# Mechanistic models of human decision-making and ecological dynamics in small-scale fisheries

BY

Sophie Wulfing

B.S., Colorado College, 2019

THESIS

Submitted to the University of New Hampshire

in Partial Fulfillment of

the Requirements of the Degree of

Master of Science

in

Marine Biology

May 2023

# 1 ACKNOWLEDGEMENTS

I will include acknowledgements in the final manuscript, I just didn't want yall to read them before :)

# 2 TABLE OF CONTENTS

Table of Contents, List of Figures, and List of Tables will be included in the final manuscript

# 3 ABSTRACT

Small scale fisheries are essential to the livelihoods of 40 million people worldwide. They are key sources of nutrients and income for these communities that rely on them. However, due to their abundance, understanding the status of these fisheries requires in-depth data collection, often in remote areas. Further, each small scale fishery is very individualized, and external groups attempting to impose fishing restrictions are often met with low compliance or are unsuccessful in their efforts to conserve fish stocks due to a lack of understanding of either fishing culture or the ecology of the harvested species. In this thesis, I employ various mechanistic models to small scale fisheries in order to better understand their underlying dynamics. In Chapter 1, I fit a Lefkovitch matrix population model to blue octopus data in the small scale fishery of Southwestern Madagascar in order to assess their life history and population health. In Chapter 2, I create a socio-ecological model with replicator dynamics and incorporated social hierarchy and space. Here, we found that collaboration between groups of people will be ineffective if only the financial gain of fishing is communicated, not the fishing strategies used to achieve high yields. Further, we found that fish movement was an extremely important parameter in these models. This work serves to exemplify the mathematical tools available when assessing small scale fisheries and highlight the need for a more substantive understanding of the status of the world's small scale fisheries.

# 4 Introduction

The definition of small scale fisheries is an evolving concept, but is characterized by subsistence fishing, community management, and traditional technologies (Smith 2019). 40 million people worldwide make their living off small-scale fisheries, which employs about 90% of all fishers globally. (Mills et al. 2011; FAO 2020) This metric does not include the 200-300 million people who are estimated to be employed in the processing chain of small scale fisheries, often informally (Mills et al. 2011). As many of these systems have transformed into industrial and recreational fishing, small scale fisheries are becoming increasingly associated with developing countries (Misund, Kolding, and Fréon 2002). These systems are an essential source of nutrition for these groups ("Hidden Harvest-The Global Contribution of Capture Fisheries" 2012; Chuenpagdee and Jentoft 2018; FAO 2020). Small scale fisheries have been shown to be a significant avenue of poverty alleviation through food security (Chuenpagdee and Jentoft 2018; FAO 2020). The number of fishers employed in small scale fisheries is rapidly increasing, indicating their growing importance (Jentoft and Eide 2011).

Despite the prominence of small-scale fisheries and their importance to the people who rely on them, they face many threats as they are highly susceptible to climate change (Allison et al. 2009), coastal urbanization (Kadfak and Knutsson 2017), and overfishing (Cinner et al. 2018). Because fishers are more directly reliant on these subsistence fisheries, people are more directly affected by these challenges than in large industrial fishing (Allison et al. 2009; Jentoft and Eide 2011). The issue of overfishing is also often exacerbated by large-scale industrial fishing occurring in places near small scale fisheries (Bavinck 2011). Governance of small scale fisheries is also typically difficult as different small scale fisheries often require different management styles in order to be successful (Gutiérrez, Hilborn, and Defeo 2011). Further, they are often characterized by a close connection between the ecology of the fishery and the culture of those who fish there. This means that each small scale fishery is very individualized and so there exists no "one size fits all" conservation strategy for every one. Instead, a deep understanding of both the biology of the fish being harvested and the socio-economic factors that affect fishing activity is required in order to institute effective and equitable conservation in small scale fisheries ("Saving Fish and Fishers: Toward Sustainable and Equitable Governance of the Global Fishing Sector" 2004; Kosamu 2015).

