SEASONAL DYNAMICS IN ECOSYSTEM SERVICES

A CASE STUDY OF SMALL-SCALE FISHERIES

Ruby W. Grantham, B.Sc., M.Res

April 2021

A thesis submitted for the degree of Doctor of Philosophy
at the Australian Research Council
Centre of Excellence for Coral Reef Studies
James Cook University

ARC CENTRE OF EXCELLENCE
Coral Reef Studies

FOR ISAAC THOMAS JAMES ELLORY (30.10.20)

“To see a World in a Grain of Sand
And a Heaven in a Wild Flower,
Hold Infinity in the palm of your hand
And Eternity in an hour.”

WILLIAM BLAKE, AUGURIES OF INNOCENCE

ACKNOWLEDGEMENTS

First, I want to thank my supervisors Graeme Cumming, Dave Mills and Cristian Rojas for their support and guidance throughout my PhD. Graeme, thank you for giving me this opportunity, for your kindness and understanding, and for pushing me to challenge myself. Dave, thank you for your continued enthusiasm towards my work and for helping me keep it real and relevant. Cristian, thank you for your patience and meticulousness. I also want to thank Pip Cohen and Simon Foale for their encouragement and many helpful chats during my PhD.

Second, I want to thank everyone in Timor-Leste who made my PhD possible and enjoyable. All the participants in the study communities who so generously shared their time and wisdom with me. The families who welcomed me into their homes, especially Xefi John and his family in Adara, and Carlotta and Nadab and his family in Akrema. My three talented research assistants Pedro, Inacia and Nelson, who were a pleasure to work with. The women who implemented the panel survey, Avila, Beminda, Joana, Merab, Olimpia, Sara, Trifena, and Natalia - who tragically passed away on 27/02/2019. I also want to thank WorldFish Timor-Leste, especially Augustina Duarte, Mario Gomes, Kim Hunnam and Alex Tilley.

Third, I want to thank all the friends who made Townsville my home: Georgie, Jorge and Andy, who kept me sane and fit with regular therapeutic stomps up Castle Hill; Jacqui, a force of incredible calm as a friend and mentor; and Tom, my balcony beers buddy and fellow 'pom'. Ale, I want to thank you for listening to all my grumbling and for being the reason I stuck it out, your commitment and passion for science and rice-and-lentils is an inspiration.

Finally, I want to thank my families. Jamie and Robert, my two dads with my two hairy brothers, thank you for welcoming me into your beautiful home. Robyn and David, my Nine Mile mum and dad, thank you for your open arms and unconditional generosity when I needed it most. Mum (Nichola), dad (Rupert), Maya, Ken and Mutti, thank you for being there always, even when I am a bit spikey and on the other side of the world.

STATEMENT OF THE CONTRIBUTION OF OTHERS

THESIS COMMITTEE

Professor Graeme S. Cumming, ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland, Australia

Dr David J. Mills, ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland, Australia; WorldFish, Timor-Leste

Dr Cristian Rojas, ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland, Australia; Department of Ecology, Pontificia Universidad Católica de Chile, Santiago, Chile

FUNDING

James Cook University: Scholarship salary

James McDonnell Foundation: Fieldwork

ARC Centre of Excellence for coral reef studies: Travel costs to conferences

David Yellowlees Award 2019: Publication fees

Crawford-in-Queensland Award: Contribution to fieldwork costs

RESEARCH SUPPORT

Research assistants: Pedro Correia Monteiro, Inacia Clart, Nelson da Costa

Panel survey implementers: Avila de Araujo, Beminda Martins, Joana da Costa, Merab Cabral, Natalia da Costa, Olimpia Gomes, Sara de Castro, Trifena Guterres.

Methods design: Graeme Cumming and David Mills.

Statistical analyses: Cristian Rojas, Graeme Cumming, Alexandre Siqueira, and Rhondda Jones.

Editorial support: Graeme Cumming, David Mills, Cristian Rojas, Jacqueline Lau (Chapters 5 and 6), Jorge Álvarez-Romero (Chapter 3) and Daniker Kleiber (Chapter 6)

ETHICS AND PERMITS

Research presented in this thesis was conducted in accordance with the James Cook University human ethics guidelines and approved by Human Research Ethics Committee of James Cook University (reference number H7626 and H7385). Permission to conduct research on Atauro Island was granted by the Ministry of Fisheries and Agriculture, Timor-Leste. Prior to implementing the research, the lead author met with the Xefi aldeia (community leader) of each study community to discuss the research objectives and approaches and obtain permission to carry out data collection. Participants in all data collection activities were informed of the nature and purpose of research activities through a verbal statement in local language and, if they were willing to participate, they were asked to give signed consent.

CONTRIBUTIONS

PEER-REVIEWED PUBLICATIONS

Grantham, R., Lau, J., Kleiber, D., 2020. Gleaning: beyond the subsistence narrative. Maritime Studies. 19, 509–524. https://doi.org/10.1007/s40152-020-00200-3%0A

Grantham, R., Álvarez-romero, J.G., Mills, D.J., Rojas, C., Cumming, G.S., 2021. Spatiotemporal determinants of seasonal gleaning. People and Nature. https://doi.org/10.1002/pan3.10179

Grantham, R., Lau, J., Mills, D.J. and Cumming, G.S., (in review Ecosystems and People). Allocation and everyday agency mediate ecosystem service benefits across seasons.

CONFERENCE PRESENTATIONS

Grantham, R. 2020. Spatiotemporal determinants of seasonal gleaning in dynamic coastal livelihoods. Coral Reef Virtual Symposium, ARC Centre of Excellence for Coral Reef Studies

Grantham, R. 2018. Using seasonal calendars to understand expectations and livelihood structures. 3rd World Small-Scale Fisheries Congress

OTHER REPORTS AND PUBLICATIONS DURING CANDIDATURE

Bellwood, D.R., Pratchett, M.S., Morrison, T.H., Gurney, G.G., Hughes, T.P., Álvarez-Romero, J.G., Day, J.C., Grantham, R., Grech, A., Hoey, A.S., Jones, G.P., Pandolfi, J.M., Tebbett, S.B., Techera, E., Weeks, R., Cumming, G.S., 2019. Coral reef conservation in the Anthropocene: Confronting spatial mismatches and prioritizing functions. Biol. Conserv. 236, 604–615. https://doi.org/10.1016/j.biocon.2019.05.056

Soe, KM, Baran, E, Grantham, R, Tezzo, X & Johnstone, G 2020, Myanmar inland fisheries and aquaculture: a decade in review, monograph no. 209, Australian Centre for International Agricultural Research, Canberra, & WorldFish, Yangon, 93 pp.

ABSTRACT

Seasons are a major driver of livelihood and wellbeing dynamics for the rural poor in low-income countries. Yet there has been limited attention to the temporal aspects of ecosystem services, and in particular, little is understood about how people mediate ecosystem services through time. The aim of my thesis was to contribute to a dynamic social-ecological approach to ecosystem services by exploring how people interact with ecosystems through time and why those interactions matter. My research examines three mediating mechanisms of the ecosystem service cascade: mobilisation of services from ecosystems; allocation of services across benefit streams; and, appreciation of benefits. Building on concepts of materiality, access, agency and plural values, this thesis strengthens understanding of the human dimensions of seasonal ecosystem services using the case study of small-scale fisheries in dynamic coastal social-ecological systems.

I used a mixed-method, case study approach in my research, with a focus on small-scale fisheries on Atauro Island, Timor-Leste. Timor-Leste is a Small-Island Developing State in the Indo-pacific. There is a pressing need to understand the seasonal contribution of fishery ecosystem services in Timor-Leste because the occurrence of an annual lean season is a major cause of food insecurity and poverty in the country, particularly for rural communities. I collected data in eight coastal communities on Atauro Island at the individual, household and community level. I triangulated qualitative and quantitative data to explore how people mediate seasonal ecosystem services in my four data chapters.

First, I looked at how biophysical characteristics of coastal environments influence the ability of people to mobilise fishery ecosystem services through time. Specifically, I analysed social data and spatial-habitat data to understand factors affecting the decision of households to glean (the manual collection of marine organisms from the littoral zone) in different seasons. I found that area and type of shallow habitat proximate to a community mattered, meaning the ability of people to benefit from the littoral zone was affected by its materiality. Hence, materiality was an important determinant of ecosystem service access. Seasonal changes in the ability to interact with coastal ecosystems affects the distribution of diverse wellbeing values at fine spatial and temporal scales. Therefore, my findings highlight the importance of context specific and dynamic perspectives in ecosystem services.

Second, I explored ecosystem service access by examining the interplay between social identity and materiality in ecosystem service mobilisation. I analysed seasonality in gendered fishing strategies and show that divisions of labour lead to shifts in the gender balance of household fishing at different times of the year. Worryingly, my findings indicate that current fisheries assessments and management underrepresent and undervalue components of fishing most important as a source of nutrition in adverse conditions and during periods of food scarcity. Hence, seasonal and gender disaggregated perspectives of social-ecological interactions provide insight of how and when people realise flows of ecosystem services, which is crucial for supporting equitable coastal management for food security.

Third, I examined everyday agency in the allocation of ecosystem services by comparing how households used fish depending on amount caught and time of year. Using household panel data on catch use in three seasons, I show that people allocate ecosystem services according to seasonal livelihood priorities and capabilities. Social processes therefore underpin a relationship between ecosystem services and benefits for people that is neither direct nor constant. My findings highlight the need for human-centric perspectives that place everyday agency central to our understanding of ecosystem services and how people navigate variability and uncertainty in dynamic social-ecological systems.

Fourth, I elicited the diverse ways people value ecosystem services at different times of the year using the example of women's gleaning. I show that women gleaned for reasons linked to achieving material outcomes and enjoying the activity itself, and reasons perceived as most important differed between individuals and season. My findings shed light on an underrepresented and undervalued small-scale fishery and show that coastal communities in low-income countries value local ecosystems in diverse and incommensurable ways. Pluralistic valuation approaches sensitive to the dynamic social-ecological context, can reveal the changing importance of coastal ecosystems to people through time. Specifically, my findings demonstrate the importance of moving beyond essentialised narratives of women and the subsistence framing of gleaning.

In sum, my thesis contributes to advancing our understanding of the temporal aspects of ecosystem services as social-ecological interactions in low-income countries. My findings highlight the ways people mediate seasonal links between ecosystems and human wellbeing. Ecosystem services would benefit from deeper critical engagement with social science to

build a stronger understanding of the social processes that underpin how people interact with and value ecosystems through time. People's preferences, priorities and capabilities influence how they interact with ecosystems and navigate seasonal dynamics. My findings also support a number of recommendations regarding the importance of inclusive and seasonally sensitive approaches for sustainably and equitably managing small-scale fisheries.

Finally, to advance theory on the links between nature and human wellbeing, more research is needed on how social-ecological interactions and ecosystem service access change seasonally. Integrating social analysis into landscape scale ecosystem service assessments would place people central to our understanding of the seasonal links between multiple ecosystem services. In particular, in rural areas of low-income countries accounting for seasonal ecosystem service access is essential for the sustainable and equitable management of natural resources. The ethical implications of choices of temporal scale in ecosystem services research deserve greater attention. Especially when the wellbeing of vulnerable groups is at stake, there is a need for careful consideration from whose perspective ecosystem services are defined, valued and managed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Appendices

SEASONAL DYNAMICS IN ECOSYSTEM SERVICES

A CASE STUDY OF SMALL-SCALE FISHERIES

1. INTRODUCTION

1.1. Background

It's a December afternoon in Adara on the western coast of Atauro Island. I'm sat with an elderly couple, Tsi Maun and Esperenza, under the palm frond porch of their home sheltering from the pouring rain. The sea is an ominous grey and we watch the small wooden fishing boats rock in their moorings as the waves crash on to the beach. Tsi Maun and Esperenza are soaking wet. They've just returned from their small field a thirty-minute walk along the coast path. They tell me this is the time to work on the land because the rains indicate it's time to plant the corn. Like all families in Adara, subsistence crops of corn and beans are a main staple food for Tsi Maun and Esperenza and the heavy rain is a hopeful sign for a good harvest. But this is also a very challenging time of the year. The rains coincide with what is known as the lean season, when household food stores are low and rough sea conditions mean fishing is dangerous and sometimes impossible. During the lean season, Tsi Maun and Esperenza often have to skip meals and they tell me that for a number of days they have eaten only plain rice.

The next morning is unusually calm for the time of year. I'm relieved because I need to travel to a neighbouring village by boat. As we motor across the bay, we pass Tsi Maun in his wooden canoe, fishing at the edge of the reef. He gives us a wave with a huge smile on his face. Tonight, they will eat fish with their rice!

Photograph. Tsi Maun fishing

The seasonal rhythm of life in coastal communities captured in the story of Tsi Maun and Esperenza is at the heart of my thesis. Through my research I seek to elucidate the fine scale dynamics in how people interact with, and depend on, coastal ecosystems through seasonal small-scale fisheries in low-income countries. My research sheds light on the links between coastal ecosystem services and human wellbeing which, in line with the social wellbeing approach, refers to the material, relational and subjective dimensions that enable people to pursue a life they value (White, 2008). I argue that to understand how ecosystems contribute to human wellbeing we need to assess, evaluate and define ecosystem services at temporal resolutions relevant to the dynamic lives of the people who depend on them.

1.2. ECOSYSTEM SERVICES

People have long been aware that nature is fundamental for human wellbeing and that their actions can have detrimental impacts on the nature on which they depend. Between the 5th and 4th Centuries BC, Hippocrates wrote one of the earliest known texts linking human health and nature (Dove 2014) and Plato pointed to links between resource use and land degradation (Goldin 1997). However, unprecedented rates of global ecological decline and the associated impacts on people are evidence that we are not yet effectively managing linked social-ecological systems (Berkes et al. 2000). Over the last 50 years, anthropogenic activities that directly and indirectly drive change in the world's ecosystems have accelerated (IPBES 2019). The impacts of human actions on the environment are now so profound they risk destabilising the earth's climate (Steffen et al. 2018). The historical costs and future threats of global environmental change for human wellbeing are not equally distributed, with low-income countries disproportionately affected (IPCC 2014a, Ware and Kramer 2019). The ethical and instrumental necessity of addressing global environmental change is the basis of the ecosystem services concept.

HISTORY AND ORIGINS

The origins of ecosystem services were a reaction to the inadequacies of neoclassical economics to address sustainability challenges. Critiques highlighted the absurdity of economic approaches that overlooked planetary limits and were fixated on economic growth with no regard for environment maintenance (Daly 1974). Mounting evidence showed losses of ecosystem functions resulting from human caused species extinctions were non-

substitutable and compromising the ecosystem services critical to humanity (Ehrlich and Mooney 1983). The concern that serious sustainability issues stemmed from the failure of economic paradigms to deal with natural resources and a lack of attention to human behaviour in ecology, led to call for the integration of ecological and economic thinking (Costanza and Daly 1987).

Hence, ecosystem services emerged as a tool to formalise knowledge and costs of environmental change for people (Chaudhary et al. 2015). The foundations of the ecosystem service concept were established by two landmark publications that stressed the importance of giving weight to ecosystems in decision-making by emphasising the reliance of humanity on complex natural cycles (Daily 1997) and, controversially, by attempting to economically value ecosystem services (Costanza et al. 1997). The initial attempt to place a monetary value on the importance of the environment for sustaining humanity propelled issues of environmental degradation onto the global agenda. The launch of the UN Millennium Ecosystem Assessment (MA) in 2001 and the release of the MA synthesis report mainstreamed ecosystem services (MA 2005a). The MA presented a conceptual framework that used a basic stock-flow model to illustrate how provisioning (products obtained from ecosystems), cultural (non-material benefits obtained from ecosystems), regulating (benefits from the regulation of ecosystem processes) and supporting (services necessary for all other services) services from the environment provide benefits for people (MA 2005b). Scholarship in ecosystem services has proliferated, and between 1997 and 2017 more than 17,000 papers were published that included the term “ecosystem services” in their title, keywords or abstract (Costanza et al. 2017). By elucidating the links between human wellbeing and the environment, ecosystem services help highlight the synergies and trade-offs between social and ecological objectives in environmental management (Howe et al. 2014, Cord et al. 2017). Ecosystem services have been important for integrating people’s hopes and desires into conservation thinking (Armsworth et al. 2007, Mace 2014) and they are recognised to be a useful paradigm in poverty and development policy (ESPA 2018).

However, ecosystem services has yet to fully deliver on promises of improved environmental management and human wellbeing (Daily et al. 2009, Bennett and Chaplin-Kramer 2016, Chan and Satterfield 2020) and doubts have been raised regarding its appropriateness for valuing why nature matters. Specifically, concerns that the generalising approach of

ecosystem services limits the inclusion of different world views and the integration of social science, which led to the proposed alternative notion of Nature's Contributions to People (NCP) by IPBES (Díaz et al. 2018). The NCP claims to nurture a paradigm shift at the knowledge-policy interface that embraces the pluralistic values of nature (Pascual et al. 2017). However, some argue that NCP is founded on incorrect criticisms of ecosystem services that fail to recognise substantial development in the field (Braat 2018). The evolution of novel and innovative interdisciplinary approaches in ecosystem services has marked considerable departure from the narrow economic focus of the original MA framework (Maes et al. 2018). Whether the NCP represents substantial scientific advancement from ecosystem services remains contested. In my research I use an ecosystem service framing, as opposed to NCP, because there is considerably more scholarship in ecosystem services on which to build. Further, a number of frontiers in ecosystems services of direct relevance to my research are not explicitly attended to in NCP, including dynamic social-ecological feedbacks and coproduction (Peterson et al. 2018).

1.3. RESEARCH GAPS

One major knowledge gap hampering the ability of ecosystem services thinking to contribute to human wellbeing is limited understanding of how ecosystem services are distributed through time. Ecosystem services can change in linear, periodic and event-driven ways across multiple temporal scales (Rau et al. 2018). For example, research in Bangladesh shows that wetland areas, and the services they support, fluctuate periodically with seasonal rainfall but follow declining trends over longer time scales (Huq et al. 2019). However, temporal aspects of ecosystem services, in particular periodic fluctuations, have gained little research attention and most of our understanding of ecosystem services is based on single snap-shots in time (Rau et al. 2020). Snap-shots cannot answer pressing questions around change and variability in ecosystem services or trade-offs between services (Renard et al. 2015) and may be biased in the type and magnitude of services they represent.

Assessments of the temporal aspects of ecosystem services are grounded in choices of scale. At different scales dominant processes may change, so choices of scale determine the phenomenon studied (Peterson and Parker 1998). In ecosystem services, at certain scales different social and ecological processes may dominate or be better observed.

Consequently, the scale of observation and assessment in ecosystem services has direct implications for what is measured, managed and valued (MA 2003) and, by extension, relevance to the interests of stakeholders and decision-makers. Mismatch between the scale of scientific analysis and the reach and responsibilities of local decision-makers in space and time can create discord between knowledge and information needs (Cash and Moser 2000). Knowledge of the "fast" processes that dominate localised social-ecological dynamics is important for managing ecosystem services for human wellbeing (Kandziora et al. 2013, Scholes et al. 2013).

Seasons, the recurrent and predictable intra-annual cycles in meteorological and environmental conditions driven by the earth's orbit around the sun, are a major driver of social-ecological system dynamics, particularly in rural areas of low-income countries. In higher income countries technology (e.g., air conditioning), infrastructure (e.g., markets) and wealth buffer the impacts of seasonality on people. But in low-income countries, seasons are a dominant rhythm in people's lives, particularly for the rural poor who depend directly on natural resources (Huq et al. 2020). Seasons influence the availability and accessibility of natural resources, and livelihoods are adapted to maximise returns and minimise risks created by seasonal variability (Marschke and Berkes 2006). Diversified livelihood strategies enable households to move in and out of seasonally productive activities. For example, in the Tonle Sap region in Cambodia, snake fisheries are an important source of income for poorer groups at times of the year when there are few livelihood alternatives (Brooks et al. 2008).

There are, however, limits to adaptation and seasons are often directly linked to fluctuations in food and income (Dostie et al. 2002, da Costa et al. 2013). Seasonal food scarcity is the greatest cause of hunger globally (Devereux et al. 2008). Rainfed agriculture is an obvious example of a seasonal livelihood; seasonal rains determine when crops are planted and harvested and therefore associated cycles in food availability (Vaitla et al. 2009). Seasonal hardships are often multi-faceted, for instance rainy seasons are also associated with increased disease prevalence and limited mobility (Chambers et al. 1981, Chambers 1982). Managing seasonal vulnerabilities can trap people in cycles of poverty and food insecurity because coping strategies can deplete household assets (Longhurst et al. 1986) and degrade natural resources (Kalaba et al. 2013). Across the globe climate change is driving seasonal shifts including changes in temperatures and precipitation, that are likely to lead to

extreme events such as drought and flooding (Krinner et al. 2013). Climate related seasonal shifts are already perceived to be impacting those whose livelihoods depend directly on weather conditions, such as small-holder farming and small-scale fisheries (Jennings and Magrath 2009). The increasing unpredictability of seasons risks exacerbating existing vulnerabilities and food insecurity (Blackmore et al. 2021). Ecosystem services knowledge at seasonal resolutions is therefore important for understanding the links between ecosystems and human wellbeing to support sustainable and equitable environmental management in a changing climate, especially in rural areas of low-income countries.

HUMAN DIMENSIONS

In my thesis I address knowledge gaps around the temporal aspects of ecosystem services by using a social-ecological perspective to deepen understanding of the human dimensions of seasonal ecosystem services. Human inputs are often required for ecosystem services to be realised from ecosystems (Burkhard et al. 2014, Huntsinger and Oviedo 2014, Díaz et al. 2015). Therefore, the ways people interact with ecosystems in space and time and why those interactions matter determines the distribution of ecosystem services and benefits, and their value to human wellbeing (Fisher et al. 2009, Rieb et al. 2017). Hence, metrics of ecosystem services need to be grounded in social-ecological production functions (Reyers et al. 2013). However, there is little systematic understanding of the combinations of human and ecological inputs that determine flows of ecosystem services (Bennett et al. 2015) and their importance to people. Social-ecological approaches create opportunity for progress in the social sciences to be incorporated in our understanding of how ecosystems contribute to human wellbeing. Unlike the basic stock-flow model of ecosystem services in which people are only beneficiaries, social-ecological perspectives include people as an integral component of how ecosystem services are produced and realised (Reyers et al. 2013). Framing people according to their interactions with rather than their impacts on nature can help move beyond conservation paradigms focused on excluding people from the environments that matter to them (Fisher et al. 2014, Huntsinger and Oviedo 2014). The role that people play within social-ecological systems is often dependent on timing, and fitting people into systems needs to account for where they are and what they are doing at a point in time (Hägerstrand 1970). To examine the human dimensions of ecosystem services through time, in my thesis I draw on four main concepts: materiality, access, agency and plural values.

Materiality

Materiality refers to the biophysical properties of the material world that enable or constrain the social-ecological interactions through which resources are produced (Bakker and Bridge 2006). Hence, materiality describes how the properties of a thing (i.e., an ecosystem) influences the ability of people to benefit from it (Myers and Hansen 2020). For example, for urban populations in the Solomon Islands the limited physical availability of ecosystem services, such as food, is perceived to be a main barrier to accessing benefits (Lapointe et al. 2020). The relationship between ecosystems and beneficiaries in a landscape is an important determinant of where and to what magnitude actual ecosystem services (as opposed to theoretical ecosystem services) are distributed (Bagstad et al. 2014). However, materiality is not explicitly included in access theory (outlined below), which represents a major gap in our understanding of how ecosystem services are distributed (Myers and Hansen 2020). Materiality is often overlooked in ecosystem services, for example in assumptions that stakeholder groups will benefit from an increase in a resource regardless of whether they can physically access that resource (Wieland et al. 2016). In *Chapter 3,* I contribute to addressing knowledge gaps around materiality in ecosystem services by examining how the biophysical environment influences the ability of people to benefit from ecosystem services in different seasons.

Access

Access theory emphasizes that multiple social, cultural and economic factors influence the ability (rather than the rights) of people to benefit from natural resources (Ribot and Peluso 2003). Access theory has been used in ecosystem services research to understand the pathways that link ecosystems to the wellbeing of different stakeholders (Berbés-Blázquez et al. 2017). Accounting for differentiated access in ecosystem services is particularly important for poverty alleviation to understand why certain groups are unable to benefit from resources that are physically available (Fisher et al. 2014). Especially in the context of environmental change, access can help identify winners and losers to inform targeted approaches for improving the wellbeing of the most vulnerable groups (Daw et al. 2011).

In my thesis I explore social identity and ecosystem service access. Social identity, including gender, underpins power relations that have profound impacts on the ability of people to benefit from ecosystem services (Ribot and Peluso 2003). Context-specific socially

constructed roles, responsibilities and rights of gender groups determine divisions of labour and the ways that people use and value natural resources (de la Torre-Castro et al. 2017, MacGregor 2017, Fortnam et al. 2019). Gendered divisions of labour represent gendered processes of ecosystem service co-production (Fortnam et al. 2019). The social objectives that underpin divisions of labour do not necessarily optimise livelihood outputs (Bliege Bird 2007) and can manifest in ways that limit adaptation in social-ecological systems (Carr 2019). As livelihood tasks change at different times of the year so do household labour demands and how they are distributed across gender groups, meaning gender roles and seasonality in livelihoods are intrinsically linked (Langill 2020). Accounting for gender disaggregated access in ecosystem services has both ethical and instrumental implications (Agarwal 2009, Lau 2020). In *Chapter 4*, I examine the intersection between season and divisions of labour to contribute to addressing blind-spots around gender in ecosystem services (Brown and Fortnam 2017), and specifically how gendered ecosystem service co-production changes through time

Agency

Agency refers to the ability of people to exercise choice over their lives, including through micro-practices of evaluation and adaptation in everyday agency (Selimovic 2019). Everyday agency enables people to navigate uncertainty and stressors in their day-to-day lives through the "quiet accommodation of change" (Mcmichael et al. 2019) and can underpin macro-scale transformation and resilience (Selimovic 2019). Agency determines human responses to stressors and is therefore at the core of resilient livelihoods (Tanner et al. 2015). Yet people's choices and actions are often a black-box in ecosystem service assessments. For instance, in the context of land use change, human decision-making remains one of the greatest causes of uncertainty and a key barrier to sustainable land-use management (Crossman et al. 2013). Without accounting for agency, vulnerability to ecosystem change is understood as being structurally determined (Mclaughlin and Dietz 2008) because the capabilities, opportunities and constraints that determine how people negotiate the social-ecological context are overlooked (Brown and Westaway 2011). In particular, the ordinary actions and decision-making of everyday agency are often overlooked, with emphasis placed on remarkable responses to extreme events (Payne 2012). In *Chapter 5*, I address this gap by examining how people exercise everyday agency to navigate seasonal variability in ecosystem services.

Plural values

Pluralistic values approaches recognise that interactions with and benefits from ecosystems matter to people in diverse ways. People perceive ecosystems as being important across co-existing value domains (Arias-Arévalo et al. 2017): ecosystems satisfy people's preferences (instrumental values), nature has inherent worth (intrinsic values) and the relationships and responsibilities between people and nature are meaningful (relational values) (Chan et al. 2016). The bundles of (sometimes inseparable) values that individuals attribute to ecosystems (Klain et al. 2014) are underpinned by their worldviews, cultural context and value systems (Díaz et al. 2018). Hence, pluralistic valuation approaches are needed to capture "the multiple and incommensurable ways in which [ecosystem services] are important for people" (Arias-arévalo et al. 2018).

Relational values in particular capture the different value languages through which people perceive and convey their relationships with nature (Himes and Muraca 2018). Relational values reflect principles and virtues that determine how people conduct themselves within social-ecological systems (Chan et al. 2016) and can help engage diverse stakeholders in environmental decision-making (Klain et al. 2017). However, emphasis placed on valuing ecosystem services using monetary approaches has masked incommensurable relational values and driven problematic commodification of ecosystem services (Kosoy and Corbera 2010). Monetary approaches prioritise capitalistic values over other complex value systems (Folkersen 2018), which is particularly inappropriate in low-income contexts (Christie et al. 2020). Pluralistic approaches that engage with stakeholders are an important step towards equitable valuation of ecosystem services, a prerequisite for sustainability (Pascual et al. 2017). Although people's preferences and how they perceive ecosystems to be important determine the value of and demand for ecosystem services, ecosystem service assessments rarely include stakeholder valuation (Lautenbach et al. 2019) and little is understood about how ecosystem service values change through time (Hein et al. 2016). In *Chapter 6*, I address this gap and extend work on pluralistic ecosystem service values by using a seasonal lens to compare the ways that ecosystems matter to people through time.

1.4. THESIS AIMS

The overarching aim of my thesis was to contribute to a dynamic social-ecological approach in ecosystem services by strengthening understanding of the human dimensions of ecosystem services through time. Specifically, I used a seasonal lens to examine ecosystem services as human-nature interactions. Using empirical case studies grounded in social science theory, I addressed my aim through three main research objectives:

1) Identify opportunities and constraints created by the seasonal context that affect how and why people interact with ecosystems
2) Explore how people's choices, actions and priorities influence the ways that they benefit from ecosystems at different times of the year
3) Compare seasonal perspectives of the links between ecosystems and human wellbeing to examine how choices of temporal scale shape our understanding of ecosystem services

I summarise how I address my three research objectives to varying extents in each of my data chapters in Table 1.1.

TABLE 1.1 SUMMARY TABLE OF HOW I ADDRESS EACH OF MY RESEARCH OBJECTIVES IN MY DATA CHAPTERS

	Objective 1: Identify seasonal opportunities and constraints to human-nature interactions	Objective 2: Explore the ways that people influence seasonal ecosystem service benefits	Objective 3: Elucidate how temporal scale affects understanding of ecosystem services
Ch.3	Identify factors affecting the seasonal decision to glean	Link seasonal gleaning to seasonal stability in seafood consumption	Demonstrate how access to littoral ecosystem services varies between places and seasons
Ch.4	Evaluate seasonal sensitivities of gendered fishing activities	Elicit links between gendered divisions of labour and seasonal fishing strategies	Discern differences between seasonally aggregated and disaggregated perspectives of fishing strategies
Ch.5	Examine the influence of the seasonal livelihood context on the function of fishing	Evaluate how people influence seasonal livelihood outcomes of fishing by choosing how to use catches	Illustrate non-linearities in the relationship between fish catch and benefits to people through time
Ch.6	Characterise how seasonal conditions affect motivations and benefits of gleaning	Provide insight of how wellbeing benefits of gleaning change seasonally with value priorities.	Highlight seasonal changes in the diverse ways that ecosystem services are important for people

Main research objective addressed | Secondary research objective addressed | Findings relevant to objective

1.5. STUDY REGION

I focused on small-scale fishery ecosystem services on Atauro Island, Timor-Leste as a pertinent case study in which to address my research objectives. Small-scale fisheries offer an informative case study for four main reasons. First, small-scale fisheries are an important but threatened source of livelihoods. It is estimated there are 32 million small-scale fishers globally, a large majority of whom live in low-income countries (World Bank et al. 2012), including 6 million who depend on coral reef fisheries (Teh et al. 2013). Small-scale fisheries are vulnerable to continuing anthropogenic and environmental stressors (Allison et al. 2009, Freduah et al. 2017), which pose major threats to the sustainability of coastal and marine ecosystems and the wellbeing of the many people who depend on them. Low-income countries and small island states are most vulnerable to the impacts of climate change on marine fisheries (Blasiak et al. 2017).

Second, the social values of small-scale fisheries are not well understood. Fisheries contribute to society in material (e.g., nutrition and income) and non-material (e.g., life satisfaction) ways (Johnson 2018). Social values determine the ways people interact with and benefit from coastal ecosystems through small-scale fisheries. However, research, management and decision-making often conceptualise small-scale fisheries as production systems, a hangover from the focus of conventional fisheries science on the industrial sector (Kolding and van Zwieten 2011, Kolding et al. 2014). Production-based approaches equate the social values of fisheries to the economic value of what is taken out of the sea. This perspective underpins a misleading assumption that social and ecological objectives are irreconcilable in fisheries. In reality, social objectives are often aligned with and even dependent on ecological objectives (Chan et al. 2016). Further, failure to account for the social values of small-scale fisheries means their contributions to wellbeing are underrepresented in decision-making and visions for the ‘blue economy’. Consequently, small-scale fishers risk being squeezed out of contemporary coastal governance (Cohen et al. 2019).

Third, small-scale fisheries are sensitive to environmental conditions. Seasonal changes in the availability and accessibility of fishery resources, for instance linked to species migrations (Maynou et al. 2011) and weather conditions (Gill et al. 2019), have direct impacts on small-scale fisheries. Seasonal variability in other livelihood activities can also drive dynamics in fisheries as a means of smoothing income and consumption fluctuations (Neiland et al. 2000,

Sarch and Birkett 2000). The recurrent and quasi-predictable nature of seasonality in fisheries is often well understood in traditional ecological knowledge (Gunawardena et al. 2016) and reflected in fishing adaptations, such as in decisions of where and when to focus fishing effort and what fishing methods to use (Moreno-Báez et al. 2012). However, capacity to adapt to fishery seasonality is affected by household socio-economics (Brooks et al. 2008) and level of livelihood specialisation (Coulthard 2008), and for many fishers seasonality is associated with cycles of hardship (Siar 2003). Seasonal variability affects market prices of fish (Erisman et al. 2015) and has implications throughout small-scale fishery value chains (Jueseah et al. 2020). Accounting for seasonal dynamics in small-scale fisheries as part of adaptive livelihoods is fundamental for diagnosing vulnerabilities and promoting resilience, particularly, in the context of a changing climate (Sievanen 2014). For example, changes in the timing of seasonal temperatures can cause range shifts in marine species (Burrows et al. 2011), so to maintain fishing activities fishers will have to adjust their distribution of fishing effort in space and time, therefore to remain effective, management tools will have to adapt accordingly (Daw et al. 2009, Koubrak and VanderZwaag 2020).

Fourth, there is a dearth of empirical ecosystem services research in low-income countries. Ecosystem services work in general (Lautenbach et al. 2019) and in coastal systems in particular (Blythe et al. 2020) has mostly focused on the Global North. Ecosystems and people's relationships with them differ geographically and with cultural context (Díaz et al. 2018). Meaning our understanding of ecosystem services and why they matter in one place cannot be assumed to also hold in another. Therefore, the lack of empirical work in low-income countries represents a worrying blind spot in our understanding of coastal ecosystem services, especially small-scale fisheries.

My thesis examines the human dimensions of seasonal small-scale fishery ecosystem services to strengthen understanding of fisheries as the interface between dynamic social and ecological systems. I focus on the social contributions of small-scale fisheries through time to contribute a more meaningful understanding of seasonality in small-scale fisheries. Using the case study of Atauro Island where, similar to many coastal areas in low-income countries, small-scale fisheries are part of dynamic and diversified livelihood strategies (Mills et al. 2017), my thesis provides empirical research on coastal ecosystem services in low-income countries.

1.6. THESIS OUTLINE

To attend to my research objectives, I structure my thesis using the ecosystem services cascade framework (hereafter 'cascade framework', Figure 1.1). The cascade framework elucidates the distinct but linked stages that connect ecosystems to human wellbeing. By distinguishing between the biophysical and social components of ecosystem services, and recognising that potential ecosystem service supply is not necessarily realised (Potschin-Young et al. 2018), the cascade framework helped to address some of the inconsistencies in how ecosystem services were defined in the literature (Nahlik et al. 2012). Later adaptations of the cascade framework more explicitly incorporated the influence of social processes by including the mediating mechanisms through which people coproduce ecosystem services (Spangenberg et al. 2014b, 2014a). The cascade framework continues to evolve, elaborated with the inclusion of contextual factors and human values that shape social-ecological feedbacks and the ways that people mediate ecosystem service delivery (Fedele et al. 2017).

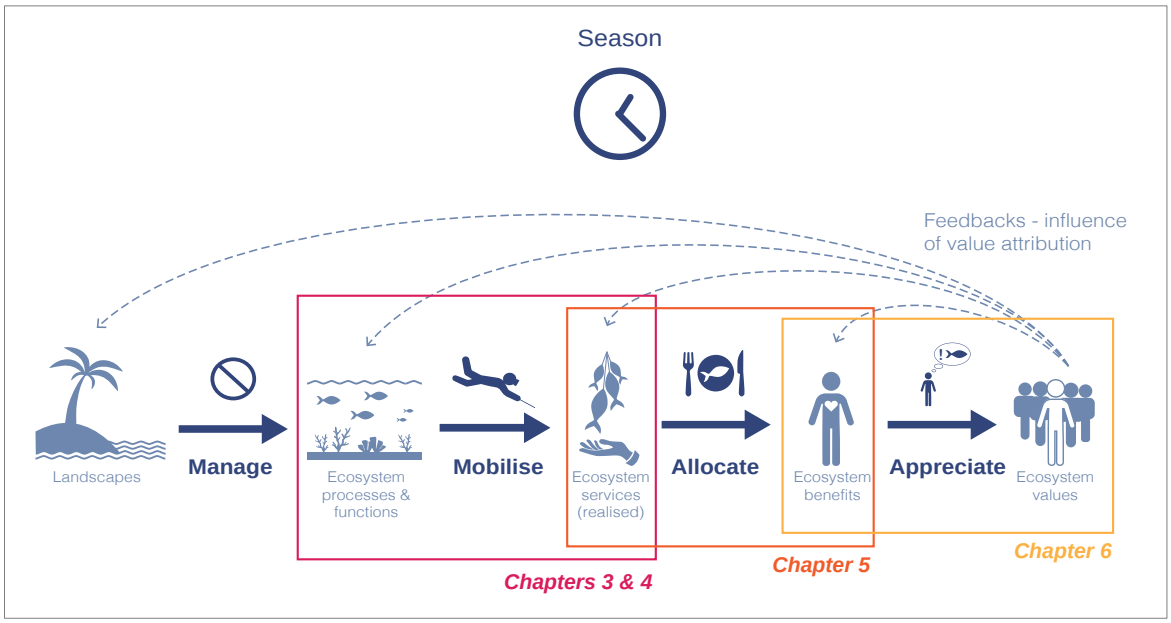


FIGURE 1.1 FOCUS OF CHAPTERS 3-6 ILLUSTRATED ON THE ECOSYSTEM SERVICE CASCADE FRAMEWORK (ADAPTED FROM FEDELE ET AL. 2017), WITH SEASON AS THE OVERARCHING CONTEXTUAL INFLUENCE. MECHANISMS THROUGH WHICH PEOPLE MEDIATE LINKS BETWEEN STAGES ARE INDICATED WITH ARROWS AND LABELLED IN BOLD.

I structure my thesis around the version of the cascade framework presented by Fedele et al. (2017) because of its explicit inclusion of co-production processes and contextual factors. I focus on how people mediate the stages linking ecosystem processes and functions to human wellbeing, namely through the mobilisation, allocation and appreciation of ecosystem services. I focused on these mediating mechanisms because they are often implemented at

individual or household levels and so represent processes through which people directly influence flows of wellbeing values from ecosystems. Conversely, ecosystem management (the mediating mechanism linking landscapes to ecosystem processes and functions) tends to be implemented at community scales or above. I attend to the different stages of ecosystem service mediation sequentially in my chapters, examining how people co-produce ecosystem services seasonally at each stage. This structure supports a clear and coherent narrative throughout my thesis and provides a logical approach to breakdown the complex and dynamic social-ecological interactions that underpin coastal ecosystem services.

In my first two data chapters (*Chapters 3* and *4*) I examine how people mobilise flows of ecosystem services from coastal ecosystems through time. By mobilising ecosystem services people mediate the flows of realised services that actually provide benefits to human wellbeing (Fedele et al. 2017). It is realised services rather than service capacity that must be managed to achieve human wellbeing outcomes (Villamagna et al. 2013). *Chapter 3* focuses on how the materiality of coastal environments influences the ability of people to mobilise ecosystem services through time. Specifically, I look at how in different seasons spatial-habitat factors affect the decision of households to glean[1] and thereby whether households realise the material and relational benefits of interacting with littoral habitats. In *Chapter 4*, I focus on social identity and access in the mobilisation of ecosystem services. I analyse how gendered fishing strategies change seasonally to evaluate the roles of different fishing methods and gender groups for coproducing fish as food at different times of the year.

In *Chapter 5* I use the concept of everyday agency to explore how people allocate realised services amongst different benefit streams. Through allocation, people determine the type of benefits they derive from an ecosystem service and how final benefits are distributed across beneficiaries (Daw et al. 2016). In *Chapter 5* I ask; how do households determine the seasonal livelihood function of fishing through their choices of how to use fish catch?

Finally, in *Chapter 6* I explore the diverse ways that people appreciate ecosystem benefits at different times of the year. Specifically, I elicit the reasons why women glean and how the importance of reasons changes seasonally. *Chapter 6* extends pluralistic valuation by accounting for the ways that ecosystems matter to people through time.

[1] NB. In this thesis I use the term gleaning to refer to the manual collection of marine organisms in intertidal areas and shallow water. The term gleaning is also used in terrestrial/agricultural contexts to describe the gathering of leftover crops

2. METHODS

2.1. RESEARCH PHILOSOPHY AND METHODOLOGICAL APPROACH

My thesis is grounded in a post-positivist research philosophy. Research philosophies refer to the principles and assumptions, concerning what is real (ontology) and how we understand the world (epistemology), that underpin scientific research (Ryan 2018). The philosophical approach of research influences the questions asked and how they are answered (Moon et al. 2019). Post-positivism is influenced by critical realist philosophy (Chilisa and Kawulich 2012), the fundamental premise of which is that a biophysical reality exists but our knowledge of that reality is necessarily fallible, because the understanding that underpins knowledge is grounded in interpretation (Carolan 2005). Post-positivism rejects the claim of positivism that science can know reality with certainty, which is argued to be naïve and unsuitable in the social sciences (Houghton 2011). Post-positivism and critical realism advocate methodological plurality and falsification, with discovery being a key line of inquiry (Guba and Lincoln 1994). A post-positivist philosophy allowed me to explore my research problem from different perspectives, reflecting the view that there are multiple legitimate ways to understand reality (Greene 2008).

Accordingly, I chose to use a mixed-method, case study approach to tackle my thesis from multiple perspectives as a body of problem-driven social research. There have long been debates on the comparative usefulness and scientific legitimacy of quantitative and qualitive research, with each bearing distinct strengths and weaknesses. Combining both methods in mixed approaches allows the researcher to draw on the complementary strengths of each; the generalizability and scope of quantitative research with the depth of qualitative research (Osborne 2008). Specifically, I used a sequential strategy mixed-method approach (Creswell 2009); initial qualitative data collection informed the development of following quantitative/qualitative methods.

Case study methodology describes the study of an issue by examining it in the context of one of more bounded systems (cases) using multiple sources of information (Creswell 2007). Case studies are the preferred methodology for asking questions of ‘how and why’ regarding phenomena in a real life context, particularly when boundaries between the phenomenon and context are unclear (Yin 2009), such as in my research. Case studies are fundamental to good social science. They are an ideal approach for falsification and theory building, and the context dependent insights gained from case studies are at the core of understanding human

behaviour (Flyvbjerg 2006). Specifically, case study methodologies enable the complexity and narrative of real life to be examined at a level of detail lost in methods focused on the breadth of summary (Flyvbjerg 2006). Case study methodologies are particularly useful for empirical work on social-ecological systems for providing fine grain perspectives of the relationships that link system dynamics (Poteete et al. 2010).

2.2. Positionality

The conduct, outcomes and results of research are influenced by the positionality of the researcher. Positionality is linked to a person's worldviews that are reflected in the ontological and epistemological assumptions of their philosophical approach (which I describe in the previous section). Positionality is also influenced by ascribed traits, such as gender, race and nationality and subjective aspects, including the political views and personal life history of the researcher, which influence their position in relation to the research subject, participants and process (Holmes 2020). Positionality and power relations in research and knowledge production raise a number of ethical challenges, particularly in cross-cultural research (Scheyvens and Leslie 2000). As a researcher, reflexive self-assessment of positionality is important for recognising how your own views and position may influence the design, execution and interpretation of findings (Holmes 2020).

Researcher positionality lies along a continuum of 'insiderness' and 'outsiderness' (Mercer 2007). For my thesis research, my positionality was as an external-outsider (Banks 1998). I am a white, British female and I do not speak any of Timor-Leste's native languages. I had no prior intimate knowledge and no cultural association with the research subject or participants. There are both strengths and weaknesses to outsiderness (Mercer 2007). My detachment and distance from the subject and participants enabled me to abstract information from the cultural context to provide an etic account; my thesis explores theory in a way that aims to be independent of culturally specific terminology or references and is targeted at an external scientific audience (Holmes 2020). However, the lack of familiarity with the subject and participants will have impeded my ability to pursue meaningful lines of inquiry, been a barrier to honest participant responses, and weakened the authenticity of my interpretation (Holmes 2020). Positionality changes continually with the evolution of a researcher's worldviews and with the situation and context. I believe that my positionality changed over the course of the

research. I conducted multiple and extended periods of fieldwork, during which I lived with families in the study communities. Developments in my own awareness of and engagement in the cultural context and in my relationships with the communities led to a slight increase in the 'insiderness' of my positionality. As relationships of care, trust, dignity and reciprocity developed between myself and the study communities I was afforded a greater depth of insight by research participants. The social and emotional skills invested in building these relationships reflect the importance of researcher personality, alongside positionality, in the conduct and outcomes of field research (Moser 2008).

2.3. STUDY SITES

Data were collected in eight coastal communities on Atauro Island Timor-Leste (Figure 2.1). Timor-Leste is a Small-Island Developing State in the Indo-pacific that sits geopolitically and culturally between Southeast Asia and the Pacific Islands (Sousa-santos 2015). Timor-Leste is one of the world's youngest countries, having gained independence in 2002 after decades of violent and repressive colonisation by Portugal (1765-1975) and Indonesia (1975-1999). Despite rapid progress since independence, Timor-Leste's tumultuous history has left a legacy of under development; it is ranked 132/188 for human development globally (UNDP 2018). Of the 1.293 million people who live in Timor-Leste, 41.8% live below the national poverty line (World Bank 2018).

