable aspects of the modeling process was "*stakeholders providing their own knowledge/experience to help inform others*" (S5, R9). Participants noted the value of the project's iterative nature, explaining, "*you can go to one [workshop], provide information, and then at the second one they'd show how they incorporated that into the project. Because lots of times you go to one- or two-day workshop and then you never see the results of it. So, when we were able to provide our information, it was used and that helped to improve the process*" (I3, R7). As this comment illustrates, by demonstrating that the information provided was integrated into model revisions, the research team validated participant efforts. Indeed, the model was specifically purposed for social learning (*sensu* Edmonds et al., 2019) as part of an adaptive environmental management plan (see Fig. 2 in Wang et al., 2025).

4.2 Opportunities to expand traditional roles

Participants reported that the opportunity to take on greater responsibility than in previous situations motivated them to continue engaging with the collaborative process. For example, their responses indicated that being responsible for identifying gaps in the initially presented model, providing vital information that could improve model sensitivity, and functioning as a liaison with residents who were unable to participate, contributed directly to achieve a sense of their own standing in management decisions related to the Guadalupe-San Antonio and Mission-Aransas estuaries . More than legal standing, we refer to the broad sense articulated by Senecah (2004, p. 24) as the "*civic legitimacy, respect, esteem, and consideration that should be given to stakeholder perspectives*." One participant expressed appreciation for opportunities to engage in sensitivity and scenario

testing, noting that, "*we were able to choose which indicators we thought were most helpful, crabs, oysters, things like that, and also where we wanted to put tide instruments [flow meters] to see circulation in the bays*" (I3, R7). Others mentioned their appreciation for the flexibility that gave everyone opportunities to serve as an information provider, with formats for these sessions ranging from formal oral presentations to posters to panel discussions. Overall, participants agreed that allowing all participants to self-identify the particular functions they felt most capable of fulfilling was important for productive and accurate information sharing and contributed to the desirability of participating in the collaborative process (Voinov & Bousquet, 2010). Participants also felt more empowered to communicate their pluralistic priorities to the higher bureaucratic authorities and thereby influence decision making (Macpherson et al., 2024).

4.3 Connecting management with science

The third theme was the desire to more closely connect science to management of the estuary. One participant stated they were motivated by the "unique" opportunity the workshops provided for "*getting science to managers*" (S11, R3). This individual believed participation in the collaborative workshops provided a direct vehicle for ensuring that managers had access to the most relevant science. Participants were motivated by opportunities to promote "*improved freshwater inflow requirements for the estuary - i.e., have more information to justify the recommended inflow standards*" (S5, R3). All participants were unified in their overriding motivation to contribute to science-based management of the estuary. Here we note the difference between consensus and collaboration. Collaboration does not oppose consensus, but it enables a more organic consensus to emerge through the joint efforts of all stakeholders. By giving stakeholders real responsibilities in decisions (i.e., modifying the model), they better understood how difficult tradeoffs must be made when trying to connect science and management (Ostrom, 2007).

4.4 Opportunity to influence estuary management

Responses also revealed how the three previously noted themes interrelated to provide them with hope that, by engaging in the NERR collaborative process, they could have an influence that would contribute to sustaining the Guadalupe-San Antonio and Mission-Aransas estuaries. Participants demonstrated the interconnected motivational impacts of the three themes in several ways. One person emphasized theme 1 and 2 by self-identifying with the role of observer, which enabled him to "*attend meetings and gain knowledge*" (S14, R7). He highlighted the importance of information sharing, which provided "*a better understanding of how the estuaries work and how the system responds to a variety of external factors*" (R3). He explained that his primary motivation was to "*continue to gain knowledge and stay informed*" (R2). Another participant emphasized themes one and three by saying, "*I would like to hope that understanding more about how the estuaries are managed means you can make the science fit legally what is needed to protect the things that you want to protect*" (I1, R2). Another participant described "*gaining exposure to new science*" as a way to "*advance/inform the decision-making process regarding freshwater inflow needs*" (S6, R3). Their motivations for continued participation were based on the belief that knowledge gained from information sharing, both among and beyond those who participated in the collaborative process, would lead to more scientifically informed policy decisions. Participants had developed a sense that their collaborative work gave them a right and a responsibility to directly contribute to these decisions.

5. Summary

For this project, we selected a strong collaboration approach. Workshop participants collaboratively developed a conceptual model of the system of interest, which we then formalized into a quantitative model representing spatial-temporal dynamics of system. Consensus-based processes are most effective in cases where "scientific information has high predictive power and its application is relatively uncontested" (Peterson et al., 2005). In contentious and power-laden situations, however, consensus processes often fail to reach their goal of mutual agreement or result in forced consensus. These processes tend to reinforce public apathy by setting unrealistic expectations for harmony; legitimize damage to the ecosystem by suggesting that all opinions have equal validity, no matter the evidence; and damage future possibilities for democratic change by reinforcing existing power relationships (Peterson et al., 2005).

The strong collaboration approach we adopted for this project differs from the consensus approach in its emphasis on guided argument, including facilitation techniques that encourage participants to critically examine both their own and others' claims and reasoning (Tunnell et al., 2015). Our use of a quantitative model allowed participants to better assess the logical numerical consequences of each other's reasoning. Rather than setting mutual agreement as the central metric of success (as in consensus), strong collaboration sought the generation of technically feasible and culturally legitimate recommendations. Mutual agreement very often emerged together with such recommendations but was not the primary goal.

The collaborative learning framework we designed to involve local stakeholders in the development of policy recommendations for managing freshwater inflows related to the Guadalupe-San Antonio and Mission-Aransas estuaries employed a combination of 1) interviews with primary resource users, 2) stakeholder-guided workshops, and 3) mediated modeling. Mediated modeling helped build capacity to understand and use different approaches to assess stakeholder understanding, foster the development of shared knowledge, and move diverse stakeholder groups toward mutually understood improvements in management and policy within the Mission Aransas National Estuarine Research Reserve and surrounding areas.

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CRediT

PB - conceptualisation, methodology, validation, writing - original draft, writing - review and editing. HHW - methodology, software, validation, formal analysis, writing - original draft, writing - review and editing, visualization. CJR - conceptualisation, methodology, validation, writing - original draft, writing - review and editing. WEG - methodology, software, validation, formal analysis, writing - original draft, writing - review and editing. TRP - conceptualisation, methodology, validation, writing - original draft, writing - review and editing, supervision, project administration, funding acquisition.

Ethics statement

The studies involving human participants were reviewed and approved by the Institutional Review Board at Texas A&M University (TAMU) College Station, TX, USA, IRB2012-0187D. The ethics committee waived the requirement of written informed consent for participation.

Supplementary Material

The Supplementary Material for this article can be found online at https://sesmo.org/article/view/18724/18362.

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