Assessing the spatial management of mangroves and small-scale fisheries in protected areas on the Brazilian Amazon coast

Rebecca Borges e Silva

A dissertation presented to Faculty 2 (Biology & Chemistry), at the University of Bremen, in partial fulfillment of the requirements for the degree of *Doctor rerum naturalium* (Doctor of Natural Sciences)

September 2019

Supervision Committee

Prof. Dr. Matthias Wolff
Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
Supervisor

PD Dr. Marion Glaser
Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
Co-supervisor

Dr. Roberta Barboza
Universidade Federal do Pará (UFPA), Campus de Bragança, Pará, Brazil
Co-supervisor

Dr. Annette Breckwoldt
Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
Committee member

Thesis reviewers

Prof. Dr. Matthias Wolff

Leibniz Centre for Tropical Marine Research (ZMT)

University of Bremen

Prof. Dr. Fábio de Castro

Centre for Latin American Research and Documentation (CEDLA)

University of Amsterdam

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University of Bremen

Dr. Marie Fujitani
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Prof. Dr. Martin Zimmer
Leibniz Centre for Tropical Marine Research (ZMT)

Dr. Roberta Barboza
Federal University of Pará (UFPA)

M.Sc. Astrid Sánchez Jiménez
Leibniz Centre for Tropical Marine Research (ZMT)
University of Bremen

Adamu Hussaini
University of Bremen

Acknowledgments

I would like to pay special thankfulness, warmth, and appreciation to the persons below who made my research successful and assisted me at every point to cherish my goal:

First and foremost, I would like to thank the **fishers and other local users** that participated in the research, who were so kind in sharing their precious knowledge and/or took the GPS with them to the mangroves. Thanks for sharing and carrying!

I also thank the other stakeholders who participated in the project: professors, local managers, and others with great knowledge of the region, its nature, and people. Special thanks for the amazing work under such harsh conditions by the Chico Mendes Institute for Biodiversity - ICMBio and the Brazilian Institute of the Environment and Renewable Natural Resources - IBAMA and their dedicated professionals. I am grateful for the support of the local managers: Sheyla, Ednaldo, Claudia, and Willian. Thanks to ICMBio and IBAMA for the brave work!

To the users' associations, ASSUREMACATA, Auremat, and AEXQUAT: my thanks and best wishes for the challenges ahead. Also, I was lucky to count with the help and support of assistants for the fieldwork and the transcription of the interviews. Thanks a ton to all of them: Jo, Betina, Bárbara, Ivan, sr Antonio, sr Custódio, sr Carlos, sr Bodinho and dona Marilene, Tati, Márcio, Thay, Raquel, Alan, Ray, Marília, and Indira.

The advice and support given by Indira Eyzaguirre, Prof. Dr. Drude Lacerda, Dr. Alex Ferreira, Andreza Santos, Prof. Dr. Marileide Alves, Prof. Dr. Priscila Lopes, Dr. Karin Boos, Dr. Annette Breckwoldt, and Prof. Dr. Josinaldo Reis have been a great help in my data collection and writing process.

I would like to express my deepest appreciation to my committee: Matthias Wolff, Marion Glaser, Annette Breckwoldt, Marie Fujitani, Dr. Claire Reymonds, and Prof. Dr. Roberta Barboza for the supervision and support. I would like to express my gratitude to the members of the defense committee for their availability and to the journal reviewers that helped improved the paper published during the PhD. I would like to thank my thesis reviewers and defense committee: Prof. Dr. Matthias Wolff, Prof. Dr. Fábio de Castro, Prof. Dr. Wilhelm Hagen, Dr. Marie Fujitani, Prof. Dr. Martin Zimmer, Dr. Roberta Barboza, M.Sc. Astrid Sánchez Jiménez, and Adamu Hussaini.

I am particularly grateful for the assistance given by DAAD, especially for the German course before the PhD start and for the facilitated health insurance. For all the amazing support by the University of Bremen (great courses and open-access publishing support), especially the BYRD team and AStA, all my thanks. I would also like to express my gratitude to ZMT for all logistic support. At ZMT, my thanks to the non-violent communication group, the running team, and the librarians (especially Christina: Thanks for the great books!).

Part of this work was carried out within the financial support from Rufford Foundation (20310-1), especially for the small grant which enabled me to expand this project towards a more applied approach and to give back to the local stakeholders the results they helped me construct.

My appreciation to GLOMAR for the chance to participate in courses, events, meetings, to do an internship, for the financial support, as well as for the possibility of actively contributing to the Graduate school as a PhD representative. Special thanks to Tina Close, Karin Boos, Martin Lukas, and the Ocean and Society theme group.

For the great experience in science communication, I thank all my Once Upon A Time friends and colleagues, especially Dharma Reyes. And for the support with the defense, I thank the group ScienceChat at Uni Bremen.

I also had the pleasure of working and sharing ideas with, besides getting valuable help from, my groups and other ZMT colleagues: Theresa, Eike, Jennifer, Paul, Gashaw, Astrid, Pilar, Gustavo, Lotta, Manuel, Jonas, Sara, Steffi, Paul, Moritz, Regina, Seth, Isabel, Lisa, Adam, Dhanisha, Christine, Gui, Agustín, Inés, Mercè, and Janine.

I am deeply grateful to Jan Kleine-Büning at the deutsche Gesellschaft für Internationale Zusammenarbeit - GIZ and the Blue Solutions initiative for the opportunity to do an internship at the Marine Spatial Planning division in Bonn. Similarly, I would like to thank Dr. Ratana Chuenpagdee and Too Big To Ignore (TBTI) crew for the amazing networking and learning experience at the 3rd Small-Scale Fisheries Congress in Chiang Mai, October 2018 and for the invitation to participate in the Training of Trainers workshop parallel to the conference.

I want to thank friends and family for all the encouragement and support. Special thanks to my friends: Kelly, Carol, Andrea, Isadora and Co., Paula, Ale, Mimi, May, Yoyo, Aline (sábia amiga), Amandita, Bebels, Gervina, Germano, Érica B., Kim, Kiki, Yi, Natália, Anne, Jen, Dorota, Dharma, Érica F., Malin, Theresa, Célia, Claudia, Gabriela, Angelo, Germana, Vanessa, Astrid (my running mate), Dani, Fernando, Fabiana, Mafe, and Ju. [S**t happens!] Vielen Dank an meine Gastmutter, Barbara Heitkamp. Thanks should also go to Dini's friends, Kim, Dharma, Thorben, Érica F., Katie, Daniel, Andrés, Flor, and Astrid, for taking care of Dini while I went to all those conferences. I would also like to extend my thanks to my mother, my grandmas, and grandpas, to my cousins Dan, Vitorina, Sasha, Ie, my aunts Veronica, Geruza, and Sheily, my brother Bruno, and my sisters Tatá, Camila, and Cínthia.

Lastly and most importantly, I am incredibly grateful to the Brazilian people and especially to our country's scientific and environmental institutions. Special thanks to the Brazilian Council for Scientific and Technological Development - CNPq (Process 290055/2014-8) and to the "Science without Borders" program. I am grateful to former presidents Luiz Inácio Lula da Silva and Dilma Rousseff for the increased opportunities in research and education.

#lulainocente #mariellepresente #elenão

"Louvada seja a maré, que trás no ventre a flor da fé, da poção semente. Somos metade gente, outra de caranguejo, seguindo na corrente de um desejo. Nas nossas veias flui o sangue das tantas ceias vindas dos mangues."

Vergara Filho

Abstract

Mangroves are important providers of ecosystem services. Despite their relevance for conservation, they have been impacted by dynamic drivers that are causing loss of mangrove area worldwide. In Brazil, mangrove conservation strategies, such as spatial planning and protected areas, have not been fully implemented due to data deficiency on various social-ecological aspects of mangroves, including the spatial dynamics of small-scale fisheries. This thesis aims to investigate how multiple knowledge systems and assessment methods, including the ecosystem-based approach, participatory mapping, and GPS tracking can be combined for integrated management of mangrove protected areas, having as focus study areas two extractive reserves (RESEXs) in northeastern Pará, Brazil. In order to achieve an ecosystem-based management approach, mangrove ecosystems need to be managed as an integrated system, and interconnections with other coastal ecosystems must be assessed and taken into account. Regarding the spatial management of small-scale fisheries that take place in mangroves, this research shows that a combination of participatory mapping and GPS tracking can help identify fishing areas and the origin of the crab demand for each area. These findings can be applied to the spatial management of the crab fisheries, including integrated zoning strategies for protected areas. This thesis also proposes a framework to establish the starting geographic level for integrated spatial planning. In northeastern Pará, the spatial management of the four existing protected areas needs to be done in an integrated manner.

Keywords: Amazon coast, planning level, small-scale fisheries, marine spatial planning, coastal-marine protected areas, fisheries spatial management

Zusammenfassung

Obwohl Mangroven wichtige ökosystemare Funktionen erfüllen, werden sie von dynamischen Treibern beeinflusst, die weltweit den Verlust von Mangrovenflächen verursachen. Der Erfolg von Mangrovenschutzstrategien wie Raumplanung und Schutzgebiete wird durch Datenmangel in Bezug auf verschiedene sozial-ökologische Aspekte der Mangroven herabgesetzt, einschließlich der Faktoren des Wandels und der räumlichen Dynamik der Kleinfischerei. In dieser Arbeit wird untersucht, wie mehrere Wissenssysteme, einschließlich des ökosystembasierten Ansatzes, der Wahrnehmung des Managements, der partizipativen Kartierung und des GPS-Trackings, für ein integriertes Management von Mangrovenschutzgebieten kombiniert werden können. Zwei Schutzgebiete mit eingeschränkten Nutzungen („extraktive Reserven - RESEXs") im Nordosten Pará, Brasilien, dienen hierzu als Untersuchungsschwerpunkte. Um einen ökosystembasierten Managementansatz zu erreichen, sollten Mangroven-Ökosysteme als integriertes System verwaltet und die Zusammenhänge mit anderen Küstenökosystemen und Schutzgebieten bewertet und berücksichtigt werden. In Bezug auf die raümiliche Planung von Kleinfischerei in Mangroven, diese Arbeit zeigt auch, dass eine Kombination aus partizipativer Kartierung und GPS-Ortung dabei helfen kann, Fanggebiete und den geographischen Ursprung der ökonomischen Nachfrage nach Krebsfleisch für jedes Gebiet zu identifizieren. Diese Erkenntnisse können auf das räumliche Management der Krabbenfischerei angewendet werden, einschließlich integrierter Zonenstrategien für lokale Schutzgebiete. In dieser Arbeit wird zudem vorgestellt, in wie weit die räumliche Planungseinheit für eine integrierte Raumplanung entscheidend ist und festgelegt werden sollte. In dem untersuchten Gebiet sollte das räumliche Management der vier bestehenden Schutzgebiete im Nordosten von Pará vorzugsweise auf integrierte Weise erfolgen.

Schlüsselwörter: Mangroven, Meeresraumplanung, Küsten- und Meeresschutzgebiete, Planungsebene, Kleinfischerei, räumliches Fischereimanagement

Resumo

Os manguezais, apesar de serem importantes provedores de serviços ecossistêmicos, tem sido impactados por fatores dinâmicos que causam a perda de cobertura de manguezal em todo o mundo. As estratégias de conservação de manguezais, como o planejamento espacial e as unidades de conservação, são dificultadas pela deficiência de dados sobre vários aspectos sócio-ecológicos desses ecossistemas, incluindo aspectos relativos às dinâmicas espaciais da pesca de pequena escala e percepções por parte de atores locais. Esta tese tem como objetivo investigar como múltiplos sistemas de conhecimento e seus métodos, incluindo a abordagem ecossistêmica, mapeamento participativo e rastreamento por GPS, podem ser combinados para o manejo integrado de manguezais em unidades de conservação, tendo como estudo de caso duas reservas extrativistas no nordeste Pará, Brasil. A fim de alcançar uma abordagem ecossistêmica para o manejo, os manguezais devem ser gerenciados como um sistema integrado, e as interconexões com outros ecossistemas costeiros devem ser avaliadas e levadas em consideração. Em relação manejo espacial da pesca de pequena escala em manguezais, a presente pesquisa mostra também que uma combinação de mapeamento participativo e rastreamento por GPS pode ajudar a identificar áreas de pesca e a origem da demanda por caranguejo para cada território pesqueiro. Esses achados podem ser aplicados ao manejo espacial da pesca de caranguejo, incluindo estratégias de zoneamento integrado para unidades de conservação locais. Esta tese também propõe uma abordagem para se estabelecer o nível geográfico inicial para o planejamento espacial integrado. Para o estudo de caso analisado, o manejo espacial das quatro áreas protegidas existentes no nordeste do Pará deve ser feito preferencialmente de forma integrada. Esta tese também aponta para certas diferenças entre dados científicos e percepções dos pescadores.

Palavras-chave: costa amazônica, planejamento espacial marinho, unidades de conservação costeiro-marinhas, nível geográfico de planejamento, pesca de pequena escala, ordenación espacial pesquera

Resumen

Los manglares, a pesar de ser importantes proveedores de servicios ecosistémicos, se han visto afectados por factores dinámicos que están causando una pérdida significativa en su área de cobertura a nivel mundial. Las estrategias de conservación de los manglares, como la planificación espacial y las áreas protegidas, se ven obstaculizadas por una deficiencia de datos en relación a varios aspectos socio-ecológicos de los manglares, incluidos los impulsores del cambio, la dinámica espacial de las pesquerías en pequeña escala y las percepciones de las personas interesadas. Esta tesis tiene como objetivo investigar cómo se pueden combinar los múltiples sistemas de conocimiento y sus métodos, incluido el manejo basado en el ecosistema, las percepciones de gestión, el mapeo participativo y el seguimiento GPS para la gestión integrada de las áreas protegidas de manglares, teniendo como foco de estudio dos reservas extractivas en el noreste de Pará, Brasil. Para lograr un enfoque de gestión basado en el ecosistema, los ecosistemas de manglares deben gestionarse como un sistema integrado, y las interconexiones con otros ecosistemas costeros deben evaluarse y tenerse en cuenta. Con respecto a la planificación espacial de la pesca en pequeña escala en manglares, esta investigación también muestra que una combinación de mapeo participativo y rastreo GPS puede ayudar a identificar las áreas de pesca y el origen de la demanda de cangrejo para cada área. Estos hallazgos se pueden aplicar al manejo espacial de la pesquería de cangrejo, incluidas las estrategias de zonificación integrada para las áreas protegidas locales. La presente tesis también propone un marco para establecer una línea base de planificación espacial integrada. Para el estudio de caso, recomendamos que el manejo espacial de las cuatro áreas protegidas existentes en el noreste de Pará se realice de manera integrada.

Palabras clave: costa amazónica, planificación espacial marina, áreas protegidas costeras-marinas, nivel geográfico de planificación, pesca en pequeña escala, ordenación espacial pesquera

摘要

红树林是生态系统服务的重要提供者。尽管它们与保护息息相关，因受到外部因素的影响，红树林面积在全球范围内减少。在巴西，由于有关红树林的各种社会生态方面（包括小规模渔业的空间动态变化）的数据不足，所以尚未充分执行空间规划和保护区等红树林保护战略。本文旨在研究如何结合多种知识系统和评估方法，包括基于生态系统的方法，参与式制图和GPS跟踪，以对红树林保护区进行综合管理，并将重点放在巴西帕拉的两个采掘保护区（RESEXs）作为研究区。为了实现基于生态系统的管理方法，需要将红树林生态系统作为一个综合系统进行管理，并且必须评估并考虑与其他沿海生态系统的相互联系。这项研究表明, 关于在红树林中进行的小型渔业的空间管理，参与性地图绘制和GPS跟踪相结合可以帮助识别捕鱼区域和每个区域对螃蟹的需求来源。这些发现可用于螃蟹渔业的空间管理，包括保护区的综合分区策略。本文还提出了一个框架，以建立用于综合空间规划的起始地理层次。在帕拉东北部，需要以综合的方式对四个现有保护区进行空间管理。

关键词：亚马逊海岸，规划水平，小型渔业，海洋空间规划，沿海海洋保护区，渔业空间管理

Table of Contents

List of Figures

List of Tables

Manuscripts and contribution of the doctoral candidate

Manuscript 1. Borges R, Ferreira AC and Lacerda LD (2017). Systematic Planning and Ecosystem-Based Management as Strategies to Reconcile Mangrove Conservation with Resource Use. Frontiers in Marine Science, 4:353. (Chapter 2)

> Experimental concept and design (90%), experimental work and/or acquisition of data (100%), data analysis and interpretation (90%), preparation of figures and tables (80%), drafting of manuscript (80%).

Manuscript 2. Borges R, Barboza R, Boos K, Glaser, Wolff M, Lopes P. Combining knowledge systems and collection methods helps understand the spatial dynamics of data-deficient small-scale fisheries systems. (Chapter 4)

> Experimental concept and design (90%), experimental work and/or acquisition of data (100%), data analysis and interpretation (90%), preparation of figures and tables (80%), drafting of manuscript (80%).

Manuscript 3. Borges R, Santos A, Alves M, Barboza R. Spatial dynamics of small-scale fisheries and integrated zoning of coastal protected areas. (Chapter 5)

> Experimental concept and design (100%), experimental work and/or acquisition of data (100%), data analysis and interpretation (90%), preparation of figures and tables (80%), drafting of manuscript (70%).

Chapter 1

Introduction

Literature references can be found at the end of this thesis.

Spatial management of mangroves and small-scale fisheries

Mangroves are important providers of ecosystem services (MEA 2005, Barbier et al. 2011). However, in several countries, they are threatened by a variety of drivers, which are dynamic and have been changing in past decades (UNEP 2014). Land-use conversion is one of the most significant drivers of negative change in mangroves (UNEP 2014, Ferreira and Lacerda 2016a), especially because the coastal regions where they are found are hubs of human populations (Spalding et al. 2013).

Mangroves are transboundary ecosystems between land and sea (Rotich et al. 2016) and constitute an interesting study site to investigate transboundary issues. When designing marine management plans, spatial aspects of the environmental pressures, such as the patchiness of fishing activity, need to be taken into account (Stelzenmüller et al. 2008). According to Worm et al. (2009), "*recovering [vulnerable or collapsed] species while maintaining global catches may be possible through improved gear technology and a much more widespread use of ocean zoning into areas that are managed for fisheries benefits and others managed for species and habitat conservation*".

Successful spatial management of small-scale fisheries is a potentially complicated process and requires a thorough understanding of the social-ecological system (Le Cornu et al. 2018). In addition, the very idea of rigid and static boundaries between these systems will need to be rethought to reflect the transboundary processes and effects of climate change.

Data-poor settings

An obstacle to the implementation of fisheries management in mangroves is the fact that most of these contexts are data-poor, especially in terms of spatial information. Spatial monitoring of industrial fisheries seems to be relatively easy, and new technologies are being developed, which would better fit with this sector. On the other hand, small-scale fisheries often have poor monitoring systems and are considered marginalized by national policies (Chuenpagdee et al. 2006) despite their important contribution to food security (Teh and Pauly 2018). These fisheries are also very diffuse throughout the coasts, and landings occur in small ports spread out along the coastline (Salas et al. 2007).

To overcome this data deficiency, local knowledge has been put forth as a possible solution (Gill et al. 2017), especially because it can be cheaper and quicker to collect (McCall 2004, Brown and Kyttä 2014). Local knowledge could also help engage local people in research and management (Reed 2008), even though outcomes for biodiversity conservation can be only partial or indirect (Young et al. 2013). Integrating local and technical expert knowledge is crucial to inform locally relevant fisheries management and conservation (Ban et al. 2017). In this research, the question is asked whether the integration of local and technical expert knowledge systems could be a tool to investigate perceptions about the ecosystem and help promote ecosystem-based management in data-poor contexts.

Management and the ecosystem-based approach

Research on marine local knowledge overall is relatively young and evolving rapidly (Thornton and Scheer 2012). There is a critical need for more substantive, deep ethnographic, and multi-scale research on marine ecosystems, as our ocean-dominated planet continues to evolve and change. Moreover, participation seems to be able to empower stakeholders (Beyerl et al. 2016). A combination of local and scientific knowledge may empower local communities to monitor and manage environmental change easily and accurately (Reed 2008), although power relations (Wallerstein 1999) and mismatching needs of involved actors (Michener 1998) need to be taken into account.

Moving on from the issue of data availability, discussions in the literature approach the appropriate planning unit for spatial management to solve specific conservation and sustainable use problems (Dallimer and Strange 2015, Oakley et al. 2018). Some of these issues are especially applicable to spatial management. The definition of scale in (Gibson et al. 2000) is adopted, where scale is “the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon”. Another important concept is that of a “level”, which the same authors describe as “the units of analysis that are located at different positions on a scale”.

Ecosystem-based management represents a broader view than the typical sector-based management, for instance (Guerry 2005, Arkema et al. 2006). It takes into account the interconnectedness and interdependent nature of the components of ecosystems, and the fundamental importance of ecosystem structure and functioning in providing humans with the broad range of services that are taken for granted (Curtin and Prellezo 2010). The United Nations Convention on Biological Diversity (CBD) integrates ecological, social and governance objectives, describing the ecosystem approach as: "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way"[1].

The Communications Partnership for Science and the Sea (COMPASS) published a more in-depth, inclusive definition developed by over two hundred science and policy experts in the United States. EBM was defined there as: "an integrated approach to management that considers the entire ecosystem, including humans. The goal of EBM is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. EBM differs from current approaches that usually focus on a single species, sector or activity or concern; it considers the cumulative impacts of different sectors"[2].

Two principles of the ecosystem approach to management relate to the spatial and temporal scales: 1) management is more effective if done at the appropriate spatial and temporal scales, and 2) ecosystem processes are characterized by temporal scales and lag-effects, meaning that management should be set for the long term. Moreover, "appropriate spatial and temporal scales" and "consideration of ecosystem connections" are among the most important principles in ecosystem-based management (Long et al. 2015).

Coastal and marine spatial planning have been discussed or even implemented at geographic levels that include a network of protected areas both within a country and between neighboring countries. Terrestrial and marine corridors between protected areas (Whitehouse 1992, Pendoley et al. 2014), as well as the so-called "zones of interaction" (DeFries et al. 2010), have also been researched and advocated for as approaches to upscale local conservation from isolated protected areas towards regional conservation strategies. However, the relationship between spatial planning and coastal marine protected areas has

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[1] United Nations Convention on Biological Diversity (CBD). Ecosystem Approach; 2011 ⟨http://www.cbd.int/ecosystem/⟩

[2] [Communications Partnership for Science and the Sea (COMPASS). Scientific consensus statement on marine ecosystem-based management; 2005 ⟨http:// www.compassonline.org/sites/all/files/document_files/EBM_Consensus_Statement_v12.pdf

not been systematized from the literature, nor have studies on zoning within protected areas been comparatively examined (Borges et al., *in Press*).

Planning unit and ecosystem services

The issue of management level emerges as a frontier in research, both because it has been rarely studied, but also because the levels of the studies differ immensely, with a concentration on regional- and national-level projects. (2015) have also identified the problem of level mismatch in conservation settings. This mismatch occurs when actions are undertaken at a level that does not reflect the level(s) required to solve a particular conservation problem. Level mismatches are generated by a wide range of social, ecological, and linked social-ecological processes, and how to best resolve level mismatches remains an open question (Cumming et al. 2006).

When the level of environmental variation and the level of social organization in which the responsibility for management resides are aligned in such a way that one or more functions of the social-ecological system are disrupted, inefficiencies occur, and/or important components of the system are lost (Cumming et al. 2006). Mismatches between the scales (and levels) of ecological processes and those of the institutions that are responsible for managing them can contribute to a decrease in social-ecological resilience, including the mismanagement of natural resources and a decrease in human well-being. An understanding of how level mismatches transpire and their likely consequences would be of value to conservation professionals because it would further the development of strategies to address problems of level (Cumming et al. 2006). Long-term solutions to level mismatch problems will depend on social learning and the development of flexible institutions that can adjust and reorganize in response to changes in ecosystems.

The development of management plans can mean the difference between a “paper” and a “functioning” park. Lopes et al. (2011) argue that neither Brazilian Amazonian reserves nor coastal ones can be regarded as conservation or sustainability models because most of them have not yet developed management plans.

Current approaches to mangrove spatial management

Zoning is a cornerstone of marine spatial planning (Kenchington and Day 2011). Marine spatial planning is “a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that typically have been specified through a political process” (Ehler and Douvere 2009). Marine spatial planning is, therefore, one element of ocean or sea use management, whereas zoning plans and other regulations are one of a set of management actions for implementing marine spatial planning (Ehler and Douvere 2009). Marine spatial planning has been evolving in the past decades as a tool to protect ecosystems while allowing for the development of human activities (Collie et al. 2013, Jones et al. 2016, Kyriazi et al. 2016) and is considered essential to ecosystem-based management (Douvere 2008).

Marine spatial planning supports management and employs resource economics, welfare economics, and institutional analyses, for instance, in fisheries management (Paterson et al. 2010). Therefore, marine spatial planning can be viewed as a transdisciplinary subject (Gissi and de Vivero 2016). Ocean zoning, in which type and level of allowable human activity are specified spatially and temporally, is a critical element of ecosystem-based fisheries management, and fisheries issues such as bycatch are shown to be ameliorated through ocean zoning (Pikitch et al. 2004).

Despite the importance of marine spatial planning and zoning for coastal and small-scale fisheries management, few studies have addressed its application in estuaries. Mangroves are no exception, and studies on spatial management strategies specifically for these ecosystems are incipient. This seems, therefore, a frontier in mangrove conservation research, with few ecosystem-based approaches recorded (Sierra-Correa and Cantera Kintz 2015) with the following foci: 1) on sea-level rise (Sierra-Correa and Cantera Kintz 2015); 2) conflict (Tuda et al. 2014); and 3) a cost-effectiveness analysis that mapped mangrove ecosystem services, such as coastal protection, fisheries, biodiversity, and carbon storage (Atkinson et al. 2016). Besides, all the relevant legislation and the participation of fishers is crucial for the maintenance and improvement of such a planning process (Prestrelo and Vianna 2016).

The Brazilian context

One of the largest mangrove belts on the planet is located in northern Brazil, on the Amazon coast (Spalding et al. 2013): a 7,423 km^2-tract (Nascimento et al. 2013) that, as a unitary system, corresponds to 4.3% of the total global mangrove area and represents over 80% of Brazilian mangroves (Spalding et al. 2010). This mangrove belt hosts the largest protected system on the planet, with 6,637 km^2 of mangrove forests and salt flats protected within 18 protected areas (Hayashi 2018). There, these mangroves have been considered relatively well-preserved, but also under increasing anthropogenic pressure (Lara et al. 2002). Land-use changes have been significant during the past few decades in Brazil (Lapola et al. 2010), especially in the Amazon region (Souza-Filho and Paradella 2003, Simmons et al. 2019). Therefore, the mangroves on the Amazon coast were recognized as important for conservation, especially after the rubber tappers' movement during the 1980s (Fearnside 1989).

As part of the social changes promoted in the left-oriented government in Brazil at the beginning of this century, a large area of the country, especially in the Amazon region, was gazetted as protected areas, with an emphasis in sustainable-use categories. About 190 federal-level protected areas were created[3], of which 51 are in sustainable-use categories[4], with a total area of approx. 69,502,667 hectares[5]. Among other factors, the protected areas and indigenous lands created in the first decade of the century helped Brazil drop its CO_2 emissions by 62% (in km^2 /year deforested) until 2011, compared to the 1990s (Boucher et al. 2013).

Brazil's reduction of deforestation by two-thirds occurred at the same time that it saw strong economic growth and a significant advance in social justice (Boucher et al. 2013). Through social programs such as "Fome Zero" (Zero Hunger) and "Bolsa Família" (Family Allowance), Brazil reduced its poverty rate from over 34% to less than 23%, and 29 million citizens transitioned into the middle class[6]. Hunger and malnutrition rates dropped

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[3] https://sustentabilidade.estadao.com.br/noticias/geral,governo-fara-revisao-geral-das-334-areas-de-protecao-ambiental-no-pais,70002822999
[4] https://tinyurl.com/y58fqugy
[5] https://uc.socioambiental.org/noticia/143366
[6] https://www.bbc.com/news/world-latin-america-11414276?print=true

substantially, and important advances were made in reducing economic inequality (Rocha 2009, Chappell and LaValle 2011). According to Boucher et al. (2013), Brazil has shown that it is possible to make progress and still maintain forests.