Food insecurity is a critical issue in Timor-Leste. Historical conflict has resulted in an underdeveloped agricultural sector (Bonis-Profumo et al. 2019). Cycles in low-yield, rainfed subsistence agriculture drive the occurrence of an annual lean season, that can last from September through to April in some places (da Costa et al. 2013). Seasonal resource shortfalls are direct drivers of stunted child growth (Spencer et al. 2017) and around half of children in Timor-Leste are stunted as a result of undernutrition, which is one of the highest rates globally (GHI 2018). The challenges of food insecurity in Timor-Leste are likely to be exacerbated by the combined impacts of rapid population growth and climate change on agricultural systems (Molyneux et al. 2012). Developing sustainable, climate resilient food systems, including prioritising nutrition sensitive approaches and women's empowerment, is critical to the future of the country (Bonis-Profumo et al. 2019, 2021).

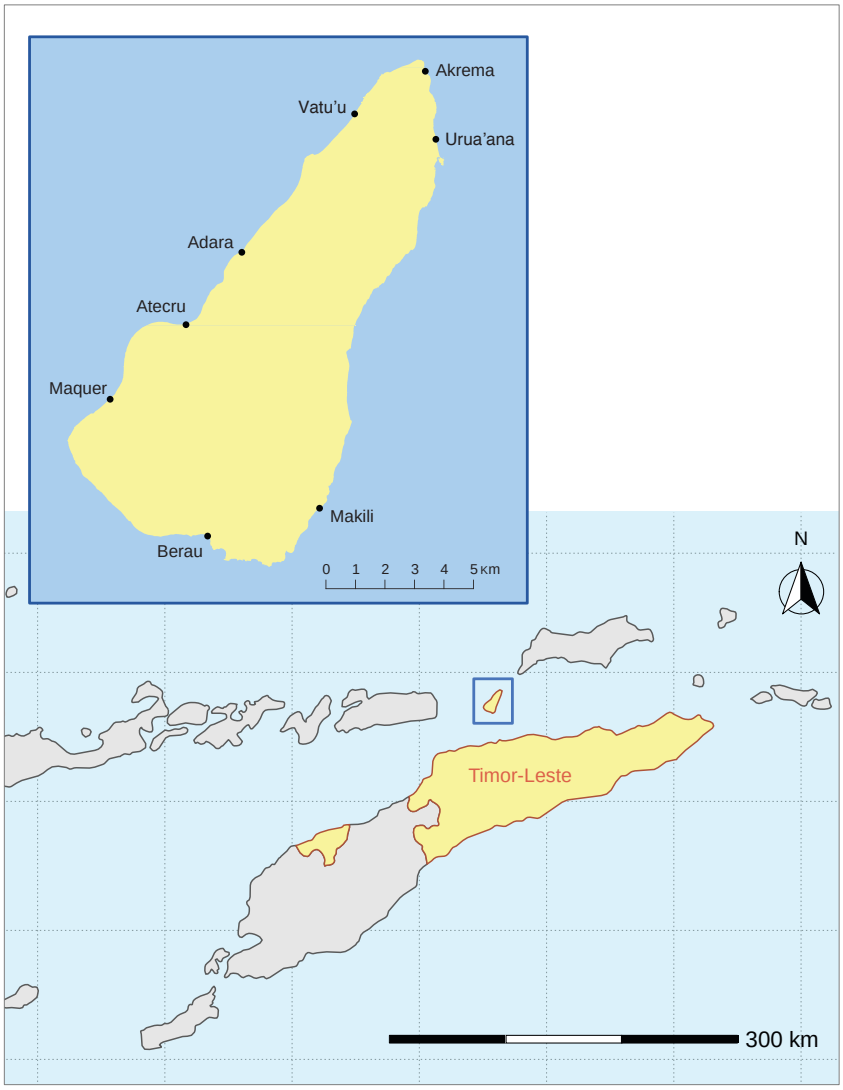


FIGURE 2.1 MAP OF TIMOR-LESTE WITH INSET OF ATAURO ISLAND INDICATING LOCATIONS OF STUDY SITES

Small-scale fisheries have the potential to contribute to food security and poverty alleviation in Timor-Leste (Andersen et al. 2013). Fish consumption in Timor-Leste is surprisingly low for an island nation. Average annual per capita fish consumption is estimated to be 6.1kg, but this is not evenly distributed between coastal (17kg) and inland (4kg) areas (AMSAT 2011a). Fish is of limited availability due to the fisheries sector being underdeveloped. There are estimated to be around 5,000 fishers in Timor-Leste (GOTL 2015). Timor-Leste's fisheries are mostly concentrated along the coastline (as opposed to inland) and are almost entirely artisanal - fishers travel by foot or small vessels, including non-motorised canoes, and use low-tech fishing equipment (AMSAT 2011b, FAO 2019). Many fishing families choose to invest in livestock rather than fisheries because of the greater cultural importance and economic value of livestock (Alonso Población 2013). Low fish consumption, particularly in rural inland

areas, also reflects a lack of storage and distribution infrastructure, including limited production and distribution of ice (Lentisco et al. 2013) and poor transport networks (Steenbergen et al. 2019a). Fishing equipment and infrastructure connecting fishers to markets were destroyed during historical conflict, including the civil unrest in 1999 surrounding independence (Sandlund et al. 2001). Fish availability in Timor-Leste is also seasonal (AMSAT 2011b). For instance, local knowledge of the sardine fishery on Timor-Leste's mainland indicates the importance of seasonally turbid river plumes for catch quantities and composition, which influence how catches are used and distributed (Hunnam et al. 2021).

Careful coastal management is needed to ensure the sustainable contribution of fisheries, as part of broader rural development strategies, to improved human wellbeing and food security in Timor-Leste. Located at the heart of the Coral Triangle, the seas around Timor-Leste are highly biodiverse and the coral reefs that fringe the coastline support some of the world's highest species richness (PIFSC 2017). These coral reef systems are important to fishery livelihoods, which raises concerns around rates of exploitation and the vulnerability of fisheries to climate change and coastal development (Mills et al. 2013). Developing Timor-Leste's fisheries sector in ways that reduces pressure on reef resources, for instance through the introduction of nearshore fishing aggregating devices (Tilley et al. 2019b), will be essential for sustainably increasing fish production. Along with increased fisheries production, sustainable coastal futures in Timor-Leste requires equitable fisheries data, policies and programmes, to ensure the historically invisible contributions of women and women's voices are represented in coastal monitoring and management (Lopes et al. 2020).

Timor-Leste's fisheries are governed by a combination of state based and community-based customary institutions. The following summary of the governance contexts draws on a more detailed description presented in Tilley et al. (2019a). The national Ministry of Agriculture and Fisheries (MAF) is responsible for monitoring marine resources, collecting export data and taxes, administering licences and marine enforcement in Timor-Leste. MAF fisheries officers in Timor-Leste's 13 municipalities carry out field extension activities, implement fishery training and manage landing centres. At the community level, governance is structured around *suco* (village) councils, with *sucos* containing multiple *aldeis* (hamlets) with locally elected leaders. *Suco* councils and local leaders are responsible for disseminating state laws

and regulations, and for promoting and adapting customary laws. One such custom-based law is *tara bandu* - a prohibition applied to regulate resource use for a set period of time. *Tara bandu* in coastal areas are being re-introduced and strengthened by NGOs as a legitimate means of community-based management or co-management of marine resources. *Tara bandu* are also now recognised in state-based law, making it a hybrid form of custom-based and contemporary resource governance (Alonso-Población et al. 2018)

Atauro Island

The challenges of sustainably and equitably managing coastal resources are particularly pressing on Atauro Island. Atauro Island is Timor-Leste's only populated sub-island, located 25km north of the capital Dili. Atauro Island is home to 9,200 people (0.8% of Timor-Leste's total population) living in 23 communities across five administrative sub-districts (GDS 2015). Livelihoods on Atauro Island are more fisheries focused than the rest of Timor-Leste and it's estimated that of the ~5000 fishers reported in national statistics, around 2000 live on Atauro Island (Mills et al. 2017, López Angarita et al. 2019). Fishing is positively linked to food and income on Atauro Island, particularly in coastal communities (Mills et al. 2017). Every Saturday, Atauro Island hosts Timor-Leste's largest regular fish market.

The beautiful beaches and rich marine life of Atauro Island also support a small but growing tourism industry and the island is at the centre of a national conservation strategy to set up a network of marine protected areas. Since 2015, 12 small co-managed marine protected areas have been established on Atauro Island through collaboration between government, international NGOs and local stakeholders and implemented through the *tara bandu* system. These village-level marine protected areas are typically located directly in-front of coastal communities and impose regulations over the use and access to coastal resources. The location and management of each of the marine protected areas was decided according to varying levels of community participation, and some have been a source of confusion and conflict. In 2019, Atauro Island's marine protected areas were formed into Timor-Leste's first national marine protected area network, under which a total of 13.251 hectares will be managed through a use zoning system. The management of coastal resources of Atauro Island must balance the multiple and sometimes conflicting stakeholder demands. The social values of small-scale fisheries must be taken into account to ensure the wellbeing of local communities is fairly represented in decision-making.

I collected data in eight coastal communities on Atauro Island (Figure 2.1) that had similarly low levels of infrastructure. All study communities were rural and isolated, being accessible only by foot or boat. Houses in the communities are built from locally made bricks or more basic materials (palm fronds). None of the study communities have regular access to electricity although some households have generators or small-solar panels used to power lightbulbs at night. Households cook on open fires fuelled by foraged firewood. Drinking water in the study communities comes from rain storage tanks and water from semi-saline wells are used to wash clothes/dishes. Timor-Leste in general is primarily Christian, and the study communities were either catholic or protestant.

Livelihoods in study communities typically involve a combination of subsistence crop farming, livestock rearing and fishing. Small gardens surrounding houses and plots of land on the steep hillsides are used for subsistence agriculture. Main crops include corn and various types of beans, most households also have papaya trees (the fruits, leaves and flowers are all eaten) and moringa trees (a drought resistant tree with highly nutritious leaves) and some also grow other fruits and vegetables (e.g., watermelon, oranges, pumpkin and cassava). Households commonly keep a small number of pigs, goats, chickens and dogs. Livestock are occasionally eaten but mostly gifted in cultural events, such as weddings, or traded as a source of income.

Fisheries in the study communities are mostly artisanal. Households use a combination of low-tech fishing gear, including gillnets, baited/hooked lines, spear and knifes, and, in some communities in the south, bamboo fish traps. Fishers use small vessels, including wooden boats with motors and wooden canoes, or fish from the shore, such as gleaning (the manual collection of marine organisms on foot). Fishing is predominantly carried out in intertidal, shallow water, reef and reef-edge habitats; very few fishers on Atauro Island have the gear needed to access offshore fisheries (Mills et al. 2013). Fisheries on Atauro Island target a variety of finfish, molluscs and crustaceans, with main target groups varying with habitat and fishing methods. The main landing group caught using gillnets on the reef edge are fusiliers (*Caesionidae* family). Baited/hooked lines are used to catch pelagic fish, such as bonito (*Scombridae* family) and long tom (*Belonidae* family). In reef habitats, which are often fished using spears, common catch groups include rabbitfish (*Siganidae* family), surgeonfish (*Acanthuridae* family), triggerfish (*Balistidae* family) and octopus (*Octopodidae* family).

Gleaning in intertidal zones and shallow water targets a huge diversity of marine organisms, including octopus, small eels (*Muraenidae* family), and numerous bivalves (i.e. clams), whelks and conch. Fishing provides a source of food and income; fish is sold directly within the village or at the weekly fish market. Some households have access to ice boxes and ice, but for many the only way to store fish is to salt and sun-dry it. Drying and selling fish is a common livelihood amongst women.

2.4. DATA COLLECTION

I collected primary data over three field trips between July 2018 and May 2019 (Figure 2.2). I used a variety of methods to collect qualitative and quantitative data at the individual, household and community level (Table 2.1).

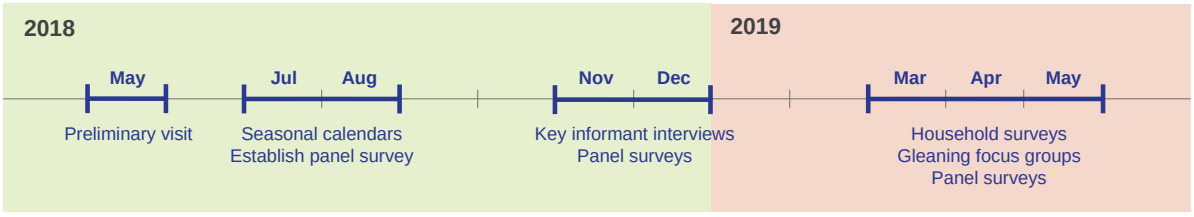


FIGURE 2.2 TIMELINE OF FIELDWORK TRIPS (SHOWN IN BOLD), WITH DATA COLLECTION ACTIVITIES DESCRIBED.

TABLE 2.1 SUMMARY OF DATA COLLECTIONS METHODS AND DATA CHAPTERS IN WHICH DATA WERE USED. METHODS CATEGORISED BY TYPE OF DATA COLLECT (QUALITATIVE OR QUANTITATIVE), LOCATION OF DATA COLLECTION (ALL STUDY COMMUNITIES, ADARA), THE UNIT AT WHICH DATA WERE COLLECTED AND THE SAMPLE SIZE.

Ch3	Ch4	Ch5	Ch6	Method	Data	Site	Unit	Sample
		X		Seasonal calendars	Qual	Ad	Community	2
		X		Panel survey	Quant	Ad	Household	15
		X	X	Key informant interviews	Qual	Ad	Individual	16
X	X		X	Household survey	Quant	All	Household	131
			X	Gleaner discussions	Quant/Qual	Ad	Individual	13
X				Informal discussions	Qual	All	Individual	NA

Throughout my research trips to Timor-Leste, I worked closely with three local research assistants who translated data collection tools and interpreted between Tetum and English. Translation and interpretation in research can introduce challenges of ensuring conceptual equivalence (Birbili 2000). Thus prior to carrying out data collection, a number of days were spent with research assistants explaining the conceptual focus of the research and data

collection tools. This ensured research assistants had sound knowledge of the research focus and objectives and that these were correctly reflected in the translation of data collection tools and interpretation between Tetum and English. Discussions throughout data collection and debriefs immediately after were used to clarify data and ensure I had a correct understanding. In the following paragraphs I describe the seasonal focus of the data collection methods and then provide a brief description of each method used in chronological order[2]. Methods are described in more detail in individual chapters.

SEASONAL STRUCTURE

Seasons were defined and examined differently in data collection methods depending on the focus of analysis (Table 2.2). I used seasonal calendars to gain an overview of typical seasonal cycles (Figure 2.3), which informed the seasonal structure used in other data collection tools. The West Pacific Monsoon is a key driver of climatic and wave-wind conditions in Timor-Leste, it characterises a marked wet season, typically from December to March and brings westerly winds that drive waves from a north-westerly direction (PCCSP 2015). From June to September, trade winds characterise the dry season and waves from a north-easterly direction (PCCSP 2015). Bad weather is a main challenge faced by fishers on Atauro Island (AMSAT 2011b).

TABLE 2.2 SUMMARY OF SEASONAL STRUCTURE USED IN DIFFERENT DATA COLLECTION TOOLS

Method	Season type	Season description	Seasonal data type
Seasonal calendars	Annual cycle	Monthly	Recall of typical conditions
Panel survey	Livelihoods/food security	Preparation, Lean, Harvest	Real time (daily)
Key informant interviews	Variable	Dependent on livelihood	Recall
Household survey	Sea/fishing	Calm, Rough	Recall of typical conditions
Gleaner discussions	Sea/fishing	Calm, Rough	Recall of typical conditions
Informal discussions	Variable	Variable	Recall and real time

[2] I only include information on methods used to collect data that were included in my thesis. However, seasonal calendars, panel surveys and key informant interviews were implemented in a second community but a number of challenges meant that the panel data were incomplete. As a result, data from the second community were not included in analysis in Chapter 5 as originally intended and so I have not included details of data collection in this community.

FIGURE 2.3 OVERVIEW OF SEASONAL CALENDAR FINDINGS OF TYPICAL SEASONAL CYCLES IN WEATHER AND SEA CONDITIONS, KEY FISHERY AND AGRICULTURAL SEASONS.

The panel surveys, which collected data on fisheries within the wider livelihood context, focused on three seasons based around food security, sea and weather conditions. The panel surveys collected real-time data and so may not necessarily represent 'typical' conditions and may be sensitive to inter-annual variation. Other data collection methods used recall of seasonal conditions in a typical year. Key informant interviews focused on different seasonal cycles in specific livelihood activities. The household survey and gleaner discussions focused on fishing seasons, which are determined by sea conditions. Prior to carrying out household surveys, typical monthly timing of westerly and easterly winds, rough and calm sea conditions, and good and bad fishing seasons were identified through discussions with the village chief and/or the chief's secretary. In all villages, the main period of rough sea conditions was reported to occur sometime between December and March associated with the western monsoon, with January and February typically the worst fishing months. Mixed sea conditions were often reported to occur during the eastern monsoon, with August considered to be a rough month with reduced fishing in some locations[3].

[3] Conversely, Mills et al. (2017) found that on the eastern and southern coasts of Atauro Island, fishing intensity decreased between December and February, but was lowest in August. More data are needed to resolve this discrepancy.

SEASONAL CALENDARS

To collect qualitative data on seasonal cycles in environmental conditions and corresponding livelihood dynamics, I used seasonal calendars in a focus group setting. The seasonal calendars were based around a large dial framework representing a typical year. During the focus groups the framework was populated with information on weather and livelihood activities in different months (recorded in note form in English and Tetum Figure 2.4). The seasonal calendar focus groups were held in July 2018 in the community of Adara in a public space open to all community members. Two focus groups were carried out with men (n=15) and women (n=19) separately. Each focus group lasted between 2-3 hours. I led the seasonal calendar activities with the support of a research assistant who translated the data collection tools and interpreted between English and Tetum during data collection.

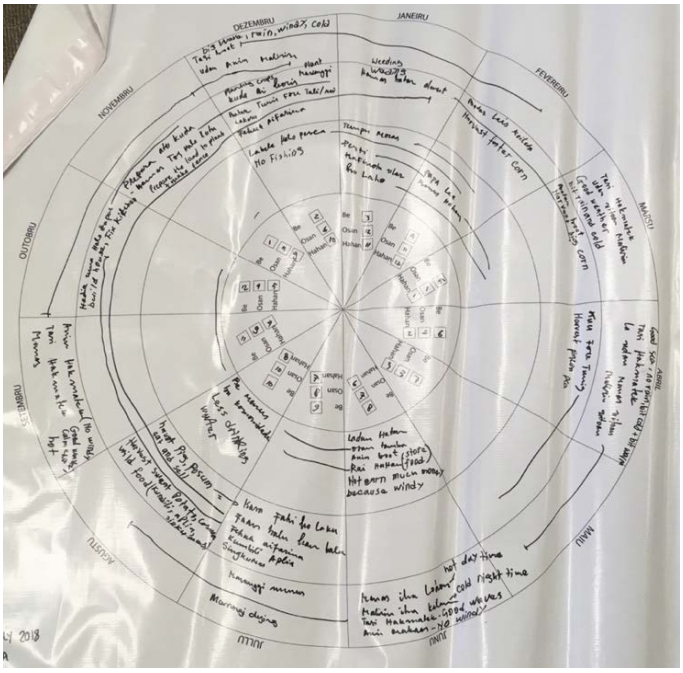


FIGURE 2.4 EXAMPLE OF SEASONAL CALENDAR POPULATED DURING FOCUS GROUP.

PANEL SURVEY

I developed a daily household survey to collect information on the livelihood activities of household members for the previous day (Appendix A.1). The survey was digitised in both English and Tetum using Kobotoolbox software (Harvard Humanitarian Initiative n.d.) and uploaded onto tablets. In July 2018, with the assistance of the research assistant who translated the survey tools I trained three women in the community of Adara to implement the survey (Figure 2.5). The women were chosen because they could read and write and had

volunteered themselves to be survey implementers. Each survey implementer was assigned five households who had agreed to participate. The survey was carried out daily following a seasonal panel structure. Two one-week survey periods were selected to coincide with the new moon and full moon in three different seasons (August 2018, January 2019, April/May 2019). Survey seasons were chosen as having different environmental and livelihood conditions according to seasonal calendar findings (see *Chapter 5* for details on survey seasons). In total the panel survey represented 630 household survey days (3 survey implementers x 5 participating households x 7 daily surveys x 2 weeks x 3 seasons).

FIGURE 2.5 RESEARCH ASSISTANT FACILITATING SURVEY TRAINING WITH THE THREE SURVEY IMPLEMENTERS IN ADARA.

KEY INFORMANT INTERVIEWS

Key informant interviews were carried out in Adara in November 2018 to collect in-depth qualitative data on livelihood seasonality. Interviews followed a structured format focused on specific livelihood activities (fishing, gleaning, agriculture, livestock, Appendix A.2). Interviews were translated into Tetum by a research assistant, who also then provided support in the implementation and interpretation of interviews. Interviews took between 60-90 minutes to complete. In total, 16 interviews were carried out with four individuals interviewed for each livelihood activity. Interviewees were purposefully selected as individuals who participated in the specific livelihood activity and who were willing and able to be interviewed.

HOUSEHOLD SURVEY

I designed a household survey to collect information on seasonal fishing activities and seafood consumption (Appendix A.3). The survey was translated into Tetum by a research assistant and digitised using Kobotoolbox software (Harvard Humanitarian Initiative n.d.). The survey was implemented by myself and the research assistant in eight coastal communities. We opportunistically sampled households using a door-to-door approach over three full days (morning - night) in each community. To reduce issues of availability bias that can arise from using door-to-door approaches, if a household was willing but unavailable to participate in the survey when we initially approached them, an alternative time convenient for the household was agreed. In total, the survey was completed with 131 households (Table 2.3). Household heads were commonly males (86%), aged between 18 and 60 years (78%) and had no formal education (50%).

TABLE 2.3 TABLE OF SAMPLE SIZES FOR THE HOUSEHOLD SURVEY ACROSS THE EIGHT STUDY COMMUNITIES

Household head		Village								
		Akrema	Urua' ana	Makili	Berau	Maquer	Atecru	Adara	Vatu' u	*Total*
Gender	Male	13	12	15	16	13	14	12	18	*113*
	Female	3	3	0	1	3	2	6	0	*18*
Age (years)	18-60	10	10	14	14	13	13	13	15	*102*
	>60	6	5	1	3	3	3	5	3	*29*
Education	None	5	7	9	7	12	10	6	9	*65*
	Primary	5	6	1	3	1	3	7	6	*32*
	>Primary	6	2	5	7	3	3	5	3	*34*
Total households		**16**	**15**	**15**	**17**	**16**	**16**	**18**	**18**	***131***

The survey included questions on household socio-economic indicators and livelihoods, and questions on seasonal fishing, including participation by different household demographic groups (children (<10 years) and female/male youth (11-18 years), adults (18-60 years) and elderly (>60 years)) in gleaning and other fishing, the nature of fishing trips and landings, how catches were used and household seafood consumption in different seasons. Based on prior knowledge of main target species, catch groups were loosely categorised in the survey. For non-gleaning fishing, catch groups included fusiliers, reef fish, pelagic fish, octopus and other, and for gleaning catch groups included shells (includes a diverse range of molluscs), crabs, eels, tiny fish (schools of juvenile fish), fish (various types of reef fish), octopus and

other. These loose categories enabled to survey to provide a broad overview, minimised confusion for enumerators, as some species have multiple names or may be referred to in different languages, and reduced the risk of survey fatigue amongst respondents.

GLEANER DISCUSSIONS

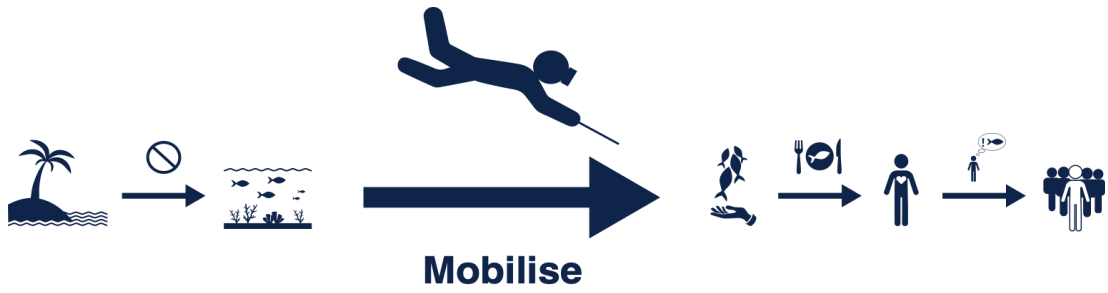
I designed a set of activities to collect quantitative and qualitative data on seasonal gleaning in a focus group setting. Activities were specifically designed to target women using non-written methods because on Atauro Island women mostly cannot read or write. I used a combination of individual and group drawing- and picture-based methods to collect data on seasonal gleaning activities and catches and the reasons why women glean at different times of the year (see *Chapter 6* for details on the different methods used in the gleaning groups). The gleaning groups were carried out in the community of Adara in April/May 2019. To keep group sizes small, I carried out two separate groups containing six and seven women each (Figure 2.6).

FIGURE 2.6 PHOTOGRAPH OF DISCUSSION GROUP WITH GLEANERS

INFORMAL DISCUSSIONS AND OBSERVATION

Throughout my fieldwork I observed daily life whilst living with families in the study communities. I also regularly engaged in informal discussions with members of the community about aspects of their livelihoods and local culture, experiences of seasons and food consumption. These informal data collection approaches provided valuable insights that I incorporated into my research and that strengthened the interpretation of my findings.

3. SPATIOTEMPORAL DETERMINANTS OF SEASONAL GLEANING



Adapted from: Grantham, R., Álvarez-romero, J.G., Mills, D.J., Rojas, C., Cumming, G.S., 2021. Spatiotemporal determinants of seasonal gleaning. People and Nature.

Contributions: I developed the research questions and methodology with advice from DJM and GSC. I collected and analysed the data and developed all figures and tables with advice from AJG, DM, CR and GSC. Spatial data were provided by AJG. I wrote the first draft of the manuscript and all co-authors provided editorial input which was included in revised versions.

ABSTRACT

Many coastal communities depend on ecosystems for goods and services that contribute to human wellbeing. As long-standing interactions between people and nature are modified by global environmental change, dynamic and diversified livelihood strategies that enable seasonal adaptation will be critical for vulnerable coastal communities. However, the success of such strategies depends on a range of poorly-understood influences. Gleaning, the hand-based collection of marine organisms from littoral habitats, provides an interesting case study of dynamic change in social-ecological interactions. It is an important coastal livelihood strategy, yet seasonal gleaning dynamics have not been empirically explored in contemporary communities. We examined seasonal gleaning in eight coastal communities on Atauro Island, Timor-Leste, using household surveys and satellite-derived maps of shallow-water benthic habitats. Our analysis explored the factors affecting household decisions to glean in each season, the relationship between gleaning and seafood consumption, and seasonal gleaning pressure on near-shore coastal resources. Dynamic marine harvesting strategies differed among households and gleaning activity was seasonally heterogeneous. That is, not all gleaning households gleaned during the season characterised by rough sea conditions despite rough season gleaning being associated with greater seafood consumption stability among seasons. Households also gleaned less regularly, and catches were smaller, in the rough season. Differences in seasonal participation in gleaning were explained mostly by type and extent of shallow habitat proximate to a community. In the calm season, household gleaning was positively related to the total area of shallow habitat, whereas in the rough season the percentage of hard-bottom shallow habitat was also an important predictor of gleaning activity. Our findings illustrate how changes in the biophysical environment mediate human-nature interactions at fine scales through time and space. Consequently, this research highlights the importance of context specific perspectives for understanding drivers and dynamics in fishing pressure on littoral ecosystems, access to ecosystem benefits, and limits to adaptation. Consideration of factors influencing when livelihood activities are feasible and desirable is important for evaluating the social impacts of climate change, particularly in the context of rural communities in low-income countries.

3.1. INTRODUCTION

Understanding how coastal communities interact with and depend on local environments is key to sustainably managing coastal social-ecological systems in a rapidly changing world. Coastal communities in low-income countries, and particularly in Small Island States and rural areas, are some of the most vulnerable to climate change (Wong et al. 2014, Bindoff et al. 2019) because their livelihoods often depend directly on fragile marine resources and climate impacts pose major risks of food insecurity and poverty (Cinner et al. 2012, Cruz-Trinidad et al. 2014). Coastal ecosystem structures, processes and functions support a diversity of provisioning (e.g., fishery resources), regulating (e.g., wave attenuation) and cultural (e.g., seascape aesthetics) ecosystem services, which provide multiple material (e.g., food) and non-material (e.g., leisure opportunities) benefits to people (Barbier et al. 2011). Through human-nature interactions of ecosystem use and management, people realise and shape the benefits derived from environments (Spangenberg et al. 2014b), including in coastal zones. These interactions also influence coastal ecosystems; for example, fishing can modify the biophysical structure and function of coastal ecosystems through the removal of resources and changes in the structure of harvested populations, changing trophic interactions and altering habitats (Mangi and Roberts 2006).

An important but poorly understood human-nature interaction in coastal areas is gleaning. Gleaning is a low-technology, multi-species and typically female-dominated small-scale fishery subsector that involves the manual collection of marine organisms from shallow-water and intertidal (hereafter “littoral”) habitats (Chapman 1987, Branch et al. 2002). Gleaning is often part of diversified fishing strategies, complementing other fishing methods, predominantly as source of subsistence (Clark et al. 2002). Gleaners usually travel by foot and use their hands or hand-held tools (knives or metal sticks) to pry and stab target species that include molluscs, crustaceans, and fish (Kleiber et al. 2014). Despite being a widespread livelihood activity in the Pacific (Kronen and Vunisea 2007) and other coastal regions of low-income countries (Fröcklin et al. 2014), gleaning is a data-limited sector, historically overlooked in fisheries and livelihoods research and underrepresented in our understanding of how people interact with coastal ecosystems (Harper et al. 2013, Kleiber et al. 2014). A rise in gender-sensitive fisheries research has increased the visibility of gleaning and particularly its importance for household food security (e.g., (Tilley et al. 2020)). The value of

gleaning in the lives of coastal communities extends beyond subsistence; for instance, gleaning also provides opportunity for socialising, knowledge sharing and enjoying nature (Grantham et al. 2020). However, gleaning can negatively affect coastal ecosystems and cause long-term ecosystem changes through direct pressure on target species' populations (Keough et al. 1993, Aswani et al. 2014) and damage of habitats from the use of destructive methods (e.g., trampling or overturning corals) (Andréfouët et al. 2013). The management of gleaning fisheries is therefore crucial for sustaining human wellbeing and coastal ecosystems. Yet, activities and ecosystems most important for women, including gleaning and fishing in littoral habitats, tend to be underrepresented in coastal management as a result of gender blind spots (de la Torre-Castro et al. 2017). More empirical work is needed on gleaning as an interaction between coastal communities and the littoral zone.

Interactions between people and coastal environments, including fishing and gleaning, are not only a means to material gain, they represent relationships to nature that are valued in themselves and contribute to quality of life. For example, through indigenous perspectives that recognise an interconnected web between all animate life and inanimate things, fisheries represent a set of responsibilities and relationships with other people and the environment (McMillan and Prosper 2016). These relational values are defined as the "[P]references, principles, virtues about/based on meaning-saturated relationships" (Chan et al. 2018) and encompass a diversity of tangible and intangible values, rooted in human-nature interactions (unlike intrinsic values) and are distinct from instrumental values by being non-substitutable (Himes and Muraca 2018). The importance of relational values is gaining traction in research frontiers that seek to better attend to the social dimensions of ecosystem services (Chan and Satterfield 2020). A key development on the concept of ecosystem services is the proposed Nature's Contributions to People (NCP) framework, which includes cultural context as a crosscutting factor in recognition that worldviews underpin how human-nature interactions are perceived and valued (Pascual et al. 2017, Díaz et al. 2018). Stock-flow metaphors, such as framing the ocean as a service provider, oversimplify and misrepresent how people connect with coastal ecosystems and fail to capture multiple, interdependent and overlapping values (Klain et al. 2014). Indeed, the inseparability of material and non-material benefits of nature to people has been demonstrated in studies that show people highly value relational aspects associated with the subsistence benefits of fishing (Klain et al. 2014). Understanding how processes of change in coastal areas will affect nature's contributions to people, such

as those associated with gleaning, therefore requires not only evaluating how the delivery of benefits from ecosystems will be affected but also the implications for how people interact with nature because the relationships these interactions pertain to are valued in themselves.

In particular, there is a need to build a better understanding of how gleaning interactions are influenced by the combined social, physical and seasonal weather conditions. Experimental methods suggest that weather, tidal conditions, habitat type and the age and gender of gleaners affect gleaning returns (De Vynck et al. 2016). Other studies have looked at temporal trends in harvests from the littoral zone, for instance to monitor fishery rehabilitation success (Calvo-Ugarteburu et al. 2017) and seasonal trends in harvests have been found to differ with the availability of target species that can vary between sites at fine spatial scales (Gina-Whewell 1992, Kyle et al. 1997). Archaeological studies of shell middens provide insight into the seasonality of gleaning amongst early humans; seasonal trends in shellfish collection varied between locations and time periods, which has been attributed to the availability and accessibility of shellfish and the availability of other foods (Burchell et al. 2013, Loftus et al. 2019). In some societies shellfish are believed to have been targeted as a supplementary source of nutrition during lean seasons (Prendergast et al. 2016), whilst in others shellfish may have been harvested opportunistically in good weather conditions (Loftus et al. 2019). However, little research has empirically explored seasonal dynamics and drivers of gleaning by contemporary communities and, particularly in the context of a changing climate, there is a pressing need to understand how access to gleaning areas and seasonal weather conditions influence how people interact with littoral ecosystems.

This study contributes to addressing some of these gaps by examining seasonal household gleaning dynamics on Atauro Island, Timor-Leste. Timor-Leste is a Small-Island Developing State in the Indo-pacific that gained independence from Indonesia in 2002. It is ranked 132/188 for human development globally (UNDP 2018) and 41.8% of the population live below the national poverty line (World Bank 2018). Challenges of growing unemployment for the young and rapidly growing population of Timor-Leste risk increasing issues of poverty, conflict and environmental degradation (Hosgelen and Saikia 2016). One major challenge will be sustainably managing the country's coastal resources. Timor-Leste is located at the heart of the Coral Triangle and the coral reefs fringing the country support some of the world's highest species richness of coral reef fishes (PIFSC 2017). These coral reefs are important

for Timor-Leste's artisanal and subsistence small-scale fisheries (Mills et al. 2013). As the country continues to develop, demand for seafood and pressure on coastal resources are projected to rise (Mills et al. 2013). Currently, average seafood consumption in Timor-Leste is low for a small-island nation due to the low-tech and small-scale nature of the fishing sector and poor transport and storage infrastructure (Mills et al. 2013), which in part is a consequence of historical conflict (Sandlund et al. 2001). Increased availability and access to seafood have the potential to improve food and nutrition security and provide an important source of income for coastal communities (Farmery et al. 2020). Fisheries in Timor-Leste are governed through a combination of centralised state-based institutions and community-based institutions, including diverse systems of customary marine tenure, that are poorly understood (McWilliam 2002, Palmer and de Carvalho 2008). Without careful management to reconcile livelihood demands with ecosystem sustainability through locally legitimate forms of governance, development of Timor-Leste's fisheries sector risks undermining the country's rich marine ecosystems. Limited data in Timor-Leste's fisheries sector, particularly the blind spot surrounding gleaning, are a barrier to sustainable and equitable management (Tilley et al. 2020).

Using data collected from households living on Atauro Island, Timor-Leste, as a detailed case study we focused on the following questions: (1) How does gleaning, as part of household marine harvesting strategies, vary seasonally? (2) What is the relationship between gleaning and seasonal variability in seafood consumption? (3) What determines the decision to glean in different seasons? Our results present a fine-grained perspective of how people interact with littoral habitats through seasonal gleaning and offer insights into dynamic and context-specific human-nature relationships.

3.2. Methods

Study site

Research was undertaken at Atauro Island, Timor-Leste (Figure 2.1). Atauro Island is located 25km north of the capital, Dili, and is Timor-Leste's only populated islet. It is home to a population of over 9,200 people (0.8% of Timor-Leste's total population) and comprises five administrative sub-districts, containing 23 communities (GDS 2015). Livelihoods on Atauro Island are predominantly diversified, dynamic and subsistence focussed, with the most

common activities being crop farming, livestock rearing and fishing (Mills et al. 2017). Livelihoods are more fishery dependent in Atauro Island than other parts of Timor-Leste and every Saturday the island hosts the country's largest regular fish market (Mills et al. 2013). Atauro residents trade finfish and other seafood, which is sold fresh, dried or barbequed, as well as crops, livestock, handicrafts and basic goods. Buyers include local residents as well as individual and commercial buyers from Dili. Fishing has been linked to food and income security on Atauro Island and measures of poverty indicate wellbeing is greater in coastal communities than upland communities (Mills et al. 2017). The beaches and reefs of Atauro Island also support a small, but growing, tourism industry and have become the focus of a national conservation programme centred around establishing a network of marine protected areas (Conservation International 2020).

The type and extent of littoral habitats of Atauro Island vary geographically. Sandy beaches stretch along most of the north-eastern coast, backed by small patches of mangroves and fringed by coral reefs and seagrass beds, with large sandy flats covered in coral rubble and rocks exposed at low tide. The southern coast of Atauro Island is characterised by steep cliffs, steep pebbly beaches and large rocky boulders. Along the western coast, mixed pebble-sand beaches meet a narrow fringing reef that drops off abruptly and, in many places, reef flats are exposed at low tide. The maximum tidal range on Atauro Island is 1.5 - 2.0 m (MAF 2018). Gleaning takes place in the littoral zone, with gleaning predominantly focused on the intertidal zone exposed at low tide, but gleaners also collect organisms from shallow water, sometimes wading up to waist deep. Gleaning is carried out in all littoral habitat types surrounding Atauro Island; this includes collecting various organisms found amongst coral rubble and rocks in the large sandy tidal flats, pools and rock crevices in exposed coral reef flats at low tide, and the splash zone on rocky boulders.

DATA

Our analyses are based on household socioeconomic data and spatial information about the littoral habitats surrounding Atauro Island.

Household data

Household data were collected as part of a seasonal livelihoods and food security survey. Questions relevant to this study addressed basic indicators of household socio-demographics and recall of typical marine harvesting activities and seafood consumption for

two fishing seasons. In the survey, marine harvesting activities were categorised as gleaning or fishing, in line with how activities are distinguished locally. In Tetum (one official language of Timor-Leste), gleaning (using hand/hand-held tool to gather marine organisms from the littoral zone) is referred to as “collecting” (meti), whilst all other fishing methods (including the use of nets, traps and line-based fishing, whether from the shore or boat) are classified as fishing (peska). Sea conditions were used to define fishing seasons (calm season and rough season) because during preliminary activities fishers identified sea conditions as the main determinant of intra-annual fishing cycles on Atauro Island and because months are not a commonly used measure of time in study communities. According to fishing households, the main rough season on Atauro Island is associated with the western monsoon (typically December - March), during which strong westerly winds create a large swell particularly on the western and southern coasts and around the northern tip of the island, but also to a lesser extent on the eastern coast. Strong easterly winds during the eastern monsoon (typically July - August) create rough sea conditions on the eastern coast and variable sea conditions around the rest of the island, with August also being considered a rough month by most communities.

The survey (Appendix A.3.) was translated into Tetum and digitised using the Kobotoolbox software (Harvard Humanitarian Initiative n.d.). The survey was implemented by the lead researcher and facilitators in eight communities (Figure 2.1). Communities were selected for being coastal and to capture a range of geographic orientations on Atauro Island. Households were opportunistically sampled using a door-to-door approach over a period of three days in each community.

Spatial habitat data

To quantify differences in the littoral zone (representing potential gleaning habitats) around the island we used an existing map of coastal habitats sourced from the Pacific Islands Fisheries Science Center of the U.S. National Oceanic and Atmospheric Administration (NOAA). The map classifies coastal areas according to benthic habitat type based on variants in the spectral signature using satellite imagery from high-resolution WorldView-2 satellite imagery (PIFSC 2017). Using ArcGIS Desktop 10 software package (ESRI 2019) we calculated the area of hard-bottom shallow habitat (habitat class ‘hard shallow’) and other shallow habitat (grouped habitat classes of soft shallow, seagrass and mangroves) within a

2-km radius of each community (Appendix B.1). Although not all areas classified as 'shallow' are necessarily accessible to gleaners, shallow habitat reflects differences in the extent and type of littoral zone proximate to each community and therefore provides a useful proxy for comparing relative differences in potential gleaning areas. The 2-km radius buffer zone was chosen based on conversations with gleaners on typical distances travelled.

Analysis

Analyses were carried out using R statistical software (R Core Team 2018). Generalised linear mixed models were fitted using the lme4 package (Bates et al. 2014), with the exception of negative binomial distributions, which were fitted using the glm.nb function from the MASS package (Venables and Ripley 2002). Residual diagnostics were checked using the DHARMa package (Hartig 2020). Pairwise comparisons of estimated marginal means (EMM) were done using the emmeans package (Lenth 2019) with post-hoc Tukey method. All results were reported using a 95% confidence interval (p-value ≤ 0.05) for statistical significance and degrees of freedom were calculated using Kenward-Roger approximation.

Dynamic marine harvesting

Dynamic marine harvesting strategies and gleaning seasonality were analysed using data on household participation in fishing and gleaning during the rough and calm seasons. Marine harvesting strategies were categorised as Glean, Fish, Glean & Fish, or None, according to whether any household member fished/gleaned during each season. Household gleaning seasonality was defined as Year round (marine harvesting strategy includes gleaning during rough and calm seasons), Rough only (marine harvesting strategy only includes gleaning in the rough season), Calm only (marine harvesting strategy only includes gleaning in the calm season), or Never (gleaning not included in marine harvesting strategy).

Seafood consumption stability and seasonal gleaning

To assess the relationship between seasonal gleaning and stability in household seafood consumption between the rough and calm seasons we developed a measure of Consumption stability. For each household in each season, the mean number of days per week that a household ate any of four categories of seafood (fresh fish, dried fish, shells and other) was calculated. Mean days in the rough season were then divided by mean days in the calm season to give rough-season seafood consumption as a proportion of calm-season consumption; thus, consumption stability values closer to one represent greater stability. To

understand how seasonal gleaning might influence household consumption stability, while controlling for seasonal fishing, we used a linear mixed effect regression model, represented as:

Stab ~ Gs + (1|Fs) + (1|V)

Where *Stab* is consumption stability and *Gs* and *Fs* are seasonal participation (i.e., year round, rough only, calm only, never) in gleaning and fishing, respectively. Seasonal fishing was included as a random effect to control for differences in seasonal seafood consumption likely associated with fishing. *V* is community and was included as a random effect to account for the nested sample design.

Determinants of gleaning

Factors affecting gleaning in the rough and calm seasons were fitted using a binomial distribution. Whether a household gleaned (*G*) was regressed against a cross-level interaction between season (*S*) and relevant spatial habitat, socio-demographic, and livelihood factors (Table 3.1) to understand how seasons and geographic location might influence gleaning activity. The model is represented as:

G ~ S : (Ar * Hd + A + W + B + L + F) + (1 | id / V)

The cross-level interaction between season and other factors was chosen because of the specific focus of this research on factors influencing seasonal gleaning. An interaction between the two spatial habitat factors Area (*Ar*) and Hard (*Hd*) was also included to capture the combined effect of spatial attributes on seasonal gleaning. Household (*id*) and community (*V*) were included as random factors to reflect the nested sample design and to account for any community-level effects on gleaning that may not be captured by factors included.

Due to uncertainty surrounding the accuracy of spatial habitat data proximate to community H (i.e., a small portion of the north-western habitat map was manually adjusted by NOAA to correct a possible error in the automated classification process of the satellite image), and to check the robustness of our results, we tested a model excluding community H (Model A) and one including all communities (Model B). To further validate our findings on habitat, we tested a simplified model including only the cross interaction between season and spatial habitat factors (Model C) and excluding data from community H:

G ~ S : (Ar * Hd) + (1 | id / V)

Throughout the results, we report the conditional goodness of fit (i.e., including the random component) and provide coefficients as log-odds based on scaled and centred data, that is, effect sizes are measured holding other factors constant at their mean.

TABLE 3.1 DESCRIPTION OF THE SPATIAL AND SOCIOECONOMIC FACTORS AND RATIONALE FOR THEIR INCLUSION IN THE MODELS

Initial	Name	Description	Type	Rationale
Ar	Area	Area (ha) of shallow habitat (includes hard bottomed and other shallow habitat), proximate (within a 2-km radius) to community	Continuous	Gleaning takes place in the littoral zone, therefore as a proxy for potential total gleaning area, larger shallow area proximate to the community is expected to be positively related to gleaning.
Hd	Hard	Percentage of proximate shallow habitat area that is hard bottomed	Percentage	Hard-bottom shallow habitats on Atauro Island mostly represent nearshore coral reefs. Tidal reef flats are an important gleaning area (Chapman 1987, Whittingham et al. 2003, Teh et al. 2013) and thus, the percentage of hard-bottom shallow area is expected to be positively related to gleaning.
A	Adults	Percentage of household members aged 18-60 years	Percentage	Human capital, including labour capacity, determines a household's ability to do things and therefore their livelihood strategies (Scoones 1998). The percentage of adult household members, as the primary labour force, could be positively related to gleaning if labour enables gleaning or negatively related to gleaning if gleaning is an activity of last resort for households that are unable to do other activities.
W	Women	The number of female (youth, adult and elderly) household members	Discrete	Gleaning in rural areas is typically a female-dominated activity (Chapman 1987, Branch et al. 2002) and so it is expected households containing more females would be more likely to glean.
B	Brick	Whether the household lives in a completed brick house	Binary	As a low-input fishery, gleaning may be an important livelihood strategy for poorer households. House material can provide a good indicator of wealth in contexts where income is highly variable (Chasekwa et al. 2018); on Atauro Island, building a brick house is a primary aspiration and a main use of income, with houses often being built incrementally over many years. Non-brick houses are typically constructed from a combination of sheet metal, palm fronds and bamboo.
L	Livelihoods	The number of livelihood activities* a household participates in	Discrete	Livelihood diversification is an important strategy for reducing seasonal variability in food and income (Ellis 2000). Households with more diverse livelihoods may be less dependent on gleaning due to available alternative sources of food and income.
F	Fishing	Whether the household fishes	Binary	As a source of seafood, gleaning may be less important for households that also fish.

