frontiers

Supplementary Material

Navigating complexities: Agent-based modeling to support research, governance and management in small-scale fisheries

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A mini-review of agent-based models in small-scale fisheries

Agent-based models in small-scale fisheries are still in their infancy. A keyword search of Web of Science ((“small-scale fisher*”) OR (“artisanal fisher*”) OR (“subsistence fisher*) OR (“coastal fisher*”)) AND (Agent-based OR multi-agent OR ABM) returned 14 publications, six of which were relevant (Rudd et al., 2003; Worrapimphong et al., 2010; Melbourne-Thomas et al., 2011; Gutierrez et al., 2017; Lindkvist et al., 2017; Plank et al., 2017). These six publications included social and ecological entities and the model has a small-scale fishery context. Through an extended search for papers on fish trade and of references within the originally found papers, six other papers were identified. Even though our search could be further expanded, we are confident to say that there is a scarcity of relevant literature on the topic.

Our review thus reflected 12 agent-based publications in small-scale fisheries (Bousquet et al., 1993, 1994a, 1994b; Rudd et al., 2003; Wilson et al., 2007; Perez et al., 2009; Worrapimphong et al., 2010; Melbourne-Thomas et al., 2011; Forrester et al., 2014; Gutierrez et al., 2017; Lindkvist et al., 2017; Plank et al., 2017). The models were used to understand phenomena, such as increased harvests emerging from cooperative forms of management (Gutierrez et al., 2017); increased harvests in relation to placement of an MPA (Rudd et al., 2003); the emergence of either fishing cooperatives or patron-client relationships as the dominant form of self-governance (Lindkvist et al., 2017); the emergence of self-governance due to competition (Wilson et al., 2007); the emergence of balanced harvesting (Plank et al., 2017), long-term effects of tourism and urbanization on coral reef health and fisheries (Perez et al., 2009; Melbourne-Thomas et al., 2011) overfishing (Bousquet et al., 1993, 1994a, 1994b; Worrapimphong et al., 2010). The papers included in the review only modeled one specific fishery or fishing community, with a notable exception of Perez et al. (2009) and Melbourne-Thomas et al. (2011) studying four economic development areas around a coral reef. Melbourne-Thomas et al. (2011) couple a biophysical model with Perez et al. (2009) model, as such the models have similar social actors and processes but in Melbourne-Thomas et al. (2011) the ecological entities and processes are more advanced. Bousquet et al. (1993, 1994a, 1994b) publications relate to the same model and are reviewed as the same.

We reviewed the models based on the crosscutting themes of the SSF challenges, more specifically the diversity of social and ecological entities, behaviors and interactions including globalization, and how they dealt with data in the broadest sense. We also reviewed the purpose of the models.

Diversity of entities, behaviors, interactions and globalization

Entities, agents and behaviors

Ecological entities represented in the SSF models ranged from including a non-spatial resource modeled by a logistic growth functions (Perez et al., 2009; Lindkvist et al., 2017; Plank et al., 2017), to spatially explicit implementations of sessile (non-mobile) fisheries and their environment (Bousquet et al., 1993, 1994a, 1994b; Rudd et al., 2003; Worrapimphong et al., 2010; Gutierrez et al., 2017). The latter build their models on empirical data from diving and measuring variables, such as abundance, size and life stage of clams, sea urchins, sea snails, kelp and sand in transects, in combination with data from other publications. These models naturally model interactions between ecological entities over time and spatial movement of species. Bousquet et al. (1993, 1994a, 1994b) also include four different biotopes where fishers could choose to diversify into other occupations. Perez et al. (2009) and Melbourne-Thomas et al. (2011) includes several reef components of coral, turf, carnivore fish, herbivore fish, and a lobster stock.

Social entities (agents) where represented by fishers (Plank et al., 2017), fishers and/or groups of fishers (Wilson et al., 2007; Melbourne-Thomas et al., 2011; Gutierrez et al., 2017; Lindkvist et al., 2017), fish buyers (Lindkvist et al., 2017), and in some cases a manager or the option to act as a manager by setting rules or MPA boundaries was included (Bousquet et al., 1994a, 1994b; Rudd et al., 2003; Worrapimphong et al., 2010). Fishers interacted by information sharing, cheating, or not at all. In Gutierrez et al. (2017) fishers can share information sharing and coordinate harvesting as would be the case in community based management. In Bousquet et al. (1993, 1994a, 1994b) different decision-making models are compared, e.g. economic individualistic decisions with those made together with other households by sharing information. In Lindkvist et al. (2017) fishers made the decision of whether to cheat on their cooperative or fish buyer or not, by abandoning their agreement and selling their catch to another fish buyer or cooperative. Fish buyers and cooperatives could also decide to dismiss a fisher that cheated a lot. Fishers thus interacted through their group rather than directly with each other. In Plank et al. (2017), Rudd et al. (2003), Perez et al. (2009), or Worrapimphong et al., (2010) fishers did not communicate with anyone. Their decision was solely to maximize harvests by choosing which size fish to target (Plank et al., 2017) or what fishery to target (Perez et al., 2009), or to maximize their income in the context of fluctuating harvests and variable gas price (Rudd et al., 2003), or to decide when, where, and how much to harvest (Worrapimphong et al., 2010).

Interactions

As for the interactions among agents and between agents and the environment, the interaction were specified through ecological dynamics, such as predation and movement, social interactions cheating, cooperating, buying and selling catch, and social-ecological interactions such as fishing and pollution. Lindkvist et al. (2017) model cross-scale interactions through micro-meso-macro organizational levels representing individuals, groups (patron-client relationships and fishing cooperatives), and the community. Perez et al. (2009) model four communities sharing three different fisheries.