In this period, Brazil made important advances in reconciling biodiversity conservation and economic development and experienced a relevant growth of the number of protected areas. Brazil has the largest terrestrial protected area system in the world: 2.47 million km^2 (UNEP-WCMC 2016). Excluding indigenous lands, *quilombola* territories (areas owned by descendants of slaves), and military areas, other categories of parks and reserves are recognized in Brazil and managed administratively at federal, state, and municipal levels. Federal-level protected areas are regulated by the National System of Conservation Units, which aims to unify and standardize administration and management (BRASIL 2000). Despite upsetting increases in the recent past (Overbeck et al. 2015, Escobar 2019), deforestation in the Amazon declined overall until 2012-13 (Hansen et al. 2013, Lapola et al. 2013, Nepstad et al. 2014), and restoration in the Atlantic Rainforest progressed (Calmon et al. 2011), with as much as 740 thousand hectares of native forests restored from 2011 to 2015 (Crouzeilles et al. 2019).

Sustainable-use areas

While responding to a societal need to guarantee land use to “traditional populations”[7] and to safeguard the ecosystems they depend on, there is a lot of criticism against sustainable-use protected areas (Locke and Dearden 2005, Freitas et al. 2015). Some criticized a strong bias in the number of protected areas towards sustainable-use reserves rather than strictly protected areas (Peres 2011). Some argue that extractive reserves are not protected areas (Locke & Dearden 2005) and do not protect biodiversity (Terborgh and Peres 2017).

Independently of use restriction, protected area creation in Brazil has been slowing down since 2009. Recent evidence suggests that the rate of protected area downgrading, downsizing, and degazettement is increasing (Bernard et al. 2014) due to a political and

[7] While legislation acknowledges “traditional populations“, the fishers on the north Brazilian coast are recognized in the literature as “neo-traditional” populations. Neo-traditional systems are defined as including elements from traditional and newly emergent systems (Berkes and Folke 1994). They include, besides traditional knowledge, new variants and knowledge that comes from outside the population.

economic landscape that favors resource use and development over investments in new and existing protected areas (Ferreira et al. 2014, Campos-Silva and Peres 2016).

Despite a large number of protected areas, biodiversity protection has not been effective (Rezende and Coelho 2016). The simple creation of protected areas does not automatically imply biodiversity protection. Creating protected areas is not enough. Concrete planning is necessary, lest they become paper parks (Rezende and Coelho 2016).

Co-management

Co-management has been shown to deliver both ecological and social benefits: it increases the abundance and habitat of species, fish catches, actors' participation, and the fishery's adaptive capacity, and induces processes of social learning (d'Armengol et al. 2018). Co-management is more effective if artisanal fishers and a diversity of other stakeholders become involved through an adaptive institutional framework.

Likewise, fisheries monitoring is also more effective if local fishers are involved in the planning process. Local fishers are more likely to report illegal fishing if they have participated in conservation planning and if they are directly linked to community-based wardens in information-sharing networks (Alexander et al. 2018).

Participatory mechanisms, such as co-management, are viewed as an appropriate model for northern Brazil. Despite clear drawbacks of the actual, implemented system in the extractives reserves (Partelow et al. 2018). There, mangroves are home to small-scale fisheries, such as crab and fish extraction (ICMBio 2018), and this strong and close interaction with human activities characterizes these contexts as social-ecological systems (Glaser et al. 2010).

Research objectives

The core objective of this work is to investigate the primary subsidies for the implementation of integrating zoning of a contiguous mangrove area, embedded in the broader research on marine spatial planning. Also, the issue of spatial data limitation in sustainable-use areas in the Amazon mangrove belt is addressed, as well as management challenges related to social changes and political disputes occurring in the protected areas.

Participatory mapping and Global Positioning System (GPS) tracking as data collection methods and local and technical knowledge systems are combined to generate spatial data and determine a planning unit for the protected areas in the region. Under an applied conservation lens, this investigation sets the scene for the implementation of a systematic, spatial planning process.

Considering the theory of the science of spatial planning, this research adds to the methodological body of knowledge tools to investigate the spatial dynamics of processes (or ecosystem services) that need to be addressed in spatial management. While proposing these new approaches, the different methods and knowledge systems are examined and possible limitations are highlighted.

Since the main ecosystem service analyzed is the small-scale crab fishery, the results presented also contribute to methods in spatial assessments of small-scale fisheries and to the theory of resource foraging, with a focus on the relationship between distance traveled and size of fished crabs. Information on the current situation of crab fisheries in the study area is added to the body of knowledge and can be used to support local policy on fisheries management.

While still connecting the topics of small-scale fisheries and spatial planning, knowledge is added to the theory and operationalization of research on governance levels of environmental management. This is done by furthering the discussion on the establishment of spatial planning unit boundaries and the starting level from which multi-level and polycentric management can be achieved.

Research questions

Specifically, based on the issues outlined and related research needs, the following questions are asked in this thesis:

1. What does the current mangrove conservation landscape in Brazil look like? (Chapter 2)
2. What are the benefits of combining different knowledge systems, including participatory mapping and GPS tracking, for spatial planning management? (Chapter 4)

3. Can the spatial dynamics of small-scale fisheries help determine the most appropriate level for spatial management of a network of protected areas? (Chapter 5)

This research accounts for ecological, socioeconomic, and political aspects. It also gives strong emphasis to strategies to combine knowledge systems and build a coherent body of knowledge and spatial datasets that can be used to conduct marine spatial planning processes in protected areas where stakeholder participation plays a key role in management. This research project aims to investigate how multiple knowledge systems and their methods, including the ecosystem-based approach, participatory mapping, and GPS tracking can be combined for integrated management of mangrove protected areas, with as focus study areas two extractive reserves in northeastern Pará, Brazil.[8]

[8] Further motivations for this research are shown in Supporting Information I.

Chapter 2

"No forest, no history."

Davi Kopenawa

The Falling Sky: Words of a Yanomami Shaman

This chapter was originally published at
https://www.frontiersin.org/articles/10.3389/fmars.2017.00353/full

Please cite it as a journal article and not as a thesis chapter.

How to cite this article:
Borges R, Ferreira AC and Lacerda LD (2017) Systematic Planning and Ecosystem-Based Management as Strategies to Reconcile Mangrove Conservation with Resource Use. Front. Mar. Sci. 4:353. doi: 10.3389/fmars.2017.00353

The format has been adapted to match the thesis.

Literature references can be found at the end of this thesis.

Systematic Planning and Ecosystem-Based Management as Strategies to Reconcile Mangrove Conservation with Resource Use

Rebecca Borges [1, 2*], Alexander C. Ferreira [3] and Luiz D. Lacerda [3]

1 Resource Management Working Group, Faculty of Biology, University of Bremen, Bremen, Germany,

2 Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany,

3 Instituto de Ciências do Mar (LABOMAR), Universidade Federal do Ceará, Fortaleza, Brazil

Abstract

About 120 million people worldwide live within 10 km of large mangrove forests, and many of them directly depend on the goods and services provided by these ecosystems. However, it remains unclear how to synchronize ecological definitions and legal conservation strategies regarding mangroves, especially in developing countries, such as Brazil. The influence of human populations' socio-economic context in mangrove conservation policies, as well as associated challenges in incorporating this influence, are underestimated or, often, largely ignored. Considering the recent threats emerging from changes in legislation and the lack of spatial and social-ecological integrated data to plan mangrove conservation in Brazil, this paper aims to answer the following questions: (1) What suitable measures could managers and other decision-makers adopt for efficient mangrove conservation planning?; (2) What are the site-specific, social-ecological aspects that need to be taken into account when deciding on conservation and management strategies?; and (3) How could science contribute to the development of these measures? In order to achieve an ecosystem-based management approach, mangrove ecosystems should not be divided into sub-systems, but instead treated as an integrated system. Furthermore, interconnections with other coastal ecosystems must be assessed and taken into account. This is crucial for effective systematic conservation planning. Also, most of the particular social-ecological aspects in the different types of mangrove ecosystems along the Brazilian coast, and how those differences might be considered while planning for conservation, remain poorly understood. Based on similar drivers of change, geological features, and likely impacts of climate change, a macro-unit approach is proposed to group mangrove systems along the Brazilian coast and guide national policies. This paper draws parallels with management approaches worldwide to find common points and hence lessons to be applied in other regional realms. It considers the issues of legal vulnerability and needs for social-ecological data on mangroves, contributing to systematic conservation planning and ecosystem-based management for these ecosystems.

Keywords: coastal-marine spatial planning, social-ecological system, marine protected area, ecosystem service, GIS-based data, Brazil

Introduction

About 120 million people worldwide live within 10 km of mangrove forests (UNEP 2014). Many of them largely depend on the goods and services provided by coastal ecosystems, such as food and timber provision, fuelwood and shoreline protection (Spalding et al. 2010, Barbier et al. 2011). Mangroves also indirectly deliver farther-reaching benefits, such as serving as habitat for terrestrial and marine species (Nagelkerken et al. 2008). At least 776 species of birds, fish, mollusks, arthropods, and plants are associated with these ecosystems in Brazil (Schaeffer-Novelli 1999), with even larger numbers in Indo-Pacific mangroves (Latham 1993). On a global level, they function as important carbon-sequestering systems (Donato et al. 2011, Ray et al. 2011, Murdiyarso et al. 2012).

In some developing countries, mangroves are estimated to contribute to national economies with US$33–57 thousand per hectare per year [e.g., Sathirathai and Barbier (2001)]. Some coastal human populations are directly dependent on mangroves, such as in northern Brazil, where 83% of rural households harvest natural resources from mangroves, which also provide 68% of their cash income (Glaser 2003). However, mangroves have been largely affected by land conversion, pollution, and overexploitation, leading to a loss 3–5 times faster than that in other forest types (Alongi 2002). Clearing of these forests is usually due to aquaculture, agriculture, and urban land uses (Spalding et al. 2010). The deforestation of coastal vegetated ecosystems corresponds to up to nearly 20% of total emissions from deforestations on the planet, with economic damages of US$6–42 billion per year (Pendleton et al. 2012).

Brazil has between 75 and 83% of its mangrove coverage within some category of protected area (Magris and Barreto 2010, Prates et al. 2012). This represents a much larger cover than the global average (~ 28%) (Juffe-Bignoli et al. 2014). The total protected extension of Brazilian mangroves kept increasing in recent years. Since 2014, the country holds the largest extent of protected mangrove in the world: 322 thousand hectares inside 11 “extractive reserves” — a sustainable-use category (Plataforma Brasil 2015). Similar protected area models have been shown to offer good conservation results elsewhere (Aheto et al. 2016). In Brazil, however, these reserves have not yet been systematically assessed. Moreover, around 58% of the total protected mangrove areas are within the category of environmental protection areas, a sustainable-use category of protected areas considered to deliver low levels of protection (Prates et al. 2012).

Despite having already lost 10–20% of its mangroves (FAO 2007), Brazil still holds a total mangrove area of over one million hectares (Magris and Barreto 2010), spread out along 6,786 km of coastline (Schaeffer-Novelli et al. 2000). Contrary to the trend in other countries, the total mangrove area in Brazil even increased in the first decade of the millennium (Aide et al. 2013).

Recent changes in conservation policy in Brazil, however, such as the new Brazilian Forest Code (BRASIL 2012), will likely have negative impacts on mangroves and other vegetation types (Silva et al. 2011, Medeiros et al. 2015, Oliveira-Filho et al. 2016, Ferreira and Lacerda 2016c). This federal law, strongly biased toward agribusiness interest (Oliveira-Filho et al., 2016), disaggregates from the mangrove the salt flats ("apicuns"), which are of special interest to shrimp farming, but also an important component of the mangrove ecosystem (Schmidt et al. 2013). The new law admits the "sustainable use" of these areas, including aquaculture and salt production ponds.

Negative impacts on coastal and marine processes and on social-economic activities are predicted consequences of this change in legislation (Rovai et al. 2012) because it fails to adopt an ecosystem-based approach when defining mangroves and the interactions between its components. Ecosystem-based management is here understood as "an integrated approach to management that considers the entire ecosystem, including humans" (McLeod et al. 2005), where the complexity and relationship within nearby ecological systems are acknowledged, together with social and governance objectives of mangrove management (Barbier 2006, Aswani et al. 2012, Carter et al. 2015, Long et al. 2015).

The recent developments and discussions on sub-systems, such as the salt flats, and the uniqueness of mangroves as ecosystems illustrate the discussion that directly affects mangrove conservation. It remains unclear how to synchronize the ecological definitions and legal conservation strategies regarding mangroves. As observed for other countries where mangrove forests are found, laws and policies in Brazil are rarely designed for the specific management requirements of mangroves. As illustrated by the Forest Code, mangroves are usually regulated under legal frameworks created originally for forests in general, environment, water, land, or marine fisheries (Rotich et al. 2016).

Mangrove management requires attention to the multidimensional benefits they provide, both ecologically and socially (Rotich et al. 2016). However, incorporation of social-ecological aspects, such as people's perception and traditional uses in conservation policies, is deficient (McConney and Charles 2008). As pointed out by (Benessaiah and Sengupta 2014), one challenge is that many ecologists and managers tend to define ecosystems in a localized sense, rather than adopting a broader understanding of ecosystems as self-organizing units composed of interacting ecological and social components operating at different levels. Adopting a social-ecological system approach explicitly defines issues as an integrated system of people and environment (Benessaiah and Sengupta 2014, Nayak and Berkes 2014). The term social-ecological is used throughout this paper in the sense of the integration of humans and nature in complex, adaptive systems (Berkes and Folke 1998).

Systematic conservation planning requires explicit goals and criteria for implementing conservation action, besides mechanisms for maintaining the conditions within reserves that are required to foster the persistence of key natural features (Margules and Pressey 2000). It is based on the extent to which conservation goals have already been met in existing reserves and clear methods to locate and design new reserves to complement existing ones (Margules and Pressey 2000).

Considering the recent threats from changes in legislation and the lack of spatial, social-ecological data integration to plan for the conservation of mangrove systems, this paper aims to answer the following questions: (1) What suitable measures could managers and other decision-makers adopt for efficient mangrove conservation planning?; (2) What are the site-specific, social-ecological aspects that need to be taken into account when deciding on conservation and management strategies?; and (3) How could science contribute to the development of these measures?

This is the first review to consider the issues of legal vulnerability and lack of integrated social-ecological data, using Brazil as a study case and systematic planning and ecosystem-based management as backbones to discuss the following suggested approaches to tackle the apparent paradox of reconciling mangrove conservation and sustainable use:

(1) mangrove as a social-ecological system; (2) mangrove as an integrated system; (3) multi-level planning; (4) standardized, GIS-based information and synthesis work; and (5) assessment of the protected area system.

Linking systematic planning and ecosystem-based management to guide further strategies

The mangrove as a social-ecological system

The involvement of stakeholders in environmental management, when underpinned by a focus on empowerment, equity, trust and learning, can (1) improve environmental decision making by considering more comprehensive information inputs (Reed 2008) and (2) increase public trust in decisions and civil society, if participatory processes are perceived to be transparent and consider conflicting claims and views (Richards et al. 2004). Stakeholder participation can increase the likelihood that environmental decisions are perceived to be holistic and fair, accounting for a diversity of values and needs and recognizing the complexity of human-environmental interactions (Richards et al. 2004). It can also empower stakeholders through the co-generation of knowledge with researchers and through increased participants' capacity to use this knowledge (Stephenson et al. 2016). To be successful, the involvement of actors must be institutionalized, creating organizational cultures that can facilitate processes where goals are negotiated and outcomes are uncertain (Reed 2008).

Scientific research can indicate concrete measures to enhance stakeholder participation and develop strategies to help involve local actors in a more efficient way. As emphasized by (Ferreira and Lacerda 2016c), in order to promote mangrove conservation, besides government enforcement of the protection legislation, people need to be aware of the goods and services provided by mangroves. Unfortunately, population awareness usually only arises after the consequences of mangrove degradation (Barbier 2006), so providing people with information about similar cases and the consequences of mangrove degradation elsewhere through experience exchange could be a shortcut to avoid human-promoted mangrove degradation by lack of knowledge. However, science often fails to translate knowledge to decision-makers and the general public (Granek et al. 2010).

In the case of fisheries, which is an important human activity developed in mangrove areas (UNEP 2014), engaging community leaders has been shown to be essential to achieve successful co-management (Gutierrez et al. 2011). Native populations, especially those directly dependent on mangrove goods and services, as well as other societal sectors, need to be integrated through community-based management (Ferreira and Lacerda 2016c). In addition, when considering the effectiveness of protected areas, besides creating more and larger reserves, it is important to concomitantly invest in education, economic incentives, and community-based enforcement (Rife et al. 2013).

Regarding fisheries management, successful outcomes of community-based initiatives benefit from (1) effective information-sharing, (2) harvesting rules that merge traditional and contemporary practices, (3) strong leadership, and (4) resource monitoring (Blythe et al. 2017). There is, though, a deficiency of information on the social dimensions of mangrove management (Rotich et al. 2016), necessary to promote these aspects. Local and scientific knowledge can be integrated to provide a more comprehensive understanding of complex and dynamic socio-ecological systems and processes (Reed 2008).

Local people often have a symbolic relationship with the mangrove forest, so the socio-cultural dimension of mangrove services needs to be considered by policymakers to tackle challenges in coastal ecosystems conservation (Queiroz et al. 2017). To tackle the financial dependency on mangroves it is vital to provide all stakeholders with the capability to influence the political aspects of governance, support institutions which foster accountability, encourage civil society to participate in decision-making processes, and ensure that views from the local level feed into the multi-level governance process (Orchard et al. 2015).

Partnerships with mangrove research groups need to be created and strengthened (Ferreira and Lacerda 2016c). Scientific research can contribute, for example, with the development of methods to incorporate local ecological knowledge, through bottom-up social studies that shed light on how to apply this knowledge to the development of conservation strategies for mangroves. This is especially relevant to assess monetary and non-monetary values of ecosystem goods and services. With such a valuation at the local level, policymakers can be made aware that the profit coming from the shrimp market, for example, is considerably smaller than the environmental damage caused, as exposed in the case of some intensive shrimp farms in NE Brazil (Ferreira and Lacerda 2016c). [One exception could be, for example, organic farms in NE Brazil and traditional “tambacs” in Asia, which may have a mutual benefit for adjacent mangrove forests (Lacerda et al. 2002).]

A lack of understanding of the values associated with wetlands is largely due to the complexity and “invisibility” of spatial relationships between groundwater, surface water, and wetland vegetation (Turner et al. 2000). Following a global pattern (Walters et al. 2008), the values associated with Brazilian mangrove ecosystems are not taken into account by policymakers, when, for example, shrimp farming is considered more valuable than mangrove preservation. Despite pressure and consequent damages over mangroves, little is known about their unique value in terms of ecosystem services, since local variation can be high due to site specificities along the Brazilian coast (Souza and Ramos e Silva 2010, Estrada et al. 2015, Ferreira and Lacerda 2016c). But even these few accurate studies are not taken into consideration by decision-makers or environmental authorities. The largest mangroves in the world, the Sundarbans, for example, lack a specific protection agenda or policy (Roy and Alam 2012).

More integrated studies to assess ecosystem services and vulnerability to environmental impacts have to be conducted for Brazilian mangroves. Integrated wetland research combining social and natural sciences can help to partly solve the information problem and provide consistency among various government policies (Turner et al. 2000). While global (Martínez et al. 2007) and local level (Saint-Paul and Schneider 2016) integrated approaches have been applied, the regional level might be the best starting point to identify cross-scale interactions which shape coastal and marine social-ecological dynamics and outcomes (Glaser and Glaeser 2014).

In order to make progress, further and intensified cooperation is needed between social and natural scientists (Turner et al. 2000). It is also imperative to collect and integrate data from different disciplines, which are essential for sustainable development and management, particularly in developing countries (Dahdouh-Guebas 2002). Including models and values of ecosystem services and vulnerability in marine spatial planning, for example, can help achieve multiple benefits for nature and people (Arkema et al. 2015). (Böhnke-Henrichs et al. 2013) provide a framework for such an ecosystem service approach in marine spatial planning. Given the peculiarities of transitional ecosystems such as mangroves, however, an even more specific typology and sets of indicators for coastal areas could be useful to assess ecosystem services. Additionally, stakeholders at different spatial levels can have very different interests in ecosystem services (Hein et al. 2006), so it is important to consider the levels of these services when valuation is applied to support the formulation or implementation of spatial plans.

In fisheries, for example, management systems are starting to value fishers' knowledge, considered part of the "best available information." Fishermen are able to provide information that can integrate ecological, economic, social, and institutional considerations of future management. Fishers' knowledge can be added to traditional assessment with appropriate analysis and explicit recognition of the intended use of the information and, if implemented in a participatory process designed to receive and use it, this knowledge can facilitate the participation of fishers in assessment and management, considered as best practice in fisheries governance (Stephenson et al. 2016).

The view of mangroves and contiguous coastal ecosystems as an assembly of interconnected exchanging matter and energy flux means that the conservation and use of such ecosystems require integrated management (Ferreira and Lacerda 2016c). Indeed, countless fishery resources recruit and grow in different coastal ecosystems, which also share mutual buffer effects (Walters et al. 2008, PEDRR 2010). Integrated, ecosystem-based management accounts for the complexity and relationship within nearby ecological systems (Macintosh and Ashton 2005, Long et al. 2015).

Also, integrated, ecosystem-based management needs to consider social and governance objectives of mangrove ecosystem management, like community-based management and social decisions, effective use of scientific knowledge, stakeholder involvement, appropriate monitoring, applying of precautionary approach and others (Macintosh and Ashton 2005, Walters et al. 2008, Granek et al. 2010, Aswani et al. 2012, Carter et al. 2015, Schmitt and Duke 2015, Long et al. 2015). Such an approach has been rarely applied worldwide, mainly due to land tenure issues, lack of interdisciplinary research and of incorporation of native populations' knowledge, weak law compliance, and ineffective governance structures (Aswani et al. 2012, Carter et al. 2015, de Almeida et al. 2016, Ferreira and Lacerda 2016c).

Standardized, GIS-based information and synthesis work

Brazil holds the world's largest nearly uninterrupted mangrove belt, between the cities of Belém and São Luís: a 6,516-km^2 tract that, as a unitary system, corresponds to 4.3% of the total global mangrove area and over 80% of Brazilian mangroves (Spalding et al. 2010). The Bragança peninsula is the data-richest area in this mangrove belt, due to intensive research work developed through the MADAM Project and subsequent projects (Saint-Paul and Schneider 2016). Geomorphological and hydrographic conditions (Souza-Filho and Paradella 2002), as well as vegetation patterns (Menezes et al. 2008), are likely similar throughout the northern mangrove region. Research gaps remain, however, as to whether data and assessment applied to the local level could be leveled-up to support a regional approach to management.

Such a vast area of populated coast calls for a conservation strategy consonant with community-based management (Ferreira and Lacerda 2016c), which could be capable of safeguarding the interests of local communities while taking into consideration the already existing protected areas and indigenous territories. In co-management arrangements, for example, priorities of the various local stakeholder groups are assessed throughout the planning and management processes. In the case of an extractive reserve in northern Brazil, interests of local communities have been assessed and incorporated into formal management instruments using, at least, three different strategies: (1) by researchers (Glaser 2003, Glaser and Oliveira 2004), generating valuable knowledge which later on was applied by decision-makers (Abdala et al. 2012); (2) by planners and managers directly (Abdala et al. 2012); or (3) as an action-research approach, where scientists facilitated co-management processes, such as participatory coastal planning (Saint-Paul and Schneider 2016).

Additionally, the monitoring of fisheries and aquaculture activities, which varies among the different mangroves on the Brazilian coast, could contribute to the assessment of ecosystem services in mangroves. Shrimp farming as the main activity in mangrove areas can be more easily monitored, while crab catching, for instance, is not detectable by GIS imagery analyses, what makes the latter more challenging to monitor (Santos et al. 2014).

Moreover, it is important that these data are made available to the general public (Walters et al. 2008). Satellite imagery, although in a limited format, are available on the internet at no or little cost through virtual globe programs (even though some areas of the world's surface remain poorly covered by the most easily accessible tools). In the hands of the public, these new tools could significantly change the socio-economic dynamics associated with these forests (Walters et al. 2008). Stakeholders should, therefore, have further and broader access to accurate and cost-effective techniques for mapping and monitoring, in order to develop and implement effective policy for the socio-economic use of mangroves (Walters et al. 2008).

(Magris and Barreto 2010) highlight the need to map and make available GIS-based databases to monitor environmental changes in mangroves and, therefore, allow for efficient conservation actions. National-level organizations in Brazil need to take more serious steps toward a GIS-based databank for coastal and marine ecosystems.

Researchers in Brazil have to report their results to the federal biodiversity conservation agency for a range of fieldwork projects. Having such results as a starting point, this agency could synthesize data produced and evaluate what information is missing, which could then be used in conservation studies. Plus, systemic and interdisciplinary studies, which include not only ecological but also social, political, and economic aspects, can provide the solution to complex problems faced by Brazilian marine protected areas (Gerhardinger et al. 2011).

Putting together pieces of information that might point to generalizations is also vital to conservation research, yet this task seems to have been left to reports and plans developed by practitioners, or are limited to a few literature reviews or meta-analyses. Research gaps do not necessarily mean a lack of primary data, but spatial planning methods and case studies in similar social-ecological contexts to guide on-the-ground application can be rare. A few initiatives worldwide constitute a step forward on the road to experience exchange, such as the Panorama platform, as an assemblage of successful examples for protected areas[9]. Regarding the ecosystem service approach, groups such as the Ecosystem Service Partnership (ESP)[10] and The Economics of Ecosystems and Biodiversity (TEEB)[11] provide case studies, which focus on the terrestrial environment, such as in the Amazon

[9] http://panorama.solutions/en
[10] http://es-partnership.org/
[11] http://www.teebweb.org/

region (Cassola 2010). Projects that directly apply the ecosystem service approach to spatial planning in Brazilian coastal and marine environments are rare[12].

Compared to fully terrestrial vegetation ecosystems, such as the Amazon rainforest, and fully marine ecosystems, like coral reefs, mangroves receive little attention from mass media (Valiela et al. 2001). But contrary to the image of mangroves as smelly swamps, charismatic species are often found in many nursing and feeding grounds offered by mangroves [a list is compiled by UNEP (2014)] which could be used to enhance support for the conservation of these ecosystems. Indeed, important species for mangrove ecology, such as the crab *Ucides cordatus*, face overfishing and decreasing population levels in some Brazilian mangroves. This can lead to overfishing of alternative stocks, for example, the red mangrove crab *Goniopsis cruentata*, which is also a key species (Ferreira et al. 2013). Consequences of these changes for mangrove functioning remain uncertain.

Furthermore, moving from policy toward action is important to improve the protection of mangroves and of the livelihoods that depend on these ecosystems (Friess et al. 2016), and these ecosystems require conservation measures such as the restoration of deforested mangroves (Ferreira and Lacerda 2016c). An inexpensive and time-saving solution would be to map and protect mangrove areas with a potential for self-recovery (Ferreira et al. 2015). Beyond specific purposes, mapping is an important tool for systematic conservation planning and ecosystem-based management (Maia et al. 2006). The zoning of protected areas in Brazil, for example, is an essential part of their management plan (BRASIL 2000), which again highlights the importance of spatial data for mangrove management.

More than the sum of its parts: the mangrove as an integrated ecosystem

In 2012 the Brazilian National Congress passed the controversial Forest Code (BRASIL 2012). While not being the main focus of most discussions about the new law, the changes in the legal framework for mangrove protection did not go unnoticed: an important sub-system, the “apicum”, an escape valve for inland migration of mangroves as an adaptive response to sea-level rise (Godoy and Lacerda 2015), was removed from the concept of

[12] One example is the Babitonga Ativa Project, in southern Brazil (http://www.babitongaativa.com/).

mangrove ecosystem, being now separately attended to by this new law in a less strict level of protection. These salt flats are non-vegetated areas, essential for the maintenance of the forested area in the mangrove systems (Schmidt et al. 2013) and are the ecosystem's last resource in terms of space to persist transitional periods and sea-level rise (Oliveira-Filho et al. 2016). The most protective legislation only covers the wooded component (mangrove forests) (Oliveira-Filho et al. 2016). This measure makes a large area (over 600,000 hectares) available for aquaculture development (Ferreira and Lacerda 2016b). Making salt flats available for occupation squeezes mangroves between open waters and human activity in these salt flats, hindering them from migrating inland following sea-level rise. Without these buffer areas, vulnerability to climate change will be increased, and mangrove forests will be doomed in the long run.

The current legislation for mangroves in Brazil, therefore, ignores the correlate features and interdependencies between these habitat types (Moura-Fé et al. 2015). Furthermore, the total mangrove extent safeguarded in permanent protection areas, which represent another important protection instrument in Brazilian legislation, will be reduced, showing how some governmental authorities and policies purposely ignore scientific warnings about the necessity and even economic advantages of mangrove conservation to favor agribusiness lobbies (Ferreira and Lacerda 2016b). While the new law has been contested by the Brazilian Academy of Sciences (Silva et al. 2011), there is no unanimity about the features that constitute mangroves in Brazil, and how these ecosystems need to be managed for conservation and sustainable development.