However, this in depth understanding is difficult to achieve as small scale fisheries are drastically understudied (Misund, Kolding, and Fréon 2002; Mills et al. 2011; FAO 2020). This can be partially attributed to the fact that small scale fisheries employ a large number of people over a large spatial distribution, and governments are often financially limited when surveying these sectors (Misund, Kolding, and Fréon 2002; Gutiérrez,

Hilborn, and Defeo 2011). Because a lot of employment in small scale fisheries is informal, it's difficult to understand exactly how many people are reliant on small scale fisheries, and existing metrics are likely to be underestimations (Mills et al. 2011). Data collection in small scale fisheries can be difficult and resource consuming as they often exist in remote places (Chuenpagdee et al. 2019). Also, effective conservation requires an understanding of the practices and culture of fishers. Fishers in certain areas can sometimes come from different ethnicities and speak different languages (Pomeroy et al. 2007; Barnes-Mauthe et al. 2013; Sari et al. 2021), making cross-cultural cooperation difficult. Further, conservationists have often ignored social hierarchies in small scale fisheries, and by doing so, have actually further entrench these inequalities (Baker-Médard 2017). The existence of social structures is extremely prevalent in human societies and this has been shown to alter how people interact with the environment.

Community management of fisheries has been shown to be one of the most effective forms of small scale fishery conservation while employing traditional knowledge and empowering local communities Gelcich and Donlan (2015). Small scale fisheries are typically characterized by tight social structures and strong reliance on the environment, therefore the intersection of culture and environment is extremely important in maintaining their sustainability (Grafton 2005; Thampi, Anand, and Bauch 2018; Barnes et al. 2019). Community management allows for reaching ecological goals while simultaneously maintaining the livelihood and economic and cultural goals of fishers (Govan 2010; Barnes-Mauthe et al. 2013). On the other hand, outsider institutions have typically ignored these cultural components to fisheries and either further entrenched inequalities in the community or conservation efforts have been met with low compliance (Bodin and Crona 2009; Katikiro, Macusi, and Ashoka Deepananda 2015; Kosamu 2015; Salas, Barragán-Paladines, and Chuenpagdee 2019; Prince et al. 2021).

Mechanistic models are one way in which we can study small scale fisheries despite challenges in data collection. Mechanistic models mathematically describe the underlying biological and physical processes that make up an ecological system (Grimm et al. 2005; André, Haddon, and Pecl 2010; Briggs-Gonzalez et al. 2016). Therefore, they do not require the extensive data collection needed to construct a statistical model (Crouse, Crowder, and Caswell 1987; Nowlis 2000; Gharouni et al. 2015). Mechanistic models are a prominent tool in fishery assessments (Lee et al. 2018; Free et al. 2020). In the following chapters, we utilize mechanistic models to better understand small scale fisheries and what social and ecological challenges they face.

**References**


Allison, Edward H., Allison L. Perry, Marie-Caroline Badjeck, W. Neil Adger, Katrina Brown, Declan Conway, Ashley S. Halls, et al. 2009. "Vulnerability of National Economies to the Impacts of Climate Change on Fisheries." *Fish and Fisheries* 10 (2): 173–96. https://doi.org/10.1111/j.1467-2979.2008.00310.x.

André, Jessica, Malcolm Haddon, and Gretta T. Pecl. 2010. "Modelling Climate-Change-Induced Nonlinear Thresholds in Cephalopod Population Dynamics: Climate Change and Octopus Population Dynamics." *Global Change Biology* 16 (10): 2866–75. https://doi.org/10.1111/j.1365-2486.2010.02223.x.

Baker-Médard, Merrill. 2017. "Gendering Marine Conservation: The Politics of Marine Protected Areas and Fisheries Access." *Society & Natural Resources* 30 (6): 723–37. https://doi.org/10.1080/08941920.2016.1257078.

Barnes, Michele L., Örjan Bodin, Tim R. McClanahan, John N. Kittinger, Andrew S. Hoey, Orou G. Gaoue, and Nicholas A. J. Graham. 2019. "Social-Ecological Alignment and Ecological Conditions in Coral Reefs." *Nature Communications* 10 (1): 2039. https://doi.org/10.1038/s41467-019-09994-1.

Barnes-Mauthe, Michele, Shawn Arita, Stewart D. Allen, Steven A. Gray, and PingSun Leung. 2013. "The Influence of Ethnic Diversity on Social Network Structure in a Common-Pool Resource System: Implications for Collaborative Management." *Ecology and Society* 18 (1): art23. https://doi.org/10.5751/ES-05295-180123.

Bavinck, Maarten. 2011. "The Megaengineering of Ocean Fisheries: A Century of Expansion and Rapidly Closing Frontiers." In *Engineering Earth*, edited by Stanley D. Brunn, 257–73. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-90-481-9920-4_16.

Bodin, Örjan, and Beatrice I. Crona. 2009. "The Role of Social Networks in Natural Resource Governance: What Relational Patterns Make a Difference?" *Global Environmental Change* 19 (3): 366–74. https://doi.org/10.1016/j.gloenvcha.2009.05.002.