Globalization

While all models except Perez et al. (2009) and Melbourne-Thomas et al. (2011) modeled a single SSF community, Lindkvist et al. (2017) and Bousquet et al. (1993, 1994a, 1994b) specifically situate their models in a globalized context. First, Lindkvist et al. (2017) show that when a fishing community experiences a high diversity in the reliability of fishers, and little previous cooperation between cooperative members, fishing cooperatives are unlikely to establish and persist, instead fishers organize to work with a fish buyer. These conditions are likely to become more common as in- and out migration in cities (fishing communities) increase as a consequence of globalization (Ostrom, 1990). In line with findings by Basurto et al. (2013) and Crona et al. (2015) patron-client relationships, are less conductive for obtaining sustainable fisheries. Next, Bousquet et al. (1993, 1994a, 1994b) argue that the introduction of new more productive equipment from Europe and Asia, together with new forms of governance introduced by the State of Mali (free access, fishing license) were the causes of the fishery crisis because they gave rise to economically rational individual behaviors. However these models use globalization as an argument when placing their model in the empirical context than something modeled endogenously. Finally, Perez et al. (2009) and Melbourne-Thomas et al. (2011) take globalization and its impact on coastal development seriously and model dynamics of urbanization and tourism, and their effects on pollution through an environmental health index, and how this impacts coral reef health, and thus the fisheries.

Dealing with data input and output

The SSF models used a variety of inputs to inform their models; theories, published literature and their own empirical social and ecological data were used. Worrapimphong et al. (2010), Gutierrez et al. (2017), Perez et al. (2009), Melbourne-Thomas et al. (2011), Bousquet et al. (1993, 1994a, 1994b) have a strong emphasis on collecting both the ecological and social data, while Lindkvist et al. (2017) is emphasizing the social data. Plank et al. (2017) instead have a thorough non-spatial ecological model based on published literature and make assumptions on the fishers' decision-model. Rudd et al. (2003) was work in progress and the social data was not yet incorporated, but seen as next steps to be gathered by interviews with fishers and other stakeholders.

None of the models claim to be able to predict any ecological or social future. However, Rudd et al. (2003), Gutierrez et al. (2017), Melbourne-Thomas et al. (2011) aim to show implications of different management scenarios for future harvests. And Melbourne-Thomas et al. (2011) speculated that their model can predict future sustainability of the fishery. Bousquet et al. (1994b) explicitly state that the model they proposed is not used to predict the behavior of the ecosystem. Instead they endeavored to simulate ecological, economic and sociological knowledge from which they drew qualitative conclusions. Thus, the model presents coherent interdisciplinary knowledge that may be a tool to improve the management of natural resources with the aim of finding a co-viability between ecological dynamics and the evolution of society, this is also supported by Worrapimphong et al. (2010), Perez et al. (2009), and Melbourne-Thomas et al. (2011). Melbourne-Thomas et al. (2011) recognize that data is lacking to fully represent the biological processes of lobster, as well as for fully validating model simulated output of profits for the tourism and fisheries industries. Lindkvist et al. (2017) use their model to suggest that data needs to be collected related to trust in order to understand cheating and its implications for different forms of self-governance. Plank et al. (2017) relate their findings to real world observations of balanced and non-balanced harvests, but do not claim to say anything about future resource abundance.

Model purposes identified in the models

The papers can broadly be clustered with respect to their different motivations, purposes and research design approaches. Gutierrez et al. (2017), Rudd et al. (2003), have empirically realistic ecosystem models aiming to directly inform which management strategies should be implemented for increasing harvests. Melbourne-Thomas et al. (2011) also aim to inform management, but rather the implications of increased urbanization and tourism for the sustainability of the reefs. Lindkvist et al. (2017), Plank et al. (2017), Bousquet et al. (1993, 1994a, 1994b), and Worrapimphong et al. (2010) instead aim to generate an understanding of a problem to share with stakeholders (e.g. fishers, managers, and government policy makers) and researchers about the implications of considering, or not considering, a specific type of human behavior for a phenomena to emerge. Perez et al. (2009) also aim to generate a shared understanding but emphasizes the consideration of impacts of external drivers. In addition Bousquet et al. (1993, 1994a, 1994b), Perez et al. (2009) and Worrapimphong et al. (2010) state explicitly that they aim to bring different knowledge systems together, to model those, and share insights with researchers and stakeholders to generate a joint understanding of the different interactions in the fishery and how they impact model outcomes.

As outlined in the main text in section 3, we identified three different approaches of how the studies used the agent-based models. The first approach had the primary purpose of explaining how some phenomena of SSF can come about, and to explain the mechanisms (i.e. factors and processes) that were effective (Lindkvist et al., 2017; Plank et al., 2017). The second approach by Gutierrez et al. (2017), Rudd et al. (2003), and Melbourne-Thomas et al. (2011), was to use their models as policy assessment tools to try to identify and explain the mechanisms behind why some policy, or way of organizing the fishery, may be better than another. Where Rudd et al. (2003) could let managers change the geographical placement and size of an MPA, and Gutierrez et al. (2017) could test different cooperative and non-cooperative organizational structures among the fishers. The third approach was to use the agent-based models as a participatory tool, as pioneered by the ComMod[1] team published by Bousquet et al. already in 1993 in SSF, with two other cases in SSF (Perez et al., 2009; Worrapimphong et al., 2010).

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[1]The Companion Modelling approach https://www.commod.org/en

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