Oliveira-Filho et al. (2016), for example, adopt the definition of mangrove ecosystem as "a tidally influenced wetland complex including progradational sand or mudflats, mangrove forests and salt marshes, hypersaline lagoons, intertidal flats, including salt flats, salt pans, salinas, salt barrens, apicuns, tannes, and coastal sabkhas." The different elements would, therefore, represent alternate states of the mangrove ecosystem (Woodroffe et al. 2016). The legislators in Brazil opted, however, for a different view of this ecosystem, assigning, through the new Forest Code, different levels of protection to the different components, and, therefore, ignoring their interdependency and interconnectedness.

In terms of applicability and monitoring, this new Forest Code also faces the issue that salt flats are not separately identified and mapped in Brazil, which leaves space for arbitrary identification of these areas during the planning and management actions at medium and large levels, moving in the opposite direction of what is required to safeguard biodiversity and the services provided by these ecosystems. Adopting such a measure reveals a national environmental policy that is dissonant with the country's intended goals to reduce carbon emissions, which were presented just before the last United Nations Framework Convention on Climate Change — COP 21 in Paris and the zero-illegal-deforestation target for the Brazilian terrestrial Amazon by 2030 (Moutinho 2015).

This legal backstep against mangroves in Brazil reflects how complex and dynamic features of systems allow for the emergence not only of a variety of ecological functions but also of a diversity of social-political perspectives on these systems. While researchers see them as an integrated ecosystem, formed by subsystems with distinct but intertwined functions, some decision-makers perceive the different vegetation types as a justification to assign different degrees of protection for areas within a highly interconnected system. Interconnectivity and interdependency, of course, do not automatically translate into uniform usage of the areas. However, such fragmentation through a national regulation might set the stage for local claims for controversial use, especially by the powerful aquaculture and salt production industries.

Worldwide, authority over mangrove forest management is overwhelmingly vested in state institutions and mangrove protection is a central objective. Within the forest sector, however, mangroves normally occupy a relatively marginal role with few policies or regulations tailored to the unique needs of mangrove forests (Rotich et al. 2016).

Mangrove ecosystems in Brazil could also profit from a unifying legal instrument, which brings together a body of regulations on mangrove use and conservation, while also recognizing the uniqueness, importance, and interconnectedness of mangroves and their sub-systems. The Amazon and Atlantic Forests, for example, have national laws as specific protection instruments (BRASIL 1953, 2006) and are recognized as biomes by both the national authority responsible for the federal-level protected areas and the Ministry of Environment. A possible solution to the mangrove legal tangle would be, therefore, a unifying, national-level legislative framework for the conservation and sustainable use of mangroves in Brazil. A framework alone, however, would not be able to tackle all the legal issues regarding mangrove conservation and, if not followed by enforcement, would eventually become a useless instrument, like many other environmental laws at municipal, state, and federal levels.

Multi-Scale, Multi-Level Mangrove Planning

In mangroves around the world, frameworks and mechanisms to enable multi-sectoral coordination across agencies and governance levels are uncommon, and where they exist, they are difficult to put into practice (Rotich et al. 2016). At the federal government level, it is important to recognize mangroves and its subsystems as one integrated ecosystem. Concurrently, legislation needs to take into consideration regional aspects and allow for flexible management strategies related to regional or local specificities. At the municipality or state level, for instance, part of the wrongs of the new Forest Code could be at least partially overcome.

Schaeffer-Novelli (1999) identified eight mangrove segments along the Brazilian coastline, according to climatic and physiographic characteristics of the mapping units. A unique combination of mangrove structure, beach characteristics, tidal regime, and species composition, among others, distinguishes each of those segments. Recent studies and management plans have approached mangroves according to macro-, meso- and microtidal regimes (Magris and Barreto 2010, MMA 2015), creating a simpler grouping that still considers major differences among the Brazilian mangrove types, while being possibly more applicable in terms of policy-making at a national level.

Following a simplified approach, but also considering regional peculiarities relevant for management, four major mangrove regions are here proposed: North, Northeast, East, and Southeast. Such a division is based on Knoppers, Ekau & Figueiredo (1999) and Godoy & Lacerda (2015), as well as on the approaches mentioned in the previous paragraphs (Figure 1).

Macro-units are thus illustrated (Figure 1 and Table 1) to guide a unified, national-level policy framework for spatial planning of mangroves. Distinctions between the macro-units are manifold (Table 1).

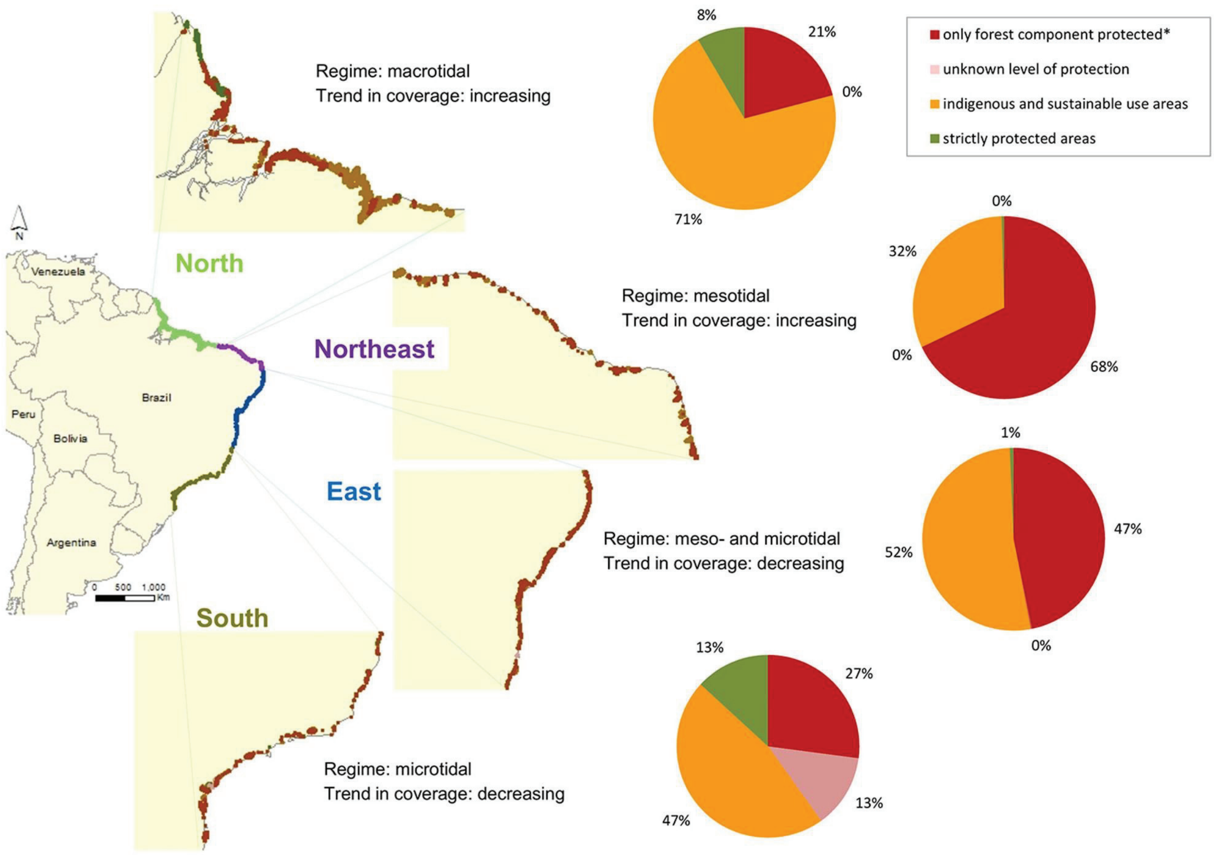


Figure 1. Brazilian mangroves and formal protection level for each proposed macro-unit. Based on (Knoppers et al. 1999), (Godoy and Lacerda 2015). The mangrove distribution data derive from (Giri et al. 2011), and the protected area data from (IUCN and UNEP-WCMC 2017). "Unknown protection" was assigned to categories whose level of protection was not declared in the UNEP-WCMC dataset. *"only forest component protected" refers to mangrove areas that are not inside a protected area or indigenous area, but are, like all forest components of mangroves in Brazil, protected under the Forest Code (BRASIL 2012) as "permanent protection areas." Considering the states in Brazil, the division goes as follows: AP, PA, and MA (North); PI, CE, and RN (Northeast); PB, PE, AL, SE, and BA (East); ES, RJ, SP, PR, and SC (Southeast).

Table 1. Distinct traits about each tide-based mangrove macro-unit.

Macro-units	Main human uses	Drivers of change	Likely climate change effects	Protected areas[13]	Information needed for ecosystem-based management
North	extractivism of crab, fish, wood, and other forest products (Glaser, 2003) very incipient shrimp farming (Tenório et al., 2015)	climate change (Godoy & Lacerda, 2015)	erosion of river mouths and coastline (Godoy & Lacerda, 2015) colonization of new areas due to saltwater input from ocean rising (Cohen et al., 2008; Ward et al., 2016)	large coverage: 66% of mangroves under sustainable use; 15% in strictly protected areas (Prates et al., 2012) corridor of protected areas currently planned for part of the mangrove belt	areas available for mangrove landward expansion monitoring of extractivism: stock changes, spatial patterns of resource extraction
Northeast (semiarid coast)	traditional fisheries (Vasconcellos et al., 2011) large-scale, expanding shrimp farming (Meireles et al., 2008; Ferreira et al., 2015)	damming of rivers, climate change (Godoy and Lacerda, 2015), and aquaculture (Guimarães et al., 2010; Santos et al., 2014; Ferreira & Lacerda, 2016b)	mangroves pushed to migrate landward (Godoy & Lacerda, 2015);	relatively small coverage: approx. 66% of mangroves remain unprotected (Prates et al., 2012)	areas available for mangrove landward expansion GIS-based information on site-specific climate change impacts, e.g. on mangrove area and beach erosion monitoring of shrimp farming, including mangrove area taken up and use of contaminants
East (meridional coast)	traditional fisheries (Santos et al., 2017) shrimp farming (Guimarães et al., 2010; Santos et al., 2014)	port activities (Ferreira and Lacerda, 2016a), urbanization, industrialization, tourism, and aquaculture (Sobrinho & Andrade, 2009)	very site-specific along the coast (Godoy and Lacerda, 2015)	large protected coverage in sustainable use areas and comparatively very small strictly protected area: only approx. 0.5% (Prates et al., 2012)	GIS-based information on site-specific climate change impacts, e.g. on mangrove area and beach erosion monitoring of port activities and urbanization
Southeast	urban expansion (Ferreira and Lacerda, 2016a)	port activities (Cunha, 2006; Ferreira & Lacerda, 2016b), urbanization (Ferreira & Lacerda, 2016a), and climate change (Godoy & Lacerda, 2015)	erosion and drowning (Godoy and Lacerda, 2015)	more than 20% strictly protected, but approx. 33% of mangroves inside *environmental protected area*[14] (Prates et al., 2012)	GIS-based information on site-specific climate change impacts, e.g. on mangrove area and beach erosion

[13] Numbers regarding protected areas in this table differ from those presented in Figure 1 because a national report (Prates et al., 2012) is used here, which categorizes protected areas according to the Federal Law 9985 of 2000 (BRASIL, 2000), while the UNEP-WCMC data used in Figure 1 includes other categories, such as "indigenous areas", and "world heritage sites".

[14] See Introduction section for further information on this category of protected area in Brazil.

A steep coastline in the Southeast and semiarid conditions in the Northeast limit a possible landward refuge of forests facing sea-level increase, hence restricting them to a narrow fringe along these coasts (Ferreira and Lacerda 2016b). These traits, summed up with strong human-use pressures (Godoy and Lacerda 2015), might hinder mangrove survival in the face of climate change. On the other hand, mangrove areas have the chance to expand in the northern part of the coastline, following predictions related to sea-level rise, because here mangroves find landward areas for expansion, such as in the Amazon estuary (Cohen and Lara 2003, Cohen et al. 2008, Ward et al. 2016).

Along the eastern and southeastern coasts, estuaries and coastlines have suffered severe damage (Magris and Barreto 2010, Prates et al. 2012). In southeastern mangroves, main drivers of degradation are coastal development, urbanization, and pollution, mostly from inadequate solid waste disposal and oil spills (Ferreira and Lacerda 2016c). In the Northeast macro-unit, mangrove loss of up to 10% is large compared to the other segments, corresponding to at least twice the country's average deforested area (Ferreira and Lacerda 2016c). Northern mangroves, despite being relatively pristine and proportionally better included in protected areas, need to be made more resilient as social-ecological systems, in order to face severe impacts that might reach these ecosystems, as it has happened in the other segments.

Differences in anthropogenic impacts on mangroves ecosystems and resulting impacts are also shown for the four macro-units proposed (Table 1). A large national coverage under the denomination of protected area alone does not systematically safeguard the various mangroves segments along the coast: the extent of mangroves inside the various categories of protected areas in Brazil varies considerably among the different macro-units, showing that the distinct mangrove systems in Brazil are unevenly protected (Figure 1).

In terms of social-economic activities developed, there is a considerable difference among these mangrove macro-units. While saltwater aquaculture is being intensively practiced in eastern (Godoy and Lacerda 2015) and northeastern Brazil (Santos et al. 2014), artisanal fisheries and crabbing as well as harvesting of other natural resources prevail in northern mangroves (Tenório et al. 2015). Northeastern mangroves suffer from severe habitat loss due to the advance of shrimp farming (Meireles et al. 2008) and other activities such as agriculture, urban expansion, and tourism (Guimarães et al. 2010). Saltpans were also a major economic activity in northeastern mangroves, and one single state in this region reached the production of approximately 95% of the country's national consumption (Bezerra and Brito 2001). In the eastern mangrove coastline, local shellfishing activity is now being devastated by port pollution in Pernambuco (Sullivan 2014). Due to the variety of habitats and anthropogenic pressures, changes in coverage and distribution of mangroves in this macro-unit needs to be more carefully assessed at the local level (Godoy and Lacerda 2015).

Local peculiarities are also important while determining which benefits derive from mangroves in each region. (Lee et al. 2014), for example, point out that effective coastal protection provided by mangroves depends on factors at landscape/geomorphic to community levels and local/species levels. It is therefore important to approach and include knowledge of local settings for mangrove management (Lee et al. 2014).

Similarly, in the case of climate adaptation for protected areas, the process should be area-specific and consider ecological and social-economic conditions within and beyond the protected areas' boundaries (Rannow et al. 2014). Management strategies for mangrove conservation in Brazil, including designation and management of protected areas, and other protection instruments have to consider regional social-ecological peculiarities.

Assessment of the Protected Area System

In Brazil, protected areas have been shown to play a role in maintaining mangrove forest structure (Cavalcanti et al. 2009). In Indonesia, (Miteva et al. 2015) concluded that protected areas reduced mangrove loss by about 14,000 hectares and avoided blue carbon emissions of approximately 13 million metric tons (CO_2-equivalent). These results were significant only for a stricter category of protected area, which does not allow for resource extraction. This highlights the importance of knowing not only if mangroves are under some sort of legal protection but also how, i.e., what the specific regulations for protection are — not to mention whether these mechanisms are actually applied on the ground, or are just "paper rules."

Mangroves clearly have a high value for conservation and are largely threatened ecosystems. Despite this, conservation planning for ecosystem services provided by mangroves, as well as its tradeoffs with biodiversity, remains an incipient research field.

The challenges of integrating methods that are currently applied to land and marine environments into the management of transitional and highly dynamic regions such as mangroves are minimally approached by the literature. Furthermore, it remains unknown to what extent decision-makers apply modeling and decision-support tools, such as InVEST and Marxan. [For more information on these tools, see Ball et al. (2009) and Guerry et al. (2012), respectively.]

A gap analysis to evaluate how well marine protected areas in Brazil meet conservation objectives for representation, connectivity, and risk-spreading revealed that objectives were far from fully attained (Magris et al. 2013). The protection of the marine environment was considered poor, with less than 1.9% of Brazil's marine jurisdiction within protected areas, from which only 0.14% within no-take areas. Only 23% of the ecosystems met the minimal number of replicates required by the risk-spreading objective. More positively, just over half (51%) of the no-take areas are a desirable distance apart. A systematic expansion is therefore needed to move toward an ecologically representative and functioning system of marine protected areas in Brazil (Magris et al. 2013).

Brazil has a 10%-target for the protection of its marine territory to be implemented based on a central management strategy that takes into consideration the distinct regions and local specificities. However, while the need for more protected areas is comprehensible, some questions remain: Are there other categories of protected areas, currently not included in the Brazilian national reserves system, which represent possible good solutions for Brazilian conflicts in the conservation of mangroves? Why is it that so many protected areas do not have a management plan yet?

Instead of addressing existing issues in the network system, the designation of more marine protected areas, in the way it is currently taking place in Brazil, could actually decrease implementation capacity and effectiveness, not achieving much beyond the fulfillment of the country's internationally established marine biodiversity targets (Gerhardinger et al. 2011). Plus, a national effectiveness monitoring scheme still lacks for marine protected areas, even though Brazil has a large number of scientists and other professionals capable of performing or assisting with such a task.

The previously mentioned data banks and the national-level macro-units proposed in this paper could be used to support the development of a national spatial plan that takes into consideration existing coastal marine protected areas, while also indicating conservation priorities outside these reserves, allowing for their expansion, the creation of corridors and of new areas.

Even if salt lands were to be considered an alternative for the allocation of economic activities inside mangrove areas, some questions would have to be addressed before allowing for this type of use: How to assign activities to the different habitats inside mangroves without negatively impacting the maintenance of interconnected systems? For example, if mangroves are valued, under an ecosystem service approach, for carbon storage, and the aquaculture performed in these areas is of high economic importance, how to balance these uses, without implying that salt flats are capable of absorbing any damaging activities as a trade-off to preserve the more highly appreciated mangrove forests?

Conclusions

Using systematic planning and ecosystem-based management as guiding strategies, we discussed the following approaches: (1) mangrove as a social-ecological system; (2) mangrove as an integrated system; (3) multi-scale, multi-level planning; (4) standardized, GIS-based information and synthesis work; and (5) assessment of the protected area system. This is, to our knowledge, the first review that shows why and how these approaches can be used to tackle the apparent paradox of reconciling mangrove conservation and sustainable use.

Complexity and extremely high economic pressure on areas such as mangroves pose a proportionally large challenge to the conservation of these ecosystems. Thorough assessment and political recognition of their social-ecological importance can greatly contribute to a larger effort in working toward its conservation.

While environmental impacts associated with global climate change are generally expected to occur sometime in the future, many mangrove areas along the Brazilian coastline are already witnessing these impacts, and possible, future impacts have already been shown (Godoy and Lacerda 2015). However, this is not taken into consideration in conservation strategies and legislation in Brazil, as can be easily concluded from the new Forest Code and the exclusion of salt flats from mangrove protection areas - this urgently calls for a revision of this legal instrument.

At the national level, policy-making lacks a comprehensive understanding of how the various types of mangrove ecosystems along the coast function, in what social-ecological aspects they differ, and how those differences might be taken into account while planning for conservation. To support systematic conservation analyses and policy-making, mangrove ecosystems along the Brazilian coast could be grouped into planning macro- units, according to social-ecological features, geological traits and expected effects of climate change (Figure 1 and Table 1). While accounting for local peculiarities, it is important to also try and draw parallels to other mangrove ecosystems and try to learn from experiences from these ecosystems (successful restoration initiatives, co-management approaches, etc.).

Despite the widespread, mandatory reporting back of research, mangrove policy-making lacks synthesized data to underpin management and conservation planning. Also, based on the deficiencies registered in the literature and the lessons learned from nearly 20 years of successes and challenges of the law that created the current national system of protected areas (BRASIL 2000), the set of protected areas requires not only expansion but also re-structuring. Across the different countries where mangroves occur, there is a lack of evidence for the success of responses (as well as analysis of the interactions and feedbacks between different responses) in terms of their effects on declining ecological states of these ecosystems and on the services they provide.

While the need remains for more robust, unified legislation for mangrove conservation, the Brazilian experience shows that legal instruments are not enough for the effective protection of these ecosystems. Due to lack of proper evaluation of mangrove functioning, as in the case of the new Forest Code mentioned above, anthropogenic drivers have the potential to increase threats and reduce the effectiveness of conservation legislation and possible following actions. Permanent periodical assessment of mangrove conservation status and sustainable use, long-term monitoring of rehabilitation experiments, community-based management and continuous adaptation of legislation are required to curb drivers of change and their negative impacts on mangroves.

Developing and applying methods for ecosystem-based management that deals with and helps overcome the complexity and pressure faced by mangroves is by definition an intricate and challenging task. Needless to emphasize, though, is the urgency to address these research gaps, in hopes that filling them up will contribute to the protection of one of our most valuable and most threatened ecosystems.

Authors' contributions

RB designed the work, compiled literature sources, drafted, and wrote the manuscript. AF and LL helped compile literature sources, wrote parts of the manuscript, checked references, and critically revised the content of the paper. RB, AF, and LL approved the final version of the manuscript to be submitted.

Funding

This work was supported by the Brazilian Council for Scientific and Technological Development—CNPq (Process 290055/2014-8).

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgments

Special thanks to Prof. Dr. Matthias Wolff, for discussing and revising the manuscript. We thank Prof. Dr. Rebecca Rendle-Bühring and Dr. Aline Quadros for kindly revising and helping improve the manuscript. We are grateful to CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior/MEC, Brazil) for providing post-doctoral grant (AF). We also thank GLOMAR—Bremen International Graduate School for Marine Sciences, University of Bremen, for supporting the research and the University of Bremen for proving financial means for the publication of the manuscript.

Chapter 3

"What you see and what you hear depends a great deal on where you are standing. It also depends on what sort of person you are."

C.S. Lewis

The Magician's Nephew

Data and methods for Chapters 4 and 5 are presented here.

Literature references can be found at the end of this thesis.

Study area

The study area encompasses mangroves and nearby waters in two sustainable-use areas in the municipalities of Tracuateua and Bragança, northern Brazil (Figure 1).

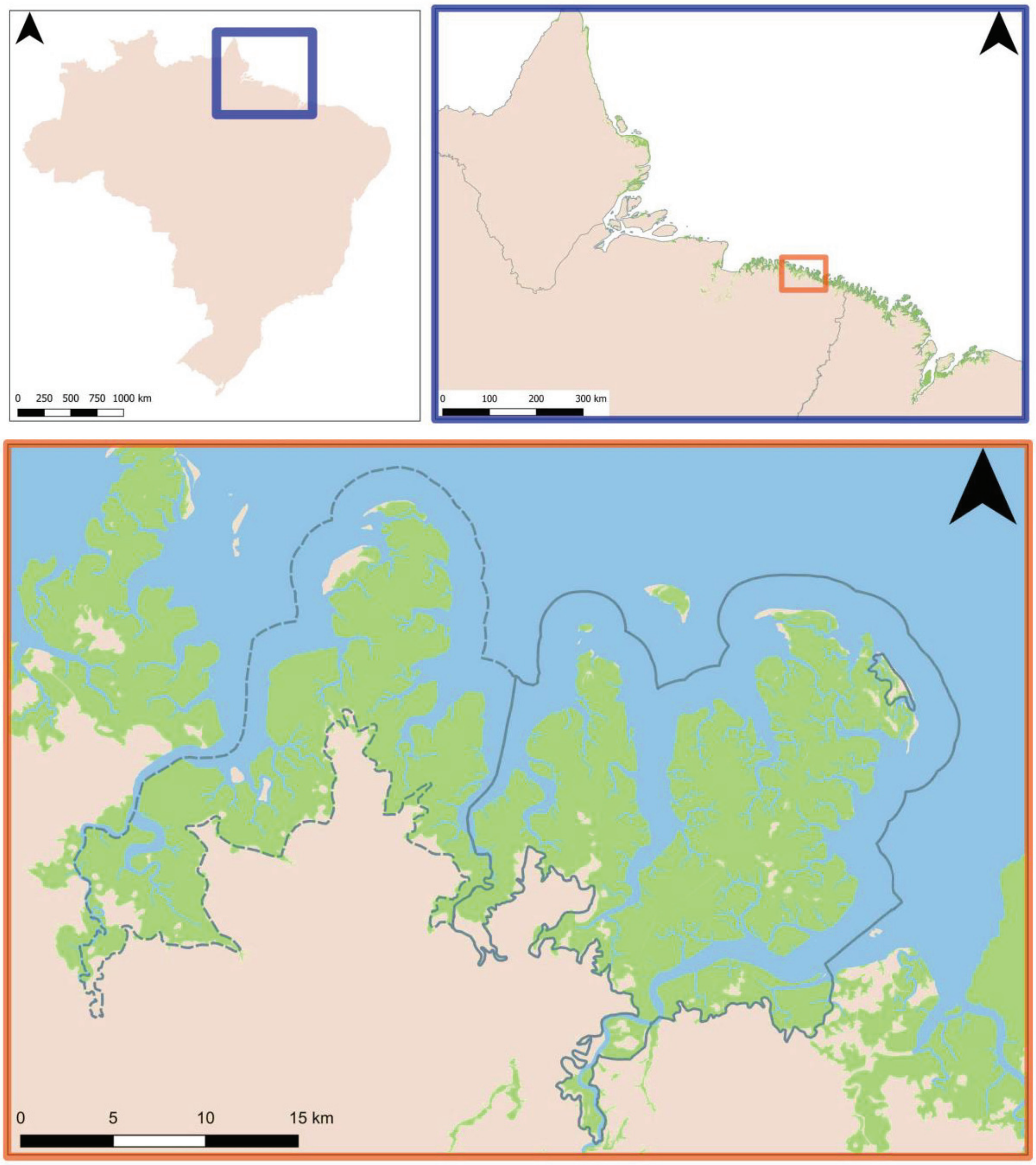


Figure 1. Study area with the delimitations of the two protected areas, Tracuateua (west) and Bragança (east). Together they hold 270 km^2 of mangrove area, which corresponds to approx. 40% of the total area of these two reserves.

The Bragança coastal plain is situated in the northeastern part of Pará State (00°46'–1°00'S and 46°36'–46°44'W) (Cohen et al. 2004). The Tracuateua coastal plain is located west of the Bragança one (00°46´S and 47°10´W). Bragança hosts a mangrove forest of about 180 km^2 (Souza-Filho and Paradella 2002, Souza-Filho et al. 2006), while

Tracuateua exhibits mangroves of about 90 km^2, according to our calculations based on data by Giri (2011)[15].

The protected areas (PAs), which are categorized as extractive reserves, function on a co-management basis, with decisions being made by a deliberative council (BRASIL 2000). Each PA has its own users' association, through which local users receive benefits from the government, such as fishing gears, houses, and household appliances. Through this association, they also participate in the council and comply with PA rules, such as formally requesting authorization to extract mangrove wood (Abdala et al. 2012). Local users have the right to extract resources within their home PA (BRASIL 2011). Through the deliberative council, local stakeholders have the power to decide over resource use within the borders of their own PA. The two reserves presented in this study were established according to the administrative boundaries of each municipality, which means that each municipality has its own PA.

The research focused on these PAs because the former already had a zoning plan, while the latter was reported to be in the process of building one. Further reasons why these two PAs were chosen are related to the fact that Bragança is a research hub in the region, where a university campus is located and substantial research has already been done. In contrast, Tracuateua has been rather neglected in the local research landscape, which is also due to the difficulty of accessing the mangroves and the villages. This PA was, in 2015, working on an EU-funded project that would help develop management instruments, including a zoning plan. These two PAs present, therefore, a favorable framework for the support of the *in situ* work and an opportunity to apply the results from this research.

The Amazon coast is an ideal setting to investigate the spatial interconnections of the subparts of a large ecosystem. This contiguous mangrove is divided into several administrative units, even though it is locally known to be connected not only in terms of ecological aspects and through the most important extractive activities in the mangroves, especially the small-scale fisheries of the mangrove crab.

Given the context identified at the onset of this research project and the management arrangement of these PAs, the elements identified as cornerstones for the scientific research necessary to develop integrated zoning strategies are: 1) the

[15] Area information and statistics about the local mangroves, municipalities, and reserves are shown in Supporting Information II.

identification of local conservation priorities (which was approached through an ecosystem service lens); 2) the construction of a database on the spatial dynamics related to these priorities; and 3) the delimitation of an initial geographical planning unit, which also identifies actors and institutions that need to be involved in the planning process.

In the Caeté-Taperaçu PA, located in the municipal region of Bragança (hereafter mentioned as "Bragança PA"), the adjacent rural socio-economic impact area of 130 km^2 has about 15,000 people, who derive the majority of their daily livelihood from the mangrove resources. (Glaser 2003) shows that household income at the Bragantinian coastal region originates from multiple sources and is subject to tidal and seasonal cycles. The analysis of the economic links between the rural population and the mangrove ecosystem reveals that 83% of the rural population relied on mangrove resources for subsistence and/or commerce and 68% of the households derived monetary income from mangrove products (Glaser 2003). While important to local communities, this ecosystem is subject to increasing anthropogenic pressures, including deforestation and other forms of degradation, that require urgent management measures to improve the protection of its biodiversity and natural resources (Menezes et al. 2008).