Briggs-Gonzalez, Venetia, Christophe Bonenfant, Mathieu Basille, Michael Cherkiss, Jeff Beauchamp, and Frank Mazzotti. 2016. "Life Histories and Conservation of Long-lived Reptiles, an Illustration with the American Crocodile (Crocodylus Acutus)." *Journal of Animal Ecology* 1365 (2656.12723): 12.

Chuenpagdee, Ratana, and Svein Jentoft. 2018. "Transforming the Governance of Small-Scale Fisheries." *Maritime Studies* 17 (1): 101–15. https://doi.org/10.1007/s40152-018-0087-7.

Chuenpagdee, Ratana, Delphine Rocklin, David Bishop, Matthew Hynes, Randal Greene, Miguel R. Lorenzi, and Rodolphe Devillers. 2019. "The Global Information System on Small-Scale Fisheries (ISSF): A Crowdsourced Knowledge Platform." *Marine Policy* 101 (March): 158–66. https://doi.org/10.1016/j.marpol.2017.06.018.

Cinner, Joshua E., W. Neil Adger, Edward H. Allison, Michele L. Barnes, Katrina Brown, Philippa J. Cohen, Stefan Gelcich, et al. 2018. "Building Adaptive Capacity to Climate Change in Tropical Coastal Communities." *Nature Climate Change* 8 (2): 117–23. https://doi.org/10.1038/s41558-017-0065-x.

Crouse, Deborah T., Larry B. Crowder, and Hal Caswell. 1987. "A Stage-Based Population Model for Loggerhead Sea Turtles and Implications for Conservation." *Ecology* 68 (5): 1412–23. https://doi.org/10.2307/1939225.

FAO. 2020. *The State of World Fisheries and Aquaculture 2020.* Food; Agriculture Organization of the United Nations. https://doi.org/10.4060/ca9229en.

Free, Christopher M., Olaf P. Jensen, Sean C. Anderson, Nicolas L. Gutierrez, Kristin M. Kleisner, Catherine Longo, Cóilín Minto, Giacomo Chato Osio, and Jessica C. Walsh. 2020. "Blood from a Stone: Performance of Catch-Only Methods in Estimating Stock Biomass Status." *Fisheries Research* 223 (March): 105452. https://doi.org/10.1016/j.fishres.2019.105452.

Gelcich, Stefan, and C. Josh Donlan. 2015. "Incentivizing Biodiversity Conservation in Artisanal Fishing Communities Through Territorial User Rights and Business Model Innovation." *Conservation Biology* 29 (4): 1076–85. https://doi.org/10.1111/cobi.12477.

Gharouni, A, Ma Barbeau, A Locke, L Wang, and J Watmough. 2015. "Sensitivity of Invasion Speed to Dispersal and Demography: An Application of Spreading Speed Theory to the Green Crab Invasion on the Northwest Atlantic Coast." *Marine Ecology Progress Series* 541 (December): 135–50. https://doi.org/10.3354/meps11508.

Govan, Hugh. 2010. "Status and Potential of Locally-Managed Marine Areas in the South Pacific:" *Munich Personal RePEc Archive* 23828.

Grafton, R. Quentin. 2005. "Social Capital and Fisheries Governance." *Ocean & Coastal Management* 48 (9-10): 753–66. https://doi.org/10.1016/j.ocecoaman.2005.08.003.

Grimm, Volker, Eloy Revilla, Uta Berger, Florian Jeltsch, Wolf M. Mooij, Steven F. Railsback, Hans-Hermann Thulke, Jacob Weiner, Thorsten Wiegand, and Donald L. DeAngelis. 2005. "Pattern-Oriented Modeling of Agent-Based Complex Systems: Lessons from Ecology." *Science* 310 (5750): 987–91. https://doi.org/10.1126/science.1116681.

Gutiérrez, Nicolás L., Ray Hilborn, and Omar Defeo. 2011. "Leadership, Social Capital and Incentives Promote Successful Fisheries." *Nature* 470 (7334): 386–89. https://doi.org/10.1038/nature09689.

"Hidden Harvest-The Global Contribution of Capture Fisheries." 2012. 66469-GLB. The World Bank. https://documents1.worldbank.org/curated/en/515701468152718292/pdf/664690ESW0P1210120HiddenHarvest0web.pdf.

Jentoft, Svein, and Arne Eide, eds. 2011. *Poverty Mosaics: Realities and Prospects in Small-Scale Fisheries.*

Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-1582-0.