* Calculated as the sum of crop farming, livestock rearing, fishing (fishing/gleaning/fish processing/fish trade), seaweed farming, tourism, transportation, salary, casual labour, and kiosk (run small shop).

Community gleaning trends

To characterise seasonal gleaning across the study communities we used descriptive statistics to summarise household gleaning trips and catches. Household gleaning seasonality was categorised as Year round, Calm only, Rough only or Never, and the regularity of gleaning trips in each season was categorised as Daily, Multi-weekly, Weekly or Occasionally (less than once per week). Gleaning catch quantities were recorded according to the typical basket level of catch collected on a typical gleaning trip, categories included Low (1/4), Mid (1/2), High (3/4) and Full. Target species were broadly categorised as Shells (includes a diversity of molluscs), Tiny fish (schools of juvenile fish trapped at low tide), Octopus, Fish (reef fish trapped in pools and rock crevices), Crab, Eel and Other (hereafter "catch groups"). In each season, the importance of each catch group to households was categorised as *Main catch* (primary group collected by gleaners), *Caught* (collected as secondary catch group), and *Not caught* (not collected by gleaners).

3.3. RESULTS

SAMPLE SUMMARY

In total, 131 households were surveyed, of which three were ultimately excluded because their livelihood strategies did not involve marine harvesting. Surveyed households were distributed evenly across study communities (Table 3.2). The final sample represented 661 individuals, with a mean household size of 5.25 and an average of 33.9% of household members being dependents (<11 or >60 years). All surveyed households participated in at least two different livelihood activities. All households farmed crops and this was the most important activity for 64.29% of households, all but one household kept livestock, and fishing was the most important livelihood activity for 32.54% of households.

TABLE 3.2 NUMBER OF HOUSEHOLDS SURVEYED IN EACH COMMUNITY

Code	A	B	C	D	E	F	G	H	
Village	Akrema	Urua'ana	Makili	Berau	Maquer	Atecru	Adara	Vatu'u	Total
Households	16	15	15	15	15	16	18	18	128

SEASONAL HOUSEHOLD GLEANING AND FISHING

Gleaning was part of dynamic and heterogeneous household marine harvesting strategies (Figure 3.1). More households gleaned in the calm season, but the relative importance of

gleaning was greater in the rough season when it was the only marine harvesting strategy for many households. In the calm season, all households did some form of marine harvesting; a majority did both gleaning and fishing or only fished, and very few only gleaned. Comparatively, in the rough season a third of households did no marine harvesting, the number of households that fished, either solely or in combination with gleaning, dropped, and the number that only gleaned increased and this was the most common strategy.

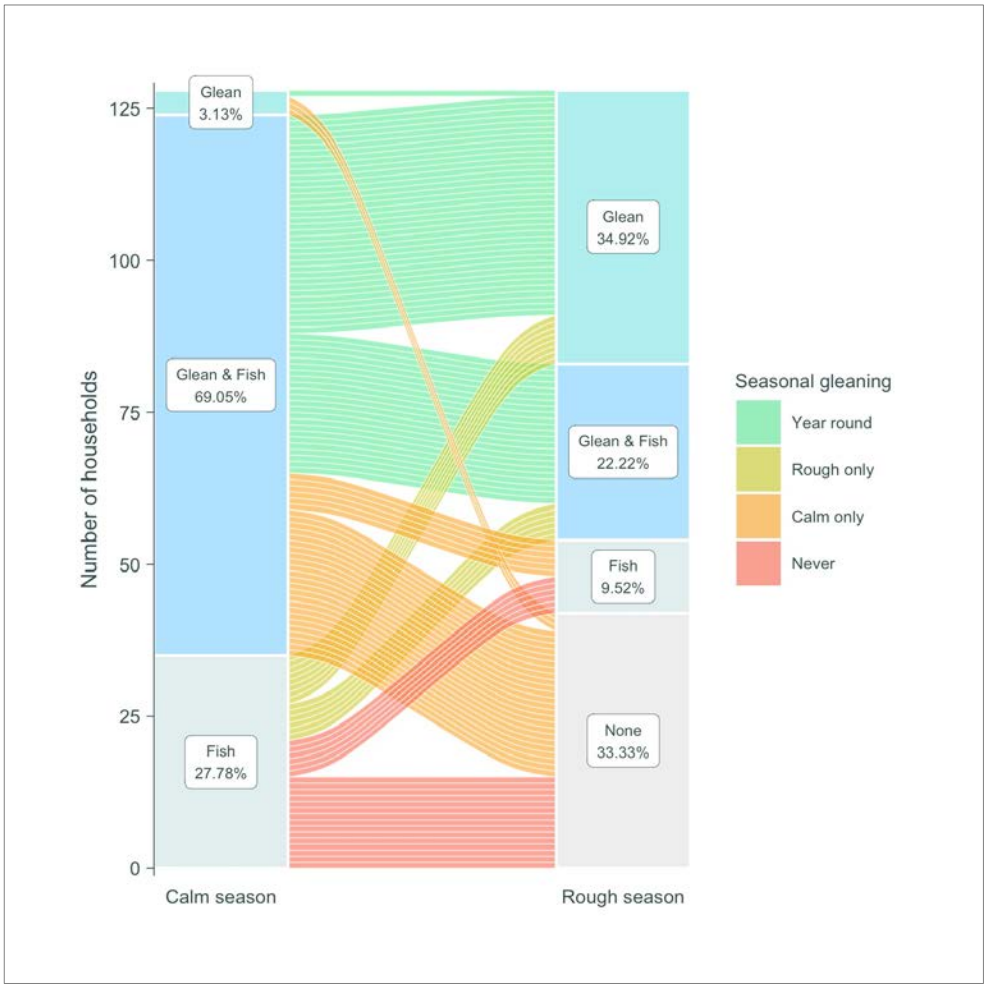


FIGURE 3.1 ALLUVIAL PLOT ILLUSTRATING HOUSEHOLD SEASONAL MOVEMENT BETWEEN MARINE HARVESTING STRATEGIES AND ASSOCIATED GLEANING SEASONALITY. CONNECTING LINES REPRESENT INDIVIDUAL HOUSEHOLDS.

Dynamic marine harvesting strategies shape different seasonal trends in gleaning. Households that gleaned year round either maintained gleaning and fishing (n=23) or gleaning only (n=1) in both seasons, or specialised from gleaning and fishing in the calm season to only gleaning in the rough season (n=36). Households for whom gleaning was only a rough-season activity fished in the calm season, and either switched to gleaning only (n=8) or diversified to gleaning and fishing (n=6) in the rough season. Households for whom gleaning was only a calm-season activity, either fished and gleaned (n=24) or only gleaned

(n=3) in the calm season and then stopped marine harvesting (n=21) or switched to fishing only (n=6) in the rough season. Households that never gleaned, fished in the calm season and either continued to do so (n=6) or stopped all marine harvesting (n= 15) in the rough season.

SEAFOOD CONSUMPTION STABILITY

Stability in seafood consumption between the rough and calm seasons was significantly related to seasonal gleaning (R^2= 0.33). Paired comparisons show that, taking account of seasonal fishing, gleaning during the rough season matters for seasonal seafood consumption (Figure 3.2, Appendix B.2). Consumption stability was similar amongst households that gleaned year round and only in the rough season, and similar amongst those who only gleaned in the calm season and those who never gleaned. Consumption was significantly more stable between seasons for households that gleaned in the rough season (Rough only and Year round) than for those who did not (Calm only and Never; Calm only/Rough only, t = -3.49, df 64, p = 0.004; Calm only/Year round t = -4.36, df 109, p <0.001; Never/Rough only t = -3.77, df = 54, p = 0.002; Never/Year round t = -4.37, df = 71, p <0.001).

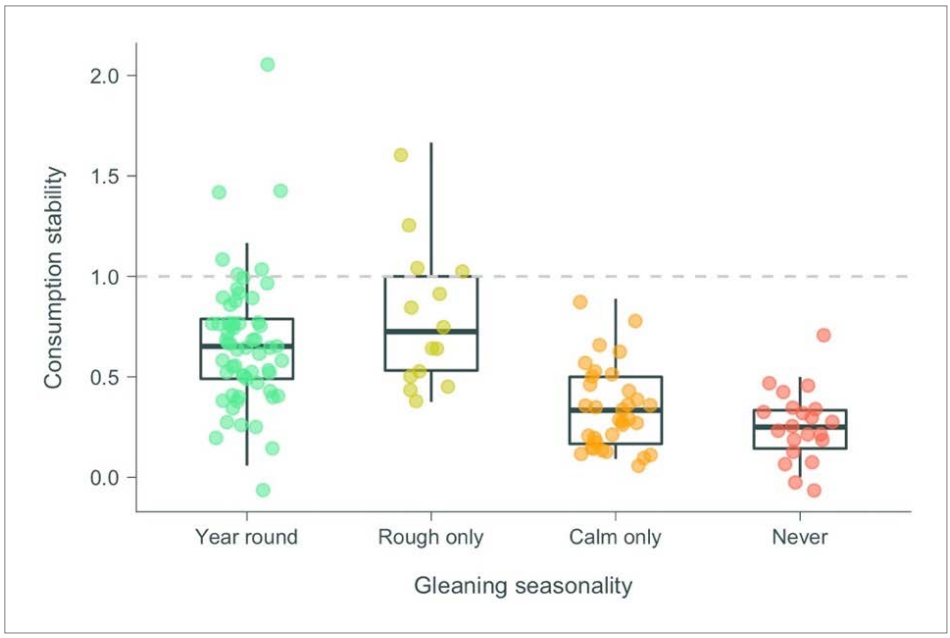


FIGURE 3.2 BOXPLOT OF HOUSEHOLD SEAFOOD CONSUMPTION STABILITY ACCORDING TO GLEANING SEASONALITY. DASHED LINE REPRESENTS STABLE CONSUMPTION.

DETERMINANTS OF GLEANING

For the analysis of determinants of seasonal household gleaning we excluded community H due to shortcomings in available spatial habitat data for this community. Comparing models, we found no qualitative difference between excluding (Model A $R^2 = 0.85$) or including (Model B $R^2 = 0.73$) community H, except that Fishing was a statistically significant driver of gleaning in the rough season in Model B but not Model A (Appendix B.3). In the remainder of the paper, we focus on Model A only. The marginal effects of Model A are summarised in Figure 3.3 and further details are available in Appendix B.3.

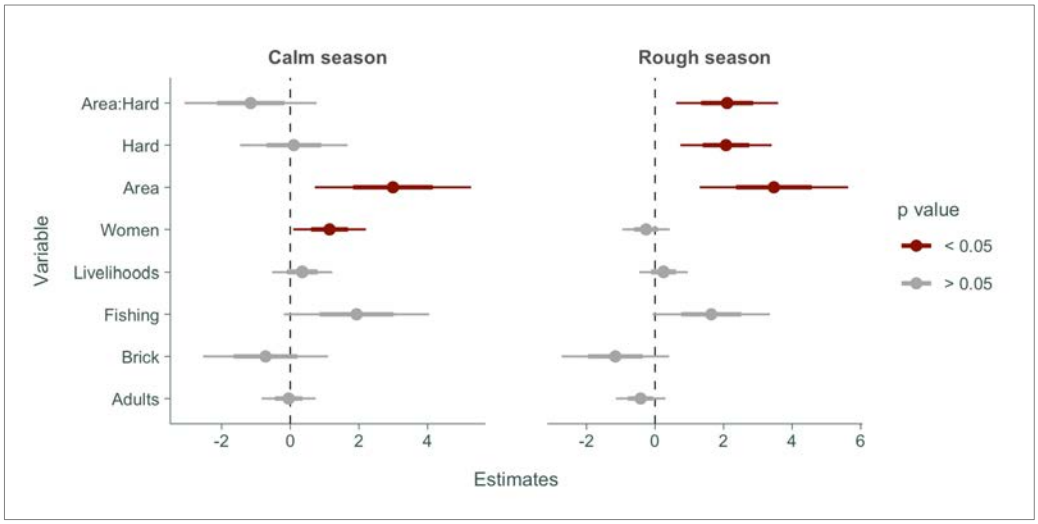


FIGURE 3.3 FOREST PLOT FOR FACTORS AFFECTING GLEANING IN THE CALM SEASON AND ROUGH SEASON, SHOWING P-VALUES, ESTIMATE COEFFICIENTS, STANDARD ERRORS (THICK LINE) AND 95% CONFIDENCE INTERVALS (THIN LINE) FOR MODEL A.

Seasonal household gleaning was explained mostly by spatial habitat factors (Figure 3.3). The odds of gleaning in the calm season were significantly and positively related to area of shallow habitat within a 2-km radius of the community (Area log-OR = 2.99, $p = 0.01$) and to a lesser extent the number of women in a household (Women log-OR = 1.14, $p = 0.034$). The odds of gleaning in the rough season were also significantly and positively related to shallow habitat area (Area log-OR = 3.47, $p = 0.002$) and, with slightly smaller marginal impacts, the percentage of shallow area that was hard bottomed (Hard log-OR = 2.07, $p = 0.002$) or the interaction between shallow area and hard-bottom coverage (Area:Hard log-OR = 2.10, $p = 0.002$). In both seasons, the odds of gleaning were greater for households who fished than for those who did not; however, the relationship between seasonal fishing and gleaning was not statistically significant (Fishing calm season log-OR = 1.93, $p = 0.074$; rough season log-OR = 1.64, $p = 0.061$). When only season and spatial habitat factors were included in the model (Model C, $R^2 = 0.67$) the relationship between habitat and seasonal gleaning held

(Appendix B.3). The relationship between shallow habitat and gleaning is evident in the geographic distribution of community-level trends in seasonal gleaning on Atauro Island (Figure 3.4).

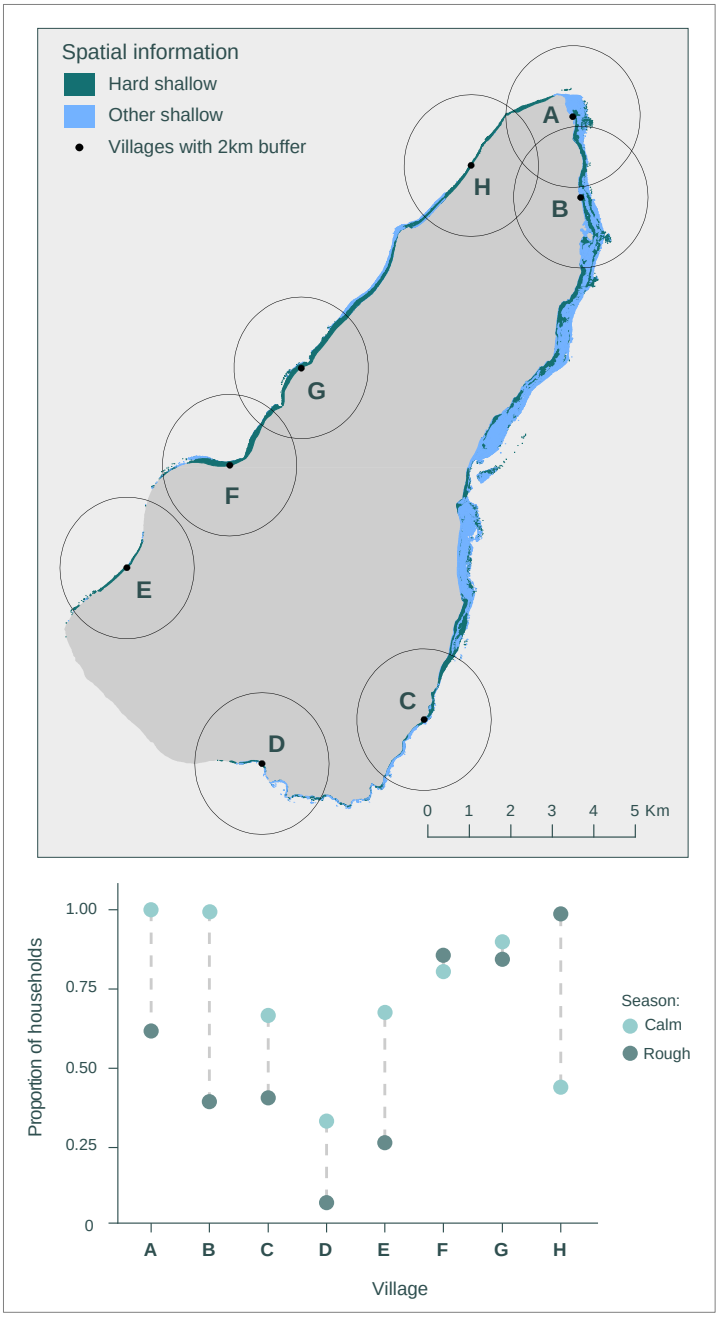


FIGURE 3.4 GEOGRAPHIC DISTRIBUTION OF SHALLOW HABITATS AND COMMUNITY-LEVEL TRENDS IN SEASONAL GLEANING ON ATAURO ISLAND. MAP SHOWING HARD-BOTTOMED SHALLOW HABITAT AND OTHER SHALLOW HABITAT, INCLUDING THE 2-KM BUFFER USED TO CALCULATE HABITAT AREA AROUND EACH COMMUNITY. PLOT SHOWING PROPORTION OF SURVEYED HOUSEHOLDS THAT GLEAN IN EACH SEASON IN EACH COMMUNITY. A MORE DETAILED VIEW OF THE DISTRIBUTION OF HABITATS IN EACH BUFFER ZONE IS PRESENTED IN APPENDIX B.1

Gleaning was highly seasonal on the north-eastern coast of Atauro Island (communities A, B) where all households gleaned in the calm season but many stopped during the rough season.

The gently sloping, sandy littoral zone that characterises this coastline provides the largest area of shallow benthic habitat, but only a small percentage is hard bottomed. Gleaners in these communities described it as being difficult to find seafood in the rough season because the sea gets "dirty" as the wind and swell lead to increased turbidity and suspended solids from the soft shallow habitat. In the southern part of the island (communities C, D, E), gleaning was less common in general and also decreased in the rough season. The steep rocky coastline in this part of the island provides only a very narrow fringe of littoral habitat that is highly exposed to rough sea conditions. On the western coast (communities F, G) gleaning was widespread amongst households and relatively stable between seasons. The littoral zone in this area is characterised by tidal reef flats that are moderate in size and dominated by hard-bottom habitat. Whilst in community (H) at the north-western tip of the island gleaning increased notably in the rough season. The data suggest the shallow habitat proximate to community H was almost entirely hard-bottom shallow habitat, however this community was not included in the model due to the limitations surrounding habitat mapping errors that mean other shallow habitat types could be more common in in this area. Anecdotal evidence from informal discussions suggests that limited gleaning in the calm season by households in community H is due to time scarcity and abundant seafood associated with a highly productive fusilier (*Caesionidae* family) fishery targeted by gillnets in the calm season.

Community gleaning trends

Gleaning trends amongst study communities illustrate differences in seasonal gleaning trips and catches (Figure 3.5). Seasonal gleaning strategies amongst households match the geographic trends in the number of households that glean in each season; notably, the number of households that never gleaned was highest in communities in the south (C, D, E) whilst the number of households who only gleaned in the rough season was highest in community H on the north-western tip (Figure 3.5a). Seasonal shifts in the regularity of gleaning trips amongst gleaning households also varied amongst communities (Figure 3.5b). In general, trips tended to be less regular amongst gleaning households in the rough season and notably the number of households that gleaned daily or multiple times a week in communities A and B decreased from the calm season (7 and 11, respectively) to the rough season (2 and 2, respectively). Comparatively, gleaning in community H was more regular in the rough season and the number of households that gleaned multi-weekly or daily increased from none in the calm season to seven in the rough season.

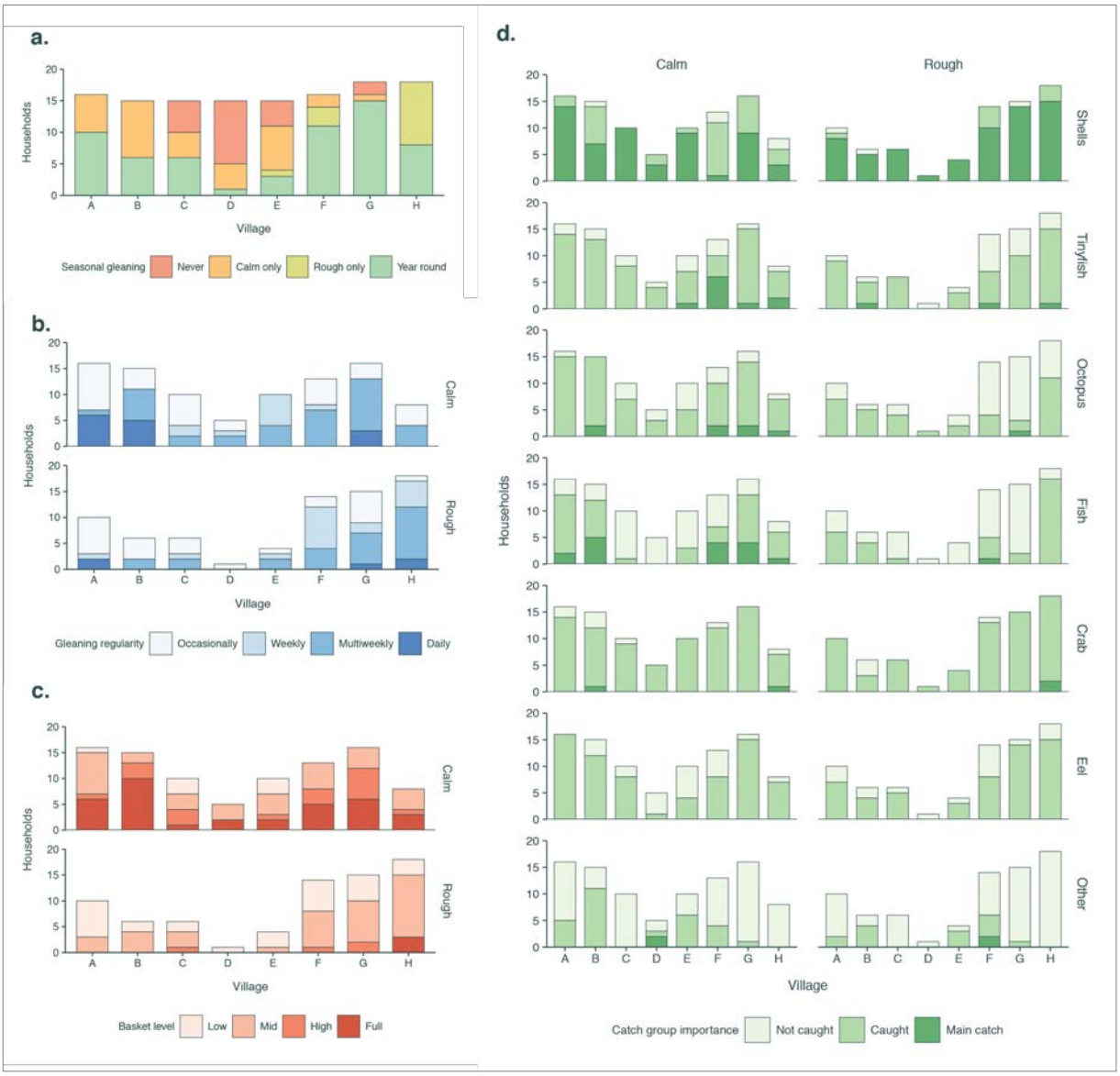


FIGURE 3.5 SEASONAL GLEANING TRENDS BY STUDY COMMUNITY, INCLUDING A) SEASONAL GLEANING PARTICIPATION (ALL SURVEYED HOUSEHOLDS), AND FOR GLEANING HOUSEHOLDS IN EACH SEASON, B) REGULARITY OF GLEANING TRIPS, C) TYPICAL CATCH QUANTITY ACCORDING TO BASKET LEVEL, AND D) IMPORTANCE OF CATCH GROUPS.

Typical catch quantities were greater in the calm season when more households reported high or full baskets in all communities (Figure 3.5c) and, in communities F and G for example, no households reported low basket levels in the calm season compared with six and five households, respectively, in the rough season. Shelled molluscs were the most widespread catch group (Figure 3.5d), reported as being collected by almost all gleaning households in the calm (88%) and rough (71%), and being the main catch for a majority of gleaners in most communities, especially in the rough season. Fish and octopus were the most seasonally-variable catch groups; for example, in community G, in the calm season 13 and 14 households reported collecting fish and octopus, respectively, compared with only two and three households, respectively, in the rough season.

3.4. DISCUSSION

Our results reveal marked heterogeneity in seasonal household gleaning. For some households gleaning was part of marine harvesting strategies year round, whilst others only gleaned in particular seasons, and some not at all. Hence, despite gleaning in the rough season being associated with greater stability in seafood consumption, many households only gleaned in the calm season. As well as being more widespread, gleaning was a more regular activity for many households in the calm season and typical catch rates were higher. Differences in seasonal gleaning were explained predominantly by the type and extent of littoral habitat proximate to communities, meaning there were distinct spatiotemporal trends in gleaning. In both seasons, gleaning was more likely in villages with larger areas of proximate shallow habitat and, additionally in the rough season, the percentage of shallow habitat that was hard bottomed and the interaction between hard- and total shallow area were also important determinants of gleaning. These fine-grain insights of seasonal gleaning highlight the importance of studying context-specific perspectives of human-nature interactions to understand relationships between people and coastal ecosystems.

Further, differences through space and time in the gleaning interactions between people and littoral ecosystems likely represent differences in the relationships that shape and are derived from those interactions. For instance, increased gleaning in the rough season in community H suggests that for households in this community, seasonal interactions with littoral ecosystems are driven by a relationship of choice; gleaning was possible in the calm season but most households in community H chose not to. Comparatively, the finding that differences in seasonal gleaning amongst other communities were linked to shallow habitat availability indicates the influence of biophysical constraints, which likely shape different relationships between people and littoral ecosystems through space and time. For instance, it is unlikely that during the rough season, households who cannot or do not glean perceive their relationship with littoral ecosystems in the same way as those who do glean. Even for households that glean year round, the human-nature relationship represented by gleaning may be different across seasons. Previous research in one of the study communities where gleaning was widespread year round (community G) found that value priorities of gleaners varied between seasons, linked to differences in risk, catches and the livelihood context (Grantham et al. 2020). Understanding existing relationships between people and nature and

how these influence interactions between societies and local ecosystems is key to legitimate environmental policy and management to ensure sustainable futures are fair and desirable (Chan et al. 2016). Other research has highlighted the importance of context-specific assessments to account for socio-cultural dimensions of relational values (Chan et al. 2012, Klain et al. 2014), particularly to support nuanced assessments of nature's contributions to people (Díaz et al. 2018). Although our analysis does not attend directly to relational values, our findings provide valuable insights about the dynamic relationships between coastal communities and local ecosystems and further support the need for in situ perspectives. Characterising coastal social-ecological interactions requires accounting for spatial and temporal dynamics at scales relevant to fisher decision-making (Moreno-Báez et al. 2012). Specifically, the finding that the biophysical environment can constrain and enable seasonal coastal human-nature interactions, such as gleaning, has important implications for evaluating patterns of resource use, factors mediating benefit access, and limits to adaptation. We discuss each of these three points in detail in the following paragraphs.

Resource use

Seasonal gleaning trends characterise spatial and temporal unevenness in the pressure exerted on littoral ecosystems. In coastal areas where gleaning is common, littoral ecosystems are exposed to consistent gleaning pressure whilst in areas where gleaning is seasonal, the pressure on these ecosystems is more periodic. The greater regularity of gleaning and higher typical catch quantities in the calm season further suggests that in many communities the intensity of the pressure on littoral ecosystems is also seasonally dependent. Ecological assessments of the study sites were beyond the scope of this research, but our results suggest that, in some locations, the rough season acts as a de facto closed season in the littoral zone, which may have localised sustainability implications through allowing recovery of harvested populations. Assessments of the effects of periodic harvesting in fisheries suggest that intermittent (as opposed to sustained) fishing pressure can have benefits for target species (Bartlett et al. 2009), particularly if closures correspond with key lifecycle stages (Cohen and Foale 2013). Even short-term closures have been found to support some degree of population recovery for species targeted by gleaners, including shelled molluscs, crabs, octopus and reef fish (Bartlett et al. 2009, Cohen and Alexander 2013, Oliver et al. 2015). The long-term influence of gleaning on target species populations is uncertain; gleaning has been an important subsistence strategy throughout human history

and historic shell middens show changes through time in the abundance and size of gleaned species, which some argue are indicative of over-exploitation whilst others attribute changes to underlying environmental conditions (Codding et al. 2014). Our results suggest that research concerned with human impacts on coastal littoral ecosystems would benefit from evaluations that capture determinants of human-nature interactions at fine grain resolutions to support a more nuanced understanding of the pressure exerted on resources by local communities through space and time. The integration of spatial habitat data with temporally-sensitive social data in this research demonstrates the strength of mixed-method approaches for understanding how the biophysical environment influences dynamic human-nature interactions, including community-scale trends in gleaning.

Factors mediating access

Weather and the biophysical environment were found to mediate gleaning, therefore influencing access to benefits from littoral ecosystems through space and time. Access, defined as "the ability to derive benefits from things" (Ribot and Peluso 2003) determines how various resource users benefit differently from coastal ecosystems and is dependent on context-specific mechanisms (Hicks and Cinner 2014). We found that household gleaning was dependent on the interaction between season and shallow habitat, which our results suggest was because wave attenuation and water clarity are important for gleaning, particularly in the rough season. That is, the sensitivity of access to benefits from littoral ecosystems to sea conditions varied between communities according to the proximate biophysical environment. Weather related risks affect fisher decision-making (Pfeiffer 2020) and poor understanding of behavioural responses of fishers to weather is a key limitation in assessing vulnerabilities of capture fisheries to climate change (Sainsbury et al. 2018). Our findings demonstrate that in gleaning fisheries, strengthening understanding of spatial drivers of access through time may help identify factors influencing responses to weather conditions.

We also found a positive relationship between gleaning and other types of fishing that may reflect shared dependencies between activities. In both seasons the odds of gleaning were notably higher for households that fished than those who did not, although no statistically-significant relationship was found between seasonal fishing and gleaning. These results do not support the expectation that gleaning and fishing would interact as complementary activities (described in factor selection for models) with alternating seasonal dynamics. We

hypothesize that the positive relationship between fishing and gleaning could reflect the benefits of swell protection for both activities. The sensitivity of fishing methods and habitat use to adverse weather and sea conditions has been highlighted by research in other small-scale fisheries (e.g., (Siar 2003, Gill et al. 2019)). If wave attenuation is a shared driver of fishing and gleaning, we can expect the ecosystem benefits accessed through those activities will occur in "bundles". In the context of ecosystem services, bundles refer to services or benefits that co-occur repeatedly through space and time (Raudsepp-hearne et al. 2010). The mechanisms that link bundles create potential co-benefits or trade-offs in ecosystem services derived from social-ecological system management and change (Bennett et al. 2009). For instance, shared dependencies between fishing and gleaning point to potential common vulnerabilities; in communities where increased storminess would have adverse impacts on gleaning, other types of fisheries may also be negatively affected having compound consequences for seafood access. Thus, understanding how the biophysical environment mediates seasonal access to bundles of coastal ecosystem benefits, such as seafood from different types of fishing, is essential for evaluating the impacts of climate change on local communities.

Limits to adaptation

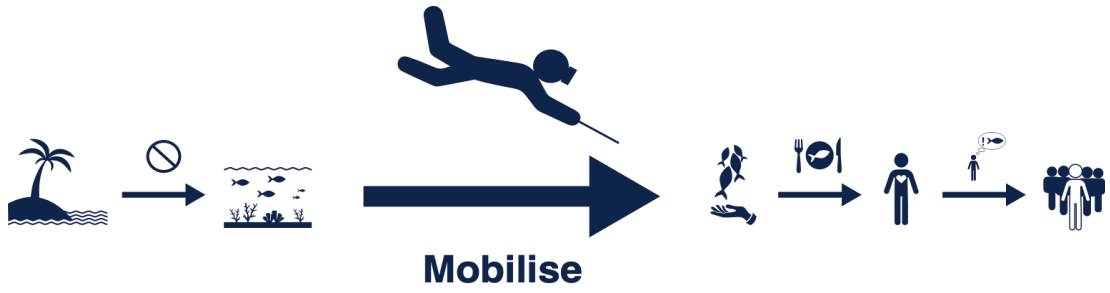
Spatial determinants of seasonal gleaning represent context-specific limits to human-nature interactions and, by extension, how they benefit people through space and time. Although gleaning in the rough season was linked to greater seasonal stability in seafood consumption, many households only gleaned in the calm season indicating gleaning was either undesirable or not feasible during the rough season, which our analysis linked to accessible coastal habitat. Therefore, although gleaning was a livelihood strategy for these households it did not provide a steady source of seafood to smooth consumption fluctuations, as has been found elsewhere in Timor-Leste (Tilley et al. 2020). These findings have important implications for understanding geographically-disaggregated experiences of seasonality and heterogeneity in the dynamic function of fisheries to coastal livelihoods (Carter and Garaway 2014). Seasonal food scarcity is the greatest cause of acute hunger and malnutrition globally (Vaitla et al. 2009) and coping with seasonal hunger often lies at the heart of deeper poverty cycles (Devereux et al. 2008). Thus, lean seasons represent a critical time window in the livelihoods of the rural poor. In Timor-Leste, similar to many low-income countries, the rural poor experience an annual lean season driven by cycles in subsistence agriculture (Erskine et al.

2014), which on Atauro Island also corresponds with the main rough season. Hence links alluded to between littoral habitat, seasonal gleaning and seafood consumption highlight how spatial factors mediate access to benefits from littoral ecosystems during this critical time window, even within the context of one small island. Small-scale fisheries are important sources of subsistence seafood in the Pacific (Charlton et al. 2016), and although seafood consumption is lower in Timor-Leste than other Pacific Island countries and territories, seafood is the main animal protein consumed and a source of vital micronutrients in coastal communities (López Angarita et al. 2019), including in the study communities. Our results demonstrate how temporal aspects of access affect the ability of households to benefit from littoral ecosystems as a source of seafood during periods of food scarcity. These findings support other research that has highlighted how spatial factors determine the ability of small-scale fishers to adapt to normal environmental variability (Sievanen 2014) and the importance of understanding how dynamic mechanisms of access determine who benefits from coastal ecosystem services (Daw et al. 2011), including for food security (Foale et al. 2013).

3.5. Conclusion

Using the case study of gleaning in a small-island, low-income country context, this research begins to disentangle the complexities of coastal human-nature interactions at fine spatial and temporal resolutions. We found that constraints and opportunities created by the type and extent of shallow habitat influence how people interact with littoral ecosystems across seasons. Relationships between local communities and coastal ecosystems, such as those supported by gleaning, cannot therefore be assumed to be homogenous through space and time. Particularly in the context of rural communities in low-income countries, accounting for dynamics in coastal human-nature interactions and the factors determining when livelihood activities are feasible and desirable, is important for evaluating social impacts of climate change. This research demonstrates the insights that can be gained from integrating spatial-habitat and social data to support place-based understanding of how and why people use and interact with coastal ecosystems differently through time. Our findings reveal heterogeneity in how households interact with littoral ecosystems through gleaning and highlight the need for context specific and dynamic perspectives of the contribution of coastal environments to local communities.

4. SEASONALITY AND GENDER IN SMALL-SCALE FISHERIES



Contributions: I developed the research questions and methodology with advice from GSC, DJM and CR. I collected and analysed the data and developed all figures and tables and wrote the first draft of the manuscript. GSC, DJM and CR all provided editorial input which was included in revised versions.

ABSTRACT

The world's rural poor often depend directly on local ecosystem services for their food security. However, there are knowledge gaps around how the interplay between gender and seasons influences the realisation of ecosystem services through time. These knowledge gaps limit the ability of ecosystem service research to address pressing issues of instability in food security. For coastal communities in low-income countries, understanding how the benefits of fish as food are realised through small-scale fisheries at different times of the year will be critical for achieving food security. Yet, little is understood about how gender and season intersect in household fishing strategies. To address these gaps, we used the case study of small-scale fisheries on Atauro Island, Timor-Leste. Our results show that fish consumption is coupled in time with the co-production of fishery ecosystem services, which highlights that understanding how services are co-produced seasonally is directly relevant to food security objectives. Seasonal differences in household fishing strategies suggest how ecosystem service co-production through time is shaped by the interplay between social identity, access and environmental conditions at different times of the year. We found that the relative importance of gleaning and women's fishing increased during adverse conditions. Worryingly, these components of fisheries are currently underrepresented in fisheries assessments and coastal management. Seasonally aggregated and gender-blind perspectives mask the ways that seasonal constraints determine how households actually realise fishery ecosystem services during adverse seasons. Without seasonally disaggregated assessments we therefore have a distorted perspective of ecosystem service access that undervalues women's fisheries and the fishery resources most critical in hard times. In conclusion, social-ecological approaches that provide seasonal perspectives of how people coproduce ecosystem services can support the shift away from theoretical metrics of ecosystem services, towards an understanding of how, when and where ecosystems actually benefit food security.

4.1. INTRODUCTION

Managing ecosystem services in ways that sustainably support food security, particularly for the rural poor, is one of societies greatest challenges. Food security is when all people, at all times, have access to safe and nutritious food (FAO 1996). All food systems rely on ecosystem services (Richardson 2010) and food security and ecological sustainability are therefore inextricably linked (Berry et al. 2015). The links between food security and ecosystems are especially tight in rural communities in low-income countries where traditional food systems dominate, meaning people are more likely to depend on local resources directly as a source of food (FAO 2016). Worryingly, these same areas are experiencing high rates of environmental change, creating growing issues of hunger and malnutrition (Wheeler and Von Braun 2013). Managing the world's ecosystems in ways that benefit the rural poor is imperative to end the growing inequalities that prevent global food security being achieved and to fulfil the commitment of the 2030 Agenda for the Sustainable Development Goals to leave no one behind (UN 2015). Ecosystem service approaches have considerable potential to support nutrition sensitive resource management (FAO 2015) that prioritises poverty alleviation and food insecurity in the short-term without compromising long-term sustainability (Poppy et al. 2014). However, major knowledge gaps hamper the ability of ecosystem services to speak to pressing issues of food insecurity. Amongst others, these gaps include gender and stability through time in ecosystem services (Cruz-Garcia et al. 2016).

GENDER AND THE CO-PRODUCTION OF ECOSYSTEM SERVICES

Gender, as a social construct that determines the rights and responsibilities of different groups, is deeply embedded in ecosystem services and food security. Gender underpins divisions of labour that influence how natural resources are used and valued (de la Torre-Castro et al. 2017, MacGregor 2017, Fortnam et al. 2019). Gender therefore has a profound influence on access (the ability to benefit from) to ecosystem services (Ribot and Peluso 2003), including mediating how people interact with nature to co-produce ecosystem services (Fortnam et al. 2019). In particular, the co-production of provisioning services of food is often highly gendered and women contribute disproportionately to the production of household food (Quisumbing et al. 1996). For instance, the collection of wild foods by women is recognised to be essential to dietary diversity and coping with scarcity (Daniggelis 2003, Cruz-Garcia and Price 2014). The subsistence focus of women's activities reflects their

reproductive roles and domestic responsibilities within households (Kotzé 2003). However, ecosystem service assessments are often gender blind and framings of ecosystem services tend to underrepresent services most important for women (Brown and Fortnam 2017). A review of literature on ecosystem services and food security in farming communities in Africa, Asia and Latin America between 1989 and 2014 found that of 31 case studies only four included gender as a component of assessments (Cruz-Garcia et al. 2016). Addressing gender blindness in ecosystem services research is required both ethically and instrumentally for achieving food security, and more empirical work is needed on the gender disaggregated processes of co-production through which people realise food from ecosystems.

Stability through time

Stability is the cross-cutting pillar of food security, that refers to certainty through time within the other three pillars: availability, access and utilization (FAO 2008). Instability is a major stressor for the food security of the rural poor because their livelihoods are highly vulnerable to environmental variability, including seasonality (Chambers et al. 1981). Seasonal food scarcity is the greatest cause of hunger globally (Vaitla et al. 2009). Seasonal food shortages and decreases in dietary diversity are associated with weight loss, malnutrition and child stunting (Spencer et al. 2017, Savy et al. 2018). Therefore, overlooking seasonality can grossly underestimate incidence of food insecurity (Reardon and Matlon 1989). Seasonality is also intrinsically linked to gendered aspects of livelihoods and food security; as livelihood tasks change with season so do household labour demands and how they are distributed across gender groups (Langill 2020). Men and women's contributions to household food production can be seasonally dependent (Hurtado and Hill 1990), with women more likely to be responsible for coping with seasonal food shortages (Longhurst et al. 1986). Understanding how the activities and contributions of men and women fit together in livelihood strategies is essential for understanding how households maintain stability across seasons (Jiggins 1986). However, ecosystem services research rarely considers temporal dynamics (Rau et al. 2020) or the stability pillar of food security (Cruz-Garcia et al. 2016). Knowledge gaps around how gendered processes of co-production influence the delivery of ecosystem service through time (Bennett et al. 2015) must be addressed to improve how ecosystems are managed for the food security of the rural poor. Specifically, a deeper understanding of the ways that people realise provisioning services of food in different seasons is needed to face the challenges of seasonal food instability.

Small-scale fisheries

The importance of linking gendered and seasonal aspects of ecosystem services to food security is particularly pressing in the context of small-scale fisheries. Subsistence fish ('fish' is used here to refer to all edible aquatic animals) obtained through small-scale fisheries are the main animal protein consumed, and a vital source of micronutrients for many rural coastal communities in low-income countries (FAO 2005). However, seasonal weather conditions affect small-scale fishing activities and catches (*Chapter 3* and *Chapter 5*), with direct implications for fish consumption among fishing households and their communities (Siar 2003, Fabinyi et al. 2017). The ability of people to realise fishery ecosystem services through time is therefore important for food stability in coastal communities in low-income countries. Yet, most of our knowledge of coastal ecosystem services is based on single snap shots in time in higher income countries (Blythe et al. 2020).

Men and women use different fishing habitats and resources, and therefore have different knowledge and priorities and are differently affected by coastal management, social-ecological change and extreme events (Siar 2003, Fröcklin et al. 2014, de la Torre-Castro et al. 2017, Thomas et al. 2019). Women tend to be mostly involved in the low-risk low-return activity of gleaning in the littoral zone, whilst men's fishing is usually more lucrative and riskier (Bird 1997). The importance of women's gleaning for smoothing consumption fluctuations during seasons when men's fishing activities are limited by rough weather conditions has been alluded to in a number of studies (Chapman 1987, Whittingham et al. 2003, Tilley et al. 2020). However, the ways that the gender profile of household fishing strategies change seasonally has not been empirically explored.

In general, women's fisheries are underrepresented and undervalued because definitions of fishing and data collection methods preferentially favour male voices and male dominated activities (Kleiber et al. 2015). The exclusion of women's fishing characterises a substantial gap in quantitative assessments of small-scale fisheries that disproportionately underrepresents the direct contributions of small-scale fisheries in household food security (Harper et al. 2020). For example, in the pacific women fishers are estimated to account for approximately 56% of landings from small-scale fisheries, most of which are used for subsistence (Harper et al. 2013). Fish are unique in their ability to address multiple dimensions of food and nutrition security, and with the right policies to protect and prioritise

local nutritional needs, fish has the potential to address widespread nutrient deficiencies (Bennett et al. 2018a, Hicks et al. 2019). However, knowledge gaps around fish as food impede the inclusion of fish and fisheries in food security policy and funding priorities and risk small-scale fisheries being squeezed out of future coastal governance (Cohen et al. 2019, Bennett et al. 2021).

In this research, we use the case study of a small-scale fishery on Atauro Island Timor-Leste, to address knowledge gaps in the gendered and temporal aspects of ecosystem service co-production for food security. We compare household fishing in different seasons to answer four research questions: 1) How does seasonal fish consumption correspond with seasonal fishing? 2) How does gendered participation and the methods used in household fishing change seasonally? 3) What aspects of household fishing are most sensitive or persistent across seasons? 4) How do seasonally aggregated and disaggregated perspectives of household fishing differ?

4.2. Methods

Case study

Atauro Island, Timor-Leste presents an apt case study to explore the interaction between gender and seasons in small-scale fisheries. Timor-Leste is a small island developing state located at the heart of The Coral Triangle. It is ranked 132/188 for human development globally (UNDP 2018) and 110/117 countries for hunger and undernutrition (GHI 2019). Fisheries have the potential to contribute substantially to poverty alleviation and food security in Timor-Leste but the fisheries sector is underdeveloped and poorly understood (Mills et al. 2013, López Angarita et al. 2019, Steenbergen et al. 2019b, Farmery et al. 2020). Timorese domestic fisheries are made up of artisanal and subsistence fisheries that are poorly managed as a consequence of a paucity of data and weak governance (López Angarita et al. 2019). In particular, women's fisheries, which contribute substantially to household landings, are underrepresented in monitoring and women are largely absent from coastal decision-making processes (López Angarita et al. 2019, Tilley et al. 2020). Gender disaggregated fisheries data is needed to build a better understanding of the role of women in Timorese fisheries (López Angarita et al. 2019).