The Bragança PA has been intensively surveyed, while its neighbor to the west, the Tracuateua reserve, has been comparatively poorly researched. Another contrast between the two is the number of management instruments in place. The Bragança PA already has a management plan [as mandatory by law, (BRASIL 2000)], while the PA in Tracuateua is still in the process of preparing one, even though both PAs were created in 2005.

The value chain of the crab fisheries in the region (northeastern Pará) is marked by the crab meat processing. Crab meat processing consists of removing meat from a cooked crab, as well as packaging and freezing it for further commercialization (Figure 2). This activity used to be performed exclusively domestically, but, since 2014, processing plants received the authorization to operate from the state regulating agency[16].

[16] http://seafoodbrasil.com.br/empresa-paraense-e-primeira-receber-registro-para-processamento-artesanal-caranguejo/

The main crab processing locations are the villages of Treme, Caratateua [in the municipality of Bragança (Fundo Vale 2018)] and the municipality of Quatipuru (Borges et al., *unpublished*) but all functioning processing plants are located in Treme. According to the Pará Public Prosecutor's Office, there are four artisanal processing plants register with the Agricultural and Livestock Defense Agency of the State of Pará (Adepará). During inspections in June 2018, only three of them were functioning. Only one of them was running regularly, while the others showed sanitary and/or environmental irregularities[17]. Conduct adjustment agreements were signed in September 2018, whereby owners committed to fixing these issues[18].

Figure 2. Crab meat processed and packaged at one of the processing plants in Treme, Bragança. Credit: R. Borges.

Datasets

The analyses were based on data collected through participatory mapping and GPS tracking and on a combination of these results with those published in the scientific literature. (The latter only applies to Chapter 4).

Data from participatory mapping

Semi-structured interviews and workshops were conducted with local stakeholders, including fishers, community leaders, scholars, and local authorities.

[17] http://www.mppa.mp.br/noticias/mppa-realiza-visita-tecnica-as-industrias-de-caranguejo-no-municipio.htm
[18] http://www.mppa.mp.br/noticias/promotoria-firma-tac-para-melhorar-producao-de-carne-de-caranguejo.htm

During the first phase of interviews (October 2016 to January 2017), 78 participants were asked to identify important areas for the crab fisheries, i.e. fishing grounds and the villages where the fishers who use each mangrove area live. The informants sometimes talk only about themselves, sometimes about other users. During the second phase of interviews (November 2017 to March 2018), most informants were revisited (n = 57) and presented with the resulting maps from the first phase[19].

Informants were initially selected based on suggestions by local stakeholders during informal conversations and subsequently using the snowball method (Goodman 1961). Participants' villages were grouped according to their association with a PA, i.e., in which one of the two PAs the village inhabitants are formally recognized as being users and have been granted access to use its natural resources. The Bragança PA has a larger population (IBGE 2019a), and a larger number of users (according to the PA managers interviewed). For this reason, we encountered more stakeholders willing to be interviewed in Bragança than in Tracuateua, so our sampling size was biased towards Bragança. Throughout this paper, the word "fisher" is used to designate crab collectors, those women or men who go to the mangrove forest to harvest the crabs, but not the users down the value chain, such as those working on crab meat processing or sales.

Large print maps of the study area were used to facilitate the spatial referencing process. These maps were prepared to be easily understood, even by informants with less formal education. The maps prompted informants to talk about geographic places, their locally given names, and how these places are used, even though informants were not used to being interviewed with maps. This identification of places helped locate the fishing grounds identified in this study.

For the second phase, focus group interviews were conducted to stimulate discussions about the results of Phase I. To avoid that certain informant's opinions dominated the mapping exercise, no focus group had more than 2-3 people and the facilitators (R.B. and collaborators) tried to stimulate discussion among all of them. However, apparent conformity of view is an emergent property of the group interaction, not a reflection of individual participants' opinions, because less-confident members of the group may not express alternative points of view, and the moderator might assume that they agree with the prevailing view (Sim 1998). Usually, the more homogenous the

[19] Further information on the informants and the interviews is shown in Supporting Information IV - VII.

group, the more likely they are to voice their opinions (Sim 1998). Therefore, homogeneous groups were formed regarding profession (fishers, administration employees, etc.) and, in the case of direct users, the village of origin, so that conflicts were avoided and informants could feel more comfortable with sharing information. For the focus groups and workshops, no differentiation was made about which informant is saying what, i.e., information is considered to come from the group and not from single individuals, since the participants tended to reach an agreement.

Informants' opinions on the maps, including new information, suggestions, and corrections were used to fine-tune the analyses. A "correction" is considered as reference places that had been previously misplaced or fishing grounds that had been obviously misplaced on the maps due to a misplacement of a reference point. Sometimes they mentioned, "only the villages A and B, over there. But not here". It was not possible to record "negative" statements, such as, "people do not go here or there". However, these negations were rare. Consensus was not pursued, but rather a wide range of perceptions, independently of whether all informants agreed with them or not.

For both rounds of interviews, the resulting information from the participatory mapping was digitalized using the free and open-source GIS application QGIS 3.4 (Quantum 2019). The coordinate reference system SIRGAS 2000[20] / UTM zone 23S, EPSG 31983 was used. Fishing grounds were digitalized based on how they had been drawn or described by the informants. After the second phase of interviews, a standardized delimitation of the fishing grounds was performed, trying to combine the names and degrees of geographical specification provided by the informants, with the information from ground-truthing and published maps.

During the participatory mapping exercise, we chose to delineate the fishing grounds based on two main criteria: 1) the names given by the informants to the places where fishers went fishing and 2) the continuous mangrove area that roughly corresponded to where the fishing ground was reported to be located[21].

For the analyses presented here, the GPS tracking method generated "technical" (sometimes referred to as "scientific") data, while the participatory mapping provided local user knowledge, based on own practice or experience with others' behavior. Even

[20] http://www.sirgas.org/en/sirgas-definition/

[21] This last criterion was largely based, therefore, on the mangrove distribution shapefile used in this study: (Giri et al. 2011). This means that our delineation of the fishing grounds was heavily influenced by the shapefile used to digitalize the information provided by the fishers.

though the GPS tracking data can be considered "technical", participant fishers might have, consciously or inadvertently, influenced the sampling of the routes, not only in terms of choosing where to go while they were carrying the GPS but also when to take it with them. For instance, some crab fishers were unwilling to take the GPS during the months of January to April, because the temporal closure takes places during some days during these months. Fishers were, at times, unwilling to participate during these months, even on days outside the temporal closure.

Data from GPS tracking

Fishing routes were tracked from November 2017 to February 2019. GPS tracker ("GT-750FL Bluetooth GPS Receiver") distribution among crab fishers was done systematically in terms of transportation means, covering at least one fisher per type of transportation means in a given village.

The fieldwork is summarized in Figure 3.

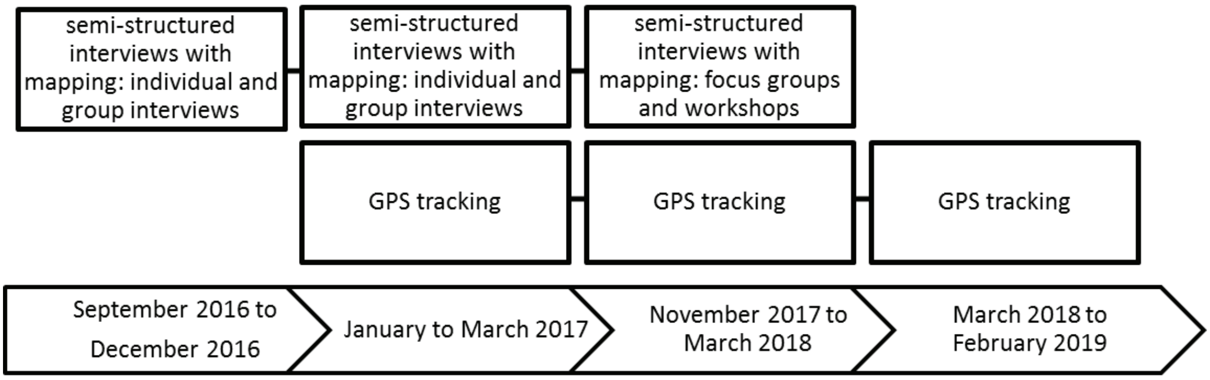


Figure 3. Fieldwork phases and different methodologies applied.

<u>The following data and methods are only applicable to Chapter 4.</u>

Data from the literature

In order to obtain a match between fishing grounds used and crab size in each fishing ground, the data from the interviews done by this study were combined with those from a relatively recent study (Oliveira 2015), which measured crab carapace width in the mangroves of Bragança.

Distances to fishing grounds

One-way distances from the fishers' village to their fishing grounds were calculated. The two collection methods (GPS tracking and participatory mapping) were compared in terms of distance traveled to check if both methods provided similar information. The two PAs were compared to check in terms of fishers' traveled different distances to fishing grounds.

Distances to fishing grounds and crab size

Crab carapace width was used as a proxy for crab size, which is an indicator of exploitation level of crabs in these mangroves (Diele et al. 2005). The inter- and extrapolation of crab carapace width followed the methods in Oliveira (2015) for the Bragança PA. Since Oliveira's study focused on Bragança, the distance vs. crab size analysis was performed only for this PA.

Oliveira (2015) measured crab carapace width in 32 different points. This author then used the mean value for each point to spatialize carapace width (as a proxy for crab size) performing the analysis "Inverse Distance Weighted" in QGIS[22].

Statistical analyses

To test the "method" effect (with two levels: GPS tracking and participatory mapping) on the respective distances recorded between home town and fishing grounds, a linear model with Gaussian error terms was applied. The sample sizes for this analysis were 17 and 112, for GPS tracking and participatory mapping, respectively.

In addition, a fully crossed model with Gaussian error terms was applied to test for the effects of "method" (with two levels: GPS tracking and participatory mapping) and "crab size" (covariate) yielded from fishing grounds on the respective distances covered when going to fishing grounds. The sample sizes for this analysis were 11 and 92, for GPS tracking and participatory mapping, respectively. Sample sizes were smaller

[22] We spatialized the mean crab carapace width shown in Oliveira (2015) and performed a similar GIS analysis to obtain the spatialized values of width. Oliveira (2015) does not present the exact parameters used for this GIS analysis. Therefore, we calibrated the parameters distance coefficient and number of columns and rows to 2 and 300, in order to obtain similar results, as visualized on the map generated by Oliveira (2015). This author does not offer the numerical results from this operation, but provides a final map, which we compared to the map we generated. A visual assessment shows that Oliveira (2015) and this study obtained comparable results for this spatialization of crab size. It is not possible to compare the spatialized sizes obtained by Oliveira (2015) with the ones here, but the general trend of larger crabs in hard-access sites is also confirmed by Oliveira (2015).

for this analysis because, as explained before, crab sizes were available only for the Bragança PA.

Prior to both analyses, the data were log-transformed to meet the assumptions of normal distribution and homogeneous variances of the residuals (checked through visual inspection of QQ plots of the residuals and scatterplots of the fitted data plotted against the residuals). The models were fitted in R, version 3.5.3 (R Development Core Team 2019), using the generic function "lm". Because the datasets are highly unbalanced, the following diagnostics of model stability were checked: leverage (Quinn & Keough, 2002) and Cook's distance and dffits (Cohen and Cohen 2008), where data points are excluded one by one from the data sets and the respective fitted values are compared with those obtained from the model based on all data points.

Overall, the checks (Cooks distance and dffits) confirmed no influential cases to exist. When checking the leverage, however, some influential deviations in both models were detected. These instabilities are likely to be on account of the unbalanced dataset (more data points for participatory mapping than for GPS tracking) and were therefore accepted. Nonetheless, the results were interpreted with caution. Significances of individual terms (interaction term and main factors) were established with likelihood ratio tests (LRT) using the R function "anova" with the argument "test" set to "F". Hereby, the full model was tested against the corresponding reduced models not comprising the respective factor and/or term of interest.

<u>The following data and methods are only applicable to Chapter 5.</u>

Two steps were taken to establish an appropriate level for integrated management: 1) defining local priorities in relation to mangroves using an ecosystem service approach and 2) identifying the spatial dynamics of the service(s) with highest local priority. The spatial dynamics of the most highly valued[23] ecosystem service were investigated initially with harvesters through participatory mapping and GPS tracking. The data generated were then used to produce arrow maps that clarify the interconnections between PAs in the region, as described above.

To complement these data, we performed interviews with local actors involved with post-harvest activities to produce a comprehensive spatial dataset on the value

[23] In this manuscript, "priority" and "value" have the same meaning, as well as "prioritized" and "valued".

chain for the region (from harvest to process)[24]. Finally, we analyzed spatial aspects related to the ecosystem services that had not been prioritized by local users. We also examined pertinent legislation, especially regulations related to buffer zones and to PA integrated management.

Defining management priorities

Initially, we consulted legislation and available management instruments that would help elucidate management priorities and goals. Among them are the National Protected Area System law (BRASIL 2000) and the current management plan of one of the PAs (Abdala et al. 2012).

The most important prerequisites for defining spatial boundaries to facilitate ecosystem-based management are considering the ecosystem services you plan to measure, and the data needed to measure those services (Oakley et al. 2018). For that purpose, we applied an ecosystem service approach to investigate the importance of each mangrove services and values attributed to them by local stakeholders.

For the definition of management priorities, informants were categorized into 1) "academia" (professors and other researchers; n = 13); 2) "organizations" (employees of local organizations, such as NGOs, and of local authorities; n = 9); 3) "leadership" (including fishers and other local users; n = 22); 4) "random interviews" (for informants randomly selected; n = 82); and 5) "people indicated for knowledge" (resource users indicated by other informants for their local knowledge; n = 25). To account for the different category sizes, the total times a service had been mentioned, calculated for each category, was divided by the total number of informants in that category.

The complexity of defining the appropriate level increases with the number of uses to be regarded. For this reason, we opted to focus on the most frequently mentioned services, which we considered the most valuable ones and, therefore, the priority of spatial management. Therefore, in order to select the most relevant uses, we applied an ecosystem service approach in spatial management (Klain and Chan 2012, Guerry et al. 2012, Ruckelshaus et al. 2015). This process, in our case study, is represented by the zoning plans of the PAs analyzed.

[24] We did not focus on post-processing stages because these involve cities very far away from the study area, such as Belém and Porto Alegre. Post-processing destinations are further discussed in the manuscript.

Having established ecosystem uses to be considered, the next step was to identify the geographical territories where these are generated and enjoyed, i.e., supply and demand, respectively. Considering extractive activities such as small-scale fisheries, this information comes down to fishing grounds and to the fishers' home municipality. Since the spatialization of small-scale fisheries is challenging due to their diffuse nature, and monitoring and funding for fine-scale investigations are usually insufficient (Salas et al. 2007), we used complementary methodologies that helped establish the resource use territories in our study site.

In the second phase of mapping, we also asked informants about their views on certain spatial strategies, such as a no-take zone or a zone dedicated to mangrove restoration. Besides that, we presented the 2012-zoning plan (with which most of them were unfamiliar) and asked for possible improvements. Based on their views and suggestions, and in combination with the fishing grounds and mobility analyses, we developed suggestions for zoning[25]. These constitute updates for the Bragança PA and recommendations for the management plan of the Tracuateua reserve, which is currently being developed.

Supply and demand flows

In order to properly design and implement integrated management and conservation measures, knowledge on many aspects of the connections between the PAs in a system is required. One approach is through the concept of supply and demand of ecosystem services, i.e., identifying locations where people require services (demand areas), and where these are obtained or provided by ecosystems (supply areas), thus, mapping the flows of ecosystem services from providing to benefitting areas.

Mapping both the supply and demand sides is essential for environmental decision making: it can indicate where management interventions should be focused, either by defining high-priority areas for protection or defining the institutional level at which these services can be effectively managed (García-Nieto et al. 2013, 2015). In Brazil, such an ecosystem service approach to investigate interconnectedness between

[25] The suggestions were specific to the study area and included places whose mentioning would be irrelevant for a possible reader of this thesis. They are available online (in Portuguese): https://tinyurl.com/y3ndobsv. These suggestions will be later systematized and given to local managers in the form of a policy brief and report for Sisbio. (See the research authorization in Supporting Information VIII.)

adjacent PAs, as we show here with the arrow maps, has not yet been applied (Borges 2013).

Arrow maps were produced as a visual aid to portray the movements of fishers inside their "home" PA (i.e. the PA to which they are officially affiliated through the users' association) and across PAs, i.e. when fishers cross the border to neighboring PAs. Participatory mapping and GPS tracking data were used to collect the data for the arrow maps. Participatory mapping did not give information about the exact routes traveled by fishers from their home village to the fishing grounds, so we used the GPS tracking data to reconstruct the specific movements of fishers. Regarding data from the participatory mapping, we selected only the fishing ground information that was provided along with the fishing village[26], so we could establish supply and demand areas (i.e. fishers' village and municipality of origin) for the crab fisheries and compare these flows to the GPS tracking data.

We then compared the two PAs in terms of what we called "intra-area" and "cross-boundary" spatial dynamics or flows. Intra-area flows or dynamics refer to when fishers from villages that belong to one PA users' association move within the boundaries of that same PA, i.e. not crossing the borders to the neighboring PAs. Cross-boundary dynamics, on the other hand, refer to fishers crossing the borders to the neighboring PAs to which they are not formally associated.

Spatial dynamics of the processing value chain

Besides the participatory mapping and GPS tracking described in the methods chapter, social data (regarding the households of crab fishers and meat process workers), and the other information regarding the marketing chain (showing the actors involved in further parts of the value chain) were independently collected via questionnaires, interviews, observations, and photographic records.

The questionnaires contained structured and semi-structured questions that were analyzed through qualitative and quantitative approaches (Chizzotti 2014). In addition, a bibliographic survey was carried out in government agencies about the crab processing activity of the Treme village, which is where the operational processing plants are located.

[26] Some fishing grounds were identified by fishers without a clear indication of the home village of the fishers using these areas. This specific piece of information was not used to produce the arrow maps but was used in other analyses of the data from this field work.

Data were obtained from the application of questionnaires in 2017 to crab fishers and owners/managing employees of the processing plants A and B[27], and crab fishers from Treme (n = 41), intermediary buyers and distributors (n = 3), community leaders (n = 5), processing plants workers[28] (n = 10), and two ICMBio staff.

Reflections on the methods of this research

This research project set out with the goal to be as participatory as possible. Collaborative or participatory research involves respecting and understanding participants. It also involves recognizing the knowledge and capabilities of the local people who can work with researchers to define problems and questions, perform analyses, and obtain solutions (Kishk Anaquot Health Research 2008). Participatory research is viewed not only as something to be done for ethical reasons but also as a way to improve the quality of research. The focus is on empowering local people to take charge of research and monitoring processes.

However, a critical analysis of the development of this research shows that the project was only partially participatory, according to the definition previously presented (Kishk Anaquot Health Research 2008). There was a full collaboration with the local university, including having a UFPA professor as co-supervisor. Nonetheless, even though stakeholders were heard regarding their research needs at the onset of the research, further decisions on the directions of the project were made indirectly through the discussions in the interviews and workshops. During these interviews, the topics approached were rather broad. Although some informants gave their impressions on the general content of the research as they perceived it, they were not directly asked about where they would like the emphasis to be.

Still regarding collaboration, this research relied heavily on the direct participation of local stakeholders. Local actors participated not only as informants tin interviews and workshops but also as collaborators in carrying the GPS loggers to the mangroves where they catch the crab.

Participation was also encouraged by showing the local users the practical importance of the research, without raising unrealistic expectations. The mere fact that

[27] Real names were purposely omitted.
[28] Process workers are those workers who manually removed the meat from cooked crabs and pack it for freezing and further selling.

they saw the results of the research returning to the communities in the form of informative material (brochure and posters, e.g.) encouraged local stakeholders to trust and engage with the research. The perspective of direct application to management also shaped the natural and social sciences involved in this research endeavor, which has many traces of an inter- and transdisciplinary project.

Short glossary

Chico Mendes Institute for Biodiversity - **ICMBio**: the federal agency that manages the PAs.

Brazilian Institute of the Environment and Renewable Natural Resources - **IBAMA**: the federal agency that, among other tasks, monitors potentially environmentally damaging activities, such as fisheries.

Chapter 4

"Not all those who wander are lost."

J.R.R. Tolkien

The Fellowship of the Ring

Literature references can be found at the end of this thesis.

Combining knowledge systems helps understand the spatial dynamics of data-deficient small-scale fisheries systems: a methodological comparison

Rebecca Borges [1,2], Roberta Barboza [3], Karin Boos [2,4], Marion Glaser [1], Matthias Wolff [1,2], Priscila Lopes [5]

[1]*Leibniz Centre for Tropical Marine Research (ZMT)*
[2]*University of Bremen*
[3]*Universidade Federal do Pará (UFPA)*
[4]*MARUM, Center for Marine Environmental Sciences, University of Bremen*
[5]*Universidade Federal do Rio Grande do Norte (UFRN)*

Abstract

Mangrove habitats provide nursery, shelter and feeding sites for many economically relevant fish, and are directly exploited for invertebrates, such as crabs. Given the highly artisanal character and the patchy spatial distribution of small-scale fishing, there is little data available to inform management, potentially threatening the sustainability of this livelihood-supporting activity. This study assesses the combination of different data collection methods and of including published data in the analyses of the spatial dynamics. We use the crab fisheries in two sustainable-use protected areas as a case study for the methods while trying to understand the patterns indicated by these multiple methods. Mangrove crab fishing grounds were mapped by overlaying crab gatherers' tracked routes with maps developed in interviews. Information from the literature was used to spatialize crab carapace width and relate it to distance traveled. Results show that crabs tended to be larger if caught farther from the villages. In terms of collection methods, even though GPS tracking is relatively time- and resource-consuming, incorporating some GPS tracking into participatory mapping helps overcome downsides of this type of mapping (e.g., lack of geographical precision) and identifies information that can be addressed through participatory techniques. This highlights the importance of linking different approaches in order to understand small-scale fisheries spatial dynamics.

Keywords: marine protected areas; participatory mapping; mangroves; fishing grounds; fishers' territories; GPS tracking, fisheries spatial management

Introduction

Small-scale fisheries support subsistence production (Hall et al. 2013), which provides, in many cases, food security to poor families who depend on mangrove ecosystems (Glaser 2003, UNEP 2014). Mangroves also sustain invertebrate and fish species that are directly fished or consumed by other organisms that are then fished (Nagelkerken et al. 2008), sustaining small-scale fisheries and food security of vulnerable human populations (Spalding et al. 2010). However, fish stocks have been collapsing in many systems, with impacts on ecosystem stability, biodiversity, and livelihoods (Worm et al. 2006, 2009). Similarly, mangroves have been disappearing, with losses of 35% of area in some parts of the world, largely attributable to human activities (Valiela et al. 2001).

These negative trends might still be reversible (Worm et al. 2006, Fulton et al. 2019), and protected areas (PAs) are widely advertised as a tool to restore these depleted resources (Worm et al. 2009, Vandeperre et al. 2011, UNEP 2014, Campos-Silva and Peres 2016). Tools for the conservation of fishery resources in mangroves, such as PAs, must not ignore the role these ecosystems and the resources they provide play for livelihood support (UNEP 2014).

However, the establishment of reserves does not automatically solve the widespread lack of data in small-scale fisheries worldwide, from landing data and stock assessments (Mills et al. 2011, Fulton et al. 2019) to social-ecological assessments (Kittinger et al. 2014), which hinders adequate management For the past ten years, there has been no official monitoring of small-scale fisheries in Brazil (Sganzerla 2017).

These types of information gap in fisheries need innovative, time-effective, and affordable approaches for data collection and synthesis. Participatory mapping and GPS tracking of fishing activities are examples of such approaches. Participatory mapping can help establish a basis for the management of resources through knowledge and values if local (indigenous, traditional, fishers', etc.) and technical knowledge systems are integrated as equally relevant for management design (Silvano and Valbo-Jorgensen 2008). GPS tracking has recently been used for small-scale fisheries [e.g. Pennino et al. (2016) and Metcalfe et al. (2017)], so the potential of this method has only started to be unveiled.

In addition to investigating the different methods separately, some mixing and matching (e.g. information from participatory mapping and technical data from landing surveys) and knowledge systems have also been previously studied. For example, there is an overlap between Brazilian fishers' perceptions and official landing data, but mainly for species that are relatively abundant in the catch (Damasio et al. 2015). Also, surveys on local perceptions and visual census of a pivotal coral fish species were used complementarily in investigating the species' associated habitats and its need for protection, as well as in identifying contexts where local participation and successful conservation outcomes are more likely (Aswani and Hamilton 2004). The spatial dynamics of migrant fishers was investigated in Kenya using a combination of participatory mapping and GPS tracking of vessels. The results from each method were analyzed comparatively and complementarily (Wanyonyi et al. 2018). In the case of the Brazilian mangrove belt, for example, GPS and participatory mapping have been combined to investigate spatial dynamics of the fisheries of the mangrove crab (*Ucides cordatus* L.) (Thies-Albrecht 2016).

Drawing on these previous investigations, this study examines the type of information that can be obtained by contrasting and merging data from participatory mapping and GPS tracking into one dataset to produce a combined, larger than the sum of its parts result. This study specifically aims to investigate how local and technical knowledge may be systematically integrated for ecosystem-based management at local and regional levels. Policy recommendations are offered to safeguard the sustainability of the crab fisheries in northern Brazil. Our study was led by two research questions:

1. What kind of spatial data on small-scale fishing grounds can be generated with a combination of participatory mapping and GPS tracking and what information does this combination provide about resource use?
2. What are the advantages and disadvantages of spatializing fishing grounds through merging participatory mapping and GPS tracking data?

As an example on how to combine the two data collection methods, we analyze the patterns of resource use between two adjacent PAs in the Brazilian coastal Amazon and investigate the correlation between distance from home village to fishing ground and crab size.

Methods

The methods for this paper are presented in Chapter 3.

Results

Reconstruction of traveled routes

Using QGIS fishing routes were "reconstructed" in order to calculate more realistic distances to fishing grounds. In this study, reconstruction means estimating the routes taken by fishers when they only mentioned, during the participatory mapping, the origin (home village) and destination (fishing ground) of their fishing movements. In order to reconstruct the fishing routes and calculate traveled distances, informants and collaborating fishers were asked about different transportation means used by all crab fishers in each fishing village analyzed (Table 1).

GPS tracked routes also had to be partially reconstructed because 1) either the way to or the way back from the fishing ground had to be chosen, in which case the shortest path was selected; and 2) a few of them were incomplete. The latter were only reconstructed, however, when the missing portion referred to the initial or final part of the trip and could be reasonably estimated. (Fishers would at times forget to turn on the GPS tracker until they were already halfway through the trip to the fishing ground, or would turn them off before they reached their home village.).

The following criteria were used to construct a plausible path:

I. Fishers use the means of transportation they mentioned in the surveys (Table 1);
II. Fishers avoid including paths that are "deep" into the mangroves because these are areas where movement is made difficult by the mangrove roots and the muddy substrate;
III. Fishers avoid what they call "river mouths" (where rivers widen, near the tips of the peninsulas);
IV. Fishers travel by boat or canoe preferably along the shores;
V. Fishers take well-known channels (locally known as "furos"). These channels were identified either by previous ground-truthing (e.g. boat trips) or by satellite imagery;

VI. Fishers prefer to travel by water, except otherwise mentioned;
VII. Fishers avoid entering or passing by other villages;
VIII. When traveling by boat or canoe, fishers leave from the local port;
IX. When the fishing ground is relatively close, fishers prefer to go on foot;
X. For further aspects, previous work [e.g. Thies-Albrecht (2016)] was consulted.