Kadfak, Alin, and Per Knutsson. 2017. "Investigating the Waterfront: The Entangled Sociomaterial Transformations of Coastal Space in Karnataka, India." *Society & Natural Resources* 30 (6): 707–22. https://doi.org/10.1080/08941920.2016.1273418.

Katikiro, Robert E., Edison D. Macusi, and K. H. M. Ashoka Deepananda. 2015. "Challenges Facing Local Communities in Tanzania in Realising Locally-Managed Marine Areas." *Marine Policy* 51 (January): 220–29. https://doi.org/10.1016/j.marpol.2014.08.004.

Kosamu, Ishmael B. M. 2015. "Conditions for Sustainability of Small-Scale Fisheries in Developing Countries." *Fisheries Research* 161 (January): 365–73. https://doi.org/10.1016/j.fishres.2014.09.002.

Lee, Qi, James T Thorson, Vladlena V Gertseva, and André E Punt. 2018. "The Benefits and Risks of Incorporating Climate-Driven Growth Variation into Stock Assessment Models, with Application to Splitnose Rockfish (Sebastes Diploproa)." Edited by Ernesto Jardim. *ICES Journal of Marine Science* 75 (1): 245–56. https://doi.org/10.1093/icesjms/fsx147.

Mills, David J., Lena Westlund, Gertjan de Graff, Yumiko Kura, Rolf Willman, and Kieran Kelleher. 2011. "Under-Reported and Undervalued: Small-Scale Fisheries in the Developing World." In *Small-Scale Fisheries Management: Frameworks and Approaches for the Developing World*, 1–15. CAB International.

Misund, Ole Arve, Jeppe Kolding, and Pierre Fréon. 2002. "Fish Capture Devices in Industrial and Artisanal Fisheries and Their Influence on Management." In *Handbook of Fish Biology and Fisheries, Volume 2*, edited by Paul J. B. Hart and John D. Reynolds, 13–36. Oxford, UK: Blackwell Science Ltd. https://doi.org/10.1002/9780470693919.ch2.

Nowlis, Joshua Sladek. 2000. "Short- and Long-Term Effects of Three Fishery-Management Tools on Depleted Fisheries." *Bulletin of Marine Science* 66 (3): 12.

Pomeroy, Robert, John Parks, Richard Pollnac, Tammy Campson, Emmanuel Genio, Cliff Marlessy, Elizabeth Holle, et al. 2007. "Fish Wars: Conflict and Collaboration in Fisheries Management in Southeast Asia." *Marine Policy* 31 (6): 645–56. https://doi.org/10.1016/j.marpol.2007.03.012.

Pomeroy, Robert, John Parks, and Lani Watson. 2004. *How Is Your MPA Doing? AGuidebook of Natural and Social Indicators for Evaluating Marine Protected AreaManagement Effectiveness.* IUCN. Gland, Switzerland; Cambridge, UK.

Prince, Jeremy, Watisoni Lalavanua, Jone Tamanitoakula, Laitia Tamata, Stuart Green, Scott Radway, Epeli Loganimoce, et al. 2021. "Spawning Potential Surveys in Fiji: A New Song of Change for <Span Style="font-Variant:small-Caps;">small-scale</Span> Fisheries in the Pacific." *Conservation Science and Practice* 3 (2). https://doi.org/10.1111/csp2.273.

Salas, Silvia, María José Barragán-Paladines, and Ratana Chuenpagdee, eds. 2019. *Viability and Sustain-*

*ability of Small-Scale Fisheries in Latin America and The Caribbean*. Vol. 19. MARE Publication Series. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-76078-0.

Sari, Irna, Muhammad Ichsan, Alan White, Syahril Abdul Raup, and Sugeng Hari Wisudo. 2021. "Monitoring Small-Scale Fisheries Catches in Indonesia Through a Fishing Logbook System: Challenges and Strategies." *Marine Policy* 134 (December): 104770. https://doi.org/10.1016/j.marpol.2021.104770.

"Saving Fish and Fishers: Toward Sustainable and Equitable Governance of the Global Fishing Sector." 2004. 29090-GLB. The World Bank. http://hdl.handle.net/10986/14391.

Smith, Hillary. 2019. "Defining Small-Scale Fisheries and Examining the Role of Science in Shaping Perceptions of Who and What Counts: A Systematic Review." *Frontiers in Marine Science* 6.

Thampi, Vivek A., Madhur Anand, and Chris T. Bauch. 2018. "Socio-Ecological Dynamics of Caribbean Coral Reef Ecosystems and Conservation Opinion Propagation." *Scientific Reports* 8 (1): 2597. https://doi.org/10.1038/s41598-018-20341-0.