Livelihoods are more fishery-based on Atauro Island than elsewhere in Timor-Leste. Atauro

Island is Timor-Leste's only populated islet located 25km north of the capital, Dili. The island comprises five administrative sub-districts, containing 23 communities which are home to roughly 9,200 people (GDS 2015). Fisheries provide an important source of nutrition and income for coastal communities on the island (Mills et al. 2017) and every Saturday the island hosts Timor-Leste's largest regular fish market (Mills et al. 2013). Fisheries are part of diversified and dynamic livelihoods on Atauro Island (Mills et al. 2017). The small wooden boats and canoes used by fishers are not robust enough to use in rough weather, so sea conditions drive seasonality in fishing activities. The main period of rough sea conditions, and the low fishing season on Atauro Island, coincides with the rainy seasons and an associated lean season (typically December and March). Dependence on low yield rainfed agriculture for subsistence in rural areas of Timor-Leste including Atauro island, leads to food shortfalls in the rainy season, when stored foods run low and crops are not yet ready to be harvested (da Costa et al. 2013). During the lean season household consumption decreases and dependence on wild foods increases (Erskine et al. 2014). Livelihoods and food security in Timor-Leste are therefore inseparably linked to the seasons, including fishing seasons associated with sea conditions.

The coral reefs of Timor-Leste support some of the world's highest species richness of coral reef fishes (PIFSC 2017). However, population growth, coastal development, water pollution and climate change all threaten Timor-Leste's coastal resources (ADB 2014). With the objective of sustainably managing Atauro Island's coastal resources, 12 village-level co-managed marine protected areas have been established since 2015. In 2019, these protected areas were integrated into Timor-Leste's first marine protected area network. However, level of local stakeholder participation in the establishment of the marine protected areas and area network has varied, and community confusion and disempowerment has led to challenges and issues of conflict, for instance, regarding the spatial delineation of protected areas and use/access rights. Sustainably and equitably managing the coastal resources of Atauro Island will require balancing the interests of different stakeholders (Tilley et al. 2019a), and particularly the livelihoods and food security of local communities. Given that women play an important role in Timor-Leste's fisheries, but are underrepresented in local and national-level coastal decision-making (López Angarita et al. 2019, Tilley et al. 2020), there is a pressing need to improve understanding of women's fisheries on Atauro Island.

DATA COLLECTION

A household survey (Appendix A.3) was used to collect data on seasonal fish consumption and household fishing. Data included participation by household demographic groups (children (<11 years), men/women youth (11-17 years), adult (18-60 years) and elderly (>60 years)) in gleaning and other fishing methods (hereafter 'non-gleaning'). Gleaning refers to the manual collection of marine organisms from intertidal and shallow water habitats whilst non-gleaning includes all other methods including the use of nets, traps, spears and line fishing methods from boats or the shore. Fishing seasons were defined by sea conditions because during preliminary activities fishers identified sea conditions as the main determinant of intra-annual fishing cycles on Atauro Island. In preliminary discussions, fishers and key informants identified the main rough season on Atauro Island occurring during the western monsoon (December – March), with January and February typically the worst months for fishing. August is also considered a rough month in most communities as the eastern monsoon can create large swell. The household survey was written in English, translated into Tetum (one official language of Timor-Leste) and then digitised using the Kobotoolbox software (Harvard Humanitarian Initiative n.d.). The survey was implemented by the lead researcher and research facilitators in eight coastal communities on Atauro Island (Figure 2.1). Using a door-to-door approach, households were opportunistically sampled over a period of three days in each community.

ANALYSIS

A total of 131 households were surveyed. After excluding households for whom fishing was not a livelihood activity (n=3), 128 households were retained for analysis. Data were analysed using R statistical software (R Core Team 2018). We provide a summary of the sample, including an overview of household demographics and participation by demographic groups in fishing methods (none/gleaning/non-gleaning/both) in the calm and rough seasons. We then present the four main stages of analysis.

First, we characterised seasonal dependence of household fish consumption on household fishing activities and analysed the relationship between seasonal fishing and fish consumption. In each season, we summarised the proportion of households that reported fishing as their main or secondary source of fish consumed. Data were missing for one household on sources of fish consumption so proportions were calculated out of a total of

127. To analyse the relationship between fishing and seafood consumption we used non-parametric tests (Mann-Whitney) to compare how often seafood was eaten in a typical week in the rough season by households that fish and those who do not. Seafood consumption was calculated as the sum of times households reported eating fresh fish, dry fish, shellfish or other fresh seafood in a typical week.

Second, we characterised gendered seasonal household fishing strategies. Due to the low numbers of households containing non-adult demographic groups, few of whom participated in fishing, for the analysis focus on gender we grouped youth, adult and elderly demographic groups by gender (men/women) and excluded children. Using descriptive statistics, we summarised and compared reliance on different methods and the gender profile of fishing in each season. Within each season, we used Cochran's Q test to compare the likelihood of households using gleaning or non-gleaning methods, whether men or women were more likely to use each fishing method and the likelihood of men or women participating in household fishing strategies.

Third, we evaluated the seasonal sensitivity of gendered fishing strategies. Using the *prop.test* function in R, we analysed the likelihood of gleaning/non-gleaning activities of men/women being seasonally sensitive (only used in the calm season), persistent (used in both seasons) or adaptation (only used in the rough season).

Fourth, to test whether changing sampling resolution led to different conclusions we compared seasonally aggregated and disaggregated perspectives of household fishing strategies. The aggregate perspective of household fishing was constructed by combining disaggregated data on calm and rough season fishing. Therefore, the aggregate perspective reflects gendered participation in fishing strategies regardless of what time of the year they are used. We used Pearson's chi-square tests to compare seasonally aggregated and disaggregated perspective of the methods used and gender participation in household fishing.

4.3. Results

Sample characteristics

In each of the eight study communities, 15-18 households were surveyed (n=128). In total, 88% of households were male headed and 12% were female headed. Surveyed households

contained 1-14 household members ($\bar{x}$ = 5.27), with the sample representing 675 individuals. A majority of households included at least one adult woman (91%, $\bar{x}$ = 1.43) and one adult man (89%, $\bar{x}$ = 1.34), and over two-thirds included children (69%, $\bar{x}$ = 1.34). Fewer households included youth (women 20%, $\bar{x}$ = 0.26; men 36%, $\bar{x}$ = 0.42) or elderly (women 27%, $\bar{x}$ = 0.28; men 19%, $\bar{x}$ = 0.20) household members.

Seasonal participation in fishing activities (Figure 4.1) shows that in the calm season, in a majority of households (containing each demographic group) adult men were involved in fishing (96%), as were adult women (70%) and elderly men (59%), whilst it was less common for elderly women (40%), youth women (42%), youth men (41%) and children (20%) to be involved in fishing. Notably, only using non-gleaning methods was more common amongst men and particularly adults, whilst only using gleaning methods was more common amongst women. In the rough season, participation in fishing decreased for adult men (50%), adult women (48%), youth (women 23%, men 26%) and elderly men (21%), whilst participation by elderly (women 37%) and children (16%) remained relatively constant. Across all demographic groups, reliance on gleaning methods only was greater in the rough season.

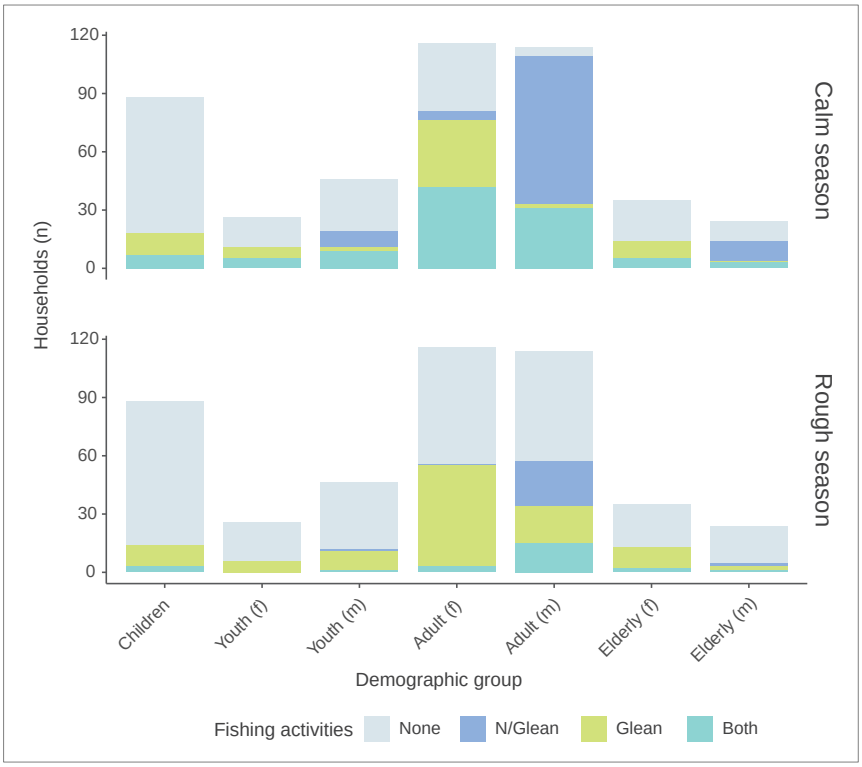


FIGURE 4.1 PARTICIPATION IN FISHING ACTIVITIES, CATEGORISED AS NON-GLEANING (N/GLEAN) ONLY, GLEANING (GLEAN) ONLY, NON-GLEANING AND GLEANING (BOTH) OR NONE, BY HOUSEHOLD DEMOGRAPHIC GROUPS IN THE CALM AND ROUGH SEASONS.

Seasonal seafood consumption

Household fishing was the main source of fish consumed for almost all households in the calm season (93%) and three-quarters of households in the rough season (73%, X^2 17.153, df 1, p <0.0001, Figure 4.2), including some households who do not fish in the rough season but rely on dried household catches as their main source of seafood. Fishing was positively related to seafood consumption in the rough season (W = 2759, p <0.001); households that fished reported eating seafood twice as often in a typical week ($\bar{x}$ = 6.22) than households that did not fish ($\bar{x}$ = 3.33).

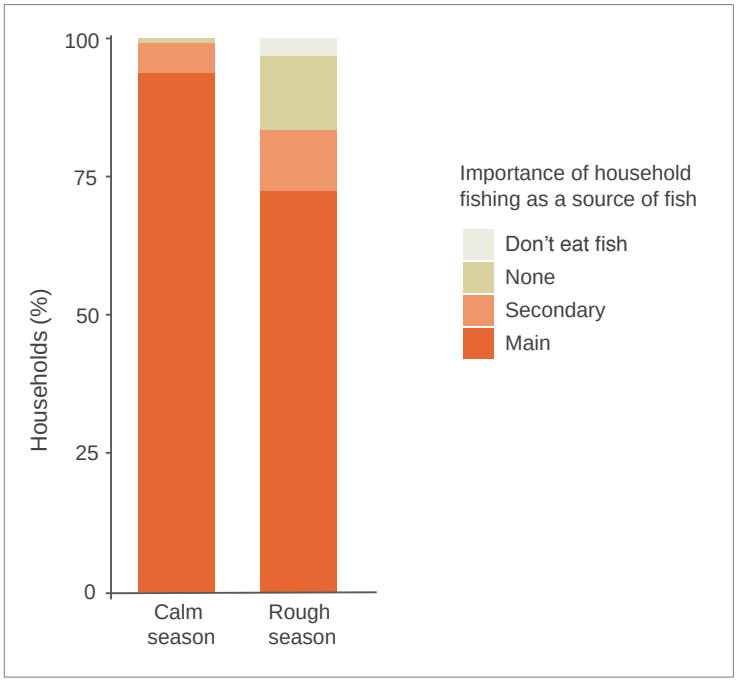


Figure 4.2 Percentage of households (n=127) in each season for whom household fishing is the main or secondary source of fish consumed, for whom no fish consumed comes from fishing or who do not eat fish in that season.

Seasonal fishing strategies

All households fished in the calm season (n=128), compared with only two-thirds of households in the rough season (n=86). Reliance on different methods and gender participation in household fishing strategies varied seasonally (Figure 4.3). There was a decrease from the calm season to the rough season in the number of households that used both gleaning and non-gleaning fishing methods (calm n=87, rough n=28) or relied only on non-gleaning methods (calm n=36, rough n=13), whilst reliance only on gleaning methods increased from the calm season (n=5) to the rough season (n=45). Consequently, the relative importance of different fishing methods was seasonally dependent. In the calm season, non-

gleaning methods (n=123) were used more commonly than gleaning methods (n=92, Q 24.641, df 1, p <0.0001), whereas in the rough season it was more common for households to glean (n=73) than to use non-gleaning methods (n=41, Q 19.105, df 1, p <0.0001).

Fishing methods differed by gender in both seasons. Gleaning methods were more likely to be used by women than by men in the calm season (women 68%, men 31% Q 38.754, df 1, p <0.0001) and the rough season (women 50%, men 31% Q 13.714, df 1, p = 0.0002). Whereas, non-gleaning methods were more likely to be used by men than by women in the calm season (men 91%, women 40% Q 53.481, df 1, p <0.0001) and the rough season (men 30%, women 4%, X^2 30.421, df 1, p <0.0001). Consequently, seasonal shifts in fishing methods were also reflected in the gender profile of household fishing. Although men (n=118) were more likely to participate in household fishing than women (n=92) in the calm season (Q 14.696, df 1, p = 0.0001), men's fishing was particularly variable between seasons and in the rough season men (n=72) and women (n=75) were equally likely to participate in fishing (Q 0.2, df 1, p = 0.6547). Notably, the number of households in which it was only men who fished decreased from the calm season (n=36) to the rough season (n=21), whilst the number in which only women fished increased (calm n=10, rough=24).

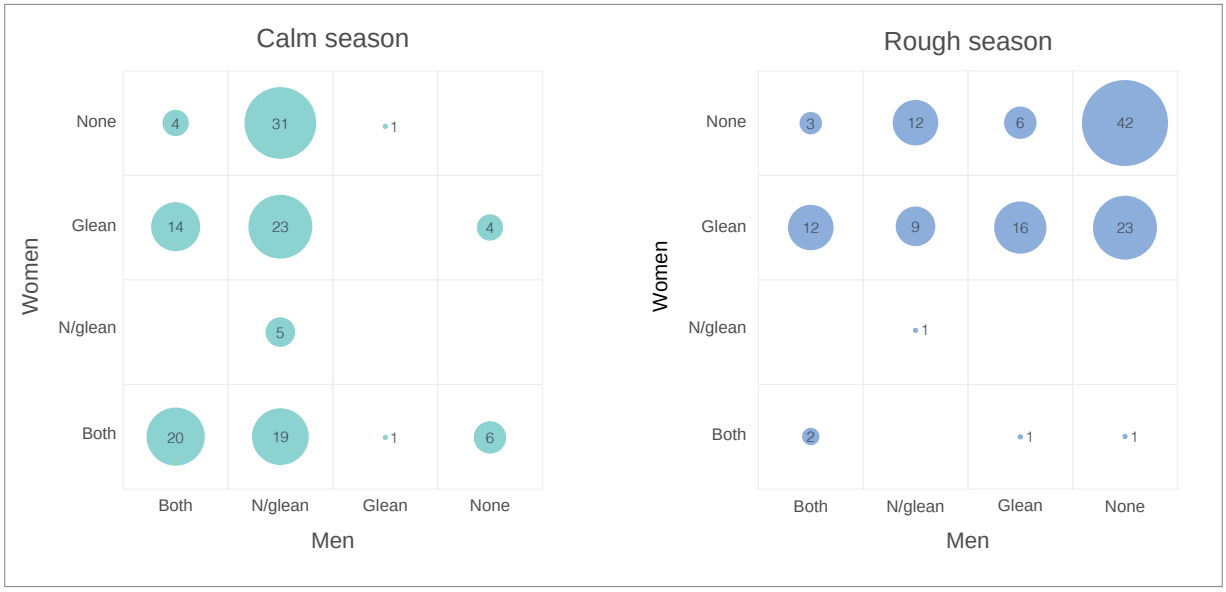


FIGURE 4.3 MATRIX ILLUSTRATING DISTRIBUTION OF HOUSEHOLDS ACROSS FISHING STRATEGIES IN THE CALM AND ROUGH SEASONS CATEGORISED ACCORDING TO THE FISHING METHODS USED BY MEN AND WOMEN.

Seasonal sensitivities

Comparing the seasonal use of gleaning and non-gleaning methods by men and women highlights differences in the seasonal sensitivity and resilience of gendered fishing strategies (Figure 4.4). Men's non-gleaning was a seasonally sensitive fishing strategy (X^2 113.36, df 2, p <0.0001); in household's where men used non-gleaning methods, they were most likely to do so only in the calm season (67%). Men's gleaning was equally likely to be a seasonally sensitive, persistent or adaptive fishing strategy (X^2 1.8957, df 2, p = 0.3878); in households where men gleaned, they did so in both seasons (40%) or only one season (calm 30%, rough 30%) in a similar proportion. Women's non-gleaning was also a seasonally sensitive fishing strategy (X^2 62.745, df 1, p <0.0001), with non-gleaning almost always only a calm season activity for women (90%). Comparatively, women's gleaning was seasonally persistent (X^2 44.938, df 2, p <0.0001); in households that women gleaned, most did so in both seasons (56%).

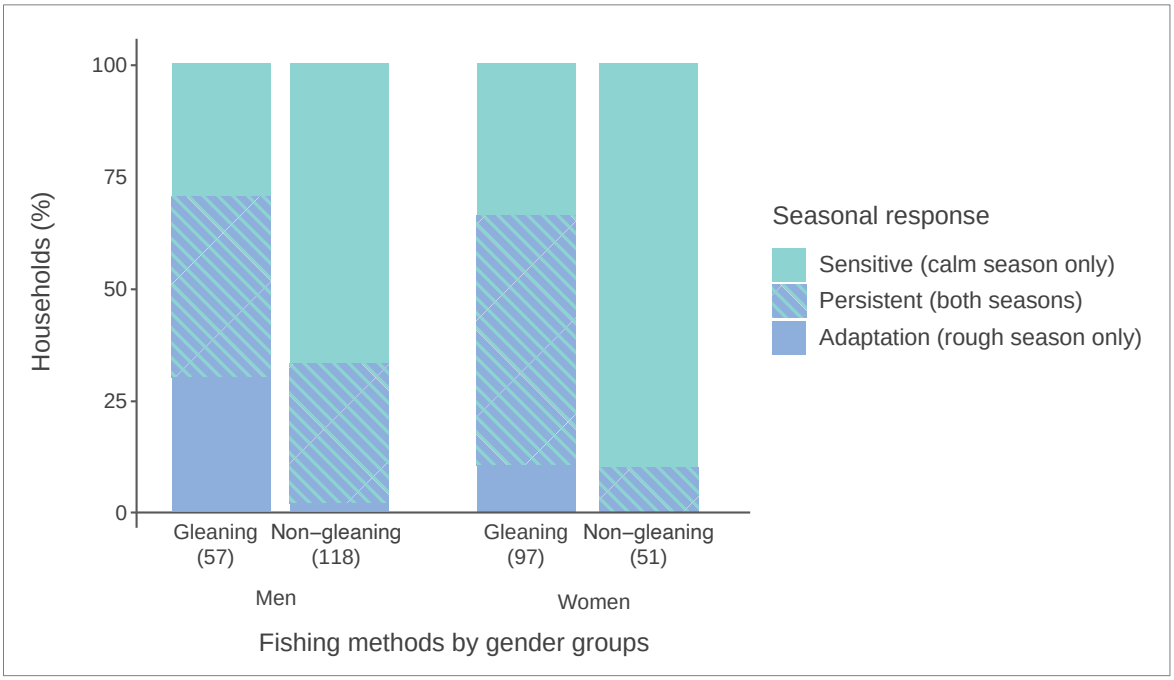


FIGURE 4.4 BAR CHARTS ILLUSTRATING TRENDS IN THE SEASONAL RESPONSES OF DIFFERENT COMPONENTS OF HOUSEHOLD FISHING STRATEGIES, CATEGORISED AS THE USE OF GLEANING/NON-GLEANING METHODS BY MEN AND WOMEN IN A HOUSEHOLD.

Aggregate perspectives

Seasonally aggregated and disaggregated perspectives of household fishing (Figure 4.5) yielded significantly different conclusions about participation by men (X^2 96.487, df 2, p <0.0001) and women (X^2 23.742, df 2, p <0.0001), and the use of non-gleaning (X^2 192.71, df 2, p <0.0001) and gleaning (X^2 20.971, df 2, p <0.0001) methods. The seasonally

aggregated characterisation of household fishing strategies closely resembles strategies used in the calm season but differs significantly from rough season fishing strategies. The percentage of households in which men and women ever fished (93% and 78%, respectively) was equal to the percentage that fished in the calm season (92% and 72%, respectively) and this was significantly greater than the percentage of households in which they fished the rough season (48% and 51%, respectively). Likewise, all households that used non-gleaning fishing methods (97%) did so in the calm season, but significantly fewer used non-gleaning methods in the rough season (32%). The percentage of households that ever-used gleaning (84%), was significantly greater than the percentage who gleaned in the calm season (73%) and this was also significantly greater than the percentage that gleaned in the rough season (58%).

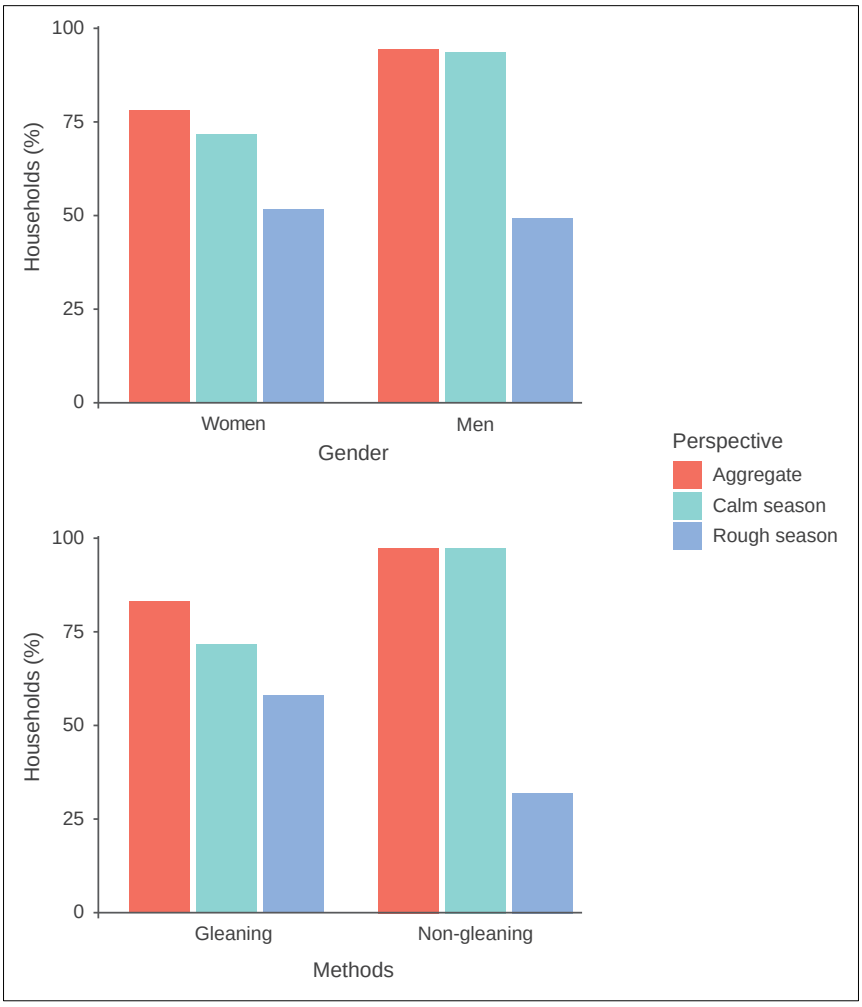


FIGURE 4.5 BAR CHARTS COMPARING AGGREGATE AND SEASONAL PERSPECTIVES OF GENDERED PARTICIPATION AND THE USE OF GLEANING AND NON-GLEANING METHODS IN HOUSEHOLD FISHING STRATEGIES.

4.4. Discussion

Consumption and fishing

Our results illustrate how the co-production of ecosystem services and benefits for consumption in small-scale fisheries are coupled in time at the household level. In the rough season, households that fished ate fish more regularly than households who did not. This finding highlights the importance of accounting for the temporal aspects of access to understand how wellbeing outcomes of ecosystem services, including food security, are realised through time. The use of biophysical metrics of ecosystem services assumes that people will benefit from an ecosystem, which overlooks the access mechanisms that determine whether benefits are actually realised (Wieland et al. 2016). Specifically, our research highlights that in small-scale fisheries, access and the distribution of benefits are seasonal.

Materiality and access

Methods used and gender participation in household fishing strategies differed between the calm and rough seasons. Similar to other small-scale fisheries (Chapman 1987, Harper et al. 2013), on Atauro Island there were gendered divisions of labour, which reflect how social identity mediates ecosystem service access (Fortnam et al. 2019). In both seasons, non-gleaning methods were more commonly used by men and gleaning methods were more commonly used by women. Changes in the biophysical properties of coastal ecosystems associated with seasonal weather conditions differently affected men and women's access to fisheries. Our results show that the way men typically interact with fishery resources was highly sensitive to weather conditions. Consequently, although men were the dominant group responsible for realising fishery ecosystem services in the calm season, in the rough season men and women were equally likely to be involved in household fishing. These seasonal changes in how fishery ecosystem services are coproduced reflect the interplay between social identity (Ribot and Peluso 2003, Lau et al. 2020) and materiality in ecosystem service access. Materiality refers to the biophysical properties of an ecosystem system or resource that affect how people interact with it (Bakker and Bridge 2006). Materiality is not explicitly accounted for in theories of access, which represents a major oversight of how people are positioned to benefit from ecosystems (Lapointe et al. 2020, Myers and Hansen 2020), including as sources of food.

Seasonal methods

Our results highlight that human-nature interactions are differently sensitive to weather conditions, and consequently the relative importance of interactions for co-producing ecosystem services changes seasonally. For instance, we found that gleaning methods, which were commonly used by women, tend to be a seasonally persistent fishing strategy. In the rough season, many households relied solely on gleaning and in a number of households it was only women who fished. Littoral habitats and women's fishing were therefore of greater relative importance in the rough season, when arguably the need for fish as food is most acute. Worryingly, these findings indicate that current bias in research and decision-making is systematically underrepresenting aspects of small-scale fisheries most important for seasonal food stability. Women are often excluded from decision-making and by extension gleaning is rarely included in coastal management (Kleiber et al. 2015, de la Torre-Castro et al. 2017) and tends to be either unregulated (Fröcklin et al. 2014) or inadvertently prohibited (Rohe et al. 2017). Littoral ecosystems on which gleaning depends are vulnerable to over exploitation and habitat degradation, including from gleaning pressure (Fröcklin et al. 2014, Furkon et al. 2020). Managing sustainable gleaning fisheries is therefore critical for ensuring littoral ecosystems continue to be able to provide timely fisheries benefits (Whittingham et al. 2003). Current fisheries management, in Timor-Leste (Tilley et al. 2020) and elsewhere (Fröcklin et al. 2014), that attends only to male-dominated non-gleaning fisheries risks totally missing the mark for supporting food security in coastal communities. If ecosystem services are to effectively support better food security outcomes in natural resource dependent communities, the ways people realise timely flows of provisioning services of food must be explicitly accounted for.

Aggregate perspective

The ways that people realise timely benefits of food are masked by misleading perspectives of access when fishing strategies are aggregated across seasons. We found that a seasonally aggregated perspective of household fishing closely resembled calm season fishing strategies but differed distinctly from rough season fishing strategies, when sea conditions limit who fishes and the methods they use. Therefore, seasonally aggregated perspectives present insight on what fishing strategies households are able use in ideal conditions but not necessarily the strategies they can or do use in adverse conditions. An aggregate perspective

of fishing overestimates the ability of households to realise the benefits of fish as food from marine ecosystems during adverse weather conditions. Accounting for the constraints created by seasonal conditions is essential for understanding opportunities and barriers to adaptation in resilient livelihoods (Sievanen 2014, Albert et al. 2015). Seasonal scale assessments of ecosystem services and the human-nature interactions through which they are coproduced are needed to identify sources of vulnerability and instability in food security and to inform systems of management that ensure people can access ecosystem services to achieve food security year-round.

Atauro Island

In the context of sustainably and equitably managing fisheries on Atauro Island, our findings indicate the importance of accounting for seasonally and gender disaggregated coastal resource use. Links between seafood consumption and seasonal fishing highlight that seasonal perspectives are needed to understand the role of fisheries in local food security, which is a pressing issue in Timor-Leste (Farmery et al. 2020). That seasons differentially affect the fishing activities of men and women on Atauro Island, and therefore their relative importance in household fishing strategies, shows that gender equitable coastal decision-making is a prerequisite for food security. Specifically, women can provide seasonally sensitive insights into the ways that communities use and depend on Atauro Island's coastal resources, which may be masked by male dominated perspectives. For instance, women's fisheries must be properly recognised and valued to ensure the seasonal importance of the littoral zone is accounted for in coastal management. Resource use considerations such as this are especially important for informing spatial management approaches, such as the Atauro Island marine protected area network. The current underrepresentation of women in coastal decision-making in Timor-Leste risks fisheries management outcomes that further exacerbate food insecurity (Tilley et al. 2020).

Next steps

Our research demonstrates that to engage with pressing issues of food insecurity in low-income countries, ecosystem services research must attend to the context-specific interactions between people and nature that determine how benefits are realised through time. Understanding ecosystem services as social-ecological interactions is important for moving beyond measuring theoretical benefits of ecosystems for wellbeing to understanding

how, when and where ecosystems actually contribute to food security. This includes recognising how social identity, such as gender, affects access to ecosystem services and the sensitivity of access to the seasonally changing materiality of ecosystems. Our findings are an important first step towards unpacking how social-processes influence the co-production of fishery ecosystem services through time. However, gender is one of many dimensions of social identity that shape disaggregated ecosystem service access and vulnerability to social-ecological change (Berbés-Blázquez et al. 2016, Djoudi et al. 2016, Lau et al. 2021). Thus, there is a need for future research that integrates seasonal perspectives as part of more nuanced explorations of social-identity and social-ecological resilience in small-scale fisheries (Kawarazuka et al. 2017). Understanding how weather-related ecosystem materiality influences disaggregated ecosystem service access is particularly important in the context of climate change. Seasonal shifts and increasing unpredictability will impact how, when and by whom ecosystem services are realised. Hence, how and why climate change is experienced and adapted to through the seasonal ecosystem interactions of different social groups is an important area for ecosystem services research, particularly that concerned with human wellbeing and food security.

5. EVERYDAY AGENCY IN SEASONAL SMALL-SCALE FISHERIES

Adapted from: Grantham, R., Lau, J., Mills, D.J. and Cumming, G.S., (in review Ecosystems and People). Allocation and everyday agency mediate ecosystem service benefits across seasons.

Contributions: I developed the research questions and methodology, analysed the data with advice from DJM and GSC. I developed all figures and tables with advice from JL and DJM. I wrote the first draft of the manuscript and all co-authors provided editorial input which was included in revised versions.

ABSTRACT

Our ability to sustainably manage social-ecological systems requires understanding the links between ecosystems and human wellbeing. However, knowledge gaps about temporal dynamics, supply and demand dynamics and the role of co-production in ecosystem services limits our understanding of how ecosystems benefit people. To address these gaps, we examined how people allocate ecosystem services across a suite of benefits (one form of co-production) at different rates of service supply and at different times using an example of small-scale fisheries. A daily household survey was used to collect panel data on fish landings from 15 households on Atauro Island, Timor-Leste over six one-week periods across three different seasons, representing 630 survey days and 179 fishing trips. We analysed how households used fish and found that the proportion of fish that was eaten, sold or shared changed with the amount landed and across seasons. Our results demonstrate how people actively mediate a non-linear relationship between ecosystem services and benefits through allocation choices that reflect seasonal livelihood priorities. These findings illustrate the role of everyday agency in shaping the links between ecosystems and human wellbeing. Specifically, these results highlight that to support management and decision-making in coastal social-ecological systems, it is important that ecosystem service assessments account for demand and co-production at temporal scales relevant to social drivers.

5.1. INTRODUCTION

Unprecedented environmental, climatic and socio-economic changes are having profound impacts on ecosystems and flows of ecosystem services (Nelson 2005). Ecosystem services support a diversity of material and immaterial benefits that influence almost all aspects of human wellbeing (McMichael et al. 2005). Human wellbeing is particularly vulnerable to changes in benefits from ecosystem services among rural communities in low-income countries, where livelihoods often depend directly on the extractive use of natural resources (Levy et al. 2005, Yang et al. 2013). Interdependencies between human wellbeing and ecosystems create feedbacks that define management problems in linked social-ecological systems (Reyers et al. 2013, Mehring et al. 2017). The ability to sustainably and equitably manage resources for human wellbeing therefore requires evaluating and predicting the ways that changes in ecosystems impact how people benefit from ecosystem services. Thus, understanding the linkages between ecosystem services and benefits for people is critical for safeguarding natural resources and particularly those important for groups most vulnerable to global change (Cinner et al. 2012, Howe et al. 2013). Recent theoretical work in ecosystem services has emphasized the need for greater attention to temporal dynamics (Rau et al. 2020), supply and demand, marginal analysis (Chan and Satterfield 2020), and the role of co-production (Bennett et al. 2015) for understanding how ecosystem services benefit and support human wellbeing.

TEMPORAL DYNAMICS

Limited consideration of temporal aspects of ecosystem services poses a significant challenge for understanding how processes of ecosystem change will affect people. Patterns of change in ecosystem services through time can be stochastic (random), linear (continuous, monotonic), periodic (oscillating around linear trend or a single attractor), or event-driven (sudden perturbation), with different temporal dynamics co-occurring at multiple scales (Rau et al. 2018). For example, research in Bangladesh shows how seasonal variation in rainfall influences short- and long-term changes in ecosystem services associated with landcover (Huq et al. 2019). Our ability to detect, understand and predict ecosystem service dynamics is affected by the temporal scale of ecosystem service assessments, including the temporal grain (time frame of minimum unit), resolution (time between minimum units) and extent (total duration) of observation and analysis (MA 2003). For instance, when changes in ecosystem

services are measured using proxies of land use and land cover based on a single image per year, the intra-annual dynamics in provisioning services that are important to local management and decision-making are not visible (Kandziora et al. 2013). Choosing the appropriate temporal scale for ecosystem services evaluation is increasingly important in the context of a changing climate because mechanisms that underpin long-term trends and shocks may only be visible at fine scales. For example, a thorough understanding of long-term dynamics in aquatic ecosystems requires observation and analysis at temporal resolutions high enough to detect ecological processes that determine ecosystem thresholds, critical time windows, and lags in system response (Adrian et al. 2012).

Supply and demand

More specifically, fine-resolution temporal analysis is necessary to understand dynamics in both the supply of and demand for ecosystem services. Ecosystem service supply is grounded in ecological systems. Landscapes support a set of ecosystem processes and functions that determine the potential supply of ecosystem services through time. For example, the seasonal availability of crops in a landscape determines the potential supply of the provisioning service of fodder (Kandziora et al. 2013). Ecosystem service demand is grounded in social systems; people derive benefits from ecosystem services to which they attribute diverse values (Klain et al. 2014), and these values can differ with time. For example, the motivations of visitors to a lake at different times of the year reflect the types of ecosystem services demanded seasonally, with summer visitors placing less importance on intangible benefits such as peacefulness than off-summer visitors (Vierikko and Yli-Pelkonen 2019). Supply side and demand side dynamics of ecosystem services interact and can change differently through time (Rau et al. 2018). As a result, specific relationships between ecosystems and human wellbeing can also change through time. Hence, accounting for both supply and demand dynamics is important for evaluating uncertainties in ecosystem service analysis and valuation for sustainability decision-making (Hein et al. 2016). In addition, alongside different relationships across time, individual ecosystem services can support multiple benefits to individuals and the importance of different benefits may differ between groups (Chaigneau et al. 2019a). Therefore, ecosystem service supply cannot be assumed to translate directly or linearly to benefits for people.

Marginal analysis

Understanding the changing relationship between the supply of ecosystem services and benefits for people requires marginal analysis. Marginal analysis is the assessment of benefits and costs associated with a unit change at different rates of supply, which is needed to support decision-making concerned with the impacts of incremental change in ecosystem services (Turner et al. 2003). For instance, marginal analysis can be used to evaluate the scale effects of land use change on ecosystem service supply (Bai et al. 2020) or compare landscape change scenarios on perceived ecosystem values (Rewitzer et al. 2017). Despite repeated calls for marginal analysis, ecosystem services tend to be valued according to their total value at a point in time (Fisher et al. 2008, Chan and Satterfield 2020). Marginal analysis is particularly important for understanding the relationship between ecosystem services and human wellbeing. The effect of a unit change in ecosystem services on flows of benefits for people depends on the total number of units of the ecosystem service they have access to (Ash et al. 2010, Ricketts and Lonsdorf 2013). More specifically, changes in the benefits for people associated with a unit change in ecosystem service supply reflects marginal utility. Marginal utility is an economic concept that describes the change in consumer satisfaction associated with a unit change in the supply of a good. Marginal utility represents the use value of ecosystem services, which underpin the opportunity costs that shape people's decisions (Farber et al. 2002).

Co-production

Finally, people co-produce ecosystem services in ways that influence both supply and demand dynamics and shape how people benefit from ecosystems. Social processes mediate every stage linking nature to human wellbeing (Spangenberg et al. 2014b, 2014a). People co-produce ecosystem services by managing landscapes to enhance particular ecosystem functions, by mobilising ecosystem services from ecosystems, allocating ecosystem services to different uses to generate particular benefits, and by attributing value to those benefits (Fedele et al. 2017). Individual identities and capabilities influence the human-nature interactions through which people co-produce ecosystem services (Fischer and Eastwood 2016) and therefore agency (the capacity of people to make choices within the bounds of contextual structures) in ecosystem service co-production plays a fundamental role in how people benefit from ecosystems (Spangenberg et al. 2014a, Rademacher et al.

2019). Crucially, the co-production process by which people allocate or allow ecosystem services to flow to different purposes (hereafter “allocation”) bridges the juncture between ecosystem service supply and demand to determine the flow and distribution of benefits from ecosystem services (Fedele et al. 2017). Choices of how to allocate ecosystem services across multiple benefits can therefore be understood to reflect differences in marginal utility of benefit types.

Despite widespread recognition that temporal dynamics, marginal changes in supply and demand dynamics, and co-production are critical in shaping how ecosystem services benefit and support human wellbeing, empirical studies that examine these dynamics—separately or together—are scarce. Firstly, ecosystem service assessments rarely include temporal aspects. Between 2000 and 2016, only 2% of ecosystem service studies considered temporal dynamics and even then, mostly only in Europe, North America and China (Rau et al. 2020). Secondly, there has been limited attention to demand-side dynamics of ecosystem services. Ecosystem services research in general (Chan and Satterfield 2020) and time-sensitive work in particular (Rau et al. 2020), has mostly focused on supply, conflating ecosystem change with ecosystem service change. Crucially, assessments of ecosystem service supply do not account for mechanisms of access that determine differences among stakeholder groups in the distribution of benefits (Daw et al. 2011) and sensitivity to ecosystem change (Daw et al. 2016). Understanding access is essential for understanding how changes in ecosystems will impact people (Bennett et al. 2015), and for ecosystem services research to contribute to poverty alleviation (Daw et al. 2011). Knowledge gaps in demand side dynamics limit the ability of ecosystem services research to inform sustainability decisions that must navigate outcomes for people (Rieb et al. 2017). Consequently, ecosystem services has developed predominantly as a theoretical field, with limited impact in more applied contexts (Bennett and Chaplin-Kramer 2016, Chan and Satterfield 2020). Finally, little is known about how social and ecological contributions co-produce ecosystem services in time and space (Bennett et al. 2015), and there are major knowledge gaps in the co-production of ecosystem services for food security (Cruz-Garcia et al. 2016). Thus, there is a pressing need for empirical work that explicitly focuses on ecosystem service demand and beneficiaries over time, to ensure advances in knowledge translate into sustainable futures (Rieb et al. 2017).

Understanding temporal aspects of ecosystem services and the role of people in mediating the linkages between ecosystems and wellbeing benefits through time is particularly important in rural coastal areas of low-income countries. Millions of people in low-income countries depend directly on coastal ecosystems for their livelihoods (World Bank et al., 2012). These ecosystems are some of the most vulnerable to climatic and socio-economic change, which pose major threats to the poverty and food security of local communities (Blasiak et al. 2017). Coastal areas are highly dynamic systems and natural processes create temporal variability in the supply of coastal ecosystem services (Koch et al. 2009). However, a majority of coastal ecosystem services research (71%) has focused on a single point in time (Blythe et al. 2020). As such, understanding of coastal ecosystem services is informed predominantly by static snapshots, mostly in Europe and North America (Liquete et al. 2013, Blythe et al. 2020). Greater levels of ecosystem service co-production have been linked to greater delivery of provisioning ecosystem services and to trade-offs between ecosystem services in marine environments (Outeiro et al. 2017). However, human dimensions of coastal ecosystem services are underrepresented in our understanding and management of coastal areas as dynamic social-ecological systems (Loomis and Paterson 2014). Hence, there is a need for more empirical work on temporal aspects of ecosystem service demand and co-production in coastal areas of low-income countries (Solé and Ariza 2019), including insights on fine resolution temporal dynamics to support understanding of long-term change in coastal social-ecological systems.

To address these knowledge gaps, we examined how people allocate coastal ecosystem services across a suite of benefits when there is different supply and at different times (marginal analysis). Small-scale fisheries provide a good case study for examining the allocation of coastal ecosystem services. In low-income countries, there are around 32 million small-scale fishers (World Bank et al., 2012). Small-scale fisheries are more sensitive to weather conditions than industrial fisheries (Johnson 2006), which create seasonal cycles in access and catches (Cetra and Petrere 2014, Gill et al. 2019). Seasonal changes in supply have direct impacts on fisher livelihoods and food security (Fabinyi et al. 2017) and throughout small-scale fishery values chains (Jueseah et al. 2020). We focused on the provisioning service of fish because provisioning services are often perceived as most important by local resource users (Huq et al. 2019, Lau et al. 2019). In addition, as a physical flow, landings of fish offer a relatively simple example for assessing allocation.

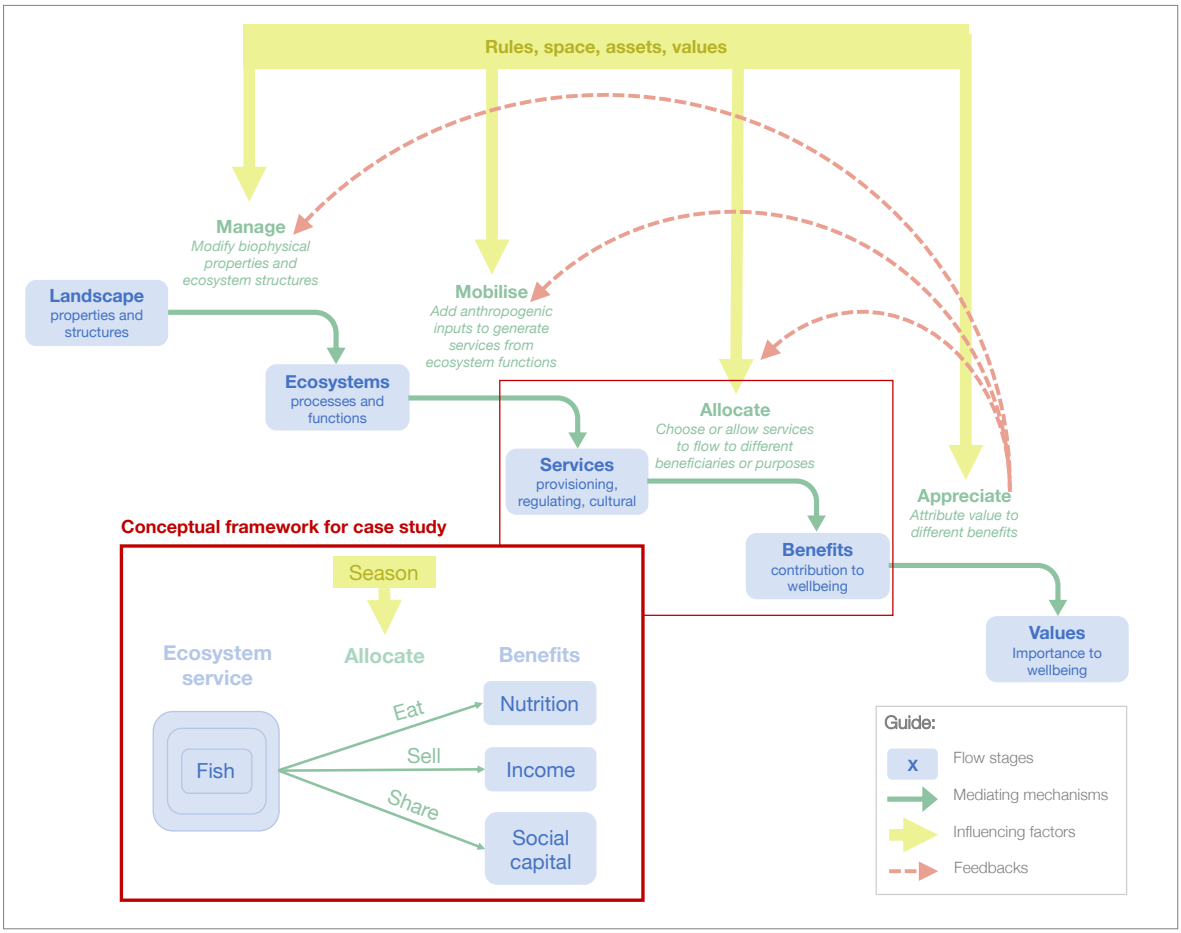


FIGURE 5.1 ECOSYSTEM SERVICE CASCADE FRAMEWORK ILLUSTRATING THE MULTIPLE LINKAGES BETWEEN NATURE AND PEOPLE (ADAPTED FROM FEDELE ET AL. 2017). INSET DETAIL SHOWS CASCADE COMPONENTS EXAMINED IN THE CASE STUDY SMALL-SCALE FISHERY, INCLUDING THE PROVISIONING ECOSYSTEM SERVICE OF FISH AT DIFFERENT RATES OF SUPPLY AND SEASON AS AN INFLUENCING FACTOR.