Table 1. Transportation means preferred by each crab fishing village in the Bragança and Tracuateua PAs, according to the interviews and surveys.

village	municipality	means of transportation used
Quatipuru	Tracuateua	canoe with engine
Tamatateua	Bragança	canoe with engine
Caratateua	Bragança	canoe with engine or boat
Mimi	Tracuateua	bicycle + canoe
Treme	Bragança	on foot, canoe with engine, or boat
Sessenta	Tracuateua	on foot or motorcycle
America	Bragança	bicycle + bus or canoe
Chapada	Tracuateua	on foot or canoe
Flexeira	Tracuateua	on foot, canoe with engine, or bicycle
Vila Cuera	Bragança	on foot or canoe with engine
Tacuandeua	Bragança	canoe with engine
Pontinha	Bragança	canoe with engine or boat
Acarajó	Bragança	car, bus, or bicycle
Cajueiro	Bragança	on foot or boat
Nanam	Tracuateua	bicycle
Patalino	Bragança	car

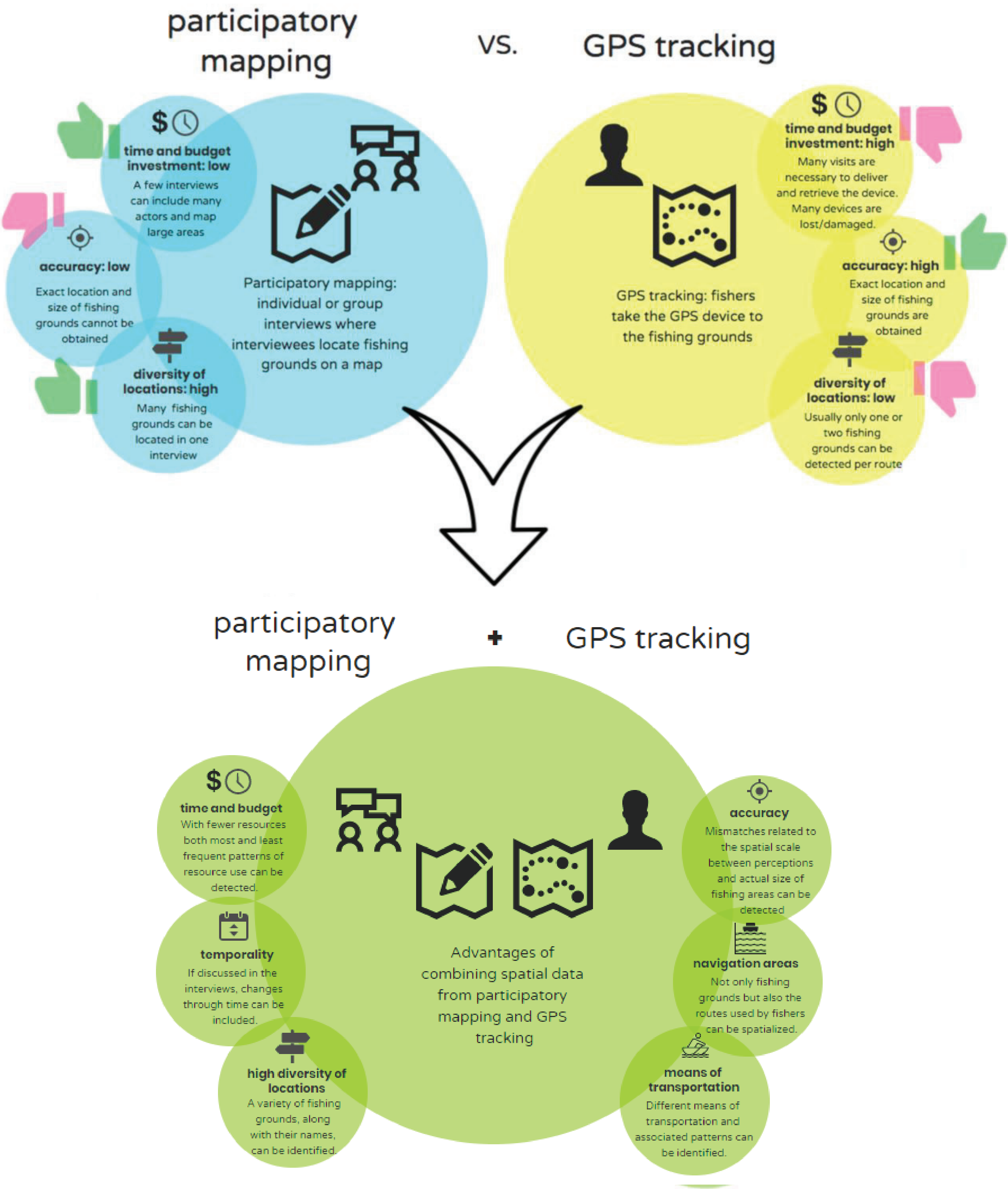
Participatory mapping and GPS tracking diverged in terms of which fishers from which villages travel the longest distances. This could indicate that the GPS tracking method failed to capture these longest distances traveled, either because they are rare among fishers or because participants refrained from taking the GPS in these longer trips. This is possible because, even though the GPS tracking covered 16 months, the sampling among the different villages was not systematic and done rather opportunistically because the fishers' willingness to participate in the research varied not only among the villages but also throughout the different seasons. This, together with the difficulties of transportation and the high rate of GPS loss, also led to a low number of routes tracked.

Regarding the participatory mapping, informants usually had difficulties estimating how far into the mangroves they have to walk to fish the crab. For example, even though many informants mentioned the road and the fishing that happens along the road, most of them could not specify how far into the mangroves the fishers go to collect the crab. When distances were estimated, they ranged from "no more than 200 meters" to "approximately two kilometers". The GPS tracking complements this piece of information by showing that fishers are not far from the edge of the mangroves. Sometimes they have to walk a long distance to find what they consider an appropriate site. But walking does not necessarily mean moving away from the border, and they remain close to the edge of the mangrove forest, as also shown by Thies-Albrecht (2016).

Three important limitations to the participatory mapping, when used alone, could be identified. Firstly, the delimited fishing grounds are simplified approximations of the many perceptions by fishers of location and designation of those fishing grounds.

Secondly, participatory mapping did not give information about the routes, so the GPS tracking data were used to reconstruct the specific movements of fishers. Fishers could have been asked to describe the routes during the participatory mapping. However, this would have required a much better understanding of the maps by the fishers, who would usually only name two points, village of origin of fishers and fishing ground. Additionally, asking for the entire route to fishing grounds would have been considerably more time-consuming. Regarding the participatory mapping, only the fishing ground information that was simultaneously provided with the fishing village was selected for the analyses, so that fishers' village and municipality of origin could be established and compared to the GPS tracking data.

Thirdly, informants mentioned it would be good to ground check the location of the fishing grounds mentioned because they were not sure about some of them on the map. For this purpose, on-site visits were performed through boat trips to confirm the exact location of places mentioned during the interviews and focus group discussions.



Combining the participatory mapping (40 grounds) and the GPS tracking data (14 grounds) (Figure 2), a total of 45 different fishing grounds were identified in the region, with a mean fishing ground area of 11.03 km^2 (SD= 9.05; min = 0.27, max =36.02) (Table 2).

Table 2. Dataset summary of distances with GPS tracking and participatory mapping.

		distance (km)
GPS tracking	mean	11.46
	standard deviation	8.47
	median	8.99
	maximum	24.81
	minimum	1.94
participatory mapping	mean	20.85
	standard deviation	14.78
	median	18.28
	maximum	86.81
	minimum	1.50

The distances between the home village and fishing grounds are significantly longer when recorded via participatory mapping compared to GPS tracking (F_{127}=11.06, p = 0.0012). In fact, the distances recorded via the participatory mapping (20.85 ± 14.78 km) were on average nearly twice as long as those recorded via GPS tracking (11.46 ± 8.47 km) (Figure 3).

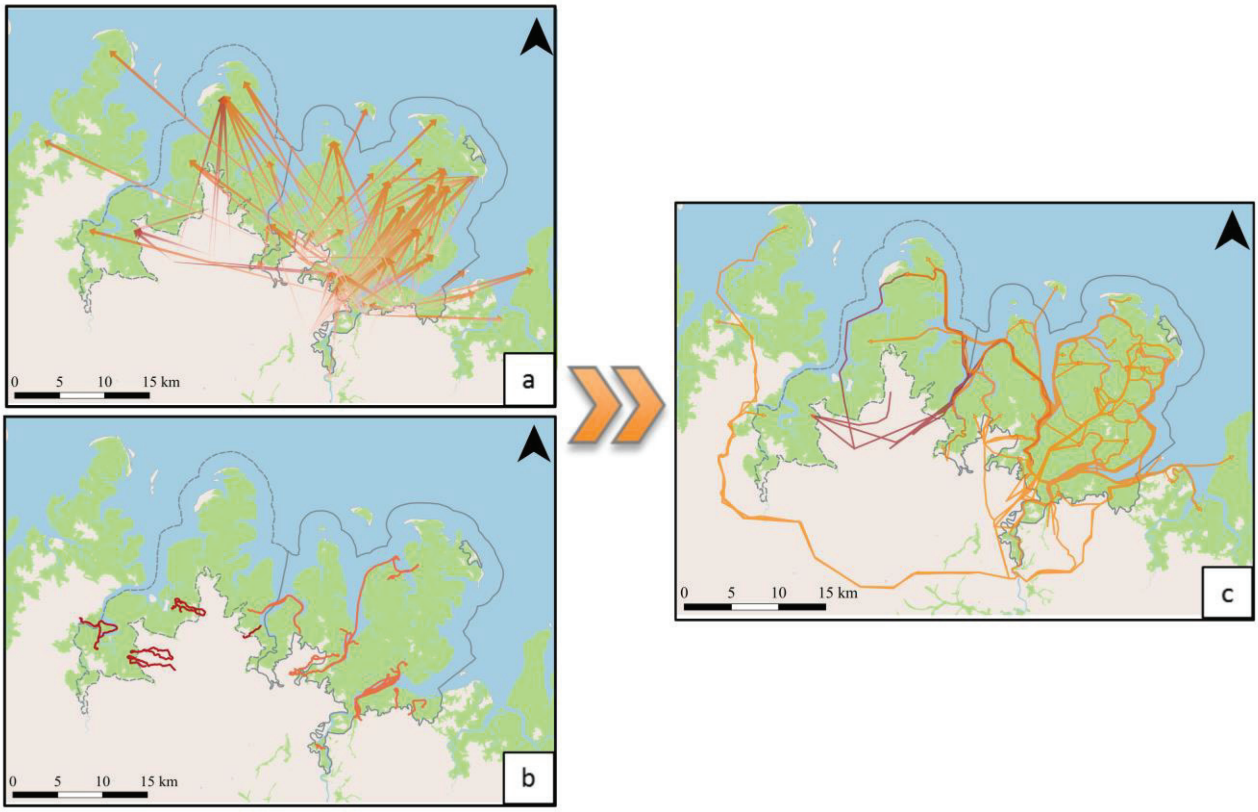


Figure 2. Movements of fishers according to (a) participatory mapping; (b) GPS tracking; and (c) reconstruction combining the two datasets. Movements of fishers from Tracuateua are shown in red, while those from Bragança are shown in orange. The arrow bases in 3a and 3c represent the home villages and the arrowheads the corresponding fishing grounds. The flows reflect the supply areas and the primary beneficiaries because only the catch and not the entire value chain of the fishing activity is considered in this study.

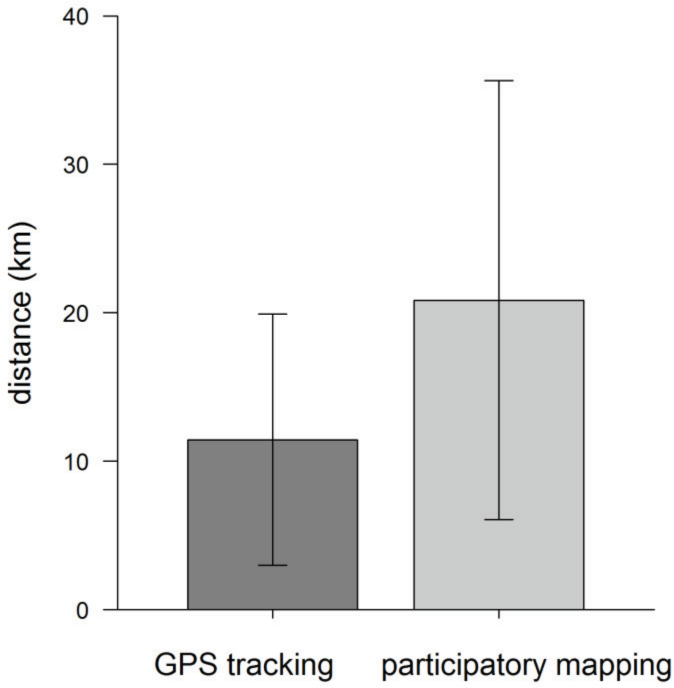


Figure 3. Average distances (± SD) recorded via GPS tracking (n = 17, dark gray) and participatory mapping (n = 112, light gray).

Distance to fishing grounds vs. crab size

We also analyzed the relationship between the distances to the fishing grounds and the spatialization of crab size, based on carapace width from Oliveira (2015). The results revealed a non-significant interaction of the terms "method" and "crab size" (LRTmethod*crab: $F_{99} = 1.661$, $p = 0.2005$), meaning that the effect of crab size on distance was the same for both methods.

Also, the results revealed that crabs tended to be larger if caught farther away from the villages ($p < 0.001$) (Figure 4), regardless of whether the distance was estimated through GPS tracking or participatory mapping ($p = 0.07$).

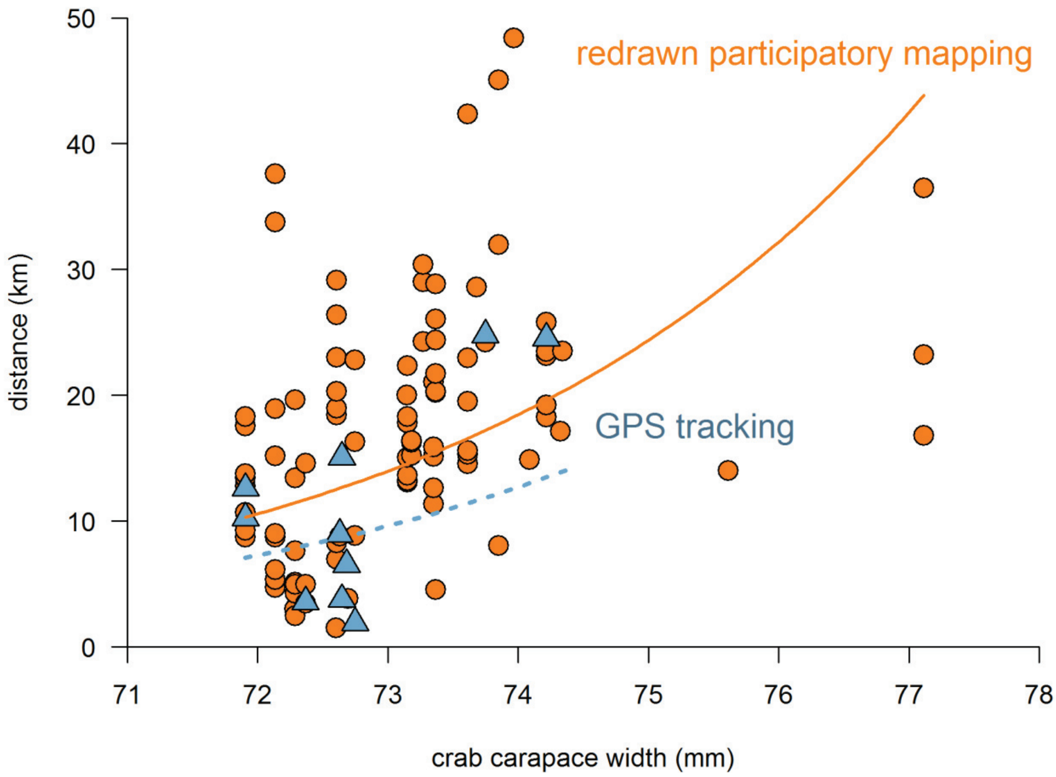


Figure 4. Relationship ($p < 0.001$) between crab sizes and distances traveled by fishers recorded via GPS tracking ($n = 11$, blue triangles and dotted line) and participatory mapping ($n = 92$, orange circles and solid line), with no significant difference between the two methods ($p = 0.07$).

Discussion

This study combines GPS tracking data and local knowledge to locate fishing grounds. We present the advantages and downsides of each method and how their application in conjunction can be performed to generate data for improved management of fisheries and marine PAs. For both methods, we shed light on concrete ways to analyze spatial data to understand user behavior, which has been identified as a challenge for participatory mapping (Brown and Kyttä 2018).

Combining participatory mapping and GPS tracking

Due to the dispersed nature of the activity and precarious investment in technical monitoring, data-poor fisheries settings, such as the mangrove crab fisheries in northern Brazil, could benefit from more research on combining and comparing data from various collection methods and knowledge systems. This could be of special use when a small set of rich but laborious to collect data, such as from GPS tracking, could feed into an easier-to-implement source of data, such as participatory mapping.

Using a combination of data collected by these two different methods, this study shows that the place of origin of the fisher and the method used to identify the fishing grounds influenced the results on distances traveled by the fisher between village and fishing grounds. Results on overall distances were longer by the participatory mapping than by the GPS tracking. These longer distances could be explained by the fact that farther fishing grounds are mentioned in the interviews. These are harder to capture by GPS tracking alone because these trips occur rarely and would need a more widespread and longer tracking effort[29]. Also, fishers could deliberately avoid these grounds when they are carrying the GPS trackers

The two methods had already been shown to yield complementary information (Wanyonyi et al. 2018). Similar to our results, these authors observed that GPS tracking provides fine-scale spatial and seasonal mapping of fishing activity and spatial allocation of fishing effort. On the other hand, mapping has the advantage of documenting a seascape that is unique to fishers (Silvano and Begossi 2012, Wanyonyi et al. 2018).

One challenge found in combining GPS tracking and participatory mapping information is the difference in fishing ground sizes: a mean of 11.03 km^2 (SD = 9.05; min = 0.27, max = 36.02) for the participatory mapping grounds and of 0.0212 km^2 for the GPS tracking grounds (Thies-Albrecht 2016). The average fishing ground from participatory mapping was approx. 520 times larger than the GPS-measured fishing area. Even though GPS tracking grounds could be incorporated into the participatory mapping data, some loss of detailed information was observed, for instance, on where exactly fishers find the crabs and on whether they visit more than one fishing ground per route. This difference could be lessened, for instance, by accompanying fishers in the trips to the mangroves to observe how far into the mangroves these fishers go (i.e. distance to the edge of the forest). However, this apparent mismatch in fishing ground size also relates to the definition of "fishing ground" in terms of 1) what is known as a "fishing ground" (sometimes referred to

[29] Also, the GPS battery might not hold long enough to cover these long trips. Fishers are aware of this constraint and might choose not to take the device on these trips. According to the fishers, the battery would hold for a maximum of about 12 hours. The fishers also mentioned during the interviews that they usually stay for at least two days when fishing in what they consider to be "very far fishing grounds".

as “fishing territory”) for an extended period (and usually named by local users) and the 2) the actual area (or “fishing point”) used by fishers during one fishing trip. How to approach this difference will depend largely on the purpose of the method combination. In the case of the zoning of a co-managed PA, for example, the delimitation of fishing territories would probably be more useful to implement spatial management strategies.

A general limitation of this study is the fact that informants tended to mention more about the PA to which they are more closely related, and there was a higher number of informants in the municipality of Bragança than in Tracuateua (87 and 48, respectively). Therefore, the higher use frequency and diversity of fishing grounds in the Bragança PA could relate to the larger population. Although this correction could not be performed, informants frequently mentioned this difference of spatial dynamics more clearly in the form of statements, associating the higher user intensity in Bragança to the processing plants in this municipality.

The benefits of analyzing spatial aspects of fisheries dynamics and management can be manifold. Adequate consideration of these aspects and the use of the local knowledge of harvesters to complement technical data such as the GPS tracking, as done in this study, can reduce conflicts over the use of resources (De Freitas and Tagliani 2009). Displaying data using GIS software and employing spatial analysis tools that allow for visualization and pattern recognition is particularly effective when working with local people because visual aids help to bridge the divide between local knowledge and technical knowledge (Aswani and Lauer 2006).

Actors and knowledge systems that create and underpin data are often excluded from decision-making, especially marginalized fishers, such as crab harvesters, which often remain at the edge of co-managed small-scale fisheries. Thus, there is a need to develop functioning mechanisms to engage and legitimate synergies between knowledge systems in a transparent and constructive way (Reid et al. 2006). Affordable and transparent participation mechanisms and knowledge integration methods, like the method match we propose here, should be further investigated and incentivized, for instance, by special issues in method-oriented journals or calls for grant proposals. We believe the combination of methods we propose here could serve to voice desires and needs of often marginalized populations and include them in management processes, especially in PAs where people live or extract resources. The combination of methods we outline enables listening to local stakeholders through participatory mapping and a deeper understanding of their behavior patterns with GPS tracking.

Challenges related to participatory mapping and GPS tracking individually remain to be tackled even when they are combined. For example, it is important to have clarity of purpose for the participatory mapping process, building trust with participants in the process, and understanding the power dynamics of the participatory mapping process (Brown and Kyttä 2018). These same barriers seem to apply to GPS tracking and are not solved by a multi-method approach to research or management, as we propose here.

Crab size and distances traveled

In our study region, the results revealed that crabs tend to be larger if caught farther away from the villages where fishers reside. Other studies have also shown this relationship, even though they used distance to "markets" instead of distance to "home villages". In our case, the villages are usually the primary market places, after crabs are brought in from the mangroves[30]. Therefore, proximity to villages/markets help explain fisheries exploitation level and need to be considered in the development of resource-management strategies (Cinner and McClanahan 2006, Brewer et al. 2013).

Further aspects still need to be examined regarding the status of the crab fisheries. There is a need to consider, for example, the emergence of processing plants of crab meat since the last comprehensive stock assessments and a possible increase in fishing effort and/or the use of distant fishing grounds outside the limits of the fishers' home PA. Concerns regarding the ecological and social sustainabilities of the crab fisheries in our study site call for inter- and transdisciplinary efforts to establish relevant fishery management priorities with the active participation of the centrally affected stakeholders (Glaser and Diele 2004). Our multi-method approach, if expanded, can shed light on these changes in spatial dynamics while promoting enhanced participation of local users in research, monitoring, and policy development.

[30]Field observations show exceptional cases where crabs are bought from the fishers in a location immediately outside the mangrove areas, for instance, along the main road in the Ajuruteua peninsula (Bragança PA), where fishers display the crabs for sale on the margins of the road.

In a future publication, we continue to employ the introduced combination of methods to assess whether fishers travel long distances to find larger crabs, or whether they systematically target areas with larger crabs or whether they prefer areas with easier access but with smaller crab sizes.

Conclusions

We used a multi-method approach to elucidate if distance traveled by the fishers and crab size are related. We present the advantages and downsides of each method and how their application in conjunction can be performed to generate data for improved management of fisheries and marine PAs. Even though a combination of participatory mapping and GPS tracking is especially useful for areas of difficult access, like mangrove forest, they could also be used in other ecosystems. The methods applied in this study can be considered a good model for studies in other contexts of marine spatial planning and small-scale fisheries. Regarding crab size and distance, we concluded that crabs tended to be larger if caught farther away from the villages.

Firstly, in a context of scarce biological and ecological knowledge about coastal fisheries to support management decisions, like on the Amazon coast, a local knowledge database about the crab fisheries is provided by this study. The methods presented here are intended as a way of complementing effort and catch monitoring techniques. Depending on the issue at hand, one or the other method could be applied. For instance, when establishing PA zones, the level of accuracy of fishing ground location identified by GPS tracking would probably not be easily identified by fishers, which could cause confusion among users. Participatory mapping, linked to other criteria, could be a better option for managers.

Beyond data generation, this multi-method approach has the potential of increasing stakeholder participation in research and management. If conservation is to play a role in safeguarding people's livelihoods as well, it needs a pluralist approach to knowledge and greater deliberation and inclusion of actors in decision-making processes (Brown 2003). Considering the co-management scheme and the sustainable-use regime of the extractive reserves in the northeastern Pará mangroves, this pluralistic approach is much needed. Further translation into policy and incorporation of different knowledge systems into management is essential. Considering the socio-economic circumstances, however, the strengthening of cooperation for conservation is key to guaranteeing the sustainability of the crab fisheries in the Amazon mangroves.

Research authorization

The research was approved by ICMBio (Sisbio process number 36427147).

Ethics statement

We followed the Code of Ethics adopted by Brazilian universities. Accordingly, participants in the study, including informants and fishers carrying GPS devices, were informed about the purpose of the questionnaire as well as data use and diffusion. We obtained verbal consent from participants prior to conducting surveys and from GPS carriers before their fishing trips. Answers were recorded anonymously, and individual informants cannot be identified in published material or other publicly available records. Whenever possible, we also recorded personal contact information to facilitate restitution of results to participants. This restitution activity started with the awareness-raising project funded by the Rufford Foundation and will continue following the conclusion of the project.

Funding

R.B. is grateful to CNPq for the scholarship to perform the doctoral research (process 290055/2014-8) and to the Rufford Foundation (20310-1) for a small grant that contributed to the fieldwork. We would like to thank the University of Bremen and the Leibniz Centre for Tropical Marine Research for funding the open-access publication of this manuscript.

Acknowledgments

We are grateful to the participants who shared their knowledge and/or were willing to take the GPS devices to the mangrove, as well as to the assistants who helped us during the fieldwork. We are also grateful to MSc. Andrés Alegría, who performed the initial map preparation and design. We also appreciate the support by GLOMAR - Bremen International Graduate School for Marine Sciences, University of Bremen, Germany and are thankful to the GLOMAR Theme D members, who provided input on the paper. We also thank the University of Bremen and Christof Dieterle for the help with language editing and proofreading of this manuscript.

Chapter 5

I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I -
I took the one less traveled by,
And that has made all the difference.

Robert Frost

The Road Not Taken

Literature references can be found at the end of this thesis.

Spatial dynamics of small-scale fisheries and integrated zoning of coastal protected areas

Rebecca Borges[1,2], Andreza Santos[3], Marileide Alves[3], Roberta Barboza[3], Marion Glaser[1]

[1]*Leibniz Centre for Tropical Marine Research (ZMT)*
[2]*University of Bremen*
[3]*Universidade Federal do Pará (UFPA)*

Abstract

Marine spatial planning is acclaimed as a tool to promote sustainable use of the ocean's resources, but scale/level mismatch remains poorly addressed in scientific literature and policy. This study investigates whether the dynamics of small-scale fisheries can help identify spatial connections between protected areas and whether these connections help establish an appropriate level for integrated management. It combines technical and local knowledge systems to identify the geographical boundaries of a spatial planning unit, to tackle sustainable-use challenges in protected areas in an integrated manner and, therefore, reduce mismatches of environmental challenges and possible solutions. We applied an ecosystem service approach and examined legal instruments to identify values and management priorities in two marine sustainable-use areas in Pará, northern Brazil. We also used spatial patterns of the crab value chain, including harvest and post-harvest activities, to investigate the lowest level of the social-ecological planning unit for integrated zoning of sustainable-use areas. Results show that crab fishing connects adjacent reserves: fishers move across these areas, and their fishing grounds do not completely match the formal geographic boundaries established by the protected areas. Other steps down the crab value chain show that flows of supply and demand cross the formal boundaries of the five reserves. This connectivity stresses the need for integrated zoning involving stakeholders. Aiming to contribute to our initial findings, we conducted participatory workshops, where participants reinforced local needs to include elements from other protected areas and confirmed the local relevance of integrated management. The analyses shown can provide insights into how to identify an appropriate level for integrated, spatial management and can support the development of zoning strategies. This approach can be applied to other spatial planning initiatives in networks of protected areas.

Keywords: ecosystem services, marine spatial planning, mangroves, GIS, sustainable-use areas, integrated management, participatory mapping, spatial management level, fisheries value chain, fisheries spatial management

Introduction

Marine spatial planning has been evolving in past decades as a tool to protect ecosystems while allowing for the development of human activities (Collie et al. 2013, Jones et al. 2016, Kyriazi et al. 2016) and is considered essential to ecosystem-based management (Douvere 2008). According to UNESCO (Ehler and Douvere 2009), "marine spatial planning is one element of ocean or sea use management; zoning plans and regulations are one of a set of management actions for implementing marine spatial planning". In this framework, zoning is "a fundamental cornerstone of effective marine spatial planning" (Kenchington and Day 2011).

Despite growing interest and research in marine spatial planning, essential steps and elements such as the setting of the planning boundaries (Ansong et al. 2017), in other words, the appropriate planning level[31] on the geographic level (Minang and Rambaldi 2004, De Freitas and Tagliani 2009) are still to be operationalized.

Finding the appropriate level at which to tackle planning and management is crucial because it determines what processes and discussions to be triggered and whom to involve, what data are needed, as well as logistic aspects such as how much money will be spent or how much time is required for each planning exercise (Guerrero et al. 2015). This task includes, therefore, primarily the question of which spatial area needs to be considered for each planning process but also by which institutions or other kinds of actors goals should be defined and tackled (Ansong et al. 2017). The key challenge is to find the right match between the issue to be tackled and the level at which it is supposed to be handled.

Norse (2010) summarizes this issue in a nutshell: "*Ecosystems are nested like matryoshka dolls, on* [levels] *from the globe as a whole and ocean basins through regional seas, gulfs, and bays down to individual reefs, seagrass beds, and even the mounds made by individual polychaetes. Jurisdictional lines drawn by governments almost never reflect*

[31] In this paper, we consider scale is the spatial, temporal, quantitative or analytical dimensions used to measure and study any phenomenon (Gibson et al. 2000), while levels represent the points at a certain scale (Cash et al. 2006, Glaser and Glaeser 2014). "Level", as defined here, is usually found in the literature as "scale". Therefore, in this paper, we translated the literature denomination "scale" to "level" whenever necessary in order to fit our definition of these two terms. We kept the use, however, of well-established terms such as "small-scale", "large-scale", or "fine-scale", even though these probably refer to "levels" instead of "scales".

meaningful biophysical or human-use phenomena — rather, they transect ecosystem boundaries. Creating a comprehensive spatial plan to facilitate ecosystem-based management, however, requires planning on a [level] *that works for management: If it is too big, we miss crucial details; if too small, we have an unwieldy number of decision-making groups*."

Regarding sustainable use and conservation, an emerging topic and need is the ecosystem-based approach, which recommends that conservation be tackled at the ecosystem level (Long et al. 2015). The definition of the spatial boundaries of the "managed ecosystems" is a first step in moving towards meaningful ecosystem-based management of coastal zones (Oakley et al. 2018), even though the boundaries defined remain porous (Guerrero et al. 2015).

Considering the effort to implement ecosystem-based management strategies, the attempt of finding an appropriate management level begins with defining what an ecosystem is. Take, for instance, the mangrove belt on the Amazon coast. From a biological perspective, it could be argued that the whole mangrove strip, although stretching for about belt over 6,800 km (Kjerfve and Lacerda 1993) and occupying an area of over 7,423 km^2 (Nascimento et al. 2013) is an ecosystem in itself, and its conservation would ideally not be managed in separate blocks. There is no doubt about the need for some type of integration in the management of this mangrove belt. However, considering its size and the fact that it encompasses different states inside Brazil alone, institutional capacity dictates some sort of compartmentalized, local-level management, at least for most of the governance strategies, such as the establishment and implementation of protected areas (PAs) and their zoning plans.

Northern Brazilian mangroves need a social-ecological system approach (Ostrom 2009), whereby humans are seen as a part of, not apart from, nature (Berkes and Folke 1998). In this case, the biologically-defined planning unit is actually not represented by the whole mangrove stretch, but rather by smaller, geographical units inside this mangrove belt. Therefore, the management level question can be formulated as follows: what criteria should be applied to determine how management could take place in a way that preserves the continuous nature of this biodiversity-rich ecosystem while ensuring human well-being and equity of the ecosystem-based management approach and administrative capacities?

The implementation of these local PAs[32] was done in the mid-2000s with the boundaries of the municipality as guidance for the establishment of each PA. In later management instruments, the use of the PA became restricted to the municipality-based users' association. This formally means the exclusion of "foreign users" (Abdala et al. 2012)[33].

While the strategy of delineating PA boundary along administrative borders seems sensible, the allocation of such boundaries in northern Brazil did not consider the ecological relations between the different "municipal mangroves". It also did not account for the fact the mangrove users themselves might not necessarily associate their resource use territories to the mangroves assigned to each PA i.e. to each municipality. It was known by the time of the creation of the PAs that users, including crab fishers, do not restrict their fishing grounds to the PAs with which they are officially associated[34] (Araújo 2006), and recent studies point to the persistence of this mismatch between PAs and fishing territories (Gomes, 2018).

In large networks of PAs, lack of knowledge on these "boundary effects" can undermine the effectiveness of fisheries policies (Song et al. 2017), including increased non-compliance by fishers (Gunawan and Visser 2012). This could be the case for the Amazon mangrove belt and its mangrove PAs. Boundary effects, or the interconnections in a network of PAs, could be represented, for example, by the spatial dynamics of small-scale fisheries, including the territoriality of fishers in a geographic space subdivided into different administrative units.

Conservation requires an integrated transboundary approach to planning and management, where the scales (and levels) of management and ecosystems are matched (Dallimer and Strange 2015). Therefore, spatial connections between PAs need to be investigated, both in terms of ecological processes and resource use. One solution to the challenge related to establishing the social-ecological level of spatial management would be to investigate in detail the resource use territoriality in the mangroves. In the case of areas

[32] These PAs are officially identified as extractives reserves, or "RESEX", the acronym for the Portuguese term "reserva extrativista".
[33] Even though conflicts have been reported, the exclusion of foreign users is not applied in practice and seems to be unknown by all the stakeholders interviewed for this study, who actually reject any sort of access to the mangroves and resource use limitation.
[34] Users are not allowed to be associated with more than one PA.

that have already been created, this information could serve to vertically (on a geographic scale) and horizontally (at one level) integrate management and promote strategies that alleviate the mismatch between traditionally-used territory and administratively-assigned grounds based on PA regulations.

This paper suggests how to identify a geographic level for management of adjacent PAs, with two sustainable-use areas in northeastern Pará, Brazil as focus study areas[35]. We analyze the limitations of the strategies used and identify further research needed to elucidate the appropriate strategies for mangrove spatial planning and management in our study area and in mangrove PAs in other regions of the globe.

This study addresses the following questions:

1) How can the dynamics of small-scale fisheries help identify spatial connections between PAs?
2) How can these connections help establish an appropriate level for integrated management? What are possible caveats and upsides to such an approach?
3) What are the implications of the different choices of spatial level for conservation policy?

Methods

The methods for this paper are presented in Chapter 3.

Results

Ecosystem services and management priorities

Based on how frequent ecosystem services were mentioned by different stakeholder groups (Figure 1) in both PAs (Figure 2), we observe that the mangrove crab as a food source is a central ecosystem service for the informants. Most informants pointed crabs or food in general as services provided by the mangroves.

[35] We use the term "focus study areas" to signal that these were the areas initially chosen for the analyses. Later on, as shown in the results, we found out that spatial management could be optimized by included nearby reserves, so that the initial ones acted as the initial focus of this research. The initial idea was to investigate only the PAs in Bragança and Tracuateua, because the former already had a zoning plan, while the latter claimed to be in the process of formulating one.

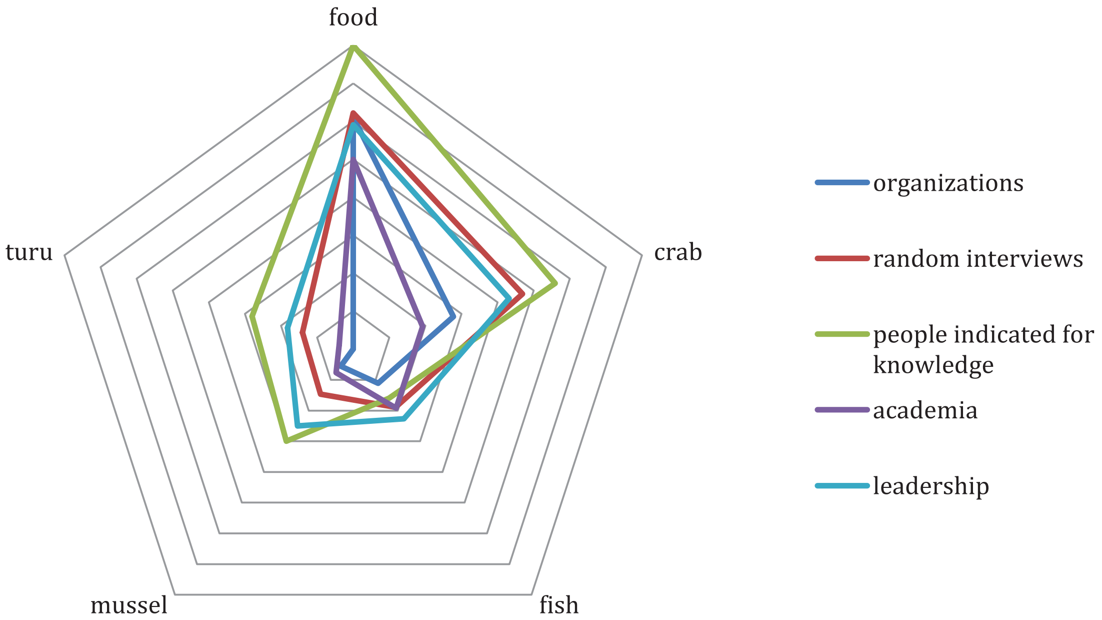


Figure 1. The five most frequently mentioned ecosystem services, by informant group. The “turu” shipworm is a mollusk (Bivalve, Terenidae) that feeds on rotten wood from mangrove trees mangrove, eaten by locals and acknowledged by our informants as having medicinal properties.

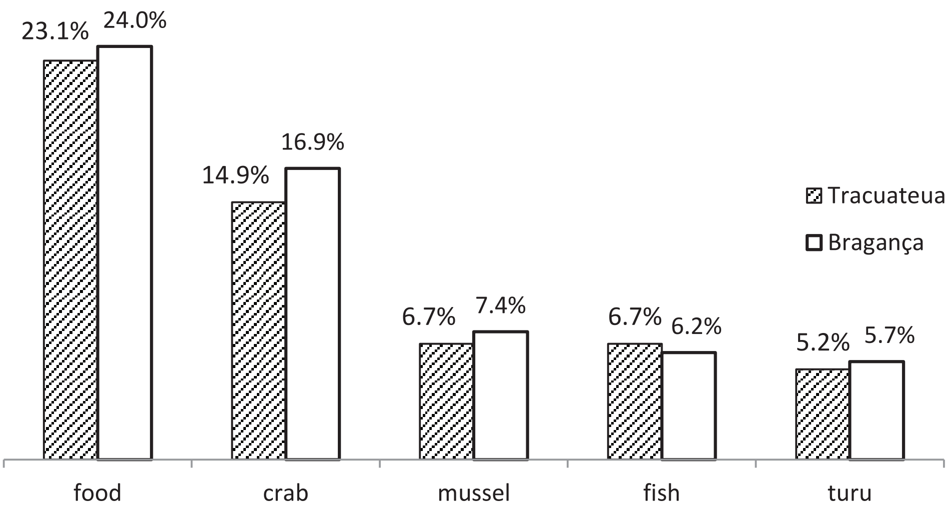


Figure 2. The five most frequently mentioned ecosystem services, by municipality.

Due to its overwhelming importance when compared to other services, we decided to focus on the crab value chain to guide the delineation of the spatial planning unit i.e. the level at which spatial management needs to be focused.

Arrow maps for supply and demand flows

The arrow maps (Figure 3) show that fishing grounds are exploited beyond the boundaries of each PA. Crab catchers from Bragança fish in other PAs, while this behavior is rarely observed in Tracuateua. Only two villages from Tracuateua go to Bragança, whereas six villages from Bragança go to Tracuateua to fish crabs. It is also possible to observe that movements from Bragança are more diverse and complex than those from Tracuateua.

We also found that movements are not restricted to the two PAs analyzed, but also involve nearby municipalities: Quatipuru (to the west) and Augusto Corrêa and Viseu (to the east) of the study area. Therefore, there is no congruence between PA delimitations and fishing grounds.

Interviews with intermediary buyers, distributors, and other actors involved in the processing of the crab meat

The crab processing in Bragança happens either at the homes of the crab process workers (domestic crab processing) or at the processing plants (crab processing), where crab process workers are informally hired to work at the plants.

Most crabs that are used by both the domestic and the plant process workers are not landed directly in the village of Treme (Bragança) but are actually fished in the municipalities of Viseu and Augusto Corrêa and transported to Treme by truck (Figure 4). Some crabs used in the processing come from Maranhão, the next state to the east. The municipality of Viseu is the main supplied of crabs for both the domestic processing and the crab processing. Until 2010, crab processing in Treme was supplied with crabs that were landed in the village, but, since 2010, there has been the need to bring crabs from another municipality, Viseu[36]. According to informants, this happens because the crab caught by Treme villagers does not have commercially viable sizes or the minimum size allowed by law[37].

[36] which has its own RESEX (Gurupi-Piriá)

[37] According to the ICMBio informants, there is a controversy with regard to the minimum size of the carapace allowed by legislation. Federal law only allows the extraction of crabs with a carapace of at least 6 cm (BRASIL 2003), but the state law is more restrictive, demanding a carapace of at least 7 cm (PARÁ 2002). According to the Brazilian constitution, the more restricted legal instrument should be the one to be adopted. However, normally the federal law is the one adopted. Indeed, the owners of the processing plants claim to abide by federal law. However, in one of the plants, we found crabs with carapace of 5 cm, smaller than legally allowed.

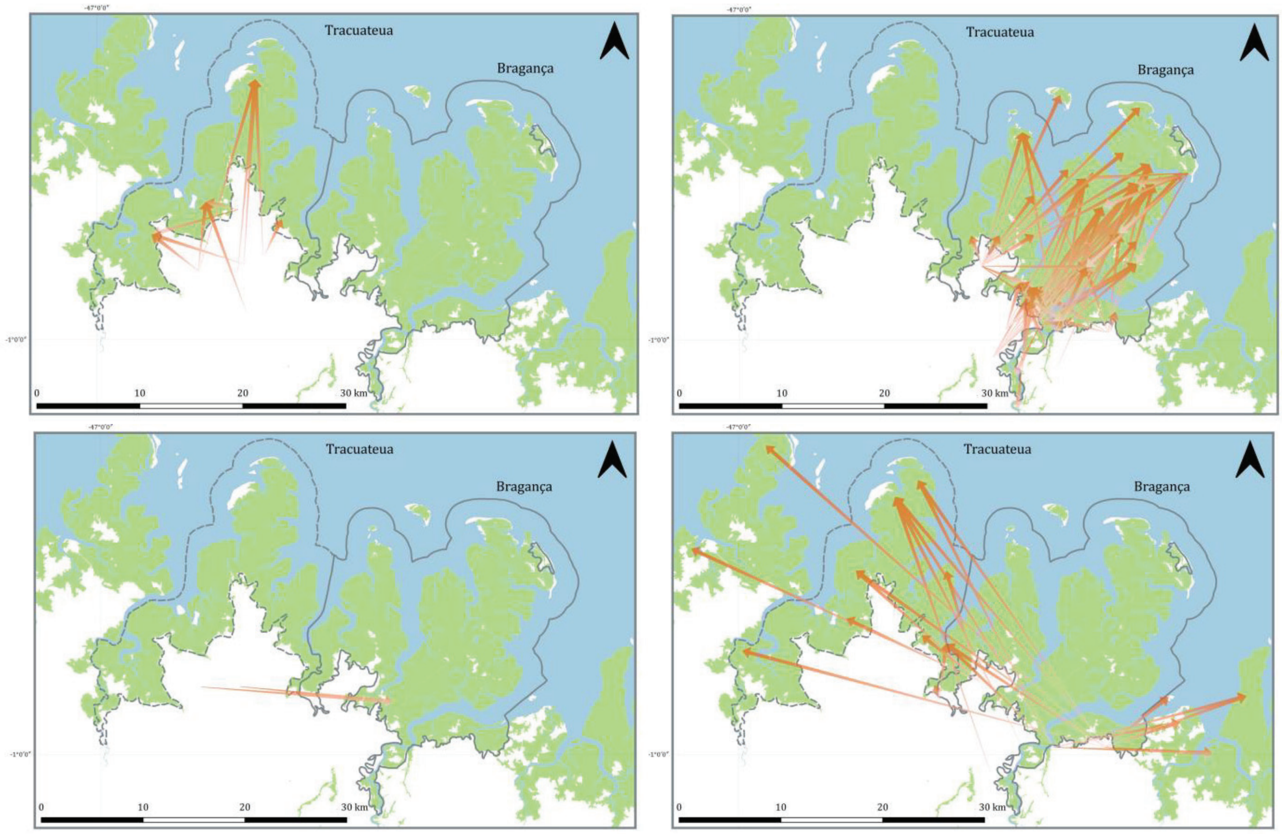


Figure 3. Intra-area spatial dynamics in Tracuateua (top left) and Bragança (top right). Cross-boundary spatial dynamics in Tracuateua (bottom left) and Bragança (bottom right). The arrow bases represent the home villages and the arrowheads, the corresponding fishing grounds.

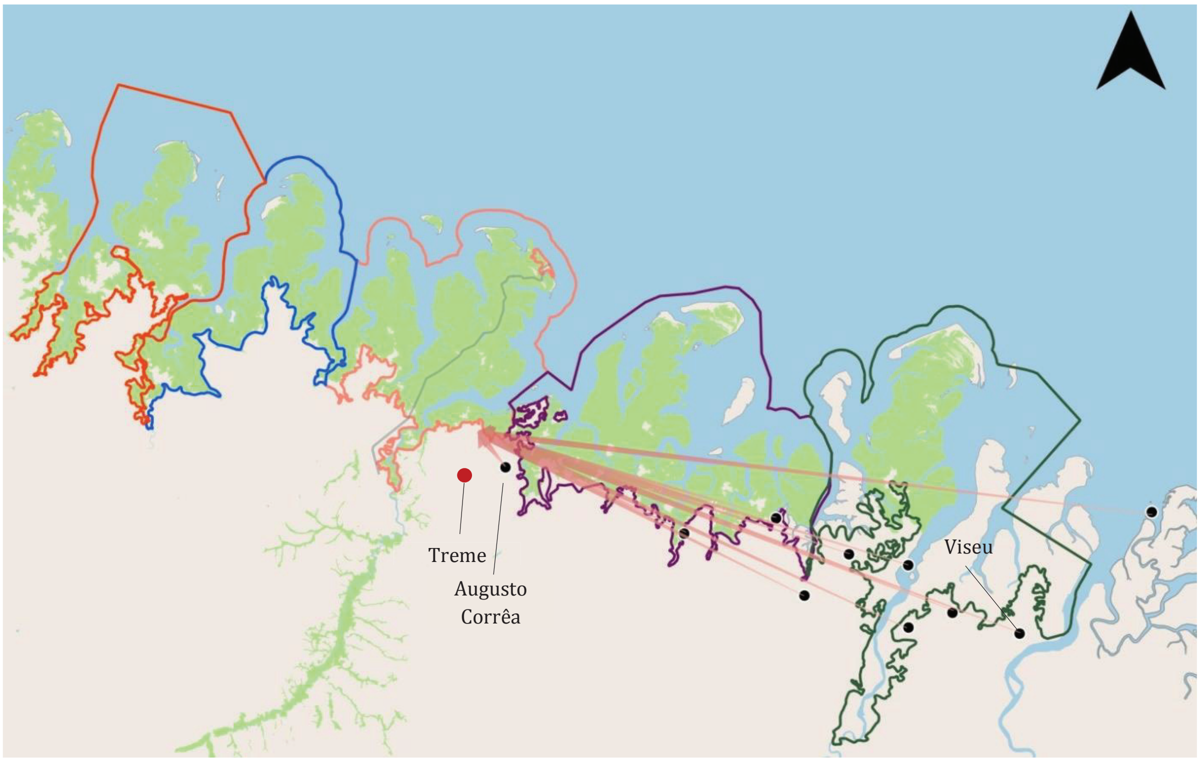


Figure 4. Spatial dynamics of the crab processing in northeastern Pará. Treme, the village where the processing plants are located, receives live crabs from the municipalities of Augusto Corrêa and Viseu. The remaining black dots represent locations inside these two municipalities that supply crabs to Treme, except for the last dot on the right, which is located in the next state, Maranhão. Other places mentioned by the informants could not be located or are beyond this map.

With the implementation of the first processing plant, the catch of crab for production of processed meat increased considerably and intensified in 2016 with the implementation of the second processing plant. With this increase in demand, mangroves in nearby municipalities, where other PAs are located, and even in another state (Maranhão[38]), started to supply the processing plants. The managers of the plants claim that the village does not produce (i.e. fish) the amount of crab needed for the meat processing activity at the processing plants.

Domestic process workers identified the villages of Nova Olinda and Araí, both in the municipality of Augusto Corrêa[39], as main suppliers for the domestic meat processing. Currently, the municipality of Viseu stands out as the main supplier to the processing

[38] The informants mentioned crab fishing in the state of Maranhão, specifically at Praia da Sardinha and Porco, to supply the Bragança processing plants.
[39] where the Araí-Peroba PA is located

plants[40]. According to the fishers, Viseu stands out because they have the largest crabs when compared to the crabs from the other PAs, due to the difficult access of these mangroves and PA regulations. Moreover, there is little commercialization in this municipality, and its capture is only allowed to locals. According to informants, these factors contribute to the existence of larger crabs in this PA.

The need for integrated management in local stakeholders' perceptions about the zoning

On the topic of zoning strategies, places were specifically indicated for demanded management measures, including, for example, those where tourism could be encouraged and supported, or where problems, including conflicts, presently occur. Of all specific locations mentioned (n = 44), 16 (36%) are located inside the nearby PAs and 22 (50%) in the buffer zones of the PAs. Participants mentioning these areas highlight the importance of both integrated management and careful management of the buffer zones.

On the edge of management: coastal islands and buffer zones

Small, coastal islands are interesting cases to demonstrate the need for cooperation at the borders of PAs. Informants pointed out Guará Island, in the Augusto Corrêa PA (Figure 5), as a possible area to be dedicated for research, meaning that no crab fishing would take place there. Otelina Island, on the border between the to-be-created Quatipuru/Primavera[41] and Tracuateua PAs, was identified by the informants from Tracuateua as an important nursing ground for birds. Even though coastal islands belong to the Union[42], Otelina Island is locally managed by the municipality of Tracuateua.

The review of the gray literature and pertinent legislation shows that buffer zones would theoretically overlap with neighboring PAs. However, in the case of Bragança, the management plan establishes a buffer zone that deliberately does not overlap with the neighboring PAs. The buffer zone of the Bragança PA has a total area of 51,323 hectares,

[40] The supplying villages are: Açaiteua, Limondeua, Santa Rosa, and Praia do Jabutitiua. Plus, mangroves near the village of Fernandes Belo and the Piriá river are considered to deliver the largest crabs in the region.
[41] Users and ICMBio employees have been articulating for almost 15 years the creation of an extractive reserve in the mangroves of the municipalities of Quatipuru and Primavera, west of Tracuateua. This extractive reserved has been formally requested and will be called "Filhos do Mangue".
[42] The "Union" is roughly equivalent to the Brazilian Federal State: http://www.planejamento.gov.br/assuntos/gestao/patrimonio-da-uniao/bens-da-uniao/ilhas

which is larger than the area of the actual PA 47,422 hectares. Its goals are to monitor urban expansion, real estate speculation, developments, and other exploiting activities that *directly* affect that PA.

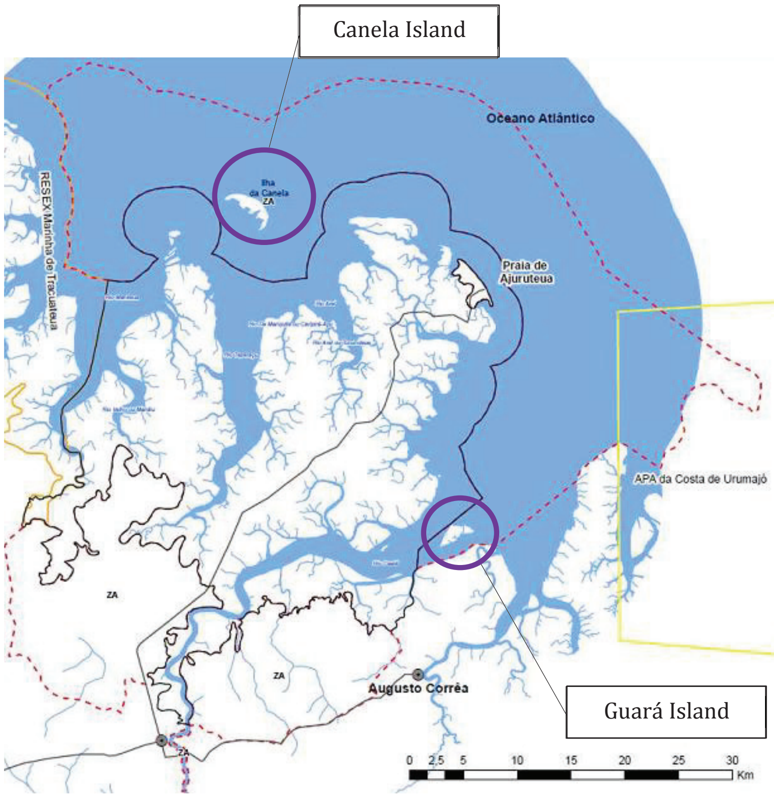


Figure 5. The limits of the Bragança PA (black, solid lines), its buffer zone (red, dashed lines), and the islands located inside the buffer zone. Map adapted from Bragança PA's management plan (Abdala et al. 2012).

The processing plants, for example, might be considered to only *indirectly* affect the PA by influencing supply and demand of crabs. However, we conclude that there is an evident need for more management interventions in the buffer zones and better coordination with local authorities. This shows the importance of integrated management.

The Bragança PA's management plan also acknowledges that fishing territories are not restricted to the limits of the PA: "*It is known that the fishers' area of use can be much more extensive than the limits presented, however, the delimitations refer to those territories of more common use, where fishers can go in their everyday life.*" It assumes that the use of areas outside the PA is not part of the fishers' everyday practice. Although our study did not investigate frequency of use, the frequency of mentioning of certain fishing grounds, added to the mentioning of these grounds when considering spatial management strategies, indicates that this fishing grounds outside the limits of the PA and its buffer zone are important to fishers and considered by them as their traditional fishing territories. The delimitation of the buffer zone in the management plan includes areas that seem to overlap with the PA to the east[43]. Guará Island is located on this overlap area. The Canela Island PA, under municipal jurisdiction, is also within the limits of the buffer zone.

Buffer zones are recommended by international treaties and conventions (e.g. Convention on Biological Diversity, World Heritage Convention). In Brazil, buffer zones are regulated by the same federal law that regulates the National System of Protected Areas (BRASIL 2000). This law defines buffer zones as "*the surroundings of a protected area, where human activities are subject to specific norms and restrictions, with the goal of minimizing negative impacts on the protected area*". The buffer zone is mandatory for the RESEX category and can be established at the creation of the PA or after that, but it must be included in the management plan of the PA. However, no standard size for the buffer zone can be found in this specific law. ICMBio must create specific regulations for the buffer zones and needs to be consulted to approve activities in the buffer zone that can be potentially harmful to the PA.

When the PA does not have a management plan, the size of the buffer zone depends on the type of activity to be approved (CONAMA 2010): two and three kilometers from the PA boundaries, for activities of low and high environmental impact, respectively, unless otherwise specified in the management plan. This flexibility reinforces the importance of the management and gives this instrument absolute power over the regulations of buffer zones. Most informants, however, seem not to know about the zones, including the existence of the buffer area (Borges et al., *in Preparation*).

In Brazil, an integrated management strategy is recommended for Brazilian PAs by national legislation (BRASIL 2017). Other federal legislation also incentivizes the creation of "ecological corridors" (BRASIL 2000), which could be a strategy for these five areas that show strong interconnectedness in terms of the crab fisheries. Ecological corridors should

[43] On the map in the management plan the PA shown is APA da Costa do Urumajó. Nowadays, this area is part of the Augusto Corrêa PA, which also expanded to the west is now delimited to the west by the boundaries of the Bragança PA. This change happened after the management plan was developed.

be established not only on ecological grounds but also considering social-ecological dynamics.

The proposed planning unit for zoning of PAs in the region

Figure 6 shows the diverse pieces of spatial information to be compiled in order to delimitate the spatial planning unit for our study areas.

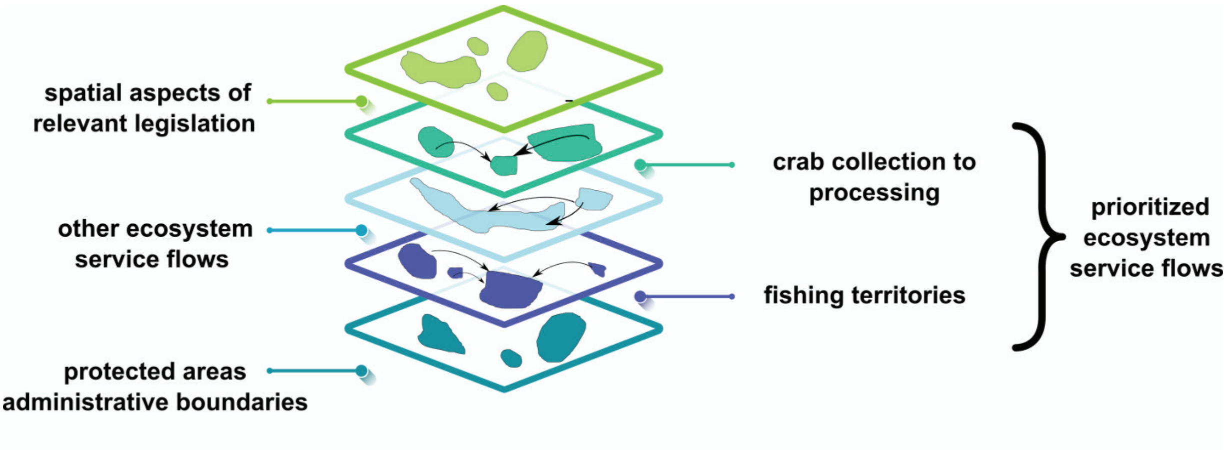


Figure 6. Aspects considered in the definition of a management planning unit.