We drew on the ecosystem service cascade conceptual framework (Figure 5.1), which illustrates the multi-stage relationship between people and nature, including the linkage between ecosystem services and benefits to people (Haines-Young and Potschin 2010). Later adaptations of the cascade framework explicitly highlight the influence of contextual factors and human values in shaping social-ecological feedbacks (Spangenberg et al. 2014b, 2014a, Fedele et al. 2017). Specifically, we examined how people mediate the linkage between ecosystem services and benefits through everyday agency. Everyday agency refers to the 'ordinary' micro-practices of evaluation and adaptation with which people navigate change and vulnerabilities in their day-to-day lives (Payne 2012, Mcmichael et al. 2019, Selimovic 2019). We used the example of the post-harvest use of fish catch in small-scale fisheries to look at how people exercise everyday agency over benefits from fishery ecosystem services through their choices of how to use fish catch (Figure 5.1). For example, fisheries support direct nutrition benefits when people choose to eat fish, whereas if people choose to sell fish, they gain income benefits. Using an in-depth case study of a small-scale

fishery in Timor-Leste, we asked how the allocation (one aspect of co-production) of fish landings varied by 1) total number of fish landed (supply); 2) season (time); and 3) the interaction between number of fish landed and season. We triangulated quantitative analysis of the post-harvest use of landings with qualitative insights into seasonal livelihoods to examine how ecosystem service supply and time influence how people allocate ecosystem services to a set of benefits.

5.2. Materials and Methods

Background and study site

Research was carried out in the community of Adara, Atauro Island Timor-Leste (Figure 2.1). Timor-Leste is a Small Island Developing State (SIDS) located at the heart of the Coral Triangle. A key challenge for the sustainable future of the country is improving human wellbeing and protecting coastal environments in concert (López Angarita et al., 2019; Rosegrant et al., 2016). In particular, addressing acute food insecurity is a high priority in Timor-Leste. Food scarcity and low dietary diversity are widespread (Bonis-Profumo et al. 2019); 36% of the population experience chronic food insecurity (IPC 2019) and 50% of children under five years of age are chronically malnourished (WFP 2018). One of the main causes of food insecurity in Timor-Leste is the occurrence of an annual lean season: high dependence on rainfed, low-yield subsistence agriculture leads to food shortfalls during the rainy season, when crops are growing but not yet ready to harvest (da Costa et al. 2013, Erskine et al. 2014). Thus, seasonality has important links to food and nutrition outcomes.

Seafood has the potential to contribute to improved food and nutrition security in Timor-Leste. National average per-capita seafood consumption is 6.1 Kg (AMSAT 2011a), which is substantially lower than other islands in the pacific (World Bank, 2018). Low seafood consumption is attributed to an underdeveloped fishery sector, poor transport and storage infrastructure, weak governance and limited integration of fisheries into food security policy (Mills et al. 2013, Steenbergen et al. 2019b, Farmery et al. 2020). However, the ecological status of marine resources in Timor-Leste is poorly documented (ADB 2014) and there is a pressing need to identify and establish sustainable coastal management strategies to support the integration of fisheries in food secure futures in Timor-Leste (López Angarita et al., 2019; World Bank, 2018).

The need to balance diverse social and ecological needs in coastal resource management is pressing on Atauro Island, Timor-Leste's only populated islet. Located 25km north of the capital Dili, Atauro Island is 140 km^2 in area, rising steeply up to 999m at its highest point. The Island is fringed by narrow coral reefs rich in marine life (PIFSC 2017). The island is home to roughly 9,200 people, living in 23 communities across five different administrative sub-districts (GDS 2015). Livelihoods and food security on Atauro Island are more fishery-based than other parts of Timor-Leste and the Island hosts the country's largest regular fish market in the community of Beloi (Mills et al. 2013). The Beloi market is held on Saturdays, and a smaller version on Thursdays, to correspond with the public ferry service connecting Atauro Island with Dili, the capital. Traders are predominantly Atauro Island residents, who travel from their various communities, usually at dawn by foot or boat, to the market. Traders operate from permanent (small-shops) and semi-permanent structures (wooden market stalls), or as informal vendors. Seafood (predominantly finfish, but also octopus and shellfish), sold fresh, dry or barbequed is the main commodity traded in the market. A number of vendors also sell crops, livestock, handicrafts and seaweed. Buyers include Atauro residents who attend the market to purchase staple foods, as well as individual and commercial (restaurants and hotels) buyers from Dili, who are drawn by the greater availability and lower prices of seafood compared to the capital. During periods of rough weather and in the rainy season market activity decreases as the supply of goods (such as seafood and crops) declines and limited boat transportation reduces the numbers of traders and buyers.

Atauro Island is also the focus of a conservation programme aimed at establishing a national network of small marine protected areas (Conservation International 2020) and its beautiful beaches and coral reefs make it one of the main attractions of a small but growing tourism industry. Understanding how different stakeholders, and particularly local communities, benefit from marine ecosystems, is thus critical to ensuring just and sustainable futures on Atauro Island.

The community of Adara, located on the western coast of Atauro Island, provided an apt case study for our research (Figure 2.1). Adara is relatively isolated, accessible only by foot or boat, and has limited infrastructure, with no running water or electricity. At the time of the research, 26 households lived in Adara, with a total population of approximately 120 people. Similar to many rural coastal communities in low-income countries, people in Adara pursue

diversified and predominantly natural resource-based livelihoods including crop farming, livestock rearing and fishing. Fisheries in Adara are low-technology and artisanal. Fishing activities are typically carried out from small wooden canoes or the shore. The main gear types used include nylon gillnets, traditional wooden spears with a sharpened metal tip, baited lines and gleaning (hand collection). Fish are used for household subsistence, traded as a source of income in the village or at the Saturday market, and also shared with friends and family. Refrigeration is limited by the lack of electricity in the village and so the main way of storing fish is salting and sun drying. Households dry fish for their own consumption and to sell.

DATA COLLECTION

Data were collected between June 2018 and May 2019. We used mixed methods (specifically, a combination of seasonal calendars, key informant interviews and daily household surveys) to collect quantitative and qualitative data on livelihoods and consumption at different times of the year. We analysed the data to evaluate 1) seasonal context and 2) fishing seasonality. Below we describe each data collection method, followed by a description of the data analysis.

Seasonal calendars

Seasonal calendars are a participatory tool used to elicit community perceptions of annual variation in processes or conditions through time. We used seasonal calendars to collect qualitative data on weather conditions, agriculture and fisheries at different times of the year. The aim of the seasonal calendars was to understand how livelihoods in the community—particularly fishing—shift with season. Seasonal calendars were carried out with men and women separately in focus groups in July 2018. Focus groups were held in a public space and were open to all community members. In total, there were 15 participants in the men's group and 19 in the women's group. The focus group was implemented by the lead author and a facilitator, who translated between English and Tetum (one of the national languages of Timor-Leste). The aims of the seasonal calendar were explained to participants and each focus area (weather, livelihoods, fisheries) was then discussed in turn within the group. Findings were recorded as notes (in English and Tetum) on to a large format dial framework representing the annual cycle. Each seasonal calendar focus group lasted between 2-3 hours.

Interviews

Individual interviews were used to explore seasonality in specific livelihood activities. Interviews were carried out in November 2018 by the lead author and a research facilitator, who translated between English and Tetum. A structured question format was used to guide interviews and interview responses were recorded as notes in a structured recording sheet. Livelihood interviews collected data on activities, harvests and challenges at different times of the year. Each interview took between 60-90 minutes to complete. Interview respondents were purposefully selected members of the community who were actively involved in each specific livelihood activity, and who were able and willing to participate. In total, 16 individuals were interviewed, including four for each fishing, gleaning (the manual collection of marine organisms from intertidal zones), agriculture and livestock rearing.

Household panel survey

We conducted a daily panel survey on household activities and consumption for two one-week periods at three different times of the year (survey seasons). Survey seasons were selected to capture differences in weather, livelihoods and food security according to the seasonal calendar findings. Within each survey season, two survey weeks were chosen to correspond with the full and new moon (Table 5.1) to control for the impact of lunar cycles on tidal conditions.

The first survey season corresponded with when households were preparing for the period of seasonal food insecurity (hereafter Preparation season), the second was during the season of food scarcity (hereafter Lean season) and the third survey season was during the main harvest season (hereafter Harvest season). The seasonal context is described in more detail in the results section. The survey was digitised using Kobotoolbox survey software (Harvard Humanitarian Initiative n.d.) and implemented by three local data collectors, who each surveyed five households daily during survey weeks. Hence in total, 15 households were surveyed for 14 days in each of the three seasons, equating to 630 household survey days.

TABLE 5.1 DATES OF HOUSEHOLD PANEL SURVEY (SHADING INDICATES DAYS THAT DATA WERE COLLECTED FOR)

Survey season	Year	Month	Day of the week						
			M	T	W	Th	F	Sa	Su
Preparation	2018	August	6	7	**8**	**9**	**10**	**11** ○	**12**
			13	**14**	15	16	17	18	19
			20	21	22	**23**	**24**	**25**	**26** ●
			27	**28**	**29**	30	31		
Lean	2019	January		1	2	**3**	**4**	**5**	**6** ○
			7	**8**	**9**	10	11	12	13
			14	15	16	17	**18**	**19**	**20**
			21 ●	**22**	**23**	**24**	25	26	27
Harvest	2019	April	15	**16**	**17**	**18**	**19** ●	**20**	**21**
			22	23	24	25	26	27	28
		May			1	**2**	**3**	**4**	**5** ○
			6	**7**	**8**	9	10	11	12

Calendar of dates of survey data collected (shaded) for each survey season, indicating timing of new moon (○) and full moon (●).

DATA ANALYSIS

Analysis was carried out in two distinct stages. First, we drew on qualitative data to evaluate the seasonal context in the study community. Second, we examined the post-harvest use of fish. Using quantitative data, we analysed how household allocation of landed fish to different uses varied with the amount landed and across seasons, and we compared differences in the total proportion of landings used in each way.

Seasonal context

We combined qualitative data from seasonal calendars, interviews and informal discussions to provide an overview of the seasonal context in the study community. Seasonal calendar data were used to inform a basic framework of typical seasonal cycles in the study community, linking weather conditions and livelihood strategies at different times of the year. Any ambiguity or uncertainty in seasonal calendar data was resolved through informal discussions with key informants. Insights from individual livelihood interviews were integrated to provide more in-depth understanding of the seasonal livelihood context presented by the seasonal calendars.

Post-harvest use of landings

We quantitatively evaluated how the allocation of fish to different post-harvest uses varied with the number of fish landed and across seasons. We analysed survey data on the post-harvest use of landings from household fishing trips using mixed models fitted using R statistical software (R Core Team 2018). Mixed models were fitted with a log-linked negative binomial distribution using the lme4 package (Bates et al., 2014). The effects of (i) total fish landings and (ii) season on post-harvest use were analysed in models represented as:

i) Count ~ Use * Landings + offset(log(Qtotal)) + (1|Household)
ii) Count ~ Use * Season + offset(log(Qtotal)) + (1|Household)

Use is a categorical variable of different post-harvest uses (*eat, sell, share*) and *Count* is the number of individual fish used in each way. *Landings* is a categorical variable that describes the total number of fish landed (<10, 10-20, >20) and *Season* is the survey season in which the fishing trip was recorded (*preparation, lean, harvest*). To standardise the model output across different landing quantities we included total number of fish landed (*Qtotal*) as an offset variable. *Household* was included as a random effect to account for the panel structure of the data. Post-hoc Tukey adjusted pairwise comparisons were carried out using the emmeans package (Lenth 2019). Landings data included fishing trips using all methods except gleaning. Gleaning was left out because there were distinct differences in the main target groups compared to other fishing methods and thus landing quantities were incomparable and data were insufficient to support a separate analysis. Unless specified, differences reported in the results were found to be significant at a 95% confidence interval (p <0.05).

To compare how fish were used across landing groups in different seasons, we aggregated catch data from fishing trips in each landing group in each season. Using chi-square goodness of fit tests, we analysed whether the post-harvest use of fish differed significantly from what would be expected if households allocated catch equally across uses. Using Pearson's chi-square comparisons, we examined whether the allocation of fish to a particular post-harvest use within each landing quantity differed among seasons.

5.3. RESULTS

SEASONAL CONTEXT

Livelihoods and the food security context in the study community correspond with seasonal weather and sea conditions (Figure 5.2). Survey seasons were chosen to capture three distinct seasons.

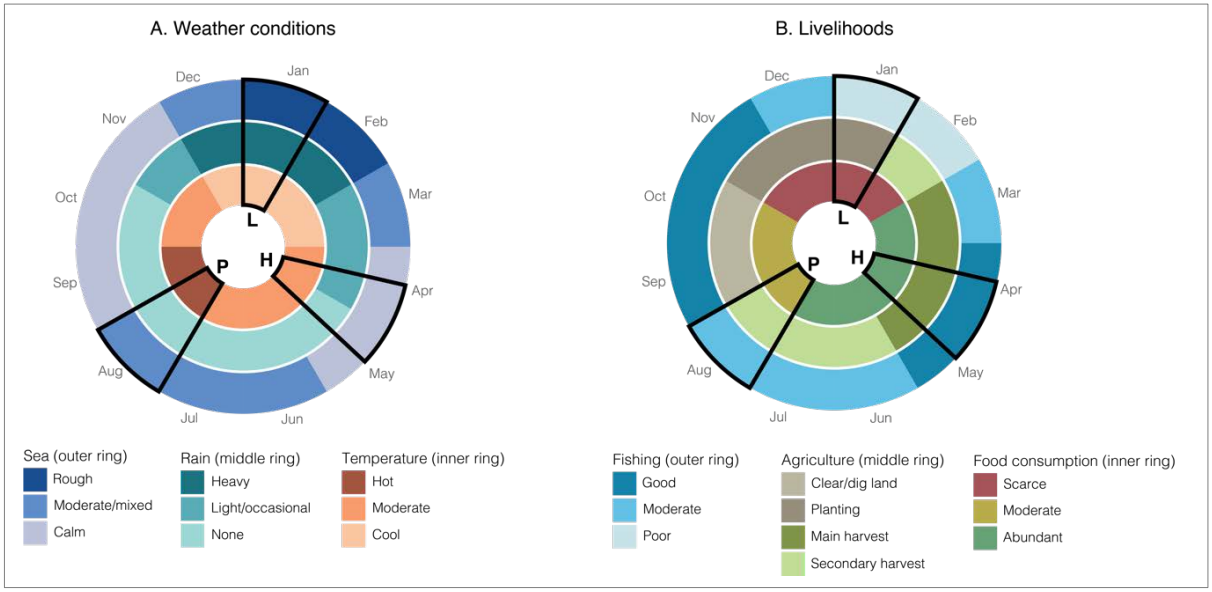


FIGURE 5.2 SUMMARY OF SEASONAL WEATHER CONDITIONS AND LIVELIHOOD CONTEXT IN THE STUDY COMMUNITY BASED ON SEASONAL CALENDARS. OUTLINED SEGMENTS INDICATE SEASONS IN WHICH DAILY HOUSEHOLD SURVEY WAS IMPLEMENTED: L = LEAN SEASON, H = HARVEST SEASON, P = PREPARATION SEASON.

The lean season survey was carried out in January (segment L, Figure 5.2). In seasonal calendars, January was identified as a main period of rainfall and rough sea conditions in the study community (Figure 5.2A). Weather conditions in January are characterised by the western monsoon, which typically occurs between December-February. The lean season coincides with the rainy season because of the high dependence on rainfed agriculture in the study community. Crops are planted during the rainy season (Figure 5.2B) and in interviews, respondents described how the first rains signify the time to start planting and that the timing, reliability and quantity of rain are all key determinants of crop success. During the planting season there are no crops available to harvest and so households must rely on stored crops and bought foods, such as rice. During interviews, focus groups and informal discussions, members of the community described how during the lean season, stored staple crops run low and households must reserve some staple crops in case of a low harvest the following year or for re-sowing. Therefore, a household may have stores of staple crops available that they don't consume during the lean season because being able to replant is the main priority.

Some interview respondents stated that in previous years, poor rains and pest damage have meant that within a single season they have had to replant crops up to three times.

The lean season also corresponds with the poor fishing season. In seasonal calendars, interviews and informal discussions, January and February were identified as the worst months for fishing (Figure 5.2B) with rough sea conditions during the western monsoon (Figure 5.2A) make fishing risky or even impossible in the study community. During rough weather fishers reported using mostly baited handlines from the shore or gleaning in the intertidal zone. Gleaning in particular is an important source of subsistence seafood during the lean season when food in general is scarce (Grantham et al. 2021). For instance, during an interview, one woman explained how she gleans when they have nothing else to accompany rice. Gleaners described being less selective during the rough season than in the calm season, for example collecting smaller shells and less preferred types of seafood. Weather conditions also affect fish processing and trade. During focus groups, women described how the processing and trade of fish cease during the rainy season because fish are sun dried outside and cannot be dried in the rain. Selling dried fish is a main source of income in the study community, particularly for women. Women buy fish from local fishermen, which they then salt and dry to sell at the weekly market held on Atauro Island's eastern coast.

The harvest season survey period was carried out in March-April (segment H, Figure 5.2). These months are characterised by light rainfall, moderate temperatures and calm seas (Figure 5.2A) and encompass the main agricultural harvest and good fishing (Figure 5.2B). In seasonal calendars and interviews, the main harvest of staple crops including corn and beans was reported to occur between March-May (Figure 5.2B). A small harvest of early corn in February is the first harvest of the year and some secondary crops are harvested through until August. Staple crops are predominantly used for household subsistence, they are harvested intensively and stored, whereas secondary crops, including fruits and vegetables, are harvested as needed and occasionally sold. Interview respondents highlighted how the success of a year's harvest can stipulate annual fishing activities. Households know how many ears of corn and sacks of beans they must harvest to be able to eat throughout the following year. If annual harvests of staple crops are insufficient to last through to the end of the following lean season, households will increase their livelihood focus on fishing as a source of income to buy food and staple crops for planting. Calm seas during the harvest

season characterise the good fishing season in the study community (Figure 5.2B). In interviews, some fishers reported that during months when the sea is calm, they may go on multiple fishing trips in a single day. Gillnets are a common fishing method in calm weather. The nets are laid from wooden canoes, usually at dawn, to target schools of fish on the reef edge. Spearfishing is also a common method in calm weather. Unusually for Timor-Leste, a number of women in the study community are spearfishers, who specifically target octopus as a high value catch.

The preparation season survey was carried out in August (segment P, Figure 5.2). In seasonal calendars, August was described as being hot, dry and windy, with variable sea conditions (Figure 5.2A). The hot weather and lack of rain between August – September (Figure 5.2A) brings the harvest season to a close (Figure 5.2B). In focus groups, community members described how as the harvest finishes, they begin to prepare for the lean season by saving money (often from fishing), stocking up on rice and managing their consumption of subsistence crops. In seasonal calendars, mixed sea conditions were reported in August (Figure 5.2A) and it was considered to be a moderate fishing season (Figure 5.2B). Poor water clarity prevents spearfishing but gillnets can be used on calm days.

Post-harvest use of landings

In total, 179 fishing trips were recorded across the three survey seasons (Preparation = 70, Lean = 48, Harvest = 61). Total landings ranged from 1 to 100 fish, with the mean number of fish landed per trip varying seasonally (P = 22, L = 10, H = 12).

Allocation across landing groups

The post-harvest use of fish was related to the number of fish landed ($R^2 = 0.43$, Figure 5.3a, Appendix C.1 Landings). Paired comparisons (Appendix C.2.1) show that the proportion of fish allocated in a particular way varied amongst landing groups (<10fish, 10-20 fish, >20 fish). Specifically, the proportion of fish eaten was greater for small landings (<10 fish) than large landings (>20 fish). The proportion of fish sold was greater for large landings, followed by medium landings (10-20 fish), and lowest for small landings. There were no differences in the proportion of fish shared across landing groups. Paired comparisons (Appendix C.2.2) of the proportion of fish used for consumption, sharing and selling within landing groups show that the relative importance of different post-harvest uses also varied with the number of fish landed. Within the small and medium landing groups the proportion of fish sold and shared

was similar and less than the proportion eaten, while for large landings the proportion of fish sold or eaten was similar and greater than the proportion that was shared.

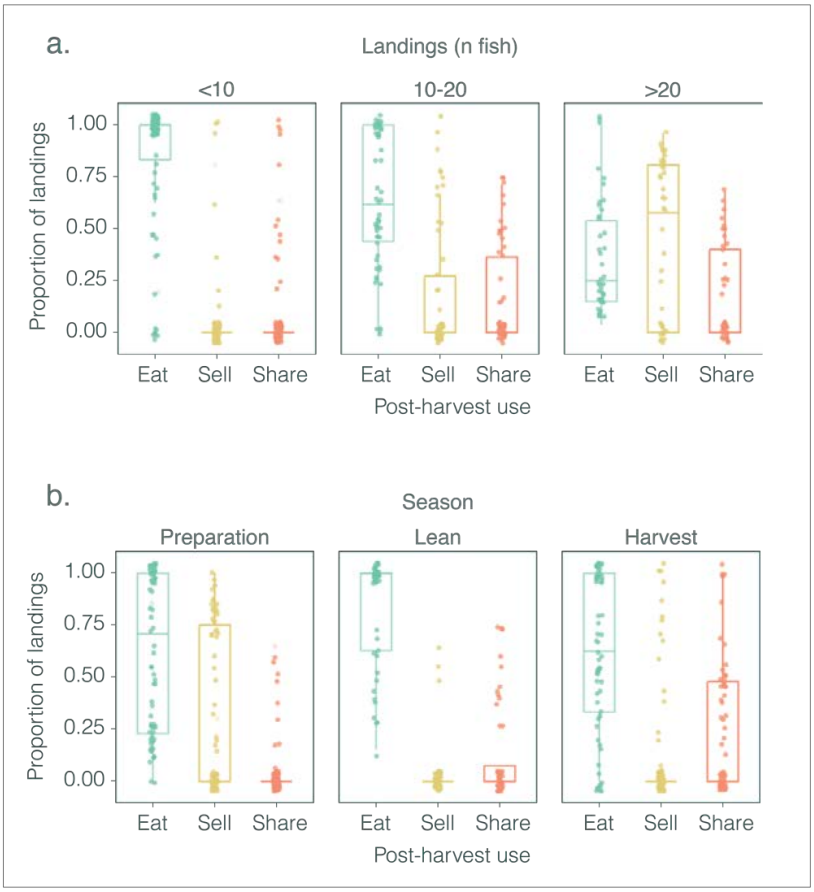


FIGURE 5.3 BOXPLOTS SHOWING PROPORTION OF TOTAL FISH LANDED THAT WERE USED IN EACH WAY FOR A) FISHING TRIPS IN EACH LANDING GROUP CATEGORY AND B) FISHING TRIPS IN EACH SURVEY SEASON.

Allocation across seasons

Season also had a significant effect on the post-harvest use of fish ($R^2 = 0.44$, Figure 5.3b, Appendix C.1 Season). The proportion of landed fish allocated to non-consumption uses differed amongst seasons (Appendix C.3.1). A greater proportion of fish were sold in the preparation season, followed by the harvest season, with the proportion of fish sold being smallest in the lean season. The proportion of fish that was shared was lower in the preparation season than other seasons. Paired comparisons of the proportion of landed fish used in different ways within each season (Appendix C.3.2) highlights differences in the relative importance of post-harvest uses. In the preparation season, the proportion of fish eaten or sold was similar and greater than the proportion shared. In the lean season, the greatest proportion of fish was used for eating, followed by sharing and the smallest proportion was sold. In the harvest season, eating was also the main use of fish, but the proportions sold and shared were similar.

Seasonal allocation within landing groups

Landed fish were not equally allocated across uses (Figure 5.4). For all landing quantities in all seasons, we compared the proportions of landed fish used in each way compared to proportion expected if fish had been allocated equally (i.e., one-third). Catches were only allocated equally across post-harvest uses for large landings (>20 fish) in the lean season (Table 5.2). For all other seasonal landing groups, significantly more than one-third of fish were eaten (paired comparisons Appendix C.4.1), with the exception of large landings in the preparation season of which significantly more than one-third of fish were sold. Significantly less than one-third of fish were sold from large landings in the harvest season, medium landings (10-20 fish) in the lean season and small landings (<10 fish) in all seasons. The proportion of fish shared was significantly less than one-third across all landing groups in the preparation season, and small landings in the lean season and large landings in the harvest season.

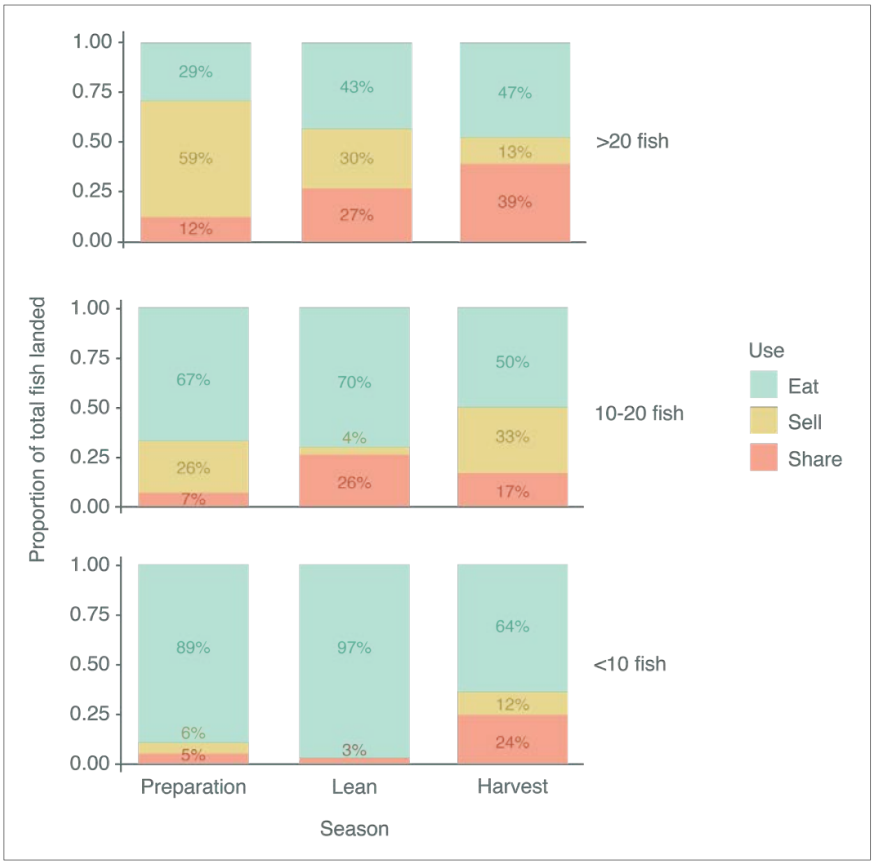


FIGURE 5.4 POST-HARVEST USE OF FISH FOR DIFFERENT LANDING GROUPS IN EACH SEASON, PROPORTION OF TOTAL LANDINGS SHOWN ON BARS.

TABLE 5.2 SUMMARY OF CHI-SQUARE TESTS COMPARING THE PROPORTION OF FISH USED IN EACH WAY IN EACH LANDING GROUP IN EACH SEASON.

Landing group	Season	X^2	df	p value
Small (<10 fish)	Preparation	147.25	2	**< 0.001**
	Lean	260.68	2	**< 0.001**
	Harvest	78.237	2	**< 0.001**
Medium (10-20 fish)	Preparation	171.17	2	**< 0.001**
	Lean	164.95	2	**< 0.001**
	Harvest	32.337	2	**< 0.001**
Large (>20 fish)	Preparation	361.02	2	**< 0.001**
	Lean	5.19	2	0.07466
	Harvest	66.916	2	**< 0.001**

There were significant seasonal differences in the proportion of fish within landing groups used in each way (Figure 5.4, Table 5.3, Appendix C.4.2). For small landings (<10 fish), the proportion eaten was greatest in the lean season, followed by the preparation season and then the harvest season. The proportion sold was similar in the preparation and harvest seasons, none were sold in lean season. The proportion shared was greater in the harvest season than in other seasons. For medium landings (10-20 fish), similar proportions were eaten in the preparation and lean seasons, and this was less than the in the harvest season. The proportion sold was similar in the preparation and harvest seasons and this was greater than in the lean season. The proportion shared was greatest in the lean season, followed by the harvest season, with the least shared in the preparation season. For large landings (>20 fish), a greater proportion was eaten in the harvest season than the preparation season. The proportion sold was greatest in the preparation season, followed by the lean season and the harvest season. The reverse was true for the proportion shared, which was greatest in the harvest season, followed by the lean season and lowest in the preparation season.

TABLE 5.3 SUMMARY TABLE OF CHI-SQUARE TESTS COMPARING THE PROPORTION OF FISH USED IN EACH WAY IN EACH LANDING GROUPS AMONGST DIFFERENT SEASONS.

Landing group	Use	X^2	df	p value
Small (<10 fish)	Eat	63.624	2	**< 0.001**
	Sell	18.647	2	**< 0.001**
	Share	40.874	2	**< 0.001**
Medium (10-20 fish)	Eat	21.577	2	**< 0.001**
	Sell	66.19	2	**< 0.001**
	Share	37.426	2	**< 0.001**
Large (>20 fish)	Eat	44.789	2	**< 0.001**
	Sell	232.61	2	**< 0.001**
	Share	125.95	2	**< 0.001**

5.4. Discussion

Households used fish differently among seasons and according to total number of fish landed. These results illustrate how through the co-production process of allocation, households mediate the linkage between coastal ecosystems and human wellbeing at both individual and community levels. Specifically, our findings address the dynamic relationship between ecosystem services and benefits, highlighting the importance of temporal scale, marginal analysis and human agency for understanding ecosystem service demand.

Seasonal differences in how households used landed fish highlight how choices of temporal scale affect measurements of coastal livelihoods and ecosystem services. In the lean season, almost all fish were consumed directly by fishing households whereas in the preparation season fish were also often sold. Therefore, as in other small-scale fisheries (Clark et al. 2002), fishing on Atauro shifted seasonally between being subsistence-focused and small-scale commercial. The different uses of fish characterise different pathways through which ecosystem service benefits from fishing contribute to livelihoods. For example, from a food security perspective, fishing provides a direct source of protein and micronutrients when landed fish are eaten (Hicks et al. 2019); when landings are sold, fishing provides a source of income critical for buying staple foods (Fabinyi et al. 2017); and when landings are shared, fishing may contribute to food security through mechanisms of reciprocal altruism in food sharing networks (Vaughan and Vitousek 2013). A seasonal lens reveals how the relative importance of these pathways through which ecosystem services benefit people changes through time, which would not be visible at annual resolutions. Fine resolution perspectives are important for understanding local drivers of change in multi- and cross-scale ecosystem service assessments (Scholes et al. 2013). Crucially, accounting for local-scale dynamics increases the relevance of ecosystem services research to the interests of key stakeholders (Folke et al. 2005) and by extension the priorities of decision-makers. For example, seasonal food scarcity is the main cause of hunger and malnutrition among the rural poor (Vaitla et al. 2009). As such, seasonal scale assessments of how ecosystem services support food security benefits could directly inform priorities in human development. Specifically, a seasonal lens on small-scale fisheries would provide important insights into the multiple and dynamic contributions of fishery ecosystem services to food and nutrition security.

Differences in how households used fish depending on the total quantity landed highlight the importance of marginal analysis for understanding how coastal ecosystems contribute to human wellbeing. Fishing households make choices to gift or sell fish once they have enough to satisfy their own consumption needs. This allocation of fish to post-harvest uses can be understood as reflecting changes in the marginal utility and therefore the opportunity costs of different benefits with changes in supply. In the context of using fish landings, the opportunity cost of one benefit (i.e., nutrition) is the other benefits forgone (i.e., income or social capital) because each fish can only be used in one way. Our results show that overall, as the quantity of fish landed increased, the proportion eaten decreased and the proportion sold increased. From a utility perspective, this finding suggests that the marginal utility of nutrition benefits diminishes with supply, reflecting the fact that households can only eat a certain amount of seafood, particularly in the context of limited options for preservation. Beyond that amount the marginal utility of keeping one more fish to eat may drop to zero because demand for nutrition benefits is saturated and so opportunity costs decrease and a fish is allocated to other benefits, such as income. Our results also suggest that changes in marginal utility and therefore opportunity costs were seasonal.

Marginal analysis in ecosystem services has been relatively limited, but is essential for recognising that ecosystem service demand may not be constant with supply and for evaluating cost-benefit trade-offs associated with ecosystem change and resource management, for example at different scales of landscape restoration (Fisher et al. 2008, Llorente et al. 2018). Accounting for marginal utility can also help to recognise the relative importance of ecosystem services to the wellbeing of different groups and particularly the poor, to support equitable ecosystem service distribution (Daw et al. 2011). Specifically, our results demonstrate how marginal analysis can strengthen understanding of the ways that people mediate a non-linear relationship between ecosystem services and benefits, which is particularly important in changing coastal social-ecological systems. Unprecedented socio-economic and environmental changes are affecting the supply of ecosystem services in coastal regions of low-income countries and the impacts of this on people are a major concern for decision-makers (IPCC 2003). We found that household allocation choices mean that changes in ecosystem service supply do not equally or consistently translate to changes ecosystem service benefits, therefore marginal analysis of ecosystem service demand is essential for understanding how changes in coastal ecosystems will impact human wellbeing.

There is a need for more human-centric perspectives of ecosystem services focused on the role of everyday agency in co-production. Through their allocation choices, households actively influenced the flow of benefits they gained from the ecosystem service of fish and adapted the seasonal function of fishing in livelihoods. The ratio of fish landings allocated to each use differed between seasons and with quantity landed, reflecting seasonal livelihood priorities and opportunities. For example, the decision to sell a greater proportion of landings in the preparation season enables fishing to provide a source of income to support food security during the lean season. Other research has also shown that fishers shift the use of catches in response to crises, for example by prioritising fishing as a source of income to support recovery rather than for subsistence (Thomas et al. 2019). Viewing people as passive recipients of benefits from ecosystems overlooks the role of co-production (Fedele et al. 2017) and agency in mediating ecosystem services (Spangenberg et al. 2014a). Agency helps explain social responses to environmental change (Brown and Westaway 2011) and underpins adaptive capacity by determining what components of adaptation people mobilize (Cinner et al. 2018). In social-ecological systems, accounting for agency is fundamental to understanding how social objectives influence system dynamics and resilience (Carr 2019). Our findings demonstrate how in coastal social-ecological systems, our understanding of the ways that people benefit from coastal resources and adapt to changing conditions would be strengthened by research perspectives that account for ecosystem service co-production and specifically how people exercise everyday agency (e.g., through allocation) over the link between ecosystem service flows and benefits to people.

Finally, how households use landings influences how fish are distributed across final consumers. Although our analysis did not explicitly attend to final consumers, different post-harvest uses of fish link to different pathways of distribution. When fish are eaten, the fishing household is the final consumer. When fish are shared final consumers are typically friends and family within the social network of the fishing household. When fish are sold, they are more likely to reach final consumers outside of the fishing household's social network. Who the final consumers of fish are has important implications for understanding the reach and distribution of nutrition benefits from small-scale fisheries. Fish in particular has the potential to substantially improve nutrition security in, and beyond, coastal areas if equitable distribution ensures fish reaches those who need it (Hicks et al. 2019). Our results illustrate that understanding how fishers allocate catch to different uses may illuminate factors affecting

how nutrition benefits from fish are distributed and how this distribution changes with the availability of fish and across seasons. Fisher choices of how to use catches and the consequential distribution of benefits from fisheries has direct implications for food security policy and decision-making. Specifically, accounting for factors affecting the pathways through which fish ends up on people's plates is essential to enhancing the role of fisheries in food security in low-income countries.

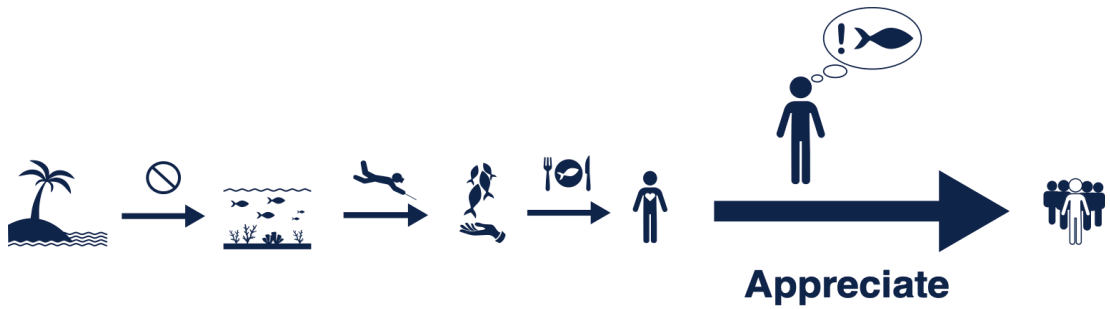
The complex and changing relationship between ecosystem service supply and benefits demonstrated in our results reemphasizes the problematic knowledge gap surrounding ecosystem service demand. How households benefit from fisheries is influenced by how fish landings are used, which changes with the total number of fish landed and among seasons. The relationship between ecosystem service supply and benefits for households was therefore neither direct nor constant. Assumptions that changes in coastal ecosystem services supply will directly equate to changes in benefits for people have been critiqued for overlooking access differences among stakeholders (Foale et al. 2013, Wieland et al. 2016). Broadly, social and ecological processes determine the potential supply of services in a landscape but the benefits actually realised are influenced by access and ecosystem service demand (Queiroz et al. 2015). Empirical research on ecosystem service demand has been limited due to the ecological genesis of this framing and the slow integration of thinking from the social sciences (Chan and Satterfield 2020). Our findings not only support the call for a more explicit focus of ecosystem services research on outcomes for people by examining the demand side of the cascade framework but also highlight the need for greater understanding of how demand side dynamics shape how people benefit from ecosystems through time.

5.5. Conclusion

Using the case study of small-scale fishing, this research shows how people actively mediate non-linear relationships between ecosystem services and benefits through time. Household choices of how to allocate ecosystem services among benefits influence how sensitive different benefits are to changes in ecosystem service supply through time. We found that when landings were small and during periods of food scarcity households chose to allocate a greater proportion of fish to household consumption. In contrast, when landings were larger and particularly when households were preparing for the lean season, households sold a

greater proportion of fish landed. By using fish in different ways, households mediate the relative flows of nutrition, social capital and income from landings and thereby actively shape the relationship between ecosystem services and benefits. Therefore, human-centric perspectives that include greater emphasis on the role human agency and ecosystem service co-production are needed to understand how coastal ecosystems contribute to wellbeing and to inform coastal management. Specifically, this research highlights the importance of ecosystem services assessments at temporal scales appropriate to how people interact with coastal ecosystems to strengthen the relevance of ecosystem services research for decision-making. To understand who benefits from what and how in coastal ecosystems we must also ask *when*.

6. GLEANING: BEYOND THE SUBSISTENCE NARRATIVE



Adapted from: Grantham, R., Lau, J., Kleiber, D., 2020. Gleaning: beyond the subsistence narrative. Maritime Studies. 19, 509–524.

Contributions: I developed the research questions and methodology, collected and analysed the data. I developed all figures and tables with advice from JL and DK. I wrote the first draft of the manuscript and all co-authors provided editorial input which were included in revised versions.

ABSTRACT

Coastal resources are important for the wellbeing and livelihoods of people in coastal communities across the world, but are used and valued differently by different people at different times. As such, managing coastal resources equitably requires understanding how different people value ecosystems. Gleaning is an important activity in many coastal communities. However, the values of gleaners, and women in general, are often left invisible in coastal ecosystem service assessments, and rarely examined in different seasons. Here, we use an exploratory case study to elicit the seasonal values of gleaning to women in a coastal community through an in-depth mixed methods case study in Timor-Leste. We found that women gave a variety of instrumental and relational reasons for gleaning, and that gleaning values shifted across seasons. Importantly, subsistence was not a priority for all gleaners. Instead, there were a diverse range of reasons for gleaning including to socialize or to spend time in nature. Our findings highlight the need to move beyond oversimplified understandings of wellbeing as simply a matter of meeting basic material needs. The diverse and seasonal value priorities of gleaners in our case study indicate the need for socially and temporally disaggregated assessments of coastal ecosystem services that recognise the importance of relational values to support more accurate depictions of coastal livelihoods and equitable management in coastal areas.

6.1. INTRODUCTION

Coastal zones are complex social-ecological systems that support the wellbeing of millions of people, many of whom live in low-income countries. Accounting for and sustaining the diverse contributions of coastal ecosystems to human wellbeing is thus particularly important, especially in the context of increasingly unpredictable environments (IPCC 2014b). Gleaning – the collection of marine organisms predominantly from the littoral zone – is an important livelihood activity for the rural poor in coastal regions of low-income countries. Gleaning makes a substantial contribution to catches and food security benefits, particularly in the context of seasonal availability and accessibility of other coastal fisheries (Chapman 1987, Kleiber et al. 2014, Tilley et al. 2020), which are influenced by the spatiotemporal distribution of resources, weather, economic constraints and regulations (Teh et al. 2007, Sievanen 2014, Gill et al. 2019). Gleaning is also an important social activity for women (Whittingham et al. 2003).

Despite its importance, gleaning has remained largely invisible in both policy and research. Gleaning tends not to be a lucrative economic activity and is thus underrepresented in fisheries assessments, decision-making, and coastal resource management (Harper et al. 2013, Fröcklin et al. 2014, Kleiber et al. 2015). When it is included, gleaning is usually seen as an activity valued for its contribution to household subsistence as part of a gendered narrative in fisheries. For example, in a report on fisheries in Timor-Leste it is stated that "[…] in many communities, women and children dominate the fishery, which shows its importance for household nutrition." (López Angarita et al., 2019, p. 21). While these contributions are a crucial part of highlighting some aspects of the importance of gleaning for food security, they do not look beyond its subsistence values.

Emphasis on the subsistence value of gleaning represents an extension of the iconic and compelling narrative of women's role in household food security. This narrative, of women as providers and caretakers, has been central to gender mainstreaming in the development discourse (United Nations n.d., Quisumbing et al. 1996). Such narratives have helped promote better representation of women in decision-making but also underpin an oversimplified representation of women and poverty based in generalisations (Cornwall et al. 2007, Chant 2008). As a consequence, there has been a tendency to attribute women's choices and behaviours to essentialized female traits (Jackson 2009). These essentialized

understandings of women's choices, values and behaviours can obscure priorities, aspects of wellbeing, and values that do not fit within the narrative of women as providers. To move beyond this narrative, more empirical work is needed on the values women derive from gleaning in coastal ecosystems and how value preferences shape women's wellbeing.

Ecosystem services provides a framework for moving beyond the subsistence narrative in gleaning by investigating the multiple values of gleaning across time. Firstly, ecosystem services approaches capture the complex, dynamic and socially disaggregated links between human wellbeing and ecosystems. Progress in ecosystem services has turned to plural value approaches to account for the diversity and distribution of coastal ecosystem values (Lau et al. 2019, Blythe et al. 2020). Such approaches emphasize that different people derive different values from ecosystems. For instance, work in ecosystem services is starting to illuminate how women and men interact with and benefit from ecosystem services in different ways, and are therefore differentially affected by processes of change (De La Torre-castro 2019, Fortnam et al. 2019). Secondly, work in ecosystem services is beginning to investigate how temporal variability may influence ecosystem values at the landscape scale, in ways relevant to the study of gleaning. For example, seasonal access and availability of ecosystem services determined differences in the values of services to local stakeholders through time in Nepal (van Oort et al. 2015). Given that climate change is predicted to affect seasonal weather and sea conditions in coastal areas (Oppenheimer et al. 2019), extending studies of temporal change in coastal service values presents an important and pressing opportunity.

To address the gap in understanding the plural and seasonal values of gleaning for women in coastal communities, we undertook an exploratory case study of gleaning in a community in Timor-Leste. We asked: 1) What are the seasonal characteristics of gleaning in the community? (2) Why do women glean and what values do they derive from gleaning? (3) How do values associated with gleaning change between seasons? We begin by outlining the theoretical underpinnings of our approach from wellbeing, ecosystem services, and plural values literature. After describing our case study and methods, we present a characterisation of the gleaning fishery and describe gleaning values over time. Finally, we outline future directions for gleaning research to move beyond the subsistence narrative.

6.2. THEORETICAL UNDERPINNINGS

This section outlines key insights from literature on wellbeing, ecosystem services, and plural values relevant to investigating the role and values of gleaning for wellbeing in coastal communities over time.

WELLBEING

Wellbeing is defined as " a state of being with others, where human needs are met, where one can act meaningfully to pursue one's goals, and where one enjoys a satisfactory quality of life" (McGregor 2008 p. 1). This definition theorizes wellbeing as emerging from the interplay between the material (assets and physical 'stuff' that people have), relational (social interactions and governance that determine what people can do) and subjective (cultural values and perceptions that influence how people feel) domains of a good life (White 2009). This expanded definition is an active move away from outdated definitions of poverty that measure the wellbeing of the poor only by material indicators (Chambers 1995, Rojas 2011). This expanded definition of wellbeing is increasingly being incorporated into environmental management and sustainability. The move beyond material measures of wellbeing is viewed as fundamental for understanding and supporting meaningful relationships between people and nature and achieving poverty alleviation objectives in environmental management (Chan et al. 2011). For example, wellbeing approaches are important for capturing the societal values of small-scale fisheries (Johnson 2018), which support more respectful representations of the lives and values of fishers by defining quality of life as more than just the ability to meet basic needs and focusing on what people have, not just what they are lacking (Camfield 2006, Weeratunge et al. 2014). Crucially, multi-dimensional wellbeing approaches enable disaggregated assessments of environmental contributions to fulfilling a meaningful life, therefore identifying the potential winners and losers, and evaluating the trade-offs and inequalities, of environmental change (Coulthard et al. 2018). As such, wellbeing approaches improve the legitimacy of policy and decision-making through recognition of values and aspirations within fisheries as a way of life and not just a means of making a living (Coulthard et al. 2011). By providing a more comprehensive understanding of why gleaning matters, this multi-dimensional wellbeing lens can contribute to moving beyond essentialized subsistence narratives of women and poverty in coastal livelihoods.