Local knowledge might not provide the exact fishing grounds. However, this information comes directly from the users who perform these activities. While their perceptions might not portrait the reality of their movements with precision, it is important to analyze how these activities are depicted by these fishers, why they would tend to mention some places over others. In this study, we deliberately chose to not show specific fishing grounds or villages, but rather to point to trends in movements between the PAs. The movement trends are enough to make a case for the need for integrated management without the need to identify fishing grounds and villages and risk disclosing possibly sensitive information.

The GPS tracking was also very useful in establishing the mobility patterns within and between the PAs. With both methodologies, we delineated the fishing territories and analyze how they are distributed among neighboring PAs. It made us aware of the importance of two other PAs (in the municipalities of Augusto Corrêa and Viseu), plus the neighboring mangrove area in the municipality of Quatipuru. We were then able to incorporate these three other areas in the iterative consultation process at an early stage.

Figure 7 shows the five PAs whose spatial management i.e. zoning planning needs to be integrated, based on (i) priority setting through ecosystem service, (ii) an investigation on management perceptions, and (iii) the spatial dynamics of the crab fisheries value chain.

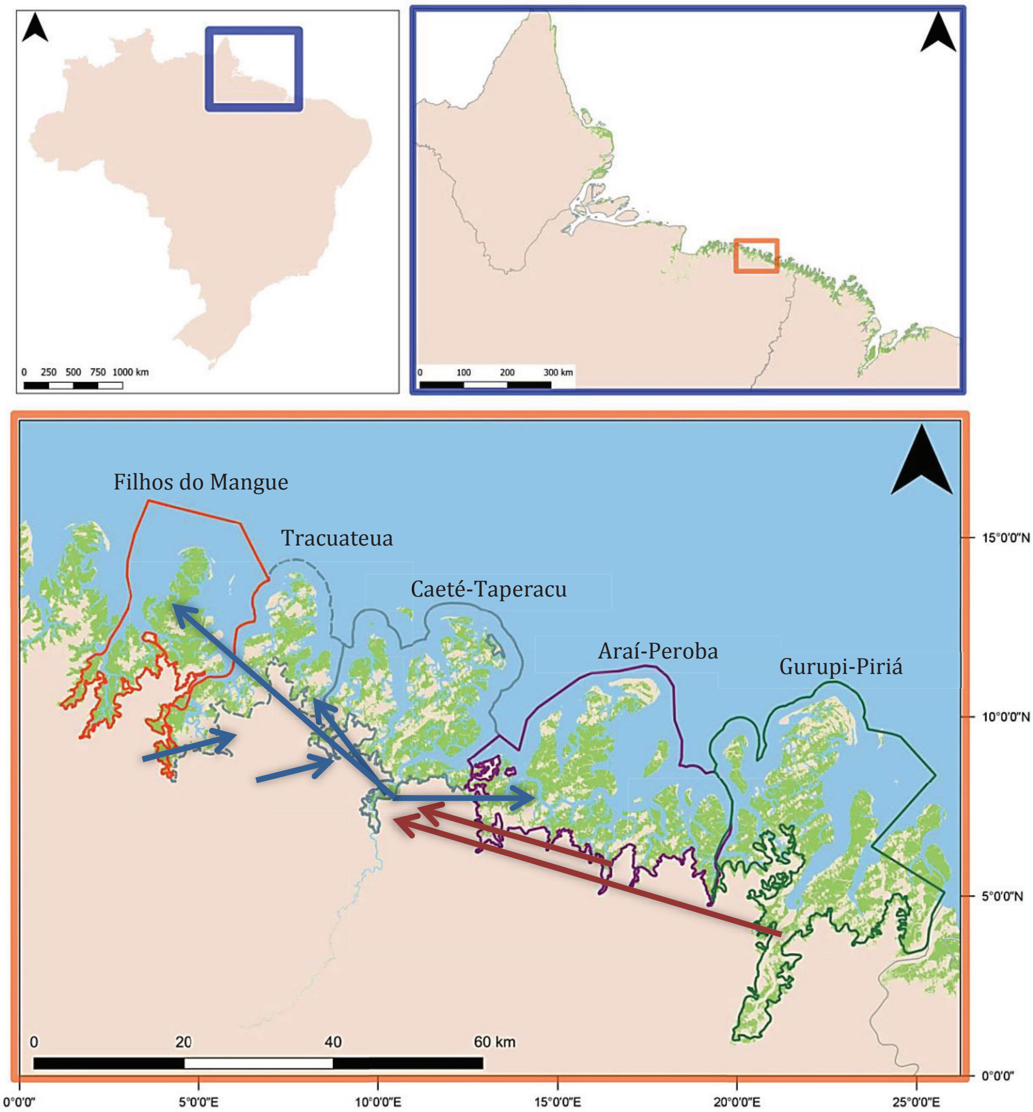


Figure 7. PAs to be included in the integrated management planning, according to the analysis of the most appropriate level. Blue arrows show examples of the movements of crab fishers from home village to fishing grounds. Red arrows show examples of cross-boundary transportation of crabs directed to processing.

Discussion

Our results concur with previous studies (Glaser 2003, Glaser and Diele 2004, Oliveira 2015, Fundo Vale 2018) which found the crab fisheries to be the most important economic activity in the Bragança region. The results also show the spatial interconnectedness between the Bragança and Tracuateua PAs, with regard to crab fisheries activities, following information provided by local stakeholders as well as the GPS tracking of the fishing routes. The results also show the differences in spatial dynamics patterns between the Bragança and Tracuateua PAs. Crab fishers from one of the PAs (Bragança) have a wider range of fishing grounds, which also extend into more nearby PAs, compared to Tracuateua[44].

Ecosystem services can be translated as benefits directly provided by nature to people. It is a simple language, which can be understood by different stakeholders, independently of formal education background. For our study, the ecosystem service approach was especially useful to investigate local populations in a system of sustainable-use PAs.

The results show the ecosystem services that seem to be most relevant to a wide range of stakeholders. The most frequently mentioned services were the ones that drive decisions regarding the management of the mangroves in this region. Therefore, focusing on these services, without neglecting others that might be prioritized by a minority, is a strategy to delimit the level of management, or, in this case, for the zoning of the Bragança and Tracuateua PAs. We, therefore, recommend a general investigation of most relevant ES in this region, in combination with an analysis of supply and demand areas, as we conducted in this study, within the design process of PAs and their integrated, cross-boundary management.

Some ecosystem services which are important to local stakeholders remain neglected by current management practices and even by research, such as the service “bird nesting” mentioned by our informants, a supporting service categorized as “habitat for

[44] These results could reflect relatively lower importance of the crab fisheries in the Tracuateua PA in terms of income generated per family.

species" by TEEB[45]. This service was also the target of conservation concerns, as expressed, for instance, in the Bragança PA's management plan.

Other services, such as cultural and recreational services, might not have been mentioned due to our open-ended-question approach. These services have already been identified to be often neglected in other mangrove areas in Brazil (Queiroz et al. 2017). In our study, cultural and recreational services can be glimpsed at in the words of some informants who mention the importance of the breeze, for instance. This overlaps with the service of local climate regulation, which has not been systematically assessed for mangroves yet. There is, therefore, some intertwining in the mentioning of ecosystem services, which reflect the nature of the cultural services category.

Environmental managers and researchers have different perceptions and priorities on ecosystem services management compared with ecosystem service users (García-Llorente et al. 2018). Like this study, they also found that different ecosystem service categories receive uneven attention in management plans. These contained measures to manage provisioning and cultural services whereas measures for managing regulating services were perceived to be largely absent (García-Llorente et al. 2018).

Sociopolitical boundaries can have substantial adverse effects on conservation because a lack of coordinated actions by those on either side of a boundary adversely impacts the efficiency and efficacy of ecosystem management. One way to lessen the effect of boundaries is to ensure that compatible ecosystem and biodiversity management policies and practices are adopted on both sides of a division (Dallimer and Strange 2015). Integrated management can serve to enable this management compatibility.

While these sociopolitical boundaries are still necessary, we argue that their negative impacts can be curbed by integrated management strategies that dialogue with institutions beyond those boundaries. We believe that zoning, as one of many spatial management instruments, can be an answer to address this challenge in the context of the mangrove belt in northern Brazil. Coordinating certain practices, such as the establishment of no-take areas for crab collection and fostering nursing habitat protection in border

[45] http://www.teebweb.org/resources/ecosystem-services/

zones, between the five PAs can be a first step towards strengthening the co-management arrangement, which is an essential element of this PA category.

The influence of a municipality as a hub of socio-economic activities in the region

Because of the processing plants in the municipality of Bragança, the mobility patterns point to an overwhelmingly unidirectional local flow of live crabs toward Bragança. Mobility patterns presented in Chapter 4 of this thesis and in this manuscript are crucial to highlight the overwhelming importance of the crab fisheries, the conflicts that might emerge, and the management perceptions that highlight the need for integrated management of the PAs that already and exist and the one to be created in Quatipuru.

When taking an integrated cross border connecting approach, as we propose here, further challenges could be addressed afterward, i.e. coordination with PAs and other management instruments outside these five PAs. At the same time, some mechanisms can only be approached at a lower level, such as the PAs or even the village level. One example is the village-managed zones, which were proposed or agreed to by stakeholders as a possible tool to prevent crab overfishing[46].

Bragança is also a hub for research and non-governmental organizations (NGOs) in the region. There is a clear concentration of scientific research, and the population is larger in Bragança than in the other coastal municipalities nearby (IBGE 2019a, 2019b). Furthermore, the office of ICMBio has its local office in Bragança, which also contributes to making this municipality into a hub for mangrove management, research, economic activities, and development aid. Holding the largest population and hosting the regional headquarters of public institutions and NGOs[47] highly contribute to Bragança's positioning as a regional hub and focus of attention.

In this study, we did not investigate the municipalities of Viseu and Augusto Corrêa but rather derived their importance through the research on the Bragança and Tracuateua PAs. Therefore, further research with the same methods is needed in these two municipalities to add specific demands and make adjustments to the proposed planning

[46] As previously mentioned, zoning strategies are available online: https://tinyurl.com/y3ndobsv

[47] Some examples are the Technical Assistance and Rural Extension Enterprise - EMATER and the "Comissão Pastoral dos Pescadores - CPP".

unit, such as adding or removing PAs. However, mangroves to the east of Viseu belong to the next federal state, which poses administrative issues in including them in the management block, although there are links to this neighboring state, as shown for the post-harvest crab fisheries.

Integrated management on the Pará coast

The regional level would be the best point of departure to generate sustainability-oriented cross-scale and multi-level analyses (Glaser and Glaeser 2014). Our results confirm this need for a regional level-perspective.

A promising example of border-crossing different sociopolitical divisions is the Integrated Management of the Maritime Waterfront Project ("Projeto Orla"), a joint effort between the Brazilian Ministry of Environment and the Federal Department of Heritage, tackles planning and management of coastal areas, especially areas under federal control, bridging the environmental, urban and heritage policies (Abreu 2015).

Regarding the management plan (Abdala et al. 2012), the methods for defining the zones in 2012 (whether through a prioritization exercise, using only the participatory mapping data or also other data resources, or whether the zoning received any feedback from local stakeholders, etc.) are unknown. The company responsible for the elaboration of the plan does not seem to exist anymore and cannot be contacted. Original shapefiles with the results from the mapping workshops and other spatial data presented in the management plan are not available. Also, the zoning already elaborated for the Bragança PA does not take into consideration possible interactions with other PAs.

Considering the connection of the areas through the mobility patterns of the fishers, we believe that an integrated zoning planning could alleviate some possible spatial conflicts, by creating, for example, areas co-managed by each village. These areas could be no-take zones, for crab collecting or for wood extraction, for instance.

Because monitoring is deficient, such a strategy would have to rely almost completely on peer monitoring. An area would have to be chosen that is approved by most affected users. All local users would need to thoroughly understand and frequently discuss the reasoning behind the creation of such an area. An attempt to create a no-take zone has been made which intended to set aside for research a small island in the Bragança, but this proposal was not approved by the PA's deliberative council (Marcos Fernandes, *personal communication*).

Two other management strategies that move toward integrated management are currently being implemented by ICMBio. One is the so-called management agreement, which establishes some common norms for the four existing PAs. Despite initial integrated discussions among the PAs, each area created its own agreement, which contains common norms for all the four areas. The elaboration of these agreements was concluded in 2015. However, only two of the four documents had been officially approved by the central management authority in Brasília in December 2018.

The second management strategy would be to constitute a management body for the four PAs, where each current manager would be a member and take over responsibility for one stream of management actions delineated in the management plan. These two ideas originated from ICMBio itself and have been recently put into practice. The delay in the ratification of the management agreement shows, however, how bureaucracy and other impediments at higher management levels might pose an obstacle to the development of fruitful ideas generated by direct managers on the ground.

As a recommendation for management, we turn to zoning and a broader spatial planning approach, which has been shown to be applicable in coastal areas to allocate human activities where conflicts are well-known and specified (Tuda et al. 2014). The overlap of buffer zones of the PAs requires integrated spatial management between them. These areas need clear spatial rules, to be established by the zoning of the PAs, as also required by law (BRASIL 2000). This includes the definition of zoning strategies for our case study PAs or revisiting these strategies (in the case of Bragança, which already has a management plan with zoning). To be legitimized by local users, these rules need to be built on existing, informal rules and practices.

Future research

We recommend a thorough examination of the whole production chain for the small-scale fisheries, especially for the crab fisheries. It is a very dynamic sector, on which probably many households depend. We also suggest research on how the creation of the PAs has been affecting the social-ecological systems, both in terms of social improvements and regarding environmental protection.

In terms of method, it is important to expand the knowledge on the relationship between spatial dynamics of ecosystem services and management of PAs by investigating contexts where other services are prioritized. For example, how would integrated zoning be operationalized in a situation where tourism is the prevalent service? What other services could have been neglected and why? How could these be included?

A follow-up would be to assess how to incorporate other levels of administration after departing from this initial spatial planning unit.

There is also an urgent need to investigate possible increases in crab demand, which has been previously observed in scenarios of low employment (Gomes 2018), such as the one observed nowadays. About 15 years ago, there was no evidence that the crab population was overfished, despite over 30 years of *de facto* open-access exploitation. Apparently, the selectivity of fishers and consumers for large male crabs as well as the local artisanal capture techniques have been key factors in preventing overfishing of the crab population until the beginning of the 2000s (Glaser and Diele 2004), but the situation might be different today.

Management implications related to the crab fisheries

Compared to the time right before the creation of the PAs, in 2005 (Araújo 2006), fishing villages are currently expanding their fishing grounds towards the other PAs. This search for better-suited resources is expected by Oliveira (2015). This author alerts that authorities should monitor fishing practices in these comparatively more intensively exploited zones. The mangrove crab fisheries in Bragança seems to be moving from a subsistence practice with low commercialization to a market-driven fishing activity, and crab stocks might be threatened (Oliveira 2015).

Our study shows that the threat of increased fishing might extend out toward nearby PAs, causing or intensifying territorial conflicts, such as those previously reported (Oliveira and Maneschy 2014), which might affect the much-needed cooperation between these neighboring reserves. The frequency of these cross-boundary trips remains to be quantified.

Conclusions

It is important for spatial management to locate fishing grounds and possible conflicts related to territorial use, during development, implementation and establishment phases. Fisheries spatial dynamics between PAs in a system could guide management strategies and their enforcement and success. This study showed that fishers from one municipality commonly fish in nearby PAs, regardless of administrative boundaries. Management attempts urgently need to implement this human behavior in their considerations and planning for achieving their respective management goals.

To identify an appropriate planning level, we applied an ecosystem service approach as an interaction language, which allowed us to investigate local values related to mangroves and neighboring ecosystems. Taking into account the fisheries mobility patterns and detailed information on the value chain of a major local fishery resource allowed us to suggest a geographic level at which spatial strategies can be jointly applied.

Our analysis of fishing dynamics shows that fishing territories do not match the municipality-based design and implementation of the PAs. To alleviate this issue, we propose a series of integrated management strategies which extend beyond the borders of the individual PAs and aim for curbing a possible overfishing scenario, which is currently perceived by the fishers. This needs to be integrated into marine spatial planning practices in order to be able to plan resource use sustainably.

Authors' contributions

R.B. conceptualized the paper, collected field data, performed the analyses, and wrote the manuscript. A.S. wrote sections of the manuscript. R.B.S., M.A., and M.G. helped design the paper and re-structure the analyses and presentation of results.

Acknowledgments

R.B. is grateful to CNPq for the scholarship to perform the doctoral research (process 290055/2014-8) and to the Rufford Foundation (20310-1) for a small grant that contributed to the fieldwork. R.B. also is thankful for the support by GLOMAR - Bremen International Graduate School for Marine Sciences, University of Bremen, Germany. R.B. is grateful to Dr. Marie Fujitani, who helped conceive the analysis regarding the different groups of informants. The authors are grateful to Theresa Schwenke for revising an earlier version of this manuscript.

Research authorization

The research was approved by ICMBio (Sisbio process number 36427147).

Ethics statement

We followed the Code of Ethics adopted by Brazilian universities. Accordingly, participants in the study, including informants and fishers carrying GPS devices, were informed about the purpose of the questionnaire as well as data use and diffusion. We obtained verbal consent from participants prior to conducting surveys and from GPS carriers before their fishing trips. Answers were recorded anonymously, and individual informants cannot be identified in published material or other publicly available records. Whenever possible, we also recorded personal contact information to facilitate restitution of results to participants. This restitution activity started with the awareness-raising project[48] and will continue following the conclusion of the project.

Funding

R.B. is grateful to CNPq for the scholarship to perform the doctoral research (process 290055/2014-8) and to the Rufford Foundation (20310-1) for a small grant that contributed to the fieldwork.

[48] A project funded by the Rufford Foundation through their small grants program.

Chapter 6

General Discussion

Literature references can be found at the end of this thesis.

In this thesis, it was analyzed how multiple data collection and assessment methods, including participatory mapping, and GPS tracking can be combined for integrated management of protected areas, having as focus study areas two extractive reserves in northeastern Pará, Brazil.

The “integration of knowledge for integrated management” was investigated by focusing on what was identified as key aspects for the elaboration of the spatial management strategies for these areas: 1) the identification of local conservation priorities; 2) a better understanding of the spatial dynamics of the prioritized uses, i.e., in the study case, the crab fisheries; and 3) the delimitation of an initial geographical planning unit. A summary with key aspects (title, state of the art, methods, and results) of the manuscripts presented in this thesis can be found in the Supporting Information III.

In the following paragraph, the questions raised by this study are being presented again and discussed in light of the study results.

What does the current mangrove spatial management landscape in Brazil look like?

In light of the recent threats emerging from changes in legislation and the deficient availability of spatial and social-ecological integrated data to plan mangrove conservation in Brazil, Chapter 2 (Borges et al. 2017) discusses (1) the suitable measures that managers and other decision-makers could adopt for efficient mangrove conservation planning, (2) the site-specific, social-ecological aspects that need to be taken into account when deciding on conservation and management strategies, and (3) how science could contribute to the development of these measures.

Chapter 2 (Borges et al. 2017) highlights that, in order to achieve ecosystem-based management, mangrove ecosystems should not be divided into sub-systems, as was recently embedded in the new Forest Code (BRASIL 2012). They need, instead, to be considered and managed as an integrated system. Furthermore, interconnections with other coastal ecosystems must be assessed and taken into account. This is crucial for effective systematic conservation planning. Also, most of the particular social-ecological aspects in the different types of mangrove ecosystems along the Brazilian coast, and how those differences might be considered while planning for conservation, remain poorly understood. Based on similar drivers of change, geological features, and likely impacts of climate change, this paper also proposes a macro-unit approach to group mangrove systems along the Brazilian coast and guide national policies.

The discussion shows that most of the particular social-ecological aspects, such as stakeholder participation or the provision of ecosystem services, in the different types of mangrove ecosystems along the Brazilian coast remain poorly understood, as well as how those differences might be considered while planning for conservation. The discussions in the manuscript consider the issues of legal vulnerability and needs for social-ecological data on mangroves and contribute toward systematic conservation planning and ecosystem-based management for these ecosystems.

What are the benefits of combining different knowledge systems, including participatory mapping and GPS tracking, for spatial planning management?

Chapter 4 investigates the current fishing territories in two adjacent protected areas in northern Brazil, and how they connect to crab size and crab demand. This study is based on semi-structured interviews, focus group discussions, and workshops, all of which were supported by a participatory mapping exercise with local stakeholders. Routes used by crab fishers in the mangroves were also tracked using GPS loggers and analyzed. Based on the stakeholders' perceptions and the tracked routes, maps of the mangrove crab fishing grounds were built. The findings highlight the importance of investigating the fishing grounds and routes used by fishers in the mangroves in order to design management measures and contribute to the development of participatory mapping techniques and spatial planning tools for integrated management.

Local knowledge, which we investigated through the participatory mapping, has been shown to provide reliable data for management. Based on a case study in Brazil, for instance, information provided by fishers on species occurrence accurately predicted species distribution and can be useful for, e.g., marine spatial planning (Lopes et al. 2018). This manuscript shows that a combination of local and technical knowledge can help identify fishing areas and the origin of the crab demand for each area. These data could, in turn, be included in zoning planning and into the development of fisheries management strategies.

The data used in this manuscript are also important to identify possible conflict areas, areas that could be assigned as no-take zones, areas where monitoring should be reinforced, etc. Embedding a conflict lens as part of the implementation of a marine spatial planning process could have transformative potential (Flannery et al. 2016). Planners need to confront issues of power and exploitation because the system of marine spatial planning that has been promoted as a way of managing the conflicts that inevitably arise (Flannery et al. 2016). In this research project, data on conflict were also obtained and will be explored in further publications.

Regarding the crab fisheries in our study region, the results revealed that crabs tended to be larger if caught farther away from the villages. Population density and proximity to markets help explain fisheries exploitation level and thus need to be considered in the development of resource-management strategies (Cinner and McClanahan 2006, Brewer et al. 2013).

Can the spatial dynamics of small-scale fisheries value chain help determine the most appropriate level for the spatial management of a network of protected areas?

Regarding the topic of spatial management and drawing on the results of the previously mentioned papers on the dynamics of the crab fisheries, Chapter 5 discusses the most appropriate level to tackle fisheries challenges in these protected areas. Coupling of different tools and methodologies that investigate the spatial dynamics of the ecosystem services locally recognized as the most relevant ones for local users can provide insights into how to identify the appropriate geographic level for integrated, spatial management. The reasons why the planning unit indicated constitutes a social-ecological planning unit for protected area zoning are exposed, as well as recommended integrated spatial management strategies. The results show that the spatial dynamics of crab fishers connect the two reserves: crab fishers move across these protected areas. This can lead to overexploited fishing grounds and conflicts between fishers.

The exercise where we asked stakeholders for their views on current and/or possible zoning strategies tested our hypothesis that small-scale fisheries dynamics could provide insights on how to determine the best level i.e. the boundaries of a planning unit for the spatial management of protected areas, even regarding issues that extend beyond the fisheries context. Besides, this exercise provided applicable recommendations for the integrated zoning of these areas.

This investigation aimed to alleviate the level mismatch between the administrative geographical region of the extractive reserves and the dynamics of fisheries and other resource uses and even biodiversity aspects present in the region. It concluded that the ecosystem service approach was helpful in identifying priorities to find the appropriate level for spatial planning and management and to access more easily the perceptions of direct users.

This research proposes a framework to improve integrated management strategies. Light is shed on at which level integration is more direly needed. For the case study, the spatial management of the five protected areas in northeastern Pará (Filhos do Mangue, Tracuateua, Caeté-Taperaçu, Araí-Peroba, and Gurupi-Piriá) should be done in an integrated manner.

Such integrated zoning is important because:

a. Fishers' territories do not correspond to the political boundaries of the protected areas or of the local municipalities;
b. There are areas around the borders, especially islands, which are intensively used by the local populations, regardless of management jurisdiction and of whether users have formal authorization to exploit these areas (e.g. Guará and Canela islands);
c. Buffer zones overlap with the neighboring protected areas; and
d. Social and economic developments in neighboring municipalities directly affect all these five reserves.

Together, these manuscripts contribute to the theory of mangrove management level. Chapter 2 highlights the need for a regional approach to mangrove spatial management and planning as part of a national strategy ("top-down"). Chapter 5 advocates for a region-level zoning of mangrove PAs, which are local and co-managed conservation tools ("bottom-up"). These two complementary approaches support the need for multi-level, polycentric marine governance and decentralized management. Polycentric systems are characterized by multiple governing authorities at differing levels (Ostrom 1999). Also for small-scale fisheries, polycentrism in governance can help achieve sustainability and adaptive capacity (Gelcich 2014).

Criticism of spatial planning and management

Not only spatial planning processes are critically viewed by scientists and managers, but protected areas in general. The creation of a reserve, regardless of where it is, does not seal the fate of local people or guarantee the biodiversity and resource conservation of an area (Pomeroy et al. 2001). Excluding communities living in reserves from the development of management plans may lead to social and ecological failure (Pomeroy et al. 2001).

Linking knowledge to action requires not only open channels of communication between technical/academic experts and decision-makers but also that participants in the resulting conversation understand each other. A mutual understanding between technical/academic experts and decision-makers is often hindered by jargon, language, experiences, and presumptions about what constitutes a persuasive argument (Cash et al. 2003).

Knowledge is more effectively linked to action when a serious commitment is made to managing boundaries between academic expertise and decision making, by investing in communication, translation, and or mediation and, thereby, more effectively balanced salience, credibility, and legitimacy in the information they produced (Cash et al. 2003). Fisher's knowledge, like any other type of knowledge, does not have to be considered uncritically. It should be analyzed and interpreted by comparing it with other types of data, such as biological (Damasio et al. 2015). Both local and technical knowledge systems are complementary sources of information (Damasio et al. 2015) and can support processes such as marine spatial planning (Lopes et al. 2018).

Research performed in our study areas does not necessarily return to the communities in the form of policy changes and livelihood improvement. However, a return, in a simple language, in the form of concise information packages about what kind of research was developed needs to be more encouraged in these areas. The interviews show that stakeholders are being over-surveyed and getting skeptical about the reasoning behind the investigations and their use and benefits for society as a whole. This is what motivated the implementation of the project "*Mangrove Spatial Management*", funded by the Rufford Foundation[49].

The ecosystem-based approach aims at enhancing trust and avoiding the arrogance of a single ex-ante "right approach," which frequently overrides the contribution of indigenous peoples, local communities, and practitioners in the context of assessment programs and development projects (Tengö et al. 2014).

Also, more importantly than successfully designing a zoning plan, social-ecological systems need to be strengthened in their capacity to learn, adapt, and innovate. Uncertainty and unpredictability are characteristics of all ecosystems, including managed ones (Berkes et al. 2000). In both cases, social learning appears to be the way in which societies respond to uncertainty (Berkes et al. 2000). Often this involves learning not at the level of the individual but social learning at the level of society or institutions. Adaptive management is designed to improve on trial-and-error learning (Berkes et al. 2000) and represents the answer to improve the efficiency of co-management strategies.

From the mapping experience in Scotland in the context of the implementation of marine spatial planning, one main critique of maps can be drawn: due to the necessary procedure of categorizing and simplifying data, maps do not always accurately represent changeable marine environments and situations. This process inevitably involves simplification and best-fit practices, as the full spectrum of an area's characteristics cannot be represented on a map (Smith and Brennan 2012).

Maps have the potential of not only informing us of the state of a marine space but also making space become what is depicted (Smith and Brennan 2012). As such, maps need to be as well informed as possible and stories that marine space users have to tell count towards this information, which is an important step in reducing the dominance of science in map-making (Smith and Brennan 2012). In this study, we only began to report on these

[49] "Spatial Planning in Brazilian Mangroves: Promoting Awareness of Zoning Strategies in Protected Areas" at https://www.rufford.org/projects/rebecca_borges

stories told by marine users, and further studies are needed to incorporate more of this knowledge in the spatial management of our study areas.

There is a need for a broader, more critical, understanding of the social and distributive impacts of marine spatial planning, requiring a radical turn in spatial planning away from a dominance of scientific rationalism and a neoliberal-oriented logic towards more equity-based, democratic decision-making and a fairer distribution of our ocean wealth (Flannery et al. 2016). Finally, Flannery et al. (2016) argue for a spatial planning process that embraces different world views, in ways that can actually go some way to achieving the sectoral harmony which the model tries so hard to achieve.

Actors who only interact with their own subgroups easily develop their own subcultures with a sense of "us and them", and different and often incompatible perceptions of the problems at hand and how to best solve them emerge between the subgroups (Borgatti and Foster 2003). Furthermore, participatory processes can also backfire and become ''talking shops'' that create ambiguities and delay action. This has been observed in lake conservation decision-making (Vedwan et al. 2008), in land-based zoning processes (Bojórquez-Tapia et al. 2004), in more recently in marine spatial planning (Jones et al. 2016).

Knowledge systems and data collection methods

The most important applicable result of this thesis is the introduction of different data collection methods to inform spatial planning and management in the sustainable-use mangrove forests.

Inter- and transdisciplinary science and participatory management through an integration of knowledge systems proved essential to the development of this research. The Sustainable Development Goals of the United Nations[50] also require partnerships amongst science and technology communities and indigenous peoples and local communities.

As pointed out by Cash et al. (2003), our study also suggests that efforts to mobilize science for sustainability are more likely to be effective when they manage boundaries between knowledge and action in ways that simultaneously enhance the credibility, and

[50] https://www.un.org/sustainabledevelopment/

legitimacy of the information they produce. Effective systems apply a variety of institutional mechanisms that facilitate communication, translation, and mediation across boundaries.

Other studies also observed that technical data, coupled with available mapping of fishing grounds exploited by southeastern Brazilian coastal fishers (Begossi 2001, Begossi and Silvano 2008, Silvano and Begossi 2012), could and should support the future establishment of exclusive areas for artisanal fisheries, as part of a broad coastal zoning system. This would reduce fishing pressure in exclusive areas by other resource users, therefore reducing social conflicts.

Further studies with more comprehensive and representative participation by local stakeholders are needed to complement the investigation presented in this thesis. We recommend a follow-up study where a higher number of months are covered for the GPS tracking, with a more systematic approach to capture seasonal differences.

Perspectives for national fisheries and protected area management

The extractive reserve model, based on co-management and a case study of collective action theory (Partelow et al. 2018), can be seen as more permissible to change than many other protected area categories. The protected area deliberative council, composed of representatives of the villages, the university, and other public or non-profit organizations and authorities, has, in theory, the possibility to tackle or prevent issues such as overfishing and territorial conflicts.

Economic crises and subsequent unemployment and impoverishment introduce further pressures on resource use from mangroves and uncertainty about the success of preservation and rehabilitation efforts in some places (de Lacerda et al. 2019).

However, in reality, ICMBio seems to still be the protagonist in deciding on and taking actions such as monitoring. Until 2018, it was represented by one single civil servant for the whole protected area, assisted by another employee who also works for a number of other protected areas in the region. A lot of the workload is related to bureaucratic tasks and assistance to projects developed in the area by third-party organizations. Even though there is a general interest for research and applicable results, the managing structures are overloaded with work and in a difficult position to revisit the management plans, zonings, or action programs, even though very little of it has already been put into practice.

Small-scale fisheries encompass the wide-ranging activities along the value chain, including harvesting, pre-, and post-harvest labor performed by both men and women, and which play an important role in food security, income generation, and poverty alleviation (FAO 2015). The emergence of the crab meat processing plants poses a question about the possible Scaling-up of artisanal fisheries and about when traditional practices change due to market pressures. These processing plants are also formally acknowledged as "traditional" practice, but they represent the possibility of an increase of crab meat demand, especially coming from outside Pará.

Because ICMBio and IBAMA are federal organs, politics at the national level play an important role in defining the future of local fisheries management. According to fisheries scientist Ana Helena Bevilacqua[51], "[t]he future is gloomier than ever for [Brazilian] stocks and […] fishers, and initiatives that aim to reach sustainability will have to come from grassroots movements and other societal initiatives."

The reasons for mistrust in the current national government are changes implemented in the first days after the inauguration of the current far-right government. This new administration turned decisions on aquatic species management over to the hands of the productive sector, which is dominated by the powerful large-scale fisheries industry. Bevilacqua quotes the current head of the Department of Aquaculture and Fisheries: "We now have a strong base to strengthen fishing and aquaculture throughout Brazil. Our people can consume more fish. We have to boost not only the catch but much more fish farming. We have a lot to grow!" and concludes: "From the current government we should only expect larger nets, smaller mesh sizes, and bad subsidies."

Despite the effort to achieve the Aichi Target 11 by 2020 regarding marine areas, Brazil is very far from it (the country currently has 1.5% of its exclusive economic zone protected, opposed to the 10%-target). Moreover, the national marine protected system is flawed, and its effectiveness is debated (Gerhardinger et al. 2009). In order to meet this target, Brazil has sped up the process of creating extremely large marine protected areas[52]. The APAs Trindade e Martim Vaz (approx. 472 thousand km^2) and São Pedro e São Paulo

[51] http://feme-group.blogspot.com/2019/03/brazilian-fisheries-management-musical.html
[52] https://www.socioambiental.org/pt-br/noticias-socioambientais/brasil-pode-aumentar-em-mais-de-15-vezes-area-marinha-protegida

(approx. 415 thousand km^2) have indeed been created in 2018[53], making the total marine area protected jump from 1.5% to approx. 26% of the Brazilian Exclusive Economic Zone. The efficiency of having almost all of its coastal-marine protected area concentrated into two immense and recently-created conservation units, which fall into the sustainable-use categories, remains in question.

[53] https://tinyurl.com/y58fqugy

Supporting Information I. Motivations for this research

This research follows-up my master thesis project on the marine spatial planning of the South Australian coastal protected areas (Borges 2013). In this master research, I investigated the caveats of performing spatial prioritization considering administrative planning units and not accounting for integrated management. In this doctoral thesis, I move on to investigate further aspects of integrated management, moving from a technical prioritization lens to a more holistic approach.

The main topics to be investigated in this thesis emerged from, on the one hand, my own expertise in marine spatial planning and, on the other hand, demands voiced during the event "Dialogue between Communities and University" hosted in November 2015 at the Federal University of Pará (UFPA) in Bragança, northern Brazil. Main concerns raised by local stakeholders were selected and matched with my expertise. Throughout the few months that followed this event, the topics raised were further narrowed down into what could be realistically approached in the timeframe of a doctoral research project.

This research also builds on the work initiated by the Mangrove Dynamics and Management (MADAM) project, which took place in the Bragança region between 1995 and 2005 (Saint-Paul and Schneider 2016). Following with initial research on spatial dynamics of small-scale fisheries and management, I decided to focus this scientific project on the spatial aspects of management in two of the extractive reserves in NE Pará, the Tracuateua and Bragança extractive reserves (RESEXs).

Not all papers produced from the data collected during the PhD work are shown in this thesis. Also, collaboration papers emerged from this research. Some examples are:

1. de Lacerda L., Borges R, Ferreira A. (2019). Neotropical mangroves: conservation and sustainable use in a scenario of global climate change. Aquatic Conserv: Mar Freshw Ecosyst, 1–18. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1002/aqc.3119

2. Borges R. Eyzaguirre, I, Barboza, R, Glaser M. (*in Preparation*) A multi-level, systematic review of spatial planning and management in marine protected areas.

3. Borges R, Barboza R, Glaser M., Wolff M., Lopes, P. (*in Preparation*) Do fishers travel longer distances to fish larger crabs?

4. Borges R, Barboza R, Breckwoldt A, Glaser M. (*in Preparation*) Challenges and opportunities related to local perceptions and attitudes for effective zoning of sustainable-use protected areas.

Supporting Information II. Area and population in the municipalities of Bragança and Tracuateua.

Table 1. Geographical areas of the municipality investigated, including their mangrove and protected areas. 1: (IBGE 2019a, 2019b); 2: calculated using (Giri et al. 2011) data; 3: ICMBio data[54].

municipality	total area (km^2)[1]	mangrove area (km^2)[2]	protected area (km^2)[3]
Bragança	2,091.93	152.66	424.89
Tracuateua	934.27	90.16	278.64

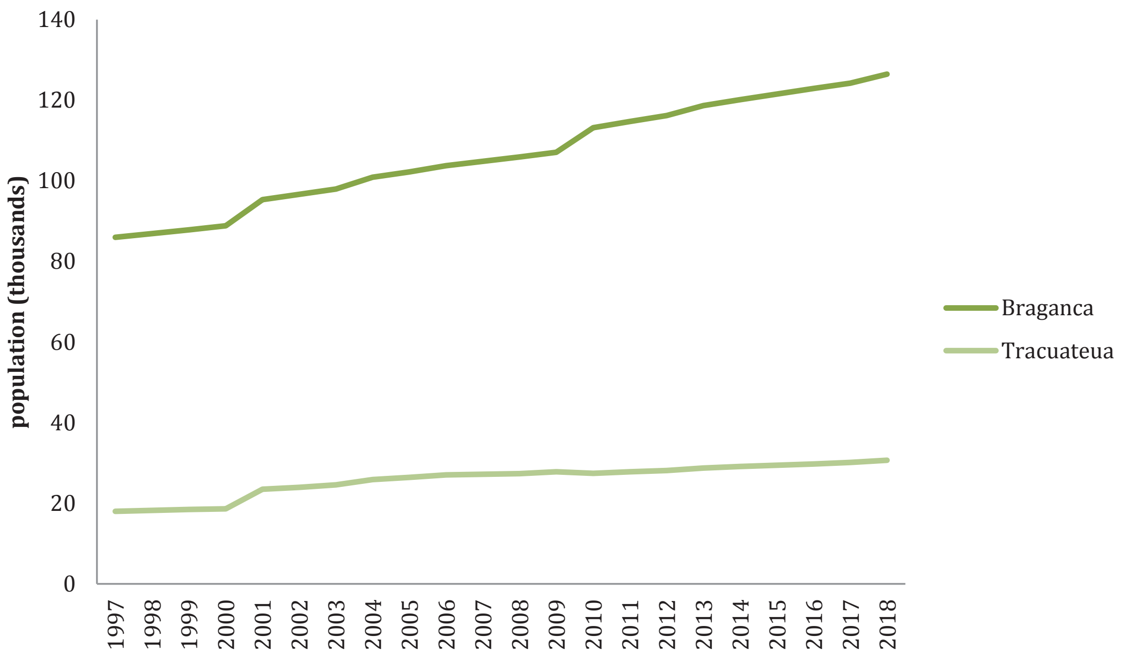


Figure 1. Population growth in Bragança and Tracuateua between 1997 and 2018. Data source: (IBGE 2019c)

[54] http://www.icmbio.gov.br/portal/unidadesdeconservacao/biomas-brasileiros/marinho/unidades-de-conservacao-marinho/2107-resex-marinha-de-caete-taperacu
http://www.icmbio.gov.br/portal/unidadesdeconservacao/biomas-brasileiros/marinho/unidades-de-conservacao-marinho/2293-resex-marinha-de-tracuateua

Supporting Information III. Overview of the main aspects of the manuscripts

article	state of the art	objectives	data	key-findings
Systematic Planning and Ecosystem-Based Management as Strategies to Reconcile Mangrove Conservation with Resource Use	Threats have recently emerged from changes in legislation and the lack of spatial and social-ecological integrated data to plan mangrove conservation in Brazil.	Identify (1) suitable measures for efficient mangrove conservation planning, (2) the site-specific, social-ecological aspects to be taken into account for conservation and management strategies, and (3) how science could contribute to the development of these measures	Review of literature	Most of the particular social-ecological aspects in the different types of mangroves in Brazil remain poorly understood, as well as how those differences might be considered while planning for conservation. There is legal vulnerability and the need for social-ecological data on mangroves in order to support systematic conservation planning and ecosystem-based management for mangroves.
Combining spatial knowledge systems and collection methods helps understand the spatial dynamics of data-deficient small-scale fisheries systems	Small-scale fisheries often have poor monitoring systems, to overcome this data deficiency, local knowledge has been put forth as a possible solution, but there is little research on how local knowledge can be combined with other knowledge systems for management.	Investigate the fishing territories in two adjacent protected areas in northern Brazil and to analyze the benefits and constraints of combining different knowledge systems in the mapping of mangrove resource use in these sustainable-use protected areas	GPS tracking, participatory mapping data, and literature data	Different tools and methodologies were coupled to investigate the spatial dynamics of the crab fisheries. The benefits of integrating local and technical knowledge and the possible caveats of each dataset are discussed, as well as possible implications on stakeholder engagement.

Spatial dynamics of small-scale fisheries and integrated zoning of coastal protected areas	Zoning inside protected areas are also rarely the object of scientific research and adopting an applied approach to investigating the development of such a spatial plan	Analyze the roles of knowledge systems can support an interactive and iterative process of spatial planning design with local stakeholders for protected area zoning and identify applicable outcomes for integrated management, e.g. delimitation of planning level	Participatory mapping related to zoning, information from interviews on the crab value chain	The spatial dynamics of crab value chain connect the Bragança and Tracuateua reserves: crab fishers move across these protected areas in search of more abundant and larger-sized resources. Integrated spatial management strategies for the protected areas are suggested. These protected areas seem to be the most appropriate planning block for the construction of a protected area zoning plan.

Supporting Information IV. Detailed information on research informants

Table 1. Number of informants in the interviews, according to fieldwork phase, user type, and interaction type. Direct users are those who extract resources from the reserve area.

Field phase	user type	interaction type	approx. number of participants
I	direct and indirect	participant observation of a local event	50
II	direct	focus group interview	15
		individual interview	32
	indirect	individual interview	31
	direct and indirect	survey	91
III	direct	focus group interview	4
		workshop	45
	indirect	focus group interview	8
total			276

Table 2. Number of informants (first field phase, and random interviews excluded), according to municipality and village.

municipality	village	number of informants
Bragança		87
	Acarajó	3
	Ajuruteua	1
	Bacuriteua	2
	Belem	3
	Bonifácio	7
	Bragança sede	21

	Cajueiro	2
	Caratateua	1
	Castelo	3
	Quatipuru-mirim	1
	Santa Tereza	1
	Tamatateua	16
	Treme	11
	Vila Cuera	13
	Vila dos Pescadores	2
Tracuateua		48
	Belem	1
	Boa Vista	2
	Boa Vista cidade	1
	Bragança sede	1
	Cigano	1
	Cocal	1
	Cueiras	1
	Fleixal	3
	Flexeira	1
	Jurussaca	1
	Mimi	2
	Nana	3
	Porto da Alemanha	1
	Quatipuru-mirim	13

	Santa Tereza	1
	Sessenta	1
	Tracuateua sede	14
total		**135**

Table 3. Number of informants (first field phase, and random interviews excluded), according to gender and group.

gender	**informant group**	**number of informants**
female		23
	academia	11
	administration	2
	direct users	7
	others	3
male		54
	academia	10
	administration	6
	users' association	1
	direct users	34
	others	3
mixed groups		58
	academia	2

	users' association	2
	direct users	51
	others	3
total		135

Supporting Information V. Interview guide - Phase 2[55]

Informant: Date: Location:

Can I record the interview?

Part I - Introduction

This questionnaire is an important part of my doctoral project. I am grateful for your participation. The information provided herein is restricted to use in doctoral research. By answering it, you agree to this use, including posting the data in the context of the survey. The survey ensures informant anonymity and will not disclose individual results with informant identification. There are no right or wrong answers. All the information you provide is important. Thank you!

Part II - Questions

1. What is your name?

2. What do you work with?

3. For how long?

4. Where do you live?

5. How long have you lived in the region?

6. Level of education:

[55] For the interview guide in Portuguese, please visit: https://docs.google.com/document/d/1fjw5Bjq_HaSVYzYYxe8MoiwuUU19PBSwF_Q6Uk2Use4/edit?usp=sharing

7. Considering the mangroves in the region, what are the benefits / good things they provide?

8. Could you locate these benefits here on the map, where they come from (source)?

9. What about the people who benefit?

10. What are other activities performed in the mangroves of the region?

11. If you perform activities (fishing, tourism, etc.) in the region, where do you perform these activities?

12. What are the following things[56]? Could you locate these areas?

a) emburuteua

b) cabeceira

c) furo

d) igarapé

e) lago, lagoa

f) mangal

g) ninhal

h) ostral ou ostreiro

i) banco de mexilhão (mussel bank)

13. Are there any activities that should be prohibited/restricted to some area / limited? Which are? Why?

14. And what should be encouraged? What is missing? What could happen more? Why?

15. What is RESEX?

16. What is the RESEX's role?

17. Where is the RESEX? How is it known (name)?

18. Are there any other RESEXs in the region?

19. Are there different areas, for different purposes, within RESEX? Or is it all the same?

[56] These terms are local ones. They cannot be properly translated into English, nor there is a need to.

20. What changes have occurred in and around the RESEX area (since the creation of RESEX)? For the better? And for the worse?

21. What if the sea changes? If it moves forward, for example, what will happen to the mangroves?

22. Is nature in RESEX threatened? How?

23. And the road? Did it have an impact (the construction or current impacts)?

24. What about these threats on this list (Fontavo-Herazo 2004)? Do they still exist?

a) decrease in size and quantity of fishery products

b) increased extraction of fishery resources; commercial value fish, crabs, mussels, lobsters

c) cutting of secondary forest areas (capoeiras)

d) increased pressure on the ecosystem caused by the immigration of people

e) death of mangroves during the dry season

f) burnings in seasonally flooded fields (natural fields)

g) increased pollution and environmental deterioration

h) changes in coastal dynamics: beach erosion, current flows

i) use of predatory fishing techniques

j) cutting mangrove areas

k) mangrove use conflicts

l) loss of soil productivity

25. Are there areas that cannot be accessed? Are there areas where people from certain communities cannot enter? Are there any other rules that have always existed? Not on paper or not from the government? Can you locate these areas on the map?

26. Are there also things that protect nature against these threats?

27. What could be done to solve these problems?

28. How is the management of the RESEX?

29. Who is responsible for the RESEX?

30. Is the RESEX well known to people (community members, managers)? Do they understand what RESEX is?

31. Is the region / the RESEX well researched?

32. Is research good for the region / the RESEX? And for the local population?

33. Does research go back to the community? Do local residents understand the research done here?

34. Have you ever been interviewed about the RESEX?

35. Do you suggest someone who might or would be interested in answering this questionnaire?

Supporting Information VI. Survey with randomly-chosen informants - Phase 2[57]

Informant: Date: Location:

Can I record the interview?

Part I - Introduction

This questionnaire is an important part of my doctoral project. I am grateful for your participation. The information provided herein is restricted to use in doctoral research. By answering it, you agree to this use, including posting the data in the context of the survey. The survey ensures informant anonymity and will not disclose individual results with informant identification. There are no right or wrong answers. All the information you provide is important. Thank you!

Part II - Questions

1. What do you work with?

2. For how long?

3. How long have you lived in the region?

4. Considering the mangroves in the region, what are the benefits / good things they provide?

5. Regarding the activities performed in the mangroves of the region. What are the most important ones?

6. If you perform activities (fishing, tourism, etc.) in the region, where do you perform these activities?

7. Are there any activities that should be prohibited/restricted to some area / limited? Which are?

[57] For the interview guide in Portuguese, please visit: https://docs.google.com/document/d/19xCE69OswlGeOj8UKi_dNJRPA6O3e8EbTLoQSEV7gBY/edit?usp=sharing

9. And should they be encouraged? What is missing or still little happening?

10. Is the nature of the region's mangroves threatened? How?

11. Are there conflicts/disputes/ rivalry in resource use in the region's mangroves? Which ones?

12. Are there also things that protect nature against these threats?

13. Are there areas that cannot be accessed? Are there areas where people from certain communities cannot enter? Are there any other informal rules?

14. What could be done to solve these problems (actions for conservation / sustainable management)?

15. Have you heard about RESEX?

16. What is this RESEX?

17. Where is the headquarters of the RESEX?

18. Are there any others?

19. Have there been changes?

20. How is the management of the RESEX?

21. Who is responsible for the RESEX?

22. Is the RESEX well known to people (community members, managers)? Do they know what the RESEX is?

23. Is the RESEX / region well researched? Have you ever been interviewed?

24. Is the research good for RESEX / region (for Nature)? And for the local population?

25. Does research go back to the community? Do local residents understand the research done here?

Supporting Information VII. Interview guide - Phase 3[58]

Date: Location: Number of participants:

Can I record the workshop?

<u>Part I - Introduction</u>

[58] For the interview guide in Portuguese, please visit: https://docs.google.com/document/d/1C0tkhC6TJz_x-rt40i1E_PUGVJuQf80Yg5ZliiJFidA/edit?usp=sharing

This questionnaire is an important part of my doctoral project. I am grateful for your participation. The information provided herein is restricted to use in doctoral research. By answering it, you agree to this use, including posting the data in the context of the survey. The survey ensures informant anonymity and will not disclose individual results with informant identification. There are no right or wrong answers. All the information you provide is important. Thank you!

Part II - Questions[59]

Questions 2nd phase of field work

* Showing preliminary results *

1. What do you work with?

2. What is the best price for fish or crab?

3. Where will people go fishing? From which villages?

4. Are fishing grounds changing?

5. How long do you stay in the mangrove crab?

6. Do you see the difference in size?

7. Can the crab end?

8. And how is the fish?

9. Where do people get crab?

10. Do people get “sururu”?

11. Do people take oysters?

12. Do people get wood?

13. And the “andada”? Is it effective?

14. What do you think you should do to improve the fishing situation?

15. Do you have bird litter?

[59] These are mere examples of the questions asked. For this fieldwork phases, the questions were much more flexible and varied from village to village and from municipality to municipality, especially because the Bragança PA already has a zoning plan, while the Tracuateua PA does not have one yet.

16. Where do people like to do tourism?

17. Why don't people use the mangrove swamps nearby to get the crab?

18. Is the shrimp shrinking?

19. How was the management agreement?

20. How is RESEX today?

21. Who is the president?

22. Anything that could be done to change the Bragança PA?

* Discussing zoning *

Comparing with the zoning of other RESEXs.

1. What do you think about these zoning?

2. What do you think about Bragança PA zoning? (Show map of the zoning).

3. Has the community made been protecting other areas?

4. What area do you think is a protected area or are you not in favor?

5. Do you have areas that are tourist hotspots?

6. Could something be done to improve as an untouchable zone?

7. What is the protection of rioters like? Have a rule?

8. What about mangrove recovery?

9. Should there be fishing control?

Supporting Information VIII. Research authorization

The research authorization from *the Sistema de Autorização e Informação em Biodiversidade* - SISBio is presented in the following pages. Sisbio is the ICMBio system that emits authorizations for research performed inside ICMBio-managed protected areas.

Ministério do Meio Ambiente - MMA
Instituto Chico Mendes de Conservação da Biodiversidade - ICMBio
Sistema de Autorização e Informação em Biodiversidade - SISBIO

Autorização para atividades com finalidade científica

Número: 54919-1	Data da Emissão: 08/08/2016 09:26	Data para Revalidação*: 07/09/2017

* De acordo com o art. 28 da IN 03/2014, esta autorização tem prazo de validade equivalente ao previsto no cronograma de atividades do projeto, mas deverá ser revalidada anualmente mediante a apresentação do relatório de atividades a ser enviado por meio do Sisbio no prazo de até 30 dias a contar da data do aniversário de sua emissão.

Dados do titular

Nome: Roberta Sá Leitão Barboza	CPF: 029.170.014-45
Título do Projeto: Serviços ambientais e planejamento espacial: Uso sustentável de recursos naturais em unidades de conservação e proteção de manguezais brasileiros	
Nome da Instituição : UNIVERSIDADE FEDERAL DO PARÁ	CNPJ: 34.621.748/0001-23

Cronograma de atividades

#	Descrição da atividade	Início (mês/ano)	Fim (mês/ano)
1	Realização de entrevistas e Mapeamentos Participativos	10/2016	12/2018

Observações e ressalvas

1	As atividades de campo exercidas por pessoa natural ou jurídica estrangeira, em todo o território nacional, que impliquem o deslocamento de recursos humanos e materiais, tendo por objeto coletar dados, materiais, espécimes biológicos e minerais, peças integrantes da cultura nativa e cultura popular, presente e passada, obtidos por meio de recursos e técnicas que se destinem ao estudo, à difusão ou à pesquisa, estão sujeitas a autorização do Ministério de Ciência e Tecnologia.
2	Esta autorização NÃO exime o pesquisador titular e os membros de sua equipe da necessidade de obter as anuências previstas em outros instrumentos legais, bem como do consentimento do responsável pela área, pública ou privada, onde será realizada a atividade, inclusive do órgão gestor de terra indígena (FUNAI), da unidade de conservação estadual, distrital ou municipal, ou do proprietário, arrendatário, posseiro ou morador de área dentro dos limites de unidade de conservação federal cujo processo de regularização fundiária encontra-se em curso.
3	Este documento somente poderá ser utilizado para os fins previstos na Instrução Normativa ICMBio nº 03/2014 ou na Instrução Normativa ICMBio nº 10/2010, no que especifica esta Autorização, não podendo ser utilizado para fins comerciais, industriais ou esportivos. O material biológico coletado deverá ser utilizado para atividades científicas ou didáticas no âmbito do ensino superior.
4	O titular de licença ou autorização e os membros da sua equipe deverão optar por métodos de coleta e instrumentos de captura direcionados, sempre que possível, ao grupo taxonômico de interesse, evitando a morte ou dano significativo a outros grupos; e empregar esforço de coleta ou captura que não comprometa a viabilidade de populações do grupo taxonômico de interesse em condição in situ.
5	O titular de autorização ou de licença permanente, assim como os membros de sua equipe, quando da violação da legislação vigente, ou quando da inadequação, omissão ou falsa descrição de informações relevantes que subsidiaram a expedição do ato, poderá, mediante decisão motivada, ter a autorização ou licença suspensa ou revogada pelo ICMBio, nos termos da legislação brasileira em vigor.
6	Este documento não dispensa o cumprimento da legislação que dispõe sobre acesso a componente do patrimônio genético existente no território nacional, na plataforma continental e na zona econômica exclusiva, ou ao conhecimento tradicional associado ao patrimônio genético, para fins de pesquisa científica, bioprospecção e desenvolvimento tecnológico. Veja maiores informações em www.mma.gov.br/cgen.
7	Em caso de pesquisa em UNIDADE DE CONSERVAÇÃO, o pesquisador titular desta autorização deverá contactar a administração da unidade a fim de CONFIRMAR AS DATAS das expedições, as condições para realização das coletas e de uso da infra-estrutura da unidade.

Equipe

#	Nome	Função	CPF	Doc. Identidade	Nacionalidade
1	ANA RAQUEL LEITE DA SILVA	Apoio na coleta de dados	003.967.742-70	6103779 pc-PA	Brasileira
2	Rebecca Borges e Silva	Aluna de Doutorado	006.837.533-63	2002009083062 SSP-CE	Brasileira

Locais onde as atividades de campo serão executadas

#	Município	UF	Descrição do local	Tipo
1		PA	RESERVA EXTRATIVISTA MARINHA DE CAETÉ-TAPERAÇU	UC Federal
2		PA	RESERVA EXTRATIVISTA MARINHA DE TRACUATEUA	UC Federal

Este documento (Autorização para atividades com finalidade científica) foi expedido com base na Instrução Normativa nº 03/2014. Através do código de autenticação abaixo, qualquer cidadão poderá verificar a autenticidade ou regularidade deste documento, por meio da página do Sisbio/ICMBio na Internet (www.icmbio.gov.br/sisbio).

Código de autenticação: 36427147

Autorização para atividades com finalidade científica

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* De acordo com o art. 28 da IN 03/2014, esta autorização tem prazo de validade equivalente ao previsto no cronograma de atividades do projeto, mas deverá ser revalidada anualmente mediante a apresentação do relatório de atividades a ser enviado por meio do Sisbio no prazo de até 30 dias a contar da data do aniversário de sua emissão.		

Dados do titular

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Título do Projeto: Serviços ambientais e planejamento espacial: Uso sustentável de recursos naturais em unidades de conservação e proteção de manguezais brasileiros	
Nome da Instituição : UNIVERSIDADE FEDERAL DO PARÁ	CNPJ: 34.621.748/0001-23

Registro de coleta imprevista de material biológico

De acordo com a Instrução Normativa nº 03/2014, a coleta imprevista de material biológico ou de substrato não contemplado na autorização ou na licença permanente deverá ser anotada na mesma, em campo específico, por ocasião da coleta, devendo esta coleta imprevista ser comunicada por meio do relatório de atividades. O transporte do material biológico ou do substrato deverá ser acompanhado da autorização ou da licença permanente com a devida anotação. O material biológico coletado de forma imprevista, deverá ser destinado à instituição científica e, depositado, preferencialmente, em coleção biológica científica registrada no Cadastro Nacional de Coleções Biológicas (CCBIO).

Táxon*	Qtde.	Tipo de amostra	Qtde.	Data

Código de autenticação: 36427147

Autorização para atividades com finalidade científica

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* Identificar o espécime no nível taxonômico possível.

Código de autenticação: 36427147

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