Ecosystem values

The pursuit of wellbeing influences how people interact with ecosystems to mediate wellbeing outcomes (Coulthard 2012). People manage landscapes to enhance ecosystem structures and processes from which they mobilise flows of ecosystem services, these services are then allocated to a set of benefits that contribute to wellbeing and are attributed value (Fedele et al. 2017). The values people derive through interactions with nature can be instrumental or relational values (Box 1) and contribute to the material, subjective and relational dimensions of wellbeing.

Box 1. Types of ecosystem values

- Instrumental values refer to ecosystem services as a means of achieving desired wellbeing outcomes, for instance as a source of nutrition or income. E.g., The market value of fish. Instrumental values that achieve the same wellbeing outcomes are substitutable.

- Relational values are the ways through which specific human-nature linkages and interactions contribute to a "good life" through sense of place, cultural identity and social cohesion. E.g., the ceremonial value of catching and consuming a particular fish species. Relational values are non-substitutable.

- Intrinsic values are inherent moral values attributed to an entity for the virtues of what it is regardless of its relationship to people. E.g., The value of knowing that fish exist. Intrinsic values are non-substitutable.

(Himes and Muraca, 2018; Pascual et al., 2017)

People's ability to realise wellbeing from ecosystems is shaped by mechanisms of access (Ribot and Peluso 2003), and the ways in which benefits are coproduced and values co-constructed are influenced by diverse world-views and value systems (Díaz et al. 2015, Fischer and Eastwood 2016). As such, in coastal social-ecological systems, ecosystem contributions to wellbeing are not necessarily linked with biophysical attributes and vary between stakeholders (Bryce et al. 2016) and relational and instrumental values may be inseparable (Fish et al. 2016). Understanding the multidimensional contributions of the environment to human wellbeing is crucial for balancing and integrating human and ecological needs to negotiate conservation and development discourses in environmental management (Chaigneau et al. 2019b). Ensuring coastal ecosystems are sustained in ways that build resilience inclusively will therefore require understanding what matters to whom and why, and how climate impacts will be differentially experienced (Kenter et al. 2011, Bennett et al. 2015, Tschakert et al. 2017). Framing gleaning through ecosystem values provides a way of integrating wellbeing objectives into understanding human-nature interactions in coastal social-ecological systems.

Plural values

Single ecosystem services can support multiple types of value important for wellbeing (Chaigneau et al. 2019a). The diversity of values people derive from how they relate to and care about nature can fall into incommensurable value domains (Arias-arévalo et al. 2018), which present different information (Martín-López et al. 2014) and therefore pluralistic approaches are needed to elicit values for equitable ecosystem service assessments (Pascual et al. 2017). Eliciting plural values requires inclusive definitions of stakeholders and approaches that elicit both the relational and instrumental values derived from human-nature interactions (Himes and Muraca 2018, Chakraborty et al. 2020). Relational values account for the role of morals in preference and choice by explicitly recognising the values people derive from their relationships with nature and other beings, and therefore challenging the misleading dichotomy that environmental management is for either the sake of people or nature (Chan et al. 2016). More specifically, excluding relational values risks commoditizing ecosystems in ways that overlook multiplicity in stakeholder values and value systems (Kosoy and Corbera 2010).

Capturing plural, relational values requires moving beyond traditional monetary-based methods commonly used in ecosystem service valuations (Chan et al. 2011). Monetary-based methods are particularly inappropriate for representing the contribution of ecosystem services to human wellbeing in low-income settings where dependence on vulnerable natural resources is high, such as small-island states in the Pacific (Folkersen 2018). As such, a number of non-monetary valuation tools are emerging both in ecosystem services and other arenas. In ecosystem services, there has been an emphasis on participatory and deliberative approaches for eliciting values (Kenter et al. 2011, Folkersen 2018). Deliberative approaches enable social learning that can reveal deep held values surrounding complex social-ecological linkages (Kenter et al. 2011). In environmental and climate change decision-making, a key priority is developing tools that enable different value languages to engage in the discourse surrounding climate change challenges and trade-offs (Jacobs et al. 2016). For instance, participatory drama and photovoice methods have been used to help identify the concerns and challenges of climate change for coastal communities (Bennett and Dearden 2013, Brown et al. 2017). Hence, to move beyond the subsistence narrative of gleaning grounded in material wellbeing concerns, requires pluralistic value approaches that use novel and inclusive methods to account for the relational dimensions of gleaning.

6.3. Background and context

Background

As a small island developing state located at the heart of the Coral Triangle, Timor-Leste is an apt focus for understanding the values of gleaning. Like many other low-income countries, coastal areas in Timor-Leste are undergoing rapid environmental and socio-economic change and sustainably managing coastal resources for human wellbeing is a key challenge (Rosegrant et al. 2016, López Angarita et al. 2019). Timor-Leste is ranked 132/188 for human development globally (UNDP 2018), 70% of the population live in rural areas (GDS 2018) and 41.8% live below the national poverty line (World Bank 2016). Many of Timor-Leste's rural poor live in coastal areas and fisheries have the potential to contribute substantially to improving food and income security (López Angarita et al. 2019, Farmery et al. 2020). The reefs that fringe the country's coastline support some of the world's highest fish species richness (PIFSC 2017). As tourism and conservation interests in the country grow, the management of coastal habitats and coral reefs faces increasing scrutiny over reconciling development and conservation with the needs and values of local communities.

Case study

Our case study of gleaning is of a coastal community located on the western coast of Atauro Island, Timor-Leste. At the time of the research, the community contained 26 households and a total population of ~90 individuals. Similar to many other communities in the Asia-pacific, the case study community is a rural coastal community with limited infrastructure (no road access, running water or electricity). Livelihoods in the community are primarily subsistence focused and households engage in a diversity of mostly natural-resource based activities that are particularly vulnerable to predicted climate changes (Rosegrant et al. 2016, López Angarita et al. 2019, Oppenheimer et al. 2019). The community's main livelihood activities include crop farming, livestock rearing and fishing. Crops are primarily used for subsistence, livestock are gifted or eaten as part of cultural events and sold for income. Fish catches are eaten, sold and shared amongst households and seafood is the main source of animal protein consumed. Non-gleaning fisheries are predominantly a male domain, although women often accompany their husbands for gillnet fishing and (unusually for Atauro Island) some women in the study community also spearfish.

Similar to gleaning fisheries elsewhere (Chapman 1987), in the study community gleaning is a low-tech and female dominated activity, with catches used predominantly for subsistence. Gleaners are mostly women and children, who travel by foot, usually in small groups of family and friends, talking, laughing and searching for target species. Gleaning primarily takes place at low tide when inter-tidal reef flats and rocky habitats are exposed. Gleaners use knives, metal sticks and bare hands to spear, pry and gather a variety of marine organisms trapped in pools and crevices. Catches are carried in hand-woven baskets and include molluscs, crabs, eels, octopus, various types of reef fish, and schools of juvenile fish. Gleaning locations extend in either direction along the coast from the community and the main gleaning areas are within 45 minutes walking time. Gleaning areas are referred to by named sections of the coastline identified by biophysical features. Extractive activities, including gleaning and fishing, are prohibited directly in front of the community by a small (4.5 ha) comanaged no-take zone (tara bandu) introduced in 2016. Livelihoods and fishing activities in the study community are sensitive to weather conditions (Mills et al. 2017) and between December and March when westerly monsoon winds create rough sea conditions non-gleaning fishing almost entirely ceases and gleaning is less intensive (Grantham et al. 2021). Hence, within the study community the main fishing seasons are defined as the calm season and the rough season, and this is how we distinguish between seasons in this research.

6.4. Methods

We used a mixed-methods in-depth case study approach over multiple visits to the study community between November 2018 and May 2019. Specifically, to 1) characterise the gleaning fishery in each season and 2) assess seasonal gleaning values, we used a mixture of qualitative and quantitative methods including interviews, surveys, and focus groups (Table 6.1). Data were collected by the lead author and three research facilitators. Facilitators were Timorese youth, one of whom was a member of the study community.

TABLE 6.1 SUMMARY OF DATA COLLECTION METHODS, INCLUDING DESCRIPTIONS OF ACTIVITIES, DATA COLLECTED AND SAMPLE.

	Method	Method description	Date	Target sample and size (n)	Sample selection
A	Key informant interviews	Structured interviews regarding seasonal fishing activities, focused on gleaning (n=4) and non-gleaning (n=2) methods	November 2018	Female fishers (6)	Targeted
B	Surveys	Digitized household survey to collect quantitative data on seasonal fishing by household members	April/May 2019	Household members (16)	Opportunistic
C	Focus groups (n=2)	Focus group setting in which a variety of non-written activities were used to collect individual data on gleaning values and seasonality	April/May 2019	Female gleaners (6, 7)	Targeted

DATA COLLECTION

Interviews

To collect data on individual experiences and perceptions of seasonal gleaning, we used structured interviews with specifically targeted key informants (Table 6.1, Activity A), who included women known to be actively involved in gleaning and non-gleaning fisheries. During interviews, participants were asked to describe their strategies, catches, objectives and challenges as they changed by season. Interviews were implemented verbally by the lead author following a structured question format. Questions and responses were translated between English and Tetum by a facilitator, with response data recorded in English on a structured recording sheet by the lead researcher. Each interview took roughly one hour to complete.

Survey

We collected quantitative data on seasonal household fishing, including gleaning using a household survey (Table 6.1, Activity B). The survey included closed question types regarding the regularity of gleaning, demographics of gleaners, nature of gleaning trips, catch quantities and target groups in each season. The survey was digitized in both English and Tetum usinig the Kobotoolbox software (Harvard Humanitarian Initiative n.d.). The survey was implemented verbally by a facilitator, accompanied by the lead author, and responses were recorded onto a tablet. Respondents were either the head of the household or their spouse. Each survey took 30-60 minutes to complete.

Focus groups

To explore gleaning experiences and values in each season, we carried out focus groups with women who gleaned (Table 6.1, Activity C). Focus groups were guided by the lead author

with the assistance of two facilitators who translated and provided support to participants. Focus groups were run on two separate occasions to keep group sizes small (one group contained six individuals and the other seven) to enable greater interaction between participants and facilitators and to ensure the active engagement of all participants. Focus groups included a number of activities that were completed individually. The study community has very low literacy rates, particularly amongst women, therefore to be inclusive of all voices activities used non-written methods, including drawing and symbol-based scale measures:

Drawing - Two separate drawing activities were used to characterise gleaning catches and gleaning scenes for each season. For drawing catches, each participant was given a sheet of paper with two basket outlines in which to draw typical catches for the rough and calm seasons. Participants were asked to think about the types and quantities of organisms they collect in each season. In the other drawing activity, each participant was given two blank sheets of paper on which to draw the typical gleaning scene for each season. For each season, gleaners were asked to think about where they go gleaning, who they glean with, what they can see and how they feel.

Scale measures - We identified a list of possible reasons to glean, coded from interviews and informal discussions with gleaners and verified these with focus group participants. Symbols to represent each reason were agreed upon and participants drew the symbols on individual cards, so that every participant had a set of cards representing the different reasons to glean. For each season participants were asked to rank the importance of reasons for gleaning by organising their 'reason cards' from most to least important. The importance ranking results were then copied onto individual recording sheets on which there was a 4-level smiley face satisfaction rating scale. Participants were asked to shade the scale to indicate how satisfied they feel with their ability to achieve each reason in each season. After each focus group activity, we held a discussion of the activity for participants to share thoughts within the group and clarify details of activity outputs. Structured data collection methods, including scale-measures, have a number of shortcomings (White, 2014). To ensure the data collection methods used in this study were relevant to context, tools were informed by an understanding of local context and discussion within focus groups were used to verify the validity and understanding of tools being used.

Data analysis

Characterising seasonal gleaning

To characterise the gleaning fishery in each season we analysed the survey data with descriptive statistics to compare household gleaning activities and catches between the calm and rough seasons. Seasonal trends identified in survey data and from discussions with gleaners informed themes used to code comparisons of focus group drawings by individuals of seasonal gleaning catches and scenes. Drawings of seasonal catches were coded according to differences in depictions of the quantity and composition of landings, and the presence of octopus. Drawings of seasonal gleaning scenes were coded according to differences in depictions of the number of gleaners, presence of other types of fishing, diversity of marine organisms, gleaner happiness and, if location was indicated, the distance and direction of gleaning. One elderly participant only gleaned in the calm season so her data could not be included in seasonal comparisons. Insights from interviews and informal discussions on gleaning activities, objectives and challenges were used to provide an in-depth understanding of some of the context around the seasonal characterisation of the gleaning fishery.

Assessing seasonal gleaning values

We explored seasonal gleaning values by analysing focus group data on reasons for gleaning to assess i) multiplicity, ii) seasonal importance and satisfaction, and iii) seasonal priorities, in gleaning values. We categorised the multiple reasons for gleaning identified according to type of ecosystem value (i.e., instrumental, relational) and whether reasons were associated with the activity or outcomes of gleaning. We then assessed seasonal shifts in the perceived importance and satisfaction with gleaning values by examining changes in individual importance rankings and trends in satisfaction ratings for each reason between the calm and rough seasons. To evaluate the seasonal value priorities of gleaners we analysed reasons ranked as the top three most important in each season by individuals. The number of focus group participants who ranked a reason highly was used as an indicator of trends in value priorities across gleaners. The co-occurrence of reasons within an individual's top-ranked reasons was used to explore relationships between priority values. Insights from interviews and informal discussions were used to provide in-depth understanding of some of the context around the findings from focus groups activities.

6.5. RESULTS

In the following sections we compare the gleaning fishery in the rough and calm seasons and evaluate seasonal gleaning values. Our results highlight distinct differences in gleaning amongst seasons and show that gleaning supports multiple values, which are seasonally dependent.

SEASONAL CHARACTERISATION OF GLEANING

The seasonal characterisation of gleaning reveals that gleaner demographics and the nature of gleaning activities differ between the rough and calm seasons. Our results show that it is more common for female household members to glean than male household members in both seasons, but that the difference is particularly stark in the rough season because male household members tend to glean only in the calm season (Figure 6.1). We also found that for most households gleaning is a more regular activity in the calm season, when gleaners travel further and harvest seafood from shallow water as well as from tidal areas (Figure 6.1). In the rough season gleaners prefer to stay closer to the community (Figure 6.1; Figure 6.2) and are reluctant to glean alone because of the risks of gleaning. Waves break across the reef flats making gleaning difficult, dangerous, and less enjoyable (Figure 6.2). Gleaners have been injured by slipping on rocks, cutting themselves on coral and being bitten by octopus and eels.

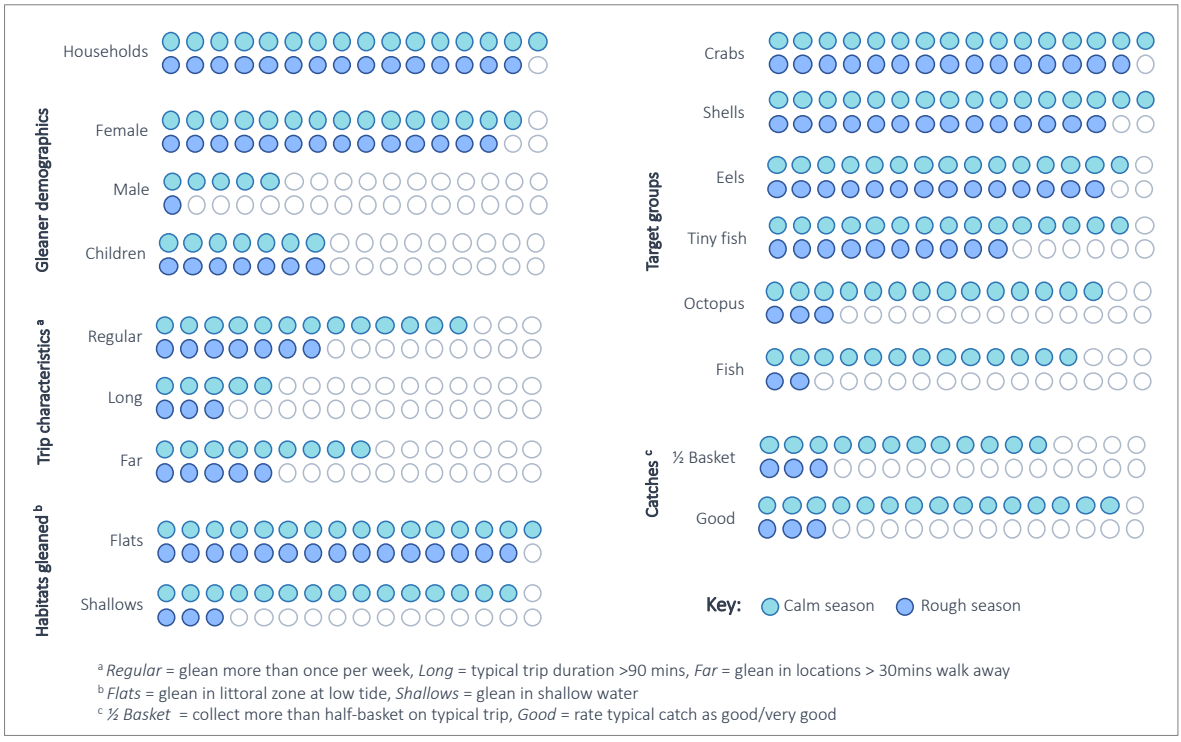
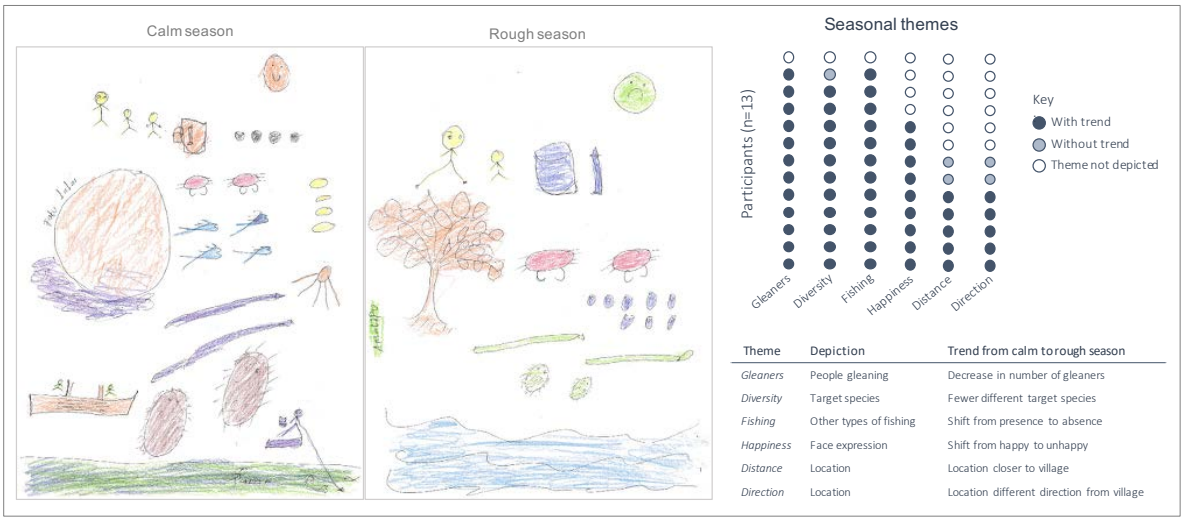


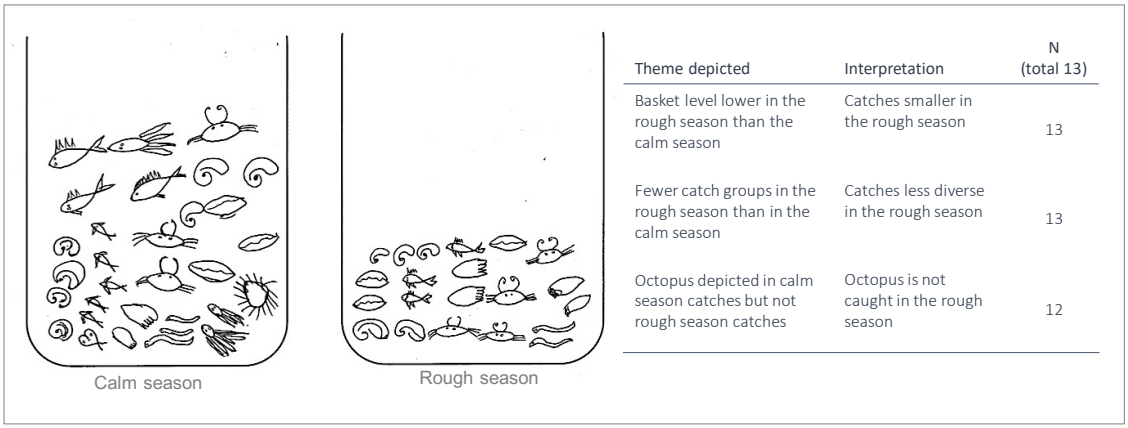
FIGURE 6.1 SUMMARY OF HOUSEHOLD SURVEY DATA ON SEASONAL GLEANING.



Theme	Depiction	Trend from calm to rough season
Gleaners	People gleaning	Decrease in number of gleaners
Diversity	Target species	Fewer different target species
Fishing	Other types of fishing	Shift from presence to absence
Happiness	Face expression	Shift from happy to unhappy
Distance	Location	Location closer to village
Direction	Location	Location different direction from village

FIGURE 6.2 . EXAMPLE OF SEASONAL GLEANING SCENES DRAWING, WITH SUMMARY OF THEMES AND SEASONAL TRENDS (SHIFT FROM CALM SEASON TO ROUGH SEASON) DEPICTED IN DRAWINGS.

Our results also highlight seasonal differences in gleaning catches and the livelihood contribution of gleaning. Catches are smaller and less diverse in the rough season, with fish and octopus the most seasonal catch groups (Figure 6.1; Figure 6.3). Octopus are the main high value target group for gleaners and they can be dried and stored for a number of months. Octopus are found in shallows and tidal pools meaning they are hard to target in rough conditions, and only one participant included octopus in drawings of rough season catches (Figure 6.3). Gleaners described being able to be more selective in targeting preferred catch groups in the calm season. In the rough season catches are dominated by small shells used for household consumption. There is a greater sense of necessity in gleaning as a source of subsistence seafood in the rough season because other types of fishing are limited (Figure 6.2). Gleaners expressed growing concern of returning with an "empty basket"; as the community grows and more people glean it is increasingly difficult to find seafood.



Theme depicted	Interpretation	N (total 13)
Basket level lower in the rough season than the calm season	Catches smaller in the rough season	13
Fewer catch groups in the rough season than in the calm season	Catches less diverse in the rough season	13
Octopus depicted in calm season catches but not rough season catches	Octopus is not caught in the rough season	12

FIGURE 6.3 EXAMPLE OF PARTICIPANT DRAWING OF SEASONAL GLEANING BASKETS, WITH SUMMARY OF CATCH THEMES DEPICTED.

SEASONAL GLEANING VALUES

Multiplicity

Women described a variety of reasons for gleaning (Figure 6.4) associated with either the activity itself or achieving material outcomes (catch). Reasons were sometimes solely instrumental or relational, but also a combination, highlighting that instrumental and relational values can be difficult to separate.

FIGURE 6.4 DESCRIPTION OF TEN REASONS WHY WOMEN GLEAN CATEGORISED ACCORDING TO WELLBEING VALUES AND ASSOCIATION WITH THE OUTCOMES OR ACTIVITY OF GLEANING.

Women talked about gleaning to find preferred seafood for personal consumption (Favourite) thus representing gleaning as a means of achieving material benefits that accrue solely to the gleaner, or an instrumental value. They also mentioned gleaning to find seafood to sell (Income) and for household consumption, either to be eaten fresh (Food) or dried and eaten at a later date (Store). All of these reasons specifically refer to the material outcomes as the objective of gleaning (instrumental values), but the benefits are shared with other members of the gleaner's household meaning they also hold relational value. Women also gleaned to find seafood to give to friends or non-household family members (Share). While the outcome of gleaning to share might be consumption (i.e., an instrumental value), the objective of sharing suggests the predominant value to the gleaner is relational, (although they may also derive instrumental values indirectly through reciprocity). Similarly, gleaning to teach children how to glean (Knowledge) is grounded in relational values but may also support instrumental values indirectly by increasing household gleaning capacity. Gleaning to teach children

frames the reason for gleaning as based in the activity itself rather than the outcomes, as does gleaning to enjoy the environment (Nature), as a means of feeling peaceful (Peace), when there is nothing else to do (Boredom) and to spend time with friends (Socialise). The four latter reasons refer only to the interactions and experiences provided by gleaning, with no mention of material gains and therefore represent relational values. For instance, one pair of elderly sisters in the community have gleaned together since they were children, and continue to do so despite their limited sight and mobility meaning they often fail to find anything. Reasons for gleaning were distinct but not mutually exclusive and a single gleaning trip can fulfil multiple reasons and therefore support multiple wellbeing values.

Seasonal importance and satisfaction

Some reasons for gleaning were more seasonally sensitive than others and seasonal differences in the perceived importance and satisfaction with reasons for gleaning varied between reasons and individuals. Notably, the importance of gleaning as a source of income (Income) and seafood to store (Store) decreased for almost all participants in the rough season (Figure 6.5) as did satisfaction ratings with these reasons (Figure 6.6). Gleaning as a source of income and seafood to store were both categorised as instrumental-relational values associated with gleaning outcomes. More specifically these values were dependent on catching octopus, which is typically only characteristic of calm season gleaning, hence the seasonal sensitivity of these values. Gleaners described feeling happy when they find lots of seafood, especially high value catch or the seafood they most enjoy eating. Reasons that demonstrated a general upward trend in importance in the rough season were finding seafood to share (Share) and enjoying nature (Nature), however satisfaction with these reasons decreased for a number of gleaners in the rough season.

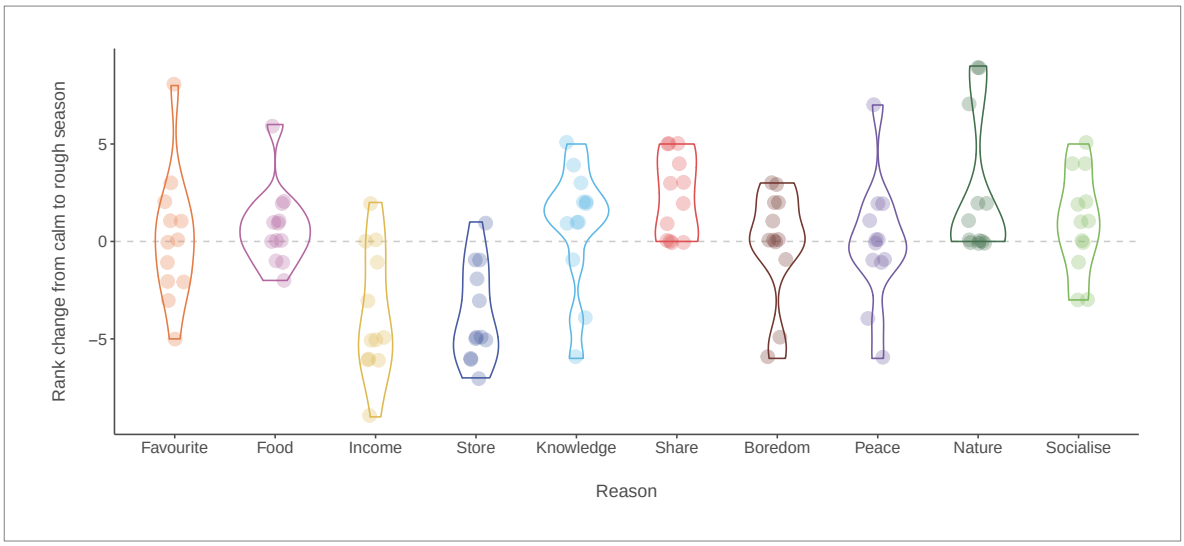


FIGURE 6.5 VIOLIN PLOT SHOWING CHANGE IN RANKED IMPORTANCE OF REASONS BY INDIVIDUALS FROM THE CALM SEASON TO THE ROUGH SEASON. DASHED HORIZONTAL LINE AT 0 REPRESENTS NO CHANGE IN RANKING BETWEEN SEASONS, POINTS ABOVE THE LINE REPRESENT AN INCREASE IN RANKED IMPORTANCE IN THE ROUGH SEASON COMPARED TO THE CALM SEASON, WHILST POINTS BELOW THE LINE REPRESENT A DECREASE IN RANKED IMPORTANCE IN THE ROUGH SEASON. WIDTH OF PLOTS INDICATES NUMBER OF INDIVIDUALS.

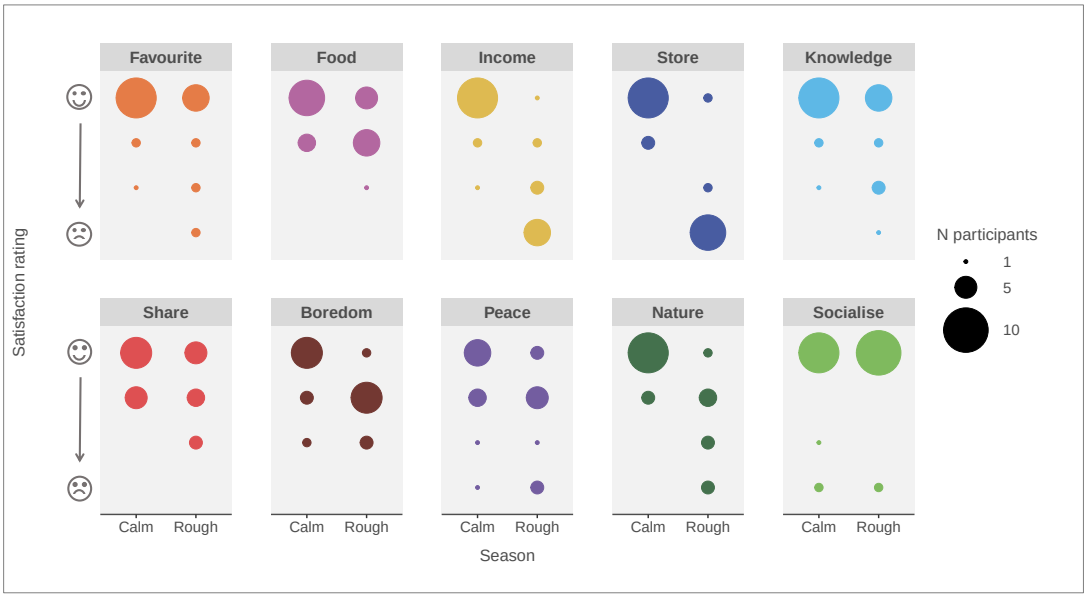


FIGURE 6.6 CHART SHOWING SEASONAL CHANGES IN OVERALL RANKING AND MEAN SATISFACTION WITH GLEANING REASONS.

Seasonal priorities

Priorities for gleaning differed amongst individuals and across seasons and indicate that there may be groups of gleaners with different value priorities. In the calm season, all reasons were ranked highly (top three) by at least two participants, with the most common being finding seafood for household consumption, alleviating boredom and peace (Figure 6.7). In the rough season gleaner's priorities converged and more gleaners nominated gleaning to find seafood

for household consumption, along with finding preferred seafood and enjoying nature. There were also more gleaners who prioritised finding seafood to share and spending time with friends in the rough season than the calm season, whilst fewer prioritised finding seafood to store, peace, boredom or teaching children and none included income. Reasons that co-occur together in individual top-rankings point to distinct value priorities. For example, in the calm season, a number of gleaners prioritised gleaning as an activity to avoid boredom and get peace. In addition, all gleaners that considered enjoying nature a priority included both boredom and peace in their top ranked reasons. This finding suggests that there is a group of gleaners for whom the perceived importance of gleaning is grounded in relational values derived from the activity of gleaning. In contrast, a number of other gleaners highly ranked finding seafood for household consumption along with finding preferred seafood or seafood to store in the calm season. This finding indicates that this group placed greater importance on the outcomes (rather than process) of gleaning and on instrumental values. This pattern was even clearer in the rough season, where women highly ranked finding seafood for household consumption alongside finding preferred seafood and sharing (Figure 6.7).

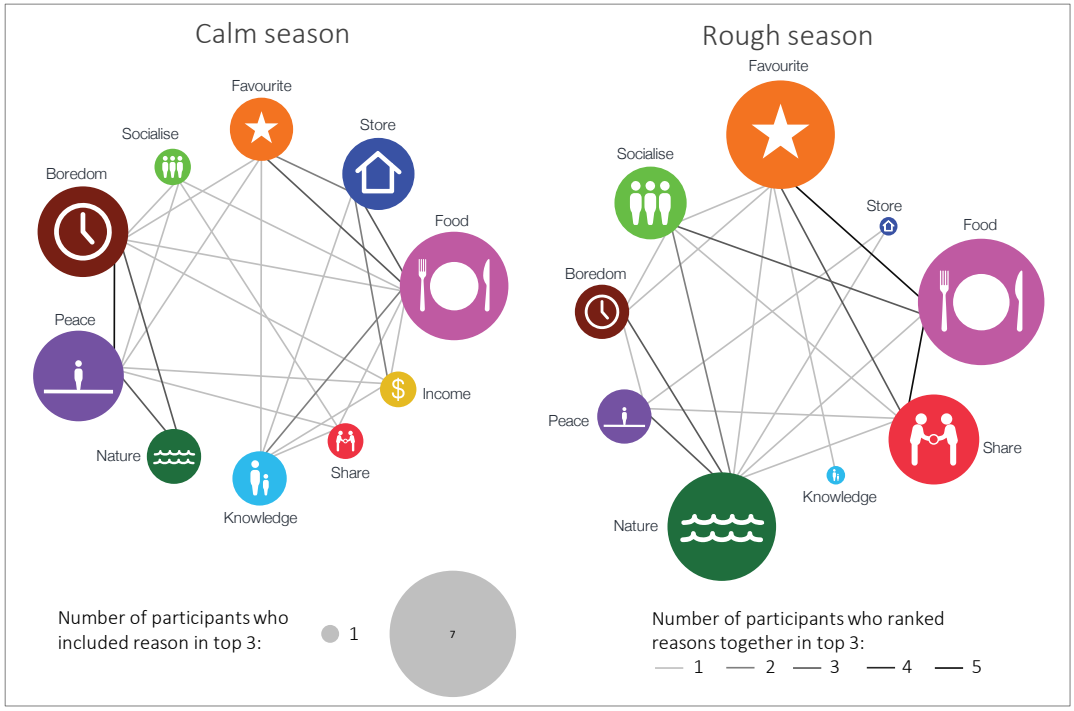


FIGURE 6.7 FIGURE ILLUSTRATING THE NUMBER OF PARTICIPANTS THAT RANKED EACH REASON AS TOP THREE MOST IMPORTANT IN THE CALM AND ROUGH SEASONS AND THE COOCCURRENCE OF REASONS IN TOP RANKINGS

6.6. Discussion

The case study presented in this research illustrates that the value of gleaning to wellbeing extends beyond its contribution to subsistence and that values differ between individuals and seasons. Our results speak to three key findings about wellbeing and gender narratives, seasonal ecosystem values, and relationships between ecosystem values, which we discuss in turn, before turning to future research directions.

Wellbeing and gender narratives

The results of this study show that women gleaned for a variety of reasons associated with a spectrum of ecosystem values. Gleaning value priorities highlight that women's choices and actions are linked to a pursuit of wellbeing that extends beyond household subsistence. For example, our results show that spending time with friends was perceived as an important reason to glean. Thus, gleaning is a social opportunity that supports meaningful interactions with other people, which are an important determinant of quality of life (Camfield et al. 2009). We also found that gleaning to enjoy nature was highly ranked, including in the rough season. This finding suggests a sense of connectedness with the environment, which has been positively linked to physiological health and wellbeing (Frumkin 2001, Nisbet et al. 2011, Howell and Passmore 2013). Increasingly, work suggests that connection to nature can support better environmental management through stewardship and tighter social-ecological feedbacks (Bennett et al. 2018b). Therefore, our findings re-emphasize arguments that overlooking gleaners likewise overlooks important connections relevant for coastal management (de la Torre-Castro et al. 2017).

Our findings also indicate the need to move beyond essentialized narratives of women's contribution to their own and their family's wellbeing. We found that household food and income security – a core part of the subsistence narrative - were not a priority for all gleaners. For example, women described how they sometimes go gleaning to find their favourite seafood that they then cook on the beach to avoid having to share with other household members. This example clearly demonstrates how personal gain and pleasure also influence women's preferences and behaviours, rather than simply gleaning's contribution to material wellbeing. These findings thus support pursuing a more complex understanding of how women's interactions with coastal environments is shaped by the pursuit of multidimensional wellbeing (Coulthard 2012).

The diversity of reasons for gleaning highlight that management or environmental change affecting gleaning will have a suite of implications for women's wellbeing beyond material impacts from the loss of catches. For example, coastal regulation that prohibits gleaning would affect women's social lives and limit the opportunities available to women to find peace away from the demands of family and domestic activities. This is particularly important given that the underrepresentation of marginal groups, including women, in decision-making mean that the resources they depend on are often excluded from sustainability strategies (de la Torre-Castro et al. 2017). As coastal resources face increasing stress from climate change, pollution and human population growth, equitable regulatory mechanisms, particularly for common pool resources such as those targeted by gleaners, will be crucial for maintaining the wellbeing of marginalised groups (Agrawal 2014). Failure to account for the multidimensional wellbeing benefits derived from marine resources risks exacerbating inequalities and hardship (Coulthard et al. 2020). Specifically, our findings caution against treating fishing communities as homogenous stakeholders and definitions of coastal resource users that incorporate gleaners with other small-scale fishers or overlook them all together.

Seasonal ecosystem values

Our findings highlight how ecosystem service values change dynamically by season. We found seasonal shifts in gleaner priorities and the relative importance of and satisfaction with reasons for gleaning. For instance, for most gleaners the perceived importance of finding seafood to share increased in the rough season and sharing became a common gleaning priority. This finding reflects an increase in the relational dimension of the values associated with gleaning catches linked to the role of food sharing networks in seasonal food security. Sharing food between households can help ensure families have secure access to food, even when catch is variable (Winterhalder 1986, 1990). Thus, the perceived benefits of reciprocal altruism may be greater in the rough season when there are limited alternative sources of seafood and gleaning is difficult and catches are smaller and variable. Our results also illustrate how seasonal ecosystem benefits and values are directly impacted by seasonal service flows. For example, in the rough season, earning income and storing seafood are considered unimportant and unsatisfactory reasons to glean predominantly because of the absence of octopus in catches.

Accounting for the complex relationship between ecosystem service flows and ecosystem values created by human-nature interactions is key to effectively managing social-ecological systems (Reyers et al. 2013). This research demonstrates seasonal differences in these relationships, which ecosystem services must account for, alongside plural values. Non-temporal assessments may provide only half the story about how and why ecosystem services matter to different people in coastal communities.

Relationships between values

Linkages between gleaning priorities found in our results indicate there may be distinct value preferences amongst gleaners. In both seasons, multiple gleaners ranked a combination of gleaning to alleviate boredom, for peace and to enjoy nature highly, suggesting that relational values derived from the activity of gleaning were important. In addition, we found that a number of other gleaners indicated a preference for instrumental values associated with gleaning catches in both seasons, with finding seafood for household consumption commonly ranked alongside finding preferred seafood, and in the rough season, finding seafood to share. These results point to socially and temporally disaggregated "bundles" of ecosystem values. In ecosystem services, bundles refer to groups of services that co-occur through space and time (Raudsepp-hearne et al. 2010). The interactions and shared dependencies that link service bundles can lead to synergies and trade-offs in ecosystem management (Bennett et al. 2009) that can raise issues of equity and environmental justice (Dawson et al. 2017). Preferences for bundles of ecosystem services have been linked to socio-economic characteristics of stakeholders (Martín-López et al. 2012) and differences in the bundles of benefits derived from an ecosystem have been shown to influence the acceptability of management strategies, for example in fishery closures (Epstein et al. 2018). However, there has been limited empirical work on when and where coastal ecosystems occur together (i.e., as bundles), and how this relates to wellbeing (Blythe et al. 2020). As an exploratory study into the diversity of gleaning values, analysing the factors that might explain differences in values between individuals was beyond the scope of this research, but other research has shown coastal ecosystem value priorities relate to level of material wellbeing (Lau et al. 2018). We hypothesize that gleaners who prioritised instrumental values are likely to be more materially vulnerable and reliant on gleaning for food, than those who prioritised purely relational values. It's also likely that the life stage and household context of gleaners shaped how and why different reasons were ranked together (Coulthard et al. 2020). The varied

priorities for gleaning within one community, support wider calls for disaggregating coastal ecosystem service beneficiaries to assess how and why coastal ecosystem values are distributed socially and therefore to support equitable resource management for poverty alleviation (Daw et al. 2011, Chan et al. 2019, Lau et al. 2019).

Our findings also suggest that women recognized trade-offs in the different reasons to glean. Exploring the relationships between different reasons was beyond the scope of this research, but anecdotal evidence suggests that there can be incompatibilities between achieving certain gleaning values. For example, during discussions some women explained how when they glean with friends, they find less seafood because they are chatting. This observation represents a trade-off between the relational values associated with socialising and the instrumental values derived from catch. These trade-offs between values may therefore influence gleaner choices. For example, whether women choose to glean with friends (and realise relational values), may depend on their willingness to forgo instrumental values associated with finding more food during gleaning, and this choice may in turn differ between individuals and seasons. Interestingly, women prioritized both socializing and outcome-based reasons (e.g., finding seafood for household consumption or sharing) together in the rough season, when gleaners are reluctant to glean alone because of higher risks. Further exploration of the linkages between reasons for gleaning is an important avenue for future research. Understanding how and why women decide to glean or not can help to build an understanding of interdependencies and potential trade-offs between the wellbeing values derived from gleaning. These insights will help ensure coastal management is congruent with the needs of diverse groups across seasons in ways that account for broad aspects of wellbeing and could lend insights into ways to support livelihoods and reduce vulnerability. Tools developed in ecosystem services studies more broadly, including deliberative approaches and choice experiment scenarios (Kenter et al. 2011), can help to explore trade-offs and dependencies between values in gleaning.

Conclusion and Future directions

The findings from our exploratory case study highlight a number of important directions for future research. Using the example of gleaning, we have illustrated the need for holistic assessments of coastal livelihoods as human-nature interactions. A lack of assessment and evaluation methods that elicit multiple values, inclusively and in context appropriate ways,

limit equitable and sustainable coastal management. To address the persistent inequalities that have shaped the narrow economic focus and historical gender and gleaning blindness in coastal research and management will require carefully designed evaluation tools. Mixed methods and novel methods, such as those used in this research, can help make visible the deeper values held by coastal communities to ensure their voices are heard in coastal decision-making (Kenter et al. 2011). This research also demonstrates how socially and temporally disaggregated assessments are needed to identify and unpack the complex linkages between coastal ecosystems and human wellbeing. In particular, multiple dimensions of wellbeing (beyond material) should be empirically linked to women's choices and actions to support a more nuanced and accurate representation of women's needs, values and preferences in coastal management and the development discourse.

7. DISCUSSION

7.1. OVERVIEW

I used the case study of small-scale fisheries to address knowledge gaps in the human dimensions and temporal aspects of ecosystem services. I have structured my thesis around the ecosystem service cascade framework to examine the different mechanisms through which people mediate the relationship between ecosystems and human wellbeing through time. Specifically, I build on progress from social sciences to contribute to a dynamic social-ecological perspective of fishery ecosystem services.

7.2. CHAPTER SUMMARIES

My data chapters examined the ecosystem service mediating mechanisms of mobilisation (*Chapters 3* and *4*), allocation (*Chapter 5*) and appreciation (*Chapter 6*). These mediating mechanisms are distinct and sequential. In isolation, each of my data chapters provides important theoretical contributions to ecosystem services and deepens our understanding of seasonality in small-scale fisheries.

In *Chapter 3* I built on theories of materiality and access to examine factors affecting the ability of people to mobilise coastal ecosystem services through time. Using an interdisciplinary mixed-method approach I explored how and why household gleaning changed seasonally. Through quantitative analysis of household socio-economic data and spatial-habitat data I elicited linkages between the biophysical environment and seasonal gleaning. I then used qualitative insights to unpack the mechanisms underpinning these linkages. My results show that at the community level seasonal trends in gleaning were related to differences in area and type of proximate littoral habitat, suggesting the biophysical characteristics of the ecosystem influenced the ability of people to mobilise flows of realised ecosystem services. This finding shows that the ability of people to benefit from something is affected by its nature, which reiterates concerns over the inattention to how materiality intersects with mechanisms of access (Myers and Hansen 2020). *Chapter 3* is grounded in the perspective that the human-nature interactions through which people mobilise ecosystem services, such as gleaning, are important for people as means to material outcomes (instrumental values) and because they represent meaningful relationships with nature and other people (relational values). Seasonal changes in the ability to interact with ecosystems to mobilise ecosystem services therefore affect the distribution of diverse wellbeing values from coastal ecosystems

at fine spatial and temporal scales. *Chapter 3* demonstrates the importance of context specific perspectives of access that account for how biophysical characteristics affect the ways people interact with the environment, for understanding how coastal ecosystems contribute to human wellbeing in space and time.

In *Chapter 4*, I explored the interplay between social identity, access and the materiality of ecosystems using the example of gender participation in seasonal small-scale fisheries. I contribute to a deeper understanding of how people co-produce ecosystem services through time and strengthen knowledge of the role of small-scale fisheries in coastal food security. Using quantitative analysis of seasonal household seafood consumption and fishing strategies, I show that fish consumption is coupled in time with fishing. My results empirically demonstrate the greater relative importance of gleaning, a fishing method used predominantly by women, during the rough season. By comparing seasonally aggregated and disaggregated perspectives of fishing I illustrate the need for seasonal assessments to move beyond oversimplified understanding of access to fishery ecosystem services. Worryingly, my findings highlight that current fisheries assessments and management underrepresent and undervalue components of fishing most important for food security in adverse conditions and during periods of food scarcity. Therefore, *Chapter 4* supports calls to address systemic bias in coastal decision-making processes and to rethink how fisheries are defined, assessed and valued to support sustainable and equitable coastal management for resilient and food secure livelihoods (Harper et al. 2013, Kleiber et al. 2015, Tilley et al. 2020). Specifically, my work highlights the benefits of seasonal and gender disaggregated perspectives of social-ecological interactions to understand how and when people realise flows of ecosystem services.

In *Chapter 5*, I explore everyday agency in dynamic coastal ecosystem services by looking at the ways people choose to allocate flows of services across different benefits. Using a mixed-method approach I analysed the post-harvest use of fish catch by households. I found that the proportion of fish a household ate, sold or shared changed with amount caught and seasonal household livelihood priorities associated with the food security context. These findings demonstrate that how people choose to allocate services to benefits changes with service supply and through time, and that this underpins a relationship between ecosystem services and benefits for people that is neither direct nor constant. *Chapter 5* echoes other

work that calls for more human-centric perspectives of ecosystem services that place human agency central to our understanding of ecosystem services and livelihood vulnerabilities (Spangenberg et al. 2014a). In particular, everyday agency operationalised in ordinary actions and decision-making, such as how to use fish catches, remains invisible in our understanding of how people navigate variability and uncertainty in dynamic coastal social-ecological systems.

In *Chapter 6*, I extended pluralistic valuation approaches by using a seasonal lens to deepen understanding of the ways that ecosystems matter to people through time. I used a qualitative approach to elicit how the wellbeing values of gleaning for women changed seasonally. I found that women gleaned for reasons linked to both achieving material outcomes (i.e., seafood catch) and enjoying the activity itself and the reasons perceived as most important differed between individuals and season. Gleaning was therefore important for material and relational aspects of wellbeing and the relative importance of wellbeing values were time specific. By moving beyond a subsistence framing of gleaning, *Chapter 6* presents a more nuanced perspective of women's preferences and priorities that influence their livelihood activities. This perspective sheds light on an underrepresented and undervalued small-scale fishery and supports a more holistic and equitable perspective of how coastal ecosystems contribute to human wellbeing. My findings support other research that shows coastal communities in low-income countries value local ecosystems in diverse and incommensurable ways (Klain et al. 2014, Lau et al. 2019). Specifically, Chapter 6 demonstrates how pluralistic valuation approaches sensitive to the dynamic social-ecological context can reveal the changing importance of coastal ecosystems to people through time.

7.3. Overarching contributions to theory

In all of my data chapters I use a seasonal lens to examine the human dimensions of small-scale fishery ecosystem services. This common thread links the research I present in my thesis into a cohesive narrative, structured around the cascade framework. Taken together, the findings of my thesis support overarching contributions to theory relating to 1) ecosystem services as social-ecological outcomes, 2) temporal aspects of ecosystem services and 3) ecosystem services in low-income countries.

Ecosystem services as social-ecological outcomes

By providing empirical examples of the ways that people mediate the relationship between coastal ecosystems and human wellbeing, my thesis contributes to a social-ecological perspective on ecosystem services. Specifically, I looked at the multiple mechanisms through which people link coastal ecosystems to human wellbeing values. I show that social processes determine whether services are realised from ecosystems, how those services are then converted into benefits for people and why they matter. My findings echo other research that argues ecosystem services cannot be measured using biophysical indicators alone (Bagstad et al. 2013, Keeler et al. 2019). Rather, ecosystem services must be understood as the product of complex dynamic social-ecological interactions (Reyers et al. 2013). Thereby, ecosystem services will benefit from deeper critical engagement with progress in social science scholarship to build a stronger understanding of the social processes that underpin how people interact with and value ecosystems (Chan and Satterfield 2020).

A social-ecological perspective requires rethinking the way that we frame people in ecosystem services. In my thesis I show that people are (bounded) agents who exercise choice to pursue desirable outcomes (Brown and Westaway 2011, Coulthard 2012). Choice was the central focus of *Chapter 5*, in which I illustrate that through everyday agency people control the ways that they benefit from fishing. I also attend to aspects of choice in other data chapters. For example, in *Chapter 3* my results indicate that in some communities' households choose not to glean in the calm season and in *Chapter 6* I show that women choose to glean for diverse reasons beyond basic household needs. These findings highlight the micro-practices through which people negotiate and shape their social-ecological environment to realise flows of ecosystem benefits. A social-ecological perspective requires recognising these micro-practices as ways that people actively influence the relationship between ecosystems and human wellbeing.

Temporal aspects of ecosystem services

By examining the ways that people interact with and benefit from coastal ecosystems in different seasons, my research addresses knowledge gaps in the temporal aspects of ecosystem services in general (Rau et al. 2020) and in coastal systems in particular (Blythe et al. 2020). I placed emphasis on the human dimensions of temporal dynamics in ecosystem services to build a deeper understanding of how ecosystem services arise from the interplay

between people and nature through time (Bennett et al. 2015). My data chapters shed light on the ways that people's preferences, priorities and capabilities at different times of the year influence how they interact with coastal ecosystems. I show that seasons affect the social processes that determine how people realise flows of ecosystem services from coastal ecosystems (*Chapters 3* and *4*), the benefits they provide (*Chapters 5*) and how they are valued (*Chapters 6*). Changes through time in the biophysical supply of ecosystem services cannot therefore be assumed to equate directly to changes in human wellbeing. My research begins to unpack the mechanisms through which people mediate the relationship between coastal ecosystems and human wellbeing, intentionally and as a result of seasonal constraints.

By situating fisheries in a seasonal livelihood context, my thesis contributes to understanding how people influence ecosystem service bundles in dynamic coastal systems. My research highlights how people navigate seasonality in coastal ecosystems and create relationships between multiple ecosystem services through diversified livelihood strategies. Specifically, *Chapter 5* shows that the availability of staple foods from agriculture influences the demand for money from fisheries. Fishery ecosystem services and agricultural ecosystem services are therefore linked by seasons as a shared driver and through livelihood interactions (Bennett et al. 2009). Understanding the linkages between ecosystem services that determine how they co-occur in bundles through space and time is important in managing landscapes (Raudsepp-hearne et al. 2010). My findings emphasize the importance of accounting for terrestrial and marine ecosystem services, and their interactions, in coastal social-ecological system management. Importantly, my thesis illustrates that ecosystem service bundles are not only determined by the spatiotemporal distribution of biophysical supply, but also by social processes that influence access and demand (Zoderer et al. 2019), reiterating the need to place people central to our understanding of coastal ecosystem services.

Ecosystem services in low-income countries

My research contributes to addressing the dearth of empirical ecosystem services research in coastal systems in low-income countries. Most ecosystem services research has focused on the Global North (Lautenbach et al. 2019), including in coastal systems (Liquete et al. 2013, Blythe et al. 2020). Extrapolating perspectives from higher income countries is problematic given that people interact with and value nature in diverse ways (Díaz et al. 2018).

Worryingly, the lack of ecosystem services research in low-income countries represents a mismatch between the geographic distribution of case studies shaping ecosystem services thinking and the reliance on natural resources, including fisheries. My thesis provides insights on the diverse and dynamic ways that fishery ecosystem services contribute to human wellbeing in coastal communities in low-income countries. By engaging with small-scale fisheries as meaning-saturated human-nature interactions, my research moves beyond production focused perspectives and deepens understanding of non-material ways that fisheries matter to people. This includes specific attention to gleaning and women's fishing, (*Chapters 3, 4* and *6*), which have historically been underrepresented in fisheries and coastal research. By increasing the visibility of gleaning and women's fishing, and emphasizing their importance in livelihoods and wellbeing, my research contributes to more equitable and sustainable perspectives in coastal ecosystem services.

7.4. Application

As well as contributing to ecosystem service theory, my thesis supports a number of recommendations for fisheries management and coastal decision-making. First, my research highlights the importance of social-ecological approaches to fisheries management. My thesis elucidates small-scale fisheries and their importance as arising from the interplay between people and marine ecosystems. Managing fisheries is about managing people (Hilborn 2007) and so fisheries management must be informed by social science as well as principles of ecology and economics (Johnson 2018). In particular, the values of local communities must be central to the management of small-scale fisheries to achieve sustainable wellbeing outcomes in coastal communities in low-income countries (Cohen et al. 2019).

Second, my thesis points to the importance of seasonal monitoring for understanding small-scale fisheries. I found distinct seasonal differences in small-scale fisheries and how they benefit people, indicating that cross-sectional assessments may provide incomplete and misleading perspectives of who fishes, how they fish and why they fish. Seasonal perspectives can strengthen how small-scale fisheries and fishery stakeholders are conceptualised in decision-making for resilient coastal social-ecological systems and provide crucial insights on vulnerabilities and adaptation. Seasonal food shortages are a key driver of

poverty and food insecurity among the rural poor, and therefore seasonal perspectives on ecosystem service realisation in fisheries, as a major supplier of nutrients, is a vital piece of the puzzle for achieving sustainable and equitable futures.

Third, my findings echo calls for comprehensive definitions of fisheries in monitoring and management (Kleiber et al. 2015, Harper et al. 2020). My research documents a prevalence and importance of gleaning in coastal communities. These findings support concerns that quantitative assessments that exclude gleaning may overlook a substantial proportion of landings (Kleiber et al. 2014, Tilley et al. 2020) and undervalue the importance of littoral habitats.

Fourth, my thesis reemphasizes inclusive coastal decision-making and gender equality as prerequisites for achieving sustainable wellbeing outcomes (De La Torre-castro 2019). Similar to other research, my results show that women are a major stakeholder group in small-scale fisheries (Harper et al. 2013) and that they use coastal resources differently to men (de la Torre-Castro et al. 2017). Ensuring women's voices are equitably represented in coastal decision-making is therefore both morally fair and instrumental to better coastal management (Lau 2020).

Finally, my research promotes the importance of livelihood perspectives in coastal management. My thesis illuminated shared dependencies and interactions that link agricultural and fishery ecosystem services. Thereby, through diversified coastal livelihoods people create interconnected webs between terrestrial and marine ecosystem services. Hence, fisheries cannot be understood and managed in isolation from the other ways through which coastal communities interact with and depend on natural resources to achieve wellbeing outcomes.

7.5. LIMITATIONS AND CAVEATS

My research has three main caveats: its small geographic scope, limited temporal extent and limited ecological data. The first two caveats limit the ability to generalize my findings in space and time. First, all of my research was carried out on Atauro Island, reflecting my choice to favour depth of insight over breadth by using a case study approach. However, ecosystems and the ways that people interact with, benefit from and value them differ geographically and culturally (Díaz et al. 2018). As I show in *Chapter 3*, there were differences even amongst

communities on Atauro Island. Therefore, specific findings of how and when people interact with coastal ecosystems and why fishery ecosystem services matter cannot be assumed to hold true elsewhere, including in other parts of Timor-Leste. Second, due to the time constraints of a PhD, my research relies on recall of typical seasons (*Chapters 3, 4* and *6*) and data collected over multiple seasons over the course of one year (*Chapter 5*). My research is therefore not contextualised within longer-term empirical perspectives and my findings are unable to link seasons with coarser scale dynamics and slower processes of change.

The third caveat, an absence of ecological data, prevented empirical testing of social-ecological feedbacks in my research. Tropical marine resources are seasonally variable, for example fish abundance is linked to seasonal habitat cover (Lim et al. 2016). Local ecological knowledge of seasonal resource accessibility and availability informs dynamic fishing strategies (Lima et al. 2017). The absence of ecological data reflects my own experience and interests as a social scientist, the time and resource constraints of a PhD, and a lack of third-party data. Timor-Leste is a young country with very limited national resources for fisheries monitoring. Data on the seasonal abundance and distribution of the ecological resources targeted by small-scale fisheries would have strengthened my analysis of small-scale fisheries as human-nature interactions.

7.6. FUTURE DIRECTIONS

I suggest four avenues for future research in ecosystem services to contribute to advancing theory on the links between nature and human wellbeing. First, more empirical work is needed in different geographic and cultural contexts on how social-ecological interactions change through time to further our understanding of ecosystem service distribution. Access theory has been pivotal in moving beyond the supply discourse in ecosystem services, yet our knowledge of beneficiaries remains limited and we know very little about *when* people benefit from ecosystem services. As I show in my thesis, seasonal access to ecosystem services and therefore the distribution of benefits through time, has profound implications for how and why nature matters to people. Seasons are a global phenomenon experienced differently across locations and between groups. Therefore, further research in other contexts on changes in ecosystem service access through time could help develop typologies of factors influencing

the temporal distribution of benefits. Differences between contexts would provide important insights on the cultural, social and biophysical factors that mediate seasonal vulnerabilities and resilience.

Second, future work on seasonality in ecosystem services should explicitly examine the impacts of climate change. Climate related seasonal shifts are a major livelihood stressor, particularly for the rural poor. Seasonal perspectives would strengthen knowledge of the implications of climate change for human wellbeing and social-ecological systems. Understanding the ways that adapting to seasonal variability and coping with seasonal risk and uncertainty influences how people interact with and value ecosystems will be essential to equitable and sustainable futures.

Third, more research on the changing relative importance of multiple ecosystem services to people at different times of the year would help deepen understanding of the links between services within a landscape. Landscapes are mosaics of ecosystems from which people realise diverse benefits that support their wellbeing. Yet often ecosystems and the services they provide are studied in isolation, representing a major gap in our understanding of social-ecological systems. For example, to understand coastal social-ecological system dynamics we must account for the ways that seasonal changes in the supply and value of terrestrial ecosystem services affect the demand and value for marine services, and therefore how people interact with marine environments, and vice-versa. Specifically, integrating social analysis into landscape scale ecosystem service assessments would help build a more complex picture of the connectivity between ecosystems created by people's seasonal priorities and preferences.

Fourth, ethical implications of choices of temporal scale in ecosystem services research deserve greater attention. The importance of scale in identifying patterns and explaining phenomena is a core concept in ecological sciences but is less well established in the social-sciences (Gibson et al. 2000). The theme underpinning my thesis is that people interact with, and benefit from, coastal ecosystems differently through time. Therefore, the timing and resolution at which we observe coastal social-ecological systems will determine our knowledge and valuation of coastal ecosystem services. Choices of scale are not neutral, and in social-ecological contexts the interests of certain groups will be favoured at different scales (MA 2003). The nature, impacts and response effectiveness to environmental change also

differ with scale (Wilbanks 2006). Particularly in contexts where the wellbeing of vulnerable groups is at stake, there is a need for careful consideration from whose perspective ecosystem services are defined, valued and managed. The seasonal variability that determines the lived realities of natural resource dependent communities, including in coastal areas of low-income countries, are not detected by single snap shots in time and are smoothed over by the coarse resolution data used in long-term modelling. Asking "ecosystem services for whom" (MA 2003) is a good starting point for identifying the appropriate choices of scale in ecosystem services.

7.7. Conclusion

People are part of dynamic social-ecological systems that they navigate and shape to achieve wellbeing outcomes, especially in rural areas of low-income countries. In my thesis, I build on progress from the social sciences to deepen understanding of how people mediate the relationship between nature and human wellbeing through time. Specifically, my research focused on seasons as a major driver of variability in the livelihoods and wellbeing of the rural poor. Using the case study of small-scale fisheries, I have shown how people interact with and benefit from ecosystems differently among seasons and therefore how social processes influence temporal dynamics in ecosystem services. My findings highlight the importance of social-ecological approaches for recognising people as an integral component of ecosystem services. The key message of my thesis is that temporal scale can have profound implications for our understanding of the human dimensions of ecosystem services. On Atauro Island, similar to many other rural communities, seasons create in a rhythm in people's lives. This rhythm underpins the ways that people interact with ecosystems and why those interactions are important. Ensuring the rhythm of people's realities are recognised and reflected has both ethical and instrumental implications for ecosystem services. Why nature matters and for whom may be better understood if we also ask *when*.

.

REFERENCES

ADB. 2014. *State of the Coral Triangle: Timor-Leste*. Asian Development Bank.

Adrian, R., D. Gerten, V. Huber, C. Wagner, and S. R. Schmidt. 2012. Windows of change: Temporal scale of analysis is decisive to detect ecosystem responses to climate change. *Marine Biology* 159(11):2533–2542.

Agarwal, B. 2009. Gender and forest conservation: The impact of women's participation in community forest governance. *Ecological Economics* 68(11):2785–2799.

Agrawal, A. 2014. Studying the commons, governing common-pool resource outcomes: Some concluding thoughts. *Environmental Science and Policy* 36:86–91.

Albert, S., S. Aswani, P. L. Fisher, and J. Albert. 2015. Keeping food on the table: Human responses and changing coastal fisheries in Solomon Islands. *PLoS ONE* 10(7):1–13.

Allison, E. H., M. C. M. Beveridge, and M. van Brakel. 2009. Climate change, small-scale fisheries and smallholder aquaculture. *Fisheries, sustainability and development.*:69–82.

Alonso-Población, E., P. Rodrigues, C. Wilson, M. Pereira, and R. U. Lee. 2018. Narrative assemblages for power-balanced coastal and marine governance. Tara Bandu as a tool for community-based fisheries co-management in Timor-Leste. *Maritime Studies* 17(1):55–67.

Alonso Población, E. 2013. Fisheries and food security in Timor-Leste: The effects of ritual meat exchanges and market chains on fishing. *Food Security* 5(6):807–816.

AMSAT. 2011a. *Fish and Animal Protein Consumption and Availability Survey in Timor-Leste*.

AMSAT. 2011b. *Regional Fisheries Livelihoods Programme Baseline Survey in Timor-Leste*. Page *Regional Fisheries Livelihoods Programme for South and Southeast Asia (GCP/RAS/237/SPA) Field Project Document 2011/TIM/1.*

Andersen, A. B., J. Pant, and S. H. Thilsted. 2013. Food and nutrition security in Timor-Leste. CGIAR Research Program on Aquatic Agricultural Systems.Project Report: AAS-2013-29.

Andréfouët, S., M. M. M. Guillaume, A. Delval, F. M. A. Rasoamanendrika, J. Blanchot, and J. H. Bruggemann. 2013. Fifty years of changes in reef flat habitats of the Grand Récif of Toliara (SW Madagascar) and the impact of gleaning. *Coral Reefs* 32(3):757–768.

Arias-arévalo, P., E. Gómez-baggethun, B. Martín-lópez, and M. Pérez-rincón. 2018. Widening the Evaluative Space for Ecosystem Services : A Taxonomy of Plural Values and Valuation Methods. *Environmental Values* 27:29–53.

Arias-Arévalo, P., B. Martín-López, and E. Gómez-Baggethun. 2017. Exploring intrinsic, instrumental, and relational values for sustainable management of social-ecological systems. *Ecology and Society* 22(4).

Armsworth, P. R., K. M. A. Chan, G. C. Daily, P. R. Ehrlich, C. Kremen, T. H. Ricketts, and M. A. Sanjayan. 2007. Ecosystem-service science and the way forward for conservation. *Conservation Biology* 21(6):1383–1384.

Ash, N., H. Blanco, C. Brown, K. Garcia, T. Henrichs, N. Lucas, C. Ruadsepp-Heane, R. D. Simpson, R. Scholes, T. Tomich, B. Vira, and M. Zurek. 2010. *Ecosystems and human well-being: a manual for assessment practitioners*. Island Press, Washington, DC.

Aswani, S., C. F. Flores, and B. R. Broitman. 2014. Human harvesting impacts on managed areas: ecological effects of socially-compatible shellfish reserves. *Reviews in Fish Biology and Fisheries* 25(1):217–230.

Bagstad, K. J., G. W. Johnson, B. Voigt, and F. Villa. 2013. Spatial dynamics of ecosystem service flows : A comprehensive approach to quantifying actual services. *Ecosystem Services* 4:117–125.

Bagstad, K. J., F. Villa, D. Batker, J. Harrison-cox, B. Voigt, and G. W. Johnson. 2014. From theoretical to actual ecosystem services : mapping beneficiaries and spatial flows in ecosystem service assessments. *Ecology and Society* 19(2):64.

Bai, Y., Y. Chen, J. M. Alatalo, Z. Yang, and B. Jiang. 2020. Scale effects on the relationships between land characteristics and ecosystem services- a case study in Taihu Lake Basin, China. *Science of the Total Environment* 716:137083.

Bakker, K., and G. Bridge. 2006. Material worlds? Resource geographies and the “matter of nature.” *Progress in Human Geography* 30(1):5–27.

Banks, J. A. 1998. The Lives and Values of Researchers : Implications for Educating Citizens in a Multicultural Society 27(7):4–17.

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81(2):169–193.

Bartlett, C. Y., C. Manua, J. Cinner, S. Sutton, R. Jimmy, R. South, J. Nilsson, and J. Raina. 2009. Comparison of outcomes of permanently closed and periodically harvested coral reef reserves. *Conservation Biology* 23(6):1475–1484.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2014. Fitting linear mixed-effects models using lme4. *arXiv preprint arXiv:1406.5823.*

Bennett, A., X. Basurto, J. Virdin, X. Lin, S. J. Betances, M. D. Smith, E. H. Allison, B. A. Best, K. D. Brownell, L. M. Campbell, C. D. Golden, E. Havice, C. C. Hicks, P. J. Jacques, K. Kleisner, N. Lindquist, R. Lobo, G. D. Murray, M. Nowlin, P. G. Patil, D. N. Rader, S. E. Roady, S. H. Thilsted, and S. Zoubek. 2021. Recognize fish as food in policy discourse and development funding. *Ambio* 50:981–989.

Bennett, A., P. Patil, K. Kleisner, D. Rader, J. Virdin, and X. Basurto. 2018a. *Contribution of Fisheries to Food and Nutrition Security: Current Knowledge, Policy, and Research.* Page *NI Report 18-02*. Durham, NC.

Bennett, E. M., and R. Chaplin-Kramer. 2016. Science for the sustainable use of ecosystem services. *F1000Research* 5:2622.

Bennett, E. M., W. Cramer, A. Begossi, G. Cundill, S. Díaz, B. N. Egoh, I. R. Geijzendorffer, C. B. Krug, S. Lavorel, E. Lazos, L. Lebel, B. Martín-López, P. Meyfroidt, H. A. Mooney, J. L. Nel, U. Pascual, K. Payet, N. P. Harguindeguy, G. D. Peterson, A. H. Prieur-Richard, B. Reyers, P. Roebeling, R. Seppelt, M. Solan, P. Tschakert, T. Tscharntke, B. L. Turner, P. H. Verburg, E. F. Viglizzo, P. C. L. White, and G. Woodward. 2015. Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability* 14:76–85.

Bennett, E. M., G. D. Peterson, and L. J. Gordon. 2009. Understanding relationships among multiple ecosystem services. *Ecology Letters* 12(12):1394–1404.

Bennett, N. J., and P. Dearden. 2013. A picture of change: Using photovoice to explore social and environmental change in coastal communities on the Andaman Coast of Thailand. *Local Environment* 18(9):983–1001.

Bennett, N. J., T. S. Whitty, E. Finkbeiner, J. Pittman, H. Bassett, S. Gelcich, and E. H. Allison. 2018b. Environmental Stewardship: A Conceptual Review and Analytical Framework. *Environmental Management* 61(4):597–614.

Berbés-Blázquez, M., M. J. Bunch, P. R. Mulvihill, G. D. Peterson, and B. van Wendel de Joode. 2017. Understanding how access shapes the transformation of ecosystem services to human well-being with an example from Costa Rica. *Ecosystem Services* 28:320–327.

Berbés-Blázquez, M., J. A. González, and U. Pascual. 2016. Towards an ecosystem services approach that addresses social power relations. *Current Opinion in Environmental Sustainability* 19:134–143.

Berkes, F., C. Folke, and J. Colding. 2000. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press.

Berry, E. M., S. Dernini, B. Burlingame, A. Meybeck, and P. Conforti. 2015. Food security and sustainability: Can one exist without the other? *Public Health Nutrition* 18(13):2293–2302.

Bindoff, N. L., W. W. L. Cheung, J. G. Kairo, J. Arístegui, V. A. Guinder, R. Hallberg, N. Hilmi, N. Jiao, M. S. Karim, L. Levin, S. O'Donoghue, S. R. Purca Cuicapusa, B. Rinkevich, T. Suga, A. Tagliabue, and P. Williamson. 2019. Changing Ocean, Marine Ecosystems, and Dependent Communities. Page *in* N. M. W. H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, editor. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*.

Birbili, M. 2000. Translating from one language to another. *Social Research Update*(31).

Bird, D. W. 1997. Delayed Reciprocity and Tolerated Theft: The Behavioral Ecology of Food-Sharing Strategies. *Current Anthropology* 38(1):49–78.

Blackmore, I., C. Rivera, W. F. Waters, L. Iannotti, and C. Lesorogol. 2021. The impact of seasonality and climate variability on livelihood security in the Ecuadorian Andes. *Climate Risk Management* 32(December 2019):100279.

Blasiak, R., J. Spijkers, K. Tokunaga, J. Pittman, N. Yagi, and H. Österblom. 2017. Climate change and marine fisheries: Least developed countries top global index of vulnerability. *PLoS ONE* 12(6):1–15.

Bliege Bird, R. 2007. Fishing and the Sexual Division of Labor among the Meriam. *American Anthropologist* 109(3):442–451.

Blythe, J., D. Armitage, G. Alonso, D. Campbell, A. C. Esteves Dias, G. Epstein, M. Marschke, and P. Nayak. 2020. Frontiers in coastal well-being and ecosystem services research: A systematic review. *Ocean and Coastal Management* 185(2020):105028.

Bonis-Profumo, G., R. McLaren, and J. Fanzo. 2019. Ravaged landscapes and climate vulnerability: The challenge in achieving food security and nutrition in post-conflict Timor-Leste. Pages 97–132 *Advances in Food Security and Sustainability,*.

Bonis-Profumo, G., N. Stacey, and J. Brimblecombe. 2021. Measuring women's empowerment in agriculture, food production, and child and maternal dietary diversity in Timor-Leste. *Food Policy* 102:102102.

Braat, L. C. 2018. Five reasons why the Science publication "Assessing nature's

contributions to people" (Diaz et al. 2018) would not have been accepted in Ecosystem Services. *Ecosystem Services* 30:2.

Branch, G. M., J. May, B. Roberts, E. Russell, and B. M. Clark. 2002. Case studies on the socio-economic characteristics and lifestyles of subsistence and informal fishers in South Africa. *South African Journal of Marine Science* 24(1):439–462.

Brooks, S. E., J. D. Reynolds, and E. H. Allison. 2008. Sustained by snakes? Seasonal livelihood strategies and resource conservation by Tonle Sap fishers in Cambodia. *Human Ecology* 36(6):835–851.

Brown, K., N. Eernstman, A. R. Huke, and N. Reding. 2017. The drama of resilience: Learning, doing, and sharing for sustainability. *Ecology and Society* 22(2):8.

Brown, K., and M. Fortnam. 2017. Gender and ecosystem services: A blind spot. Pages 257–272 *in* K. Schreckenberg, G. Mace, and M. Poudyal, editors. *Ecosystem Services and Poverty Alleviation: Trade-offs and Governance*.

Brown, K., and E. Westaway. 2011. Agency, capacity, and resilience to environmental change: Lessons from human development, well-being, and disasters. *Annual Review of Environment and Resources* 36:321–342.

Bryce, R., K. N. Irvine, A. Church, R. Fish, S. Ranger, and J. O. Kenter. 2016. Subjective well-being indicators for large-scale assessment of cultural ecosystem services. *Ecosystem Services* 21(July):258–269.

Burchell, M., A. Cannon, N. Hallmann, H. P. Schwarcz, and B. R. Schöne. 2013. Inter-site variability in the season of shellfish collection on the central coast of British Columbia. *Journal of Archaeological Science* 40(1):626–636.

Burkhard, B., M. Kandziora, Y. Hou, and F. Müller. 2014. Ecosystem service potentials, flows and demands-concepts for spatial localisation, indication and quantification. *Landscape Online* 34:32.

Burrows, M. T., D. S. Schoeman, L. B. Buckley, P. Moore, E. S. Poloczanska, K. M. Brander, C. Brown, J. F. Bruno, C. M. Duarte, B. S. Halpern, J. Holding, C. V. Kappel, W. Kiessling, M. I. O'Connor, J. M. Pandolfi, C. Parmesan, F. B. Schwing, W. J. Sydeman, and A. J. Richardson. 2011. The pace of shifting climate in marine and terrestrial ecosystems. *Science* 334(6056):652–655.

Calvo-Ugarteburu, G., S. Raemaekers, and C. Halling. 2017. Rehabilitating mussel beds in Coffee Bay, South Africa: Towards fostering cooperative small-scale fisheries governance and enabling community upliftment. *Ambio* 46(2):214–226.

Camfield, L. 2006. *The why and how of understanding "subjective" wellbeing: exploratory work by the WeD group in four developing countries.* Page *WeD Working Paper*.

Camfield, L., K. Choudhury, and J. Devine. 2009. Well-being, happiness and why relationships matter: Evidence from bangladesh. *Journal of Happiness Studies* 10(1):71–91.

Carolan, M. S. 2005. Realism without Reductionism : Toward an Ecologically Embedded Sociology. *Human Ecology Review* 12(1):1–20.

Carr, E. R. 2019. Properties and projects: Reconciling resilience and transformation for adaptation and development. *World Development* 122:70–84.

Carter, C., and C. Garaway. 2014. Shifting Tides, Complex Lives: The Dynamics of Fishing and Tourism Livelihoods on the Kenyan Coast. *Society and Natural Resources* 27(6):573–587.

Cash, D. W., and S. C. Moser. 2000. Linking global and local scales: Designing dynamic assessment and management processes. *Global Environmental Change* 10(2):109–120.

Cetra, M., and M. Petrere. 2014. Seasonal and annual cycles in marine small-scale fisheries (Ilheus - Brazil). *Fisheries Management and Ecology* 21(3):244–249.

Chaigneau, T., K. Brown, S. Coulthard, T. M. Daw, and L. Szaboova. 2019a. Money, use and experience: Identifying the mechanisms through which ecosystem services contribute to wellbeing in coastal Kenya and Mozambique. *Ecosystem Services* 38(100957):12.

Chaigneau, T., S. Coulthard, K. Brown, T. M. Daw, and B. Schulte-Herbrüggen. 2019b. Incorporating basic needs to reconcile poverty and ecosystem services. *Conservation Biology* 33(3):655–664.

Chakraborty, S., A. Gasparatos, and R. Blasiak. 2020. Multiple values for the management and sustainable use of coastal and marine ecosystem services. *Ecosystem Services* 41(101047):6.

Chambers, R. 1982. Health, Agriculture, and Rural Poverty: Why Seasons Matter. *The Journal of Development Studies* 18(2):217–238.

Chambers, R. 1995. *Poverty and livelihoods whose reality counts*. Page *Environment and Urbanization*.

Chambers, R., R. Longhurst, and A. Pacey. 1981. *Seasonal dimensions to rural poverty*. Frances Pinter Ltd.

Chan, C., D. Armitage, S. M. Alexander, and D. Campbell. 2019. Examining linkages between ecosystem services and social wellbeing to improve governance for coastal conservation in Jamaica. *Ecosystem Services* 39(100997):12.

Chan, K. M. A., P. Balvanera, K. Benessaiah, M. Chapman, S. Díaz, E. Gómez-Baggethun, R. Gould, N. Hannahs, K. Jax, S. Klain, G. W. Luck, B. Martín-López, B. Muraca, B. Norton, K. Ott, U. Pascual, T. Satterfield, M. Tadaki, J. Taggart, and N. Turner. 2016. Opinion: Why protect nature? Rethinking values and the environment. *Proceedings of the National Academy of Sciences* 113(6):1462–1465.

Chan, K. M. A., J. Goldstein, T. Satterfield, N. Hannahs, K. Kikiloi, R. Naidoo, N. Vadeboncoeur, and U. Woodside. 2011. Cultural services and non-use values. Pages 206–228 *in* H. Tallis, editor. *Natural Capital: theory and practice of mapping ecosystem services*. Oxford University Press.

Chan, K. M. A., A. D. Guerry, P. Balvanera, S. Klain, T. Satterfield, X. Basurto, A. Bostrom, R. Chuenpagdee, R. Gould, B. S. Halpern, N. Hannahs, J. Levine, B. Norton, M. Ruckelshaus, R. Russell, J. Tam, and U. Woodside. 2012. Where are Cultural and Social in Ecosystem Services? A Framework for Constructive Engagement. *BioScience* 62(8):744–756.

Chan, K. M. A., and T. Satterfield. 2020. The maturation of ecosystem services: Social and policy research expands, but whither biophysically informed valuation? *People and Nature* 00(June):1–40.

Chan, K. M., R. K. Gould, and U. Pascual. 2018. Editorial overview: Relational values: what are they, and what's the fuss about? *Current Opinion in Environmental Sustainability* 35:A1–A7.

Chant, S. 2008. The "feminisation of poverty" and the "feminisation" of anti-poverty programmes: Room for revision? *Journal of Development Studies* 44(2):165–197.

Chapman, M. D. 1987. Women's Fishing in Oceania. *Human Ecology* 15(3):267–288.

Charlton, K. E., J. Russell, E. Gorman, Q. Hanich, A. Delisle, B. Campbell, and J. Bell. 2016. Fish, food security and health in Pacific Island countries and territories: a systematic literature review. *BMC public health* 16(1):285.

Chasekwa, B., J. A. Maluccio, R. Ntozini, L. H. Moulton, F. Wu, L. E. Smith, C. R. Matare, R. J. Stoltzfus, M. N. N. Mbuya, J. M. Tielsch, S. L. Martin, A. D. Jones, J. H. Humphrey, and K. Fielding. 2018. Measuring wealth in rural communities: Lessons from the sanitation, hygiene, infant nutrition efficacy (SHINE) trial. *PLoS ONE* 13(6):1–19.

Chaudhary, S., A. McGregor, D. Houston, and N. Chettri. 2015. The evolution of ecosystem services: A time series and discourse-centered analysis. *Environmental Science and Policy* 54:25–34.

Chilisa, B., and B. Kawulich. 2012. Selecting a research approach: paradigm, methodology and methods. Page *in* B. Kawulich, C. Wagner, and M. Garner, editors. *Doing Social Research: A Global Context*.

Christie, M., I. Fazey, R. Cooper, T. Hyde, and J. O. Kenter. 2020. An evaluation of monetary and non-monetary techniques for assessing the importance of biodiversity and ecosystem services to people in countries with developing economies. *Ecological Economics* 83(2012):67–78.

Cinner, J. E., W. N. Adger, E. H. Allison, M. L. Barnes, K. Brown, P. J. Cohen, S. Gelcich, C. C. Hicks, T. P. Hughes, J. Lau, N. A. Marshall, and T. H. Morrison. 2018. Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change* 8(2):117–123.

Cinner, J. E., T. R. McClanahan, N. A. J. Graham, T. M. Daw, J. Maina, S. M. Stead, A. Wamukota, K. Brown, and O. Bodin. 2012. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change* 22(1):12–20.

Clark, B. M., M. Hauck, J. M. Harris, K. Salo, and E. Russell. 2002. Identification of subsistence fishers, fishing areas, resource use and activities along the South African Coast. *South African Journal of Marine Science* 24:425–437.

Codding, B. F., A. R. Whitaker, and D. W. Bird. 2014. Global Patterns in the Exploitation of Shellfish. *Journal of Island and Coastal Archaeology* 9(2):145–149.

Cohen, P. J., and T. J. Alexander. 2013. Catch Rates, composition and fish size from reefs managed with periodically-harvested closures. *PLoS ONE* 8(9):12.

Cohen, P. J., E. H. Allison, N. L. Andrew, J. Cinner, L. S. Evans, M. Fabinyi, L. R. Garces, S. J. Hall, C. C. Hicks, T. P. Hughes, S. Jentoft, D. J. Mills, R. Masu, E. K. Mbaru, and B. D. Ratner. 2019. Securing a just space for small-scale fisheries in the blue economy. *Frontiers in Marine Science* 6(171):8.

Cohen, P. J., and S. J. Foale. 2013. Sustaining small-scale fisheries with periodically harvested marine reserves. *Marine Policy* 37:278–287.

Conservation International. 2020. Creating a protected area network. https://www.conservation.org/timor-leste/our-work/creating-a-protected-area-network.

Cord, A. F., B. Bartkowski, M. Beckmann, A. Dittrich, K. Hermans-Neumann, A. Kaim, N. Lienhoop, K. Locher-Krause, J. Priess, C. Schröter-Schlaack, N. Schwarz, R. Seppelt, M. Strauch, T. Václavík, and M. Volk. 2017. Towards systematic analyses of ecosystem service trade-offs and synergies: Main concepts, methods and the road ahead. *Ecosystem Services* 28:264–272.

Cornwall, A., E. A. Harrison, and A. Whitehead. 2007. Gender myths and feminist fables: The struggle for interpretive power in gender and development. *Development and Change* 38(1):1–20.

da Costa, M. d. J., M. Lopes, A. Ximenes, A. do R. Ferreira, L. Spyckerelle, R. Williams, H. Nesbitt, and W. Erskine. 2013. Household food insecurity in Timor-Leste. *Food Security* 5(1):83–94.

Costanza, R., R. D'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. LK - https://royalroads.on.worldcat.org/oclc/4592801201. *Nature* 387(6630):253–260.

Costanza, R., and H. E. Daly. 1987. Toward an ecological economics. *Ecological Modelling* 38:1–7.

Costanza, R., R. de Groot, L. Braat, I. Kubiszewski, L. Fioramonti, P. Sutton, S. Farber, and M. Grasso. 2017. Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosystem Services* 28:1–16.

Coulthard, S. 2008. Adapting to environmental change in artisanal fisheries-Insights from a South Indian Lagoon. *Global Environmental Change* 18(3):479–489.

Coulthard, S. 2012. Can we be both resilient and well, and what choices do people have? incorporating agency into the resilience debate from a fisheries perspective. *Ecology and Society* 17(1):4.

Coulthard, S., D. Johnson, and J. A. McGregor. 2011. Poverty, sustainability and human wellbeing: A social wellbeing approach to the global fisheries crisis. *Global Environmental Change* 21(2):453–463.

Coulthard, S., J. A. Mcgregor, and C. White. 2018. Multiple dimensions of wellbeing in practice. Pages 243–256 *in* K. Schreckenberg, G. M. Mace, and M. Poudyal, editors. *Ecosystem Services and Poverty Alleviation: Trade-offs and Governance*. Routledge.

Coulthard, S., C. White, N. Paranamana, K. P. G. L. Sandaruwan, R. Manimohan, and R. Maya. 2020. Tackling alcoholism and domestic violence in fisheries—A new opportunity to improve well-being for the most vulnerable people in global fisheries. *Fish and Fisheries* 21(2):223–236.

Creswell, J. W. 2007. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches.* second. SAGE.

Creswell, J. W. 2009. *Research design: Qualitative, quantitative, and mixed methods approaches.* SAGE.

Crossman, N. D., B. A. Bryan, R. S. de Groot, Y. P. Lin, and P. A. Minang. 2013. Land science contributions to ecosystem services. *Current Opinion in Environmental Sustainability* 5:509–514.

Cruz-Garcia, G. S., and L. L. Price. 2014. Gathering of Wild Food Plants in Anthropogenic Environments across the Seasons: Implications for Poor and Vulnerable Farm Households. *Ecology of Food and Nutrition* 53(4):363–389.

Cruz-Garcia, G. S., E. Sachet, M. Vanegas, and K. Piispanen. 2016. Are the major imperatives of food security missing in ecosystem services research? *Ecosystem Services* 19:19–31.

Cruz-Trinidad, A., P. M. Aliño, R. C. Geronimo, and R. B. Cabral. 2014. Linking Food Security with Coral Reefs and Fisheries in the Coral Triangle. *Coastal Management* 42(2):160–182.

Daily, G. C. 1997. Introduction: What are ecosystem services? Pages 1–10 *in* G. C. Daily, editor. *Nature's services: Societal dependence on natural ecosystems*.

Daily, G. C., S. Polasky, J. Goldstein, P. M. Kareiva, H. A. Mooney, L. Pejchar, T. H. Ricketts,

J. Salzman, and R. Shallenberger. 2009. Ecosystem services in decision making: Time to deliver. *Frontiers in Ecology and the Environment* 7(1):21–28.

Daly, H. E. 1974. The economics of the steady state. *The American Economic Review* 64(2):15–21.

Daniggelis, E. 2003. Women and "wild" foods: nutrition and household security among Rai and Sherpa forager-farmers in Eastern Nepal. Pages 83–97 *in* P. L. Howard, editor. *Women and Plants*. Zed Books.

Daw, T., W. . Adger, K. Brown, and M. Badjeck. 2009. *Climate change and capture fisheries: potential impacts, adaptation and mitigation*. Page *Climate change implications for fisheries and aquaculture*.

Daw, T., K. Brown, S. Rosendo, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: The need to disaggregate human well-being. *Environmental Conservation* 38(4):370–379.

Daw, T. M., C. C. Hicks, K. Brown, T. Chaigneau, F. A. Januchowski-hartley, and W. W. L. Cheung. 2016. Elasticity in ecosystem services : exploring the variable relationship between ecosystems and human well-being. *Ecology and Society* 21(2):11.

Dawson, N. M., K. Grogan, A. Martin, O. Mertz, M. Pasgaard, and L. V. Rasmussen. 2017. Environmental justice research shows the importance of social feedbacks in ecosystem service trade-offs. *Ecology and Society* 22(3):12.

Devereux, S., B. Vaitla, and S. H. Swan. 2008. *Seasons of Hunger: fighting Cycles of Starvation Among the World's Rural Poor*. Pluto Press, London.

Díaz, S., S. Demissew, J. Carabias, C. Joly, M. Lonsdale, N. Ash, A. Larigauderie, J. R. Adhikari, S. Arico, A. Báldi, A. Bartuska, I. A. Baste, A. Bilgin, E. Brondizio, K. M. A. Chan, V. E. Figueroa, A. Duraiappah, M. Fischer, R. Hill, T. Koetz, P. Leadley, P. Lyver, G. M. Mace, B. Martin-Lopez, M. Okumura, D. Pacheco, U. Pascual, E. S. Pérez, B. Reyers, E. Roth, O. Saito, R. J. Scholes, N. Sharma, H. Tallis, R. Thaman, R. Watson, T. Yahara, Z. A. Hamid, C. Akosim, Y. Al-Hafedh, R. Allahverdiyev, E. Amankwah, T. S. Asah, Z. Asfaw, G. Bartus, A. L. Brooks, J. Caillaux, G. Dalle, D. Darnaedi, A. Driver, G. Erpul, P. Escobar-Eyzaguirre, P. Failler, A. M. M. Fouda, B. Fu, H. Gundimeda, S. Hashimoto, F. Homer, S. Lavorel, G. Lichtenstein, W. A. Mala, W. Mandivenyi, P. Matczak, C. Mbizvo, M. Mehrdadi, J. P. Metzger, J. B. Mikissa, H. Moller, H. A. Mooney, P. Mumby, H. Nagendra, C. Nesshover, A. A. Oteng-Yeboah, G. Pataki, M. Roué, J. Rubis, M. Schultz, P. Smith, R. Sumaila, K. Takeuchi, S. Thomas, M. Verma, Y. Yeo-Chang, and D. Zlatanova. 2015. The IPBES Conceptual Framework - connecting nature and people. *Current Opinion in Environmental Sustainability* 14:1–16.

Díaz, S., U. Pascual, M. Stenseke, B. Martín-López, R. T. Watson, Z. Molnár, R. Hill, K. M. A. Chan, I. A. Baste, K. A. Brauman, S. Polasky, A. Church, M. Lonsdale, A. Larigauderie, P. W. Leadley, A. P. E. van Oudenhoven, F. van der Plaat, M. Schröter, S. Lavorel, Y. Aumeeruddy-Thomas, E. Bukvareva, K. Davies, S. Demissew, G. Erpul, P. Failler, C. A. Guerra, C. L. Hewitt, H. Keune, S. Lindley, and Y. Shirayama. 2018. Assessing nature's contributions to people. *Science* 359(6373):270–272.

Djoudi, H., B. Locatelli, C. Vaast, K. Asher, M. Brockhaus, and B. Basnett Sijapati. 2016. Beyond dichotomies: Gender and intersecting inequalities in climate change studies. *Ambio* 45(suppl. 3):248–262.

Dostie, B., S. Haggblade, and J. Randriamamonjy. 2002. Seasonal poverty in Madagascar: Magnitude and solutions. *Food Policy* 27(5–6):493–518.

Dove, M. 2014. *The Anthropology of Climate Change : An Historical Reade*. Wiley, Blackwell.

Ehrlich, P. R., and H. A. Mooney. 1983. Extinction , Substitution , and Ecosystem Services. *BioScience* 33(4):248–254.

Ellis, F. 2000. The Determinants of Rural Livelihood Diversification in Developing Countries. *Journal of Agricultural Economics* 51(2):289–302.

Epstein, G., E. Andrews, D. Armitage, P. Foley, J. Pittman, and R. Brushett. 2018. Human dimensions of ecosystem-based management: Lessons in managing trade-offs from the Northern Shrimp Fishery in Northern Peninsula, Newfoundland. *Marine Policy* 97:10–17.

Erisman, B., I. Mascareñas-Osorio, C. López-Sagástegui, M. Moreno-Báez, V. Jiménez-Esquivel, and O. Aburto-Oropeza. 2015. A comparison of fishing activities between two coastal communities within a biosphere reserve in the Upper Gulf of California. *Fisheries Research* 164:254–265.

Erskine, W., A. Ximenes, D. Glazebrook, M. da Costa, M. Lopes, L. Spyckerelle, R. Williams, and H. Nesbitt. 2014. The role of wild foods in food security: the example of Timor-Leste. *Food Security* 7(1):55–65.

ESPA. 2018. *An environment for wellbeing: Pathways out of poverty Policy messages from the ESPA programme*.

ESRI. 2019. ArcGIS Release 10.6.4. Environmental Systems Research Institute, Redlands, CA, USA.

Fabinyi, M., W. H. Dressler, and M. D. Pido. 2017. Fish, trade and food Security: Moving beyond 'availability' discourse in marine conservation. *Human Ecology* 45(2):177–188.

FAO. 1996. *Report of the World Food Summit 13–17 November 1996.* Rome.

FAO. 2005. *Increasing the contribution of small-scale fisheries to poverty alleviation and food security.* Page *FAO Technical Guidelines for Responsible Fisheries. No 10.*

FAO. 2008. *An introduction to the basic concepts of food security*. Page *Food Security Information for Action*.

FAO. 2015. *Key recommandations for improving nutrition through agriculture and food system*. Rome.

FAO. 2016. *In Brief: The state of food and agriculture, 2016: Climate Change, Agriculture and Food Security*. Rome.

FAO. 2019. Fishery and Aquaculture Country Profiles - The Democratic Republic of Timor-Leste. http://www.fao.org/fishery/facp/TLS/en.

Farber, S. C., R. Costanza, and M. A. Wilson. 2002. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* 41(3):375–392.

Farmery, A. K., L. Kajlich, M. Voyer, J. R. Bogard, and A. Duarte. 2020. Integrating fisheries, food and nutrition – Insights from people and policies in Timor-Leste. *Food Policy* 91(101826).

Fedele, G., B. Locatelli, and H. Djoudi. 2017. Mechanisms mediating the contribution of ecosystem services to human well-being and resilience. *Ecosystem Services* 28:43–54.

Fischer, A., and A. Eastwood. 2016. Coproduction of ecosystem services as human–nature interactions—An analytical framework. *Land Use Policy* 52:41–50.

Fish, R., A. Church, and M. Winter. 2016. Conceptualising cultural ecosystem services: A novel framework for research and critical engagement. *Ecosystem Services* 21:208–217.

Fisher, B., K. Turner, M. Zylstra, R. Brouwer, R. De Groot, S. Farber, P. Ferraro, R. Green, D. Hadley, J. Harlow, P. Jefferiss, C. Kirkby, P. Morling, S. Mowatt, R. Naidoo, J. Paavola,

B. Strassburg, D. Yu, and A. Balmford. 2008. Ecosystem services and economic theory: Integration for policy-relevant research. *Ecological Applications* 18(8):2050–2067.

Fisher, B., R. K. Turner, and P. Morling. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68(3):643–653.

Fisher, J. A., G. Patenaude, K. Giri, K. Lewis, P. Meir, P. Pinho, M. D. A. Rounsevell, and M. Williams. 2014. Understanding the relationships between ecosystem services and poverty alleviation: A conceptual framework. *Ecosystem Services* 7:34–45.

Flyvbjerg, B. 2006. Five misunderstandings about case-study research. *Qualitative Inquiry* 12(2):219–245.

Foale, S., D. Adhuri, P. Alino, E. H. Allison, N. Andrew, P. Cohen, L. Evans, M. Fabinyi, P. Fidelman, C. Gregory, N. Stacey, J. Tanzer, and N. Weeratunge. 2013. Food security and the Coral Triangle Initiative. *Marine Policy* 38:174–183.

Folke, C., G. Cundill, and C. Queiroz. 2005. Communities, Ecosystems, and Livelihoods. Pages 261–277 *Ecosystems and Human Well-being: Sub-global*. IPCC.

Folkersen, M. V. 2018. Ecosystem valuation: Changing discourse in a time of climate change. *Ecosystem Services* 29:1–12.

Fortnam, M., K. Brown, T. Chaigneau, B. Crona, T. M. Daw, D. Gonçalves, C. Hicks, M. Revmatas, C. Sandbrook, and B. Schulte-Herbruggen. 2019. The Gendered Nature of Ecosystem Services. *Ecological Economics* 159:312–325.

Freduah, G., P. Fidelman, and T. F. Smith. 2017. The impacts of environmental and socio-economic stressors on small scale fisheries and livelihoods of fishers in Ghana. *Applied Geography* 89:1–11.

Fröcklin, S., M. De La Torre-Castro, E. Håkansson, A. Carlsson, M. Magnusson, and N. S. Jiddawi. 2014. Towards improved management of tropical invertebrate fisheries: Including time series and gender. *PLoS ONE* 9(3).

Frumkin, H. 2001. Beyond toxicity: Human health and the natural environment. *American Journal of Preventive Medicine* 20(3):234–240.

Furkon, N. Nessa, R. Ambo-Rappe, L. C. Cullen-Unsworth, and R. K. F. Unsworth. 2020. Social-ecological drivers and dynamics of seagrass gleaning fisheries. *Ambio* 49(7):1271–1281.

GDS. 2015. Statistics Timor-Leste. http://www.statistics.gov.tl/category/publications/census-publications/2015-census-publications/volume-2-population-distribution-by-administrative/.

GDS. 2018. *Timor-Leste population and housing census 2015: Analytical report on agriculture and fisheries*. Dili, Timor-Leste.

GHI. 2018. Global hunger index: Timor-Leste. https://www.globalhungerindex.org/timor-leste.html.

GHI. 2019. Global hunger index. https://www.globalhungerindex.org/results.html.

Gibson, C. C., E. Ostrom, and T. K. Ahn. 2000. The concept of scale and the human dimensions of global change: A survey. *Ecological Economics* 32(2):217–239.

Gill, D. A., H. A. Oxenford, R. A. Turner, and P. W. Schuhmann. 2019. Making the most of data-poor fisheries: Low cost mapping of small island fisheries to inform policy. *Marine Policy* 101:198–207.

Gina-Whewell, L. 1992. Roviana Women in Traditional Fishing. *Science of Pacific Island Peoples: Ocean and Coastal Studies*:12–13.

Goldin, O. 1997. The Ecology of the Critias and Platonic Metaphysics. *The Greeks and Environment*(6):73–80.

GOTL. 2015. AGRICULTURE TRENDS IN TIMOR-LESTE FROM 2010-2015. https://www.statistics.gov.tl/category/publications/census-publications/.

Grantham, R., J. G. Álvarez-romero, D. J. Mills, C. Rojas, and G. S. Cumming. 2021. Spatiotemporal determinants of seasonal gleaning. *People and Nature*:1–15.

Grantham, R., J. Lau, and D. Kleiber. 2020. Gleaning: beyond the subsistence narrative. *Maritime Studies* 19:509–524.

Greene, J. C. 2008. Is mixed methods social inquiry a distinctive methodology? *Journal of Mixed Methods Research* 2(1):7–22.

Guba, E. G., and T. S. Lincoln. 1994. Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), Handbook of qualitative research (pp. 105-117). *Thousand Oaks, CA: Sage*:105–117.

Gunawardena, N. D. P., T. Jutagate, and U. S. Amarasinghe. 2016. Patterns of species composition of beach seine fisheries off North-Western coast of Sri Lanka, fishers' perceptions and implications for co-management. *Marine Policy* 72:131–138.

Hägerstrand, T. 1970. What about people in regional science?

Haines-Young, R. H., and M. P. Potschin. 2010. The links between biodiversity, ecosystem services and human well-being. Pages 110–139 *in* D. Raffaelli and C. Frid, editors. *Ecosystem Ecology: A New Synthesis*.

Harper, S., M. Adshade, V. W. Y. Lam, D. Pauly, and U. R. Sumaila. 2020. Valuing invisible catches : Estimating the global contribution by women to small-scale marine capture fisheries production. *PLoS ONE* 15(3).

Harper, S., D. Zeller, M. Hauzer, D. Pauly, and U. R. Sumaila. 2013. Women and fisheries: Contribution to food security and local economies. *Marine Policy* 39(1):56–63.

Hartig, F. 2020. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R.

Harvard Humanitarian Initiative. (n.d.). KoBoToolbox. https://www.kobotoolbox.org/#home.

Hein, L., C. S. A. K. van Koppen, E. C. van Ierland, and J. Leidekker. 2016. Temporal scales, ecosystem dynamics, stakeholders and the valuation of ecosystems services. *Ecosystem Services* 21:109–119.

Hicks, C. C., and J. E. Cinner. 2014. Social, institutional, and knowledge mechanisms mediate diverse Ecosystem service benefits from coral reefs. *Proceedings of the National Academy of Sciences of the United States of America* 111(50):17791–17796.

Hicks, C. C., P. J. Cohen, N. A. J. Graham, K. L. Nash, E. H. Allison, C. D'Lima, D. J. Mills, M. Roscher, S. H. Thilsted, A. L. Thorne-Lyman, and M. A. MacNeil. 2019. Harnessing global fisheries to tackle micronutrient deficiencies. *Nature* 574(7776):95–98.

Hilborn, R. 2007. Managing fisheries is managing people: What has been learned? *Fish and Fisheries* 8(4):285–296.

Himes, A., and B. Muraca. 2018. Relational values: the key to pluralistic valuation of ecosystem services. *Current Opinion in Environmental Sustainability* 35:1–7.

Holmes, A. G. D. 2020. Researcher Positionality - A Consideration of Its Influence and Place in Qualitative Research - A New Researcher Guide. *International Journal of Education* 8(4):1–10.

Hosgelen, M., and U. Saikia. 2016. Timor-Leste's demographic challenges for environment, peace and nation building. *Asia Pacific Viewpoint* 57(2):244–262.

Houghton, T. 2011. Does positivism really 'work' in the social sciences? Pages 6–11.

Howe, C., H. Suich, P. van Gardingen, A. Rahman, and G. M. Mace. 2013. Elucidating the pathways between climate change, ecosystem services and poverty alleviation. *Current Opinion in Environmental Sustainability* 5(1):102–107.

Howe, C., H. Suich, B. Vira, and G. M. Mace. 2014. Creating win-wins from trade-offs? Ecosystem services for human well-being: A meta-analysis of ecosystem service trade-offs and synergies in the real world. *Global Environmental Change* 28(1):263–275.

Howell, A. J., and H.-A. Passmore. 2013. Mental well-being: International contributions to the study of positive mental health. Pages 231–257 *Mental Well-Being: International Contributions to the Study of Positive Mental Health*.

Hunnam, K., I. Carlos, M. P. Hammer, J. Dos Reis Lopes, D. J. Mills, and N. Stacey. 2021. Untangling Tales of Tropical Sardines: Local Knowledge From Fisheries in Timor-Leste. *Frontiers in Marine Science* 8(May).

Huntsinger, L., and J. L. Oviedo. 2014. Ecosystem services are social-ecological services in a traditional pastoral system: The case of California's mediterranean rangelands. *Ecology and Society* 19(1).

Huq, N., A. Bruns, and L. Ribbe. 2019. Interactions between freshwater ecosystem services and land cover changes in southern Bangladesh: A perspective from short-term (seasonal) and long-term (1973–2014) scale. *Science of the Total Environment* 650:132–143.

Huq, N., R. Pedroso, A. Bruns, L. Ribbe, and S. Huq. 2020. Changing dynamics of livelihood dependence on ecosystem services at temporal and spatial scales: An assessment in the southern wetland areas of Bangladesh. *Ecological Indicators* 110(105855).

Hurtado, A. M., and K. R. Hill. 1990. Seasonality in a Foraging Society: Variation in Diet, Work Effort, Fertility, and Sexual Division of Labor among the Hiwi of Venezuela. *Journal of Anthropological Research* 46(3):293–346.

IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Page 56 *in* S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. R. Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas, editors. IPBES secretariat, Bonn, Germany.

IPC. 2019. *The First IPC Analysis Report on the Chronic Food Security Situation in Timor-Leste*.

IPCC. 2003. Coastal Zones and Marine Ecosystems. Pages 345–379 *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Intergovernmental Panel on Climate Change.

IPCC. 2014a. Technical Summary. Pages 35–94 *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

IPCC. 2014b. Summary for Policymakers Summary for Policymakers. Pages 1–32 *Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Jackson, C. 2009. Resolving Risk? Marriage and Creative Conjugality. *Gender Myths and Feminist Fables: The Struggle for Interpretive Power in Gender and Development* 38(1):105–126.

Jacobs, S., N. Dendoncker, B. Martín-López, D. N. Barton, E. Gomez-Baggethun, F. Boeraeve, F. L. McGrath, K. Vierikko, D. Geneletti, K. J. Sevecke, N. Pipart, E. Primmer, P. Mederly, S. Schmidt, A. Aragão, H. Baral, R. H. Bark, T. Briceno, D. Brogna, P. Cabral, R. De Vreese, C. Liquete, H. Mueller, K. S. H. Peh, A. Phelan, A. R. Rincón, S. H. Rogers, F. Turkelboom, W. Van Reeth, B. T. van Zanten, H. K. Wam, and C. L. Washbourn. 2016. A new valuation school: Integrating diverse values of nature in resource and land use decisions. *Ecosystem Services* 22:213–220.

Jennings, S., and J. Magrath. 2009. *What Happened to the Seasons*. Page *Oxfam GB Research Report*.

Jiggins, J. 1986. Women and Seasonality: Coping with Crisis and Calamity. *IDS Bulletin* 17(3):9–18.

Johnson, D. 2018. The values of small-scale fisheries. Pages 1–21 *in* D. Johnson, T. Acott, N. Stacey, and J. Urquhart, editors. *Social wellbeing and the values of small-scale fisheries*. MARE Publication series.

Johnson, D. S. 2006. Category, narrative, and value in the governance of small-scale fisheries. *Marine Policy* 30(6):747–756.

Jueseah, A. S., O. Knutsson, D. M. Kristofersson, and T. Tómasson. 2020. Seasonal flows of economic benefits in small-scale fisheries in Liberia: A value chain analysis. *Marine Policy* 119(104042):11.

Kalaba, F. K., C. H. Quinn, and A. J. Dougill. 2013. The role of forest provisioning ecosystem services in coping with household stresses and shocks in Miombo woodlands, Zambia. *Ecosystem Services* 5:143–148.

Kandziora, M., B. Burkhard, and F. Müller. 2013. Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution. *Ecosystem Services* 4:47–59.

Kawarazuka, N., C. Locke, C. McDougall, P. Kantor, and M. Morgan. 2017. Bringing analysis of gender and social–ecological resilience together in small-scale fisheries research: Challenges and opportunities. *Ambio* 46(2):201–213.

Keeler, B. L., B. J. Dalzell, J. D. Gourevitch, P. L. Hawthorne, K. A. Johnson, and R. R. Noe. 2019. Putting people on the map improves the prioritization of ecosystem services. *Frontiers in Ecology and the Environment* 17(3):151–156.

Kenter, J. O., T. Hyde, M. Christie, and I. Fazey. 2011. The importance of deliberation in valuing ecosystem services in developing countries-Evidence from the Solomon Islands. *Global Environmental Change* 21(2):505–521.

Keough, M. J., G. P. Quinn, and A. King. 1993. Correlations between Human Collecting and Intertidal Mollusc Populations on Rocky Shores. *Society for Conservation Biology* 7(2):378–390.

Klain, S. C., P. Olmsted, K. M. A. Chan, and T. Satterfield. 2017. Relational values resonate broadly and differently than intrinsic or instrumental values, or the New Ecological Paradigm. *PLoS ONE* 12(8):1–21.

Klain, S. C., T. A. Satterfield, and K. M. A. Chan. 2014. What matters and why? Ecosystem services and their bundled qualities. *Ecological Economics* 107:310–320.

Kleiber, D., L. M. Harris, and A. C. J. Vincent. 2014. Improving fisheries estimates by including women's catch in the Central Philippines. *Canadian Journal of Fisheries and Aquatic Sciences* 71(5):656–664.

Kleiber, D., L. M. Harris, and A. C. J. Vincent. 2015. Gender and small-scale fisheries: A case for counting women and beyond. *Fish and Fisheries* 16(4):547–562.

Koch, E. W., E. B. Barbier, B. R. Silliman, D. J. Reed, G. M. E. Perillo, S. D. Hacker, E. F. Granek, J. H. Primavera, N. Muthiga, S. Polasky, B. S. Halpern, C. J. Kennedy, C. V. Kappel, and E. Wolanski. 2009. Non-linearity in ecosystem services: Temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment* 7(1):29–37.

Kolding, J., C. Béné, and M. Bavinck. 2014. Small-scale fisheries: Importance, vulnerability and deficient knowledge. Page *in* S. Garcia, J. Rice, and A. Charles, editors. *Governance of Marine Fisheries and Biodiversity Conservation: Interaction and Co-evolution*. Wiley-Blackwell.

Kolding, J., and P. a. M. van Zwieten. 2011. The Tragedy of Our Legacy: How do Global Management Discourses Affect Small Scale Fisheries in the South? *Forum for Development Studies* 38(3060):267–297.

Kosoy, N., and E. Corbera. 2010. Payments for ecosystem services as commodity fetishism. *Ecological Economics* 69(6):1228–1236.

Kotzé, D. A. 2003. Role of women in the household economy, food production and food security: Policy guidelines. *Outlook on Agriculture* 32(2):111–121.

Koubrak, O., and D. L. VanderZwaag. 2020. Are transboundary fisheries management arrangements in the Northwest Atlantic and North Pacific seaworthy in a changing ocean? *Ecology and Society* 25(4):1.

Krinner, G., F. Germany, M. Shongwe, S. Africa, S. B. France, B. B. B. B. Uk, V. B. Germany, O. B. Uk, C. B. France, R. C. Uk, M. E. Canada, M. Erich, R. W. L. Uk, S. L. Uk, and C. Lucas. 2013. *Long-term climate change: Projections, commitments and irreversibility*. Page *Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Kronen, M., and A. Vunisea. 2007. Women never hunt- but fish: Highlighting equality for women in policy formulation and strategic planning in the coastal fisheries sector in the Pacific Island countries. *SPC Women in Fisheries Information Bulletin* (17):3.

Kyle, R., B. Pearson, P. J. Fielding, W. D. Robertson, and S. L. Birnie. 1997. Subsistence shellfish harvesting in the Maputaland Marine Reserve in northern Kwazulu-Natal, South Africa: Rocky shore organisms. *Biological Conservation* 82(2):183–192.

De La Torre-castro, M. 2019. Inclusive Management Through Gender Consideration in Small-Scale Fisheries : The Why and the How. *Frontiers in Life Science* 6(156).

de la Torre-Castro, M., S. Fröcklin, S. Börjesson, J. Okupnik, and N. S. Jiddawi. 2017. Gender analysis for better coastal management – Increasing our understanding of social-ecological seascapes. *Marine Policy* 83:62–74.

Langill, J. C. 2020. The co-production of gendered livelihoods and seasonal livelihoods in the floodplains of the Peruvian Amazon. *Gender, Place and Culture*:1–24.

Lapointe, M., G. G. Gurney, and G. S. Cumming. 2020. Perceived availability and access limitations to ecosystem service well-being benefits increase in urban areas. *Ecology and Society* 25(4):32.

Lau, J. D. 2020. Three lessons for gender equity in biodiversity conservation. *Conservation Biology* 34(6):1589–1591.

Lau, J. D., J. E. Cinner, M. Fabinyi, G. G. Gurney, and C. C. Hicks. 2020. Access to marine ecosystem services: Examining entanglement and legitimacy in customary institutions. *World Development* 126(104730).

Lau, J. D., C. C. Hicks, G. G. Gurney, and J. E. Cinner. 2018. Disaggregating ecosystem service values and priorities by wealth, age, and education. *Ecosystem Services* 29:91–98.

Lau, J. D., C. C. Hicks, G. G. Gurney, and J. E. Cinner. 2019. What matters to whom and why? Understanding the importance of coastal ecosystem services in developing coastal communities. *Ecosystem Services* 35:219–230.

Lau, J. D., D. Kleiber, S. Lawless, and P. J. Cohen. 2021. Gender equality in climate policy and practice hindered by assumptions. *Nature Climate Change* 11:186–192.

Lautenbach, S., A. Mupepele, C. F. Dormann, H. Lee, S. Schmidt, S. S. K. Scholte, R. Seppelt, A. J. A. Van Teeffelen, W. Verhagen, M. Volk, and S. Schmidt. 2019. Blind spots in ecosystem services research and challenges for implementation. *Regional Environmental Change* 19:2151–2172.

Lenth, R. 2019. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.4.

Lentisco, A., P. Rodrigues, M. Pereira, S. Needham, and D. Griffiths. 2013. *Case study: Supporting small-scale fisheries through the reactivation of fish-landing centres in Timor-Leste*.

Levy, M., S. Babu, K. Hamilton, V. Rhoe, A. Catenazzi, M. Chen, W. V. Reid, D. Sengupta, C. Ximing, A. Balmford, W. Bond, D. Rapport, and L. Zhang. 2005. Ecosystem Conditions and Human Well-being. Pages 125–164 *Ecosystems and Human Well-being: Current State and Trends*. Island Press, Washington, DC.

Lim, I. E., S. K. Wilson, T. H. Holmes, M. M. Noble, and C. J. Fulton. 2016. Specialization within a shifting habitat mosaic underpins the seasonal abundance of a tropical fish. *Ecosphere* 7(2):1–13.

Lima, M. S. P., J. E. L. Oliveira, M. F. de Nóbrega, and P. F. M. Lopes. 2017. The use of Local Ecological Knowledge as a complementary approach to understand the temporal and spatial patterns of fishery resources distribution. *Journal of Ethnobiology and Ethnomedicine* 13(1):1–13.

Liquete, C., C. Piroddi, E. G. Drakou, L. Gurney, S. Katsanevakis, A. Charef, and B. Egoh. 2013. Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review. *PLoS ONE* 8(7):15.

Llorente, I. D. P., H. M. Hoganson, M. Windmuller-Campione, and S. Miller. 2018. Using a marginal value approach to integrate ecological and economic objectives across the minnesota landscape. *Forests* 9(7):1–24.

Loftus, E., J. Lee-Thorp, M. Leng, C. Marean, and J. Sealy. 2019. Seasonal scheduling of shellfish collection in the Middle and Later Stone Ages of southern Africa. *Journal of Human Evolution* 128:1–16.

Longhurst, R., R. Chambers, and J. Swift. 1986. Seasonality and Poverty: Implications for Policy and Research. *IDS Bulletin* 17(3):67–71.

Loomis, D. K., and S. K. Paterson. 2014. The human dimensions of coastal ecosystem services: Managing for social values. *Ecological Indicators* 44:6–10.

Lopes, J. dos R., A. Duarte, and A. Tilley. 2020. *Strong Women , Strong Nation*. Page *Samudra Report 83*.

López Angarita, J., K. Hunnam, M. Pereira, D. Jonathan Mills, J. Pant, T. Shwu Jiau, H. Eriksson, L. Amaral, and A. Tilley. 2019. *Fisheries and aquaculture of Timor-Leste in 2019: Current knowledge and opportunities*. WorldFish: Penang, Malaysia.

MA. 2003. Dealing with scale. Pages 107–147 *Ecosystems and Human Well-being: A Framework for Assessment*. Millenium Ecosystem Assessment, Island Press, Washington, DC.

MA. 2005a. Introduction and conceptual framework. Pages 26–48 *Ecosystems and Human Well-being: A Framework for Assessment*. Millenium Ecosystem Assessment, Island Press, Washington, DC.

MA. 2005b. Ecosystems and their services. Pages 49–70 *Ecosystems and Human Well-being: A Framework for Assessment*. Millenium Ecosystem Assessment, Island Press, Washington, DC.

Mace, G. M. 2014. Whose conservation? *Science* 245(6204):1558–1560.

MacGregor, S. 2017. *Routledge Handbook of Gender and the Environment*. First edition. Routledge, New York, US.

Maes, J., B. Burkhard, and D. Geneletti. 2018. Ecosystem services are inclusive and deliver multiple values. A comment on the concept of nature's contributions to people. *One Ecosystem* 3:5.

MAF. 2018. *National coastal vulnerability assessment and designing of integrated coastal management and adaptation strategic plan for Timor-Leste*.

Mangi, S. C., and C. M. Roberts. 2006. Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin* 52:1646–1660.

Marschke, M. J., and F. Berkes. 2006. Exploring strategies that build livelihood resilience: A case from Cambodia. *Ecology and Society* 11(1):42.

Martín-López, B., E. Gómez-Baggethun, M. García-Llorente, and C. Montes. 2014. Trade-offs across value-domains in ecosystem services assessment. *Ecological Indicators* 37:220–228.

Martín-López, B., I. Iniesta-Arandia, M. García-Llorente, I. Palomo, I. Casado-Arzuaga, D. G. Del Amo, E. Gómez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. González, F. Santos-Martín, M. Onaindia, C. López-Santiago, and C. Montes. 2012. Uncovering ecosystem service bundles through social preferences. *PLoS ONE* 7(6).

Maynou, F., L. Recasens, and A. Lombarte. 2011. Fishing tactics dynamics of a Mediterranean small-scale coastal fishery. *Aquatic Living Resources* 24(2):149–159.

McGregor, J. A. 2008. Wellbeing, poverty and conflict. *Briefing Paper 1/08* February:1–4.

Mclaughlin, P., and T. Dietz. 2008. Structure, agency and environment: Toward an integrated perspective on vulnerability. *Global Environmental Change* 18:99–111.

McMichael, A., R. Scholes, M. Hefny, E. Pereira, C. Palm, S. Foale, R. Norgaard, and T. Wilbanks. 2005. Linking ecosystem Services and Human Well-Being. Pages 45–60 *Millenium Ecosystem Assessment*. Island Press, Washington, DC.

Mcmichael, C., M. Katonivualiku, and T. Powell. 2019. Planned relocation and everyday agency in low - lying coastal villages in Fiji. *The Geographical Journal* 185(3):325–337.

McMillan, L. J., and K. Prosper. 2016. Remobilizing netukulimk: indigenous cultural and

spiritual connections with resource stewardship and fisheries management in Atlantic Canada. *Reviews in Fish Biology and Fisheries* 26(4):629–647.

McWilliam, A. 2002. Timorese seascapes: Perspectives on customary marine tenures in east timor. *Asia Pacific Journal of Anthropology* 3(2):6–32.

Mehring, M., U. Zajonz, and D. Hummel. 2017. Social-ecological dynamics of ecosystem services: Livelihoods and the functional relation between ecosystem service supply and demand-evidence from socotra archipelago, yemen and the sahel region, West Africa. *Sustainability* 9:15.

Mercer, J. 2007. The challenges of insider research in educational institutions : wielding a double - edged sword and resolving delicate dilemmas. *Oxford Review of Education* 33(1):1–17.

Mills, D., K. Abernethy, J. King, E. Hoddy, T. S. Jiau, P. Larocca, D. Gonsalves, A. Fernandes, and S. Park. 2013. *Developing Timor-Leste's coastal economy : Assessing potential climate change impacts and adaptation options.* WorldFish: Penang, Malaysia.

Mills, D. J., A. Tilley, M. Pereira, D. Hellebrandt, A. Pereira, and P. J. Cohen. 2017. Livelihood diversity and dynamism in Timor-Leste; insights for coastal resource governance and livelihood development. *Marine Policy* 82:206–215.

Molyneux, N., G. Rangel, R. L. Williams, R. Andersen, and N. C. Turner. 2012. Climate Change and Population Growth in Timor Leste : Implications for Food Security. *Ambio* 41:823–840.

Moon, K., D. A. Blackman, V. M. Adams, R. M. Colvin, F. Davila, M. C. Evans, S. R. Januchowski-Hartley, N. J. Bennett, H. Dickinson, C. Sandbrook, K. Sherren, F. A. V. St. John, L. van Kerkhoff, and C. Wyborn. 2019. Expanding the role of social science in conservation through an engagement with philosophy, methodology, and methods. *Methods in Ecology and Evolution* 10(3):294–302.

Moreno-Báez, M., R. Cudney-Bueno, B. J. Orr, W. W. Shaw, T. Pfister, J. Torre-Cosio, R. Loaiza, and M. Rojo. 2012. Integrating the spatial and temporal dimensions of fishing activities for management in the Northern Gulf of California, Mexico. *Ocean and Coastal Management* 55:111–127.

Moser, S. 2008. Personality: A new positionality? *Area* 40(3):383–392.

Myers, R., and C. P. Hansen. 2020. Revisiting A Theory of Access : A review. *Society & Natural Resources* 33(2):146–166.

Nahlik, A. M., M. E. Kentula, M. S. Fennessy, and D. H. Landers. 2012. Where is the consensus? A proposed foundation for moving ecosystem service concepts into practice. *Ecological Economics* 77:27–35.

Neiland, A. E., J. Weeks, S. P. Madakan, and B. M. B. Ladu. 2000. Inland fisheries of North East Nigeria including the Upper River Benue, Lake Chad and the Nguru-Gashua wetlands II. Fisheries management at village level. *Fisheries Research* 48(3):245–261.

Nelson, G. C. 2005. Drivers of ecosystem change: summary chapter. Pages 73–76 *Ecosystems and Human Well-being: Current State and Trends*.

Nisbet, E. K., J. M. Zelenski, and S. A. Murphy. 2011. Happiness is in our Nature: Exploring Nature Relatedness as a Contributor to Subjective Well-Being. *Journal of Happiness Studies* 12(2):303–322.

Oliver, T. A., K. L. L. Oleson, H. Ratsimbazafy, D. Raberinary, S. Benbow, and A. Harris. 2015. Positive catch & economic benefits of periodic octopus fishery closures: Do

effective, narrowly targeted actions “catalyze” broader management? *PLoS ONE* 10(6):1–24.

van Oort, B., L. D. Bhatta, H. Baral, R. K. Rai, M. Dhakal, I. Rucevska, and R. Adhikari. 2015. Assessing community values to support mapping of ecosystem services in the Koshi river basin, Nepal. *Ecosystem Services* 13:70–80.

Oppenheimer, M., B. Glavovic, J. Hinkel, R. van de Wal, A. K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R. M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari. 2019. Chapter 4: Sea Level Rise and Implications for Low Lying Islands, Coasts and Communities. Pages 126–129 *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*.

Osborne, J. 2008. *Best practices in quantitative methods*. SAGE.

Outeiro, L., E. Ojea, J. Garcia Rodrigues, A. Himes-Cornell, A. Belgrano, Y. Liu, E. Cabecinha, C. Pita, G. Macho, and S. Villasante. 2017. The role of non-natural capital in the co-production of marine ecosystem services. *International Journal of Biodiversity Science, Ecosystem Services and Management* 13(3):35–50.

Palmer, L., and D. do A. de Carvalho. 2008. Nation building and resource management: The politics of “nature” in Timor Leste. *Geoforum* 39(3):1321–1332.

Pascual, U., P. Balvanera, S. Díaz, G. Pataki, E. Roth, M. Stenseke, R. T. Watson, E. Başak Dessane, M. Islar, E. Kelemen, V. Maris, M. Quaas, S. M. Subramanian, H. Wittmer, A. Adlan, S. E. Ahn, Y. S. Al-Hafedh, E. Amankwah, S. T. Asah, P. Berry, A. Bilgin, S. J. Breslow, C. Bullock, D. Cáceres, H. Daly-Hassen, E. Figueroa, C. D. Golden, E. Gómez-Baggethun, D. González-Jiménez, J. Houdet, H. Keune, R. Kumar, K. Ma, P. H. May, A. Mead, P. O’Farrell, R. Pandit, W. Pengue, R. Pichis-Madruga, F. Popa, S. Preston, D. Pacheco-Balanza, H. Saarikoski, B. B. Strassburg, M. van den Belt, M. Verma, F. Wickson, and N. Yagi. 2017. Valuing nature’s contributions to people: the IPBES approach. *Current Opinion in Environmental Sustainability* 26:7–16.

Payne, R. 2012. ‘Extraordinary survivors’ or ‘ordinary lives’’? Embracing “everyday agency” in social interventions with child-headed households in Zambia.’ *Children’s Geographies* 10(4):399–411.

PCCSP. 2015. *Current and future climate of Timor-Leste*. Page *Pacific-Australia Climate Change Science and Adaptation Planning Program*.

Peterson, D., and V. Parker. 1998. *Ecological scale: theory and application*. Columbia University Press.

Peterson, G. D., Z. V. Harmáčková, M. Meacham, C. Queiroz, A. Jiménez-Aceituno, J. J. Kuiper, K. Malmborg, N. Sitas, and E. M. Bennett. 2018. Welcoming different perspectives in IPBES: “nature’s contributions to people” and “ecosystem services.” *Ecology and Society* 23(1):39.

Pfeiffer, L. 2020. How storms affect fishers’ decisions about going to sea. *ICES Journal of Marine Science*:10.

PIFSC. 2017. *Interdisciplinary baseline ecosystem assessment surveys to inform ecosystem-based management planning in Timor-Leste: Final Report*. Pacific Islands Fisheries Science Centre.

Poppy, G. M., S. Chiotha, F. Eigenbrod, C. A. Harvey, M. Honzák, M. D. Hudson, A. Jarvis, N. J. Madise, K. Schreckenberg, C. M. Shackleton, F. Villa, and T. P. Dawson. 2014. Food security in a perfect storm: Using the ecosystem services framework to increase understanding. *Philosophical Transactions of the Royal Society B: Biological Sciences* 369(20120288):13.

Poteete, A. R., M. A. Janssen, and E. Ostrom. 2010. *Working together: collective action, the*

commons, and multiple methods in practice. Princeton University Press.

Potschin-Young, M., R. Haines-Young, C. Görg, U. Heink, K. Jax, and C. Schleyer. 2018. Understanding the role of conceptual frameworks: Reading the ecosystem service cascade. *Ecosystem Services* 29:428–440.

Prendergast, A. L., R. E. Stevens, T. C. O'Connell, A. Fadlalak, M. Touati, A. al-Mzeine, B. R. Schöne, C. O. Hunt, and G. Barker. 2016. Changing patterns of eastern Mediterranean shellfish exploitation in the Late Glacial and Early Holocene: Oxygen isotope evidence from gastropod in Epipaleolithic to Neolithic human occupation layers at the Haua Fteah cave, Libya. *Quaternary International* 407:80–93.

Queiroz, C., M. Meacham, K. Richter, A. V. Norström, E. Andersson, J. Norberg, and G. Peterson. 2015. Mapping bundles of ecosystem services reveals distinct types of multifunctionality within a Swedish landscape. *Ambio* 44(1):89–101.

Quisumbing, A. R., L. R. Brown, H. S. Feldstein, L. Haddad, and C. Peña. 1996. Women: The Key to Food Security. *Food and Nutrition Bulletin* 17(1):1–2.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rademacher, A., M. L. Cadenasso, and S. T. A. Pickett. 2019. From feedbacks to coproduction: toward an integrated conceptual framework for urban ecosystems. *Urban Ecosystems* 22(1):65–76.

Rau, A. L., V. Burkhardt, C. Dorninger, C. Hjort, K. Ibe, L. Keßler, J. A. Kristensen, A. McRobert, W. Sidemo-Holm, H. Zimmermann, D. J. Abson, H. von Wehrden, and J. Ekroos. 2020. Temporal patterns in ecosystem services research: A review and three recommendations. *Ambio* 49(8):1377–1393.

Rau, A. L., H. von Wehrden, and D. J. Abson. 2018. Temporal Dynamics of Ecosystem Services. *Ecological Economics* 151:122–130.

Raudsepp-hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences* 107(11):5242–5247.

Reardon, T., and P. Matlon. 1989. Seasonal Food Insecurity and Vulnerability in Drought-Affected Regions of Burkina Faso. Pages 118–136 *Seasonal Variability in Third World Agriculture: The Consequences for Food Security*. John Hopkins University Press, Baltimore, USA.

Renard, D., J. M. Rhemtulla, and E. M. Bennett. 2015. Historical dynamics in ecosystem service bundles 112(43):13411–13416.

Rewitzer, S., R. Huber, A. Grêt-Regamey, and J. Barkmann. 2017. Economic valuation of cultural ecosystem service changes to a landscape in the Swiss Alps. *Ecosystem Services* 26:197–208.

Reyers, B., R. Biggs, G. S. Cumming, T. Elmqvist, A. P. Hejnowicz, and S. Polasky. 2013. Getting the measure of ecosystem services: A social-ecological approach. *Frontiers in Ecology and the Environment* 11(5):268–273.

Ribot, J. C., and N. L. Peluso. 2003. A theory of access. *Rural Sociology* 68(2):153–181.

Richardson, R. B. 2010. Ecosystem services and food security: Economic perspectives on environmental sustainability. *Sustainability* 2(11):3520–3548.

Ricketts, T. H., and E. Lonsdorf. 2013. Mapping the margin: Comparing marginal values of tropical forest remnants for pollination services. *Ecological Applications* 23(5):1113–1123.

Rieb, J. T., R. Chaplin-Kramer, G. C. Daily, P. R. Armsworth, K. Böhning-Gaese, A. Bonn, G. S. Cumming, F. Eigenbrod, V. Grimm, B. M. Jackson, A. Marques, S. K. Pattanayak, H. M. Pereira, G. D. Peterson, T. H. Ricketts, B. E. Robinson, M. Schröter, L. A. Schulte, R. Seppelt, M. G. Turner, and E. M. Bennett. 2017. When, Where, and How Nature Matters for Ecosystem Services: Challenges for the Next Generation of Ecosystem Service Models. *BioScience* 67(9):820–833.

Rohe, J. R., S. Aswani, A. Schlüter, and ... 2017. Multiple Drivers of Local (Non-) Compliance in Community-Based Marine Resource Management: Case Studies from the South Pacific. *Frontiers in Marine Science* 4(172).

Rojas, M. 2011. Happiness, Income, and Beyond. *Applied Research in Quality of Life* 6(3):265–276.

Rosegrant, M. W., M. M. Dey, R. Valmonte-Santos, and O. L. Chen. 2016. Economic impacts of climate change and climate change adaptation strategies in Vanuatu and Timor-Leste. *Marine Policy* 67:179–188.

Ryan, G. 2018. Introduction to positivism, interpretivism and critical theory. *Nurse Researcher* 25(4):14–20.

Sainsbury, N. C., M. J. Genner, G. R. Saville, J. K. Pinnegar, C. K. O. Neill, S. D. Simpson, and R. A. Turner. 2018. Changing storminess and global capture fisheries. *Nature Climate Change* 8:655–659.

Sandlund, O. T., I. Bryceson, D. De Carvalho, N. Rio, J. Silva, and M. I. Silva. 2001. *Assessing Environmental Needs and Priorities in East Timor*. Trondheim.

Sarch, T., and C. Birkett. 2000. Fishing and farming at Lake Chad: responses to lake-level fluctuations. *The Geographical Journal* 166(2):156–172.

Savy, M., F. Delpeuch, S. Eymard-Duvernay, P. Traissac, and Y. Martin-Prével. 2018. Dietary Diversity Scores and Nutritional Status of Women Change during the Seasonal Food Shortage in Rural Burkina Faso. *The Journal of Nutrition* 136(10):2625–2632.

Scheyvens, R., and H. Leslie. 2000. Gender, ethics and empowerment. *Women's Studies International Forum* 23(1):119–130.

Scholes, R. J., B. Reyers, R. Biggs, M. J. Spierenburg, and A. Duriappah. 2013. Multi-scale and cross-scale assessments of social-ecological systems and their ecosystem services. *Current Opinion in Environmental Sustainability* 5(1):16–25.

Scoones, I. 1998. Sustainable rural livelihoods - A framework for analysis. *IDS Working paper 72*:22.

Selimovic, J. M. 2019. Everyday agency and transformation: Place, body and story in the divided city. *Cooperation and Conflict* 54(2):131–148.

Siar, S. V. 2003. Knowledge, gender, and resources in small-scale fishing: the case of Honda Bay, Palawan, Philippines. *Environmental Management* 31(5):569–580.

Sievanen, L. 2014. How do small-scale fishers adapt to environmental variability? Lessons from Baja California, Sur, Mexico. *Maritime Studies* 13(1):1–19.

Solé, L., and E. Ariza. 2019. A wider view of assessments of ecosystem services in coastal areas: the perspective of social-ecological complexity. *Ecology and Society* 24(2):24.

Sousa-santos, J. K. L. 2015. Acting West, Looking East: Timor-Leste's Growing Engagement with the Pacific Islands Region. Pages 110–121 *in* R. Azizian and C. Cramer, editors. *Regionalism, Security & Cooperation in Oceania*. Asia Pacific Center for Security Studies, Honolulu, Hawaii.

Spangenberg, J. H., C. Görg, D. T. Truong, V. Tekken, J. V. Bustamante, and J. Settele. 2014a. Provision of ecosystem services is determined by human agency, not ecosystem functions. Four case studies. *International Journal of Biodiversity Science, Ecosystem Services and Management* 10(1):40–53.

Spangenberg, J. H., C. von Haaren, and J. Settele. 2014b. The ecosystem service cascade: Further developing the metaphor. Integrating societal processes to accommodate social processes and planning, and the case of bioenergy. *Ecological Economics* 104:22–32.

Spencer, P. R., K. A. Sanders, P. Canisio Amaral, and D. S. Judge. 2017. Household resources and seasonal patterns of child growth in rural Timor-Leste. *American Journal of Human Biology* 29(1):1–17.

Steenbergen, D. J., H. Eriksson, K. Hunnam, D. J. Mills, and N. Stacey. 2019a. Following the fish inland: understanding fish distribution networks for rural development and nutrition security. *Food Security* 11(6):1417–1432.

Steenbergen, D. J., M. Fabinyi, K. Barclay, A. M. Song, P. J. Cohen, H. Eriksson, and D. J. Mills. 2019b. Governance interactions in small-scale fisheries market chains: Examples from the Asia-Pacific. *Fish and Fisheries* 20(4):697–714.

Steffen, W., J. Rockström, K. Richardson, T. M. Lenton, C. Folke, D. Liverman, C. P. Summerhayes, A. D. Barnosky, S. E. Cornell, M. Crucifix, J. F. Donges, I. Fetzer, S. J. Lade, M. Scheffer, R. Winkelmann, and H. J. Schellnhuber. 2018. Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences of the United States of America* 115(33):8252–8259.

Tanner, T., D. Lewis, D. Wrathall, R. Bronen, N. Cradock-Henry, S. Huq, C. Lawless, R. Nawrotzki, V. Prasad, M. A. Rahman, R. Alaniz, K. King, K. McNamara, M. Nadiruzzaman, S. Henly-Shepard, and F. Thomalla. 2015. Livelihood resilience in the face of climate change. *Nature Climate Change* 5(1):23–26.

Teh, L. S. L., L. C. L. Teh, and U. R. Sumaila. 2013. A Global Estimate of the Number of Coral Reef Fishers. *PLoS ONE* 8(6).

Teh, L. S. L., D. Zeller, A. Cabanban, L. C. L. Teh, and U. R. Sumaila. 2007. Seasonality and historic trends in the reef fisheries of Pulau Banggi, Sabah, Malaysia. *Coral Reefs* 26(2):251–263.

Thomas, A. S., S. Mangubhai, C. Vandervord, M. Fox, and Y. Nand. 2019. Impact of Tropical Cyclone Winston on women mud crab fishers in Fiji. *Climate and Development* 11(8):699–709.

Tilley, A., A. Burgos, A. Duarte, J. dos R. Lopes, H. Eriksson, and D. Mills. 2020. Contribution of women's fisheries substantial, but overlooked, in Timor-Leste. *Ambio*:1–12.

Tilley, A., K. J. Hunnam, D. J. Mills, D. J. Steenbergen, H. Govan, E. Alonso-Poblacion, M. Roscher, M. Pereira, P. Rodrigues, T. Amador, A. Duarte, M. Gomes, and P. J. Cohen. 2019a. Evaluating the fit of co-management for small-scale fisheries governance in timor-leste. *Frontiers in Marine Science* 6(392).

Tilley, A., S. P. Wilkinson, J. Kolding, J. López-Angarita, M. Pereira, and D. J. Mills. 2019b. Nearshore fish aggregating devices show positive outcomes for sustainable fisheries development in Timor-Leste. *Frontiers in Marine Science* 6(JUL):1–13.

Tschakert, P., J. Barnett, N. Ellis, C. Lawrence, N. Tuana, M. New, C. Elrick-Barr, R. Pandit, and D. Pannell. 2017. Climate change and loss, as if people mattered: values, places, and experiences. *Wiley Interdisciplinary Reviews: Climate Change* 8(5):1–19.

Turner, R. K., J. Paavola, P. Cooper, S. Farber, V. Jessamy, and S. Georgiou. 2003. Valuing

nature: Lessons learned and future research directions. *Ecological Economics* 46(3):493–510.

UN. 2015. *Transforming our world: The 2030 agenda for sustainable development*. New York, US.

UNDP. 2018. *Human development indices and indicators: 2018 statistical update*. United Nations Development Programme.

United Nations. (n.d.). Rural Women - Overview:Food security. https://www.un.org/womenwatch/feature/ruralwomen/overview-food-security.html.

Vaitla, B., S. Devereux, and S. H. Swan. 2009. Seasonal hunger: A neglected problem with proven solutions. *PLoS Medicine* 6(6).

Vaughan, M. B., and P. M. Vitousek. 2013. Mahele: Sustaining Communities through Small-Scale Inshore Fishery Catch and Sharing Networks. *Pacific Science* 67(3):329–344.

Venables, W. N., and B. D. Ripley. 2002. Modern Applied Statistics with S. Fourth edition. Springer.

Vierikko, K., and V. Yli-Pelkonen. 2019. Seasonality in recreation supply and demand in an urban lake ecosystem in Finland. *Urban Ecosystems* 22(4):769–783.

Villamagna, A. M., P. L. Angermeier, and E. M. Bennett. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity* 15:114–121.

De Vynck, J. C., R. Anderson, C. Atwater, R. M. Cowling, E. C. Fisher, C. W. Marean, R. S. Walker, and K. Hill. 2016. Return rates from intertidal foraging from Blombos Cave to Pinnacle Point: Understanding early human economies. *Journal of Human Evolution* 92:101–115.

Ware, J., and K. Kramer. 2019. *Hunger Strike: The climate and food vulnerability index*. London.

Weeratunge, N., C. Béné, R. Siriwardane, A. Charles, D. Johnson, E. H. Allison, P. K. Nayak, and M. C. Badjeck. 2014. Small-scale fisheries through the wellbeing lens. *Fish and Fisheries* 15(2):255–279.

WFP. 2018. *WFP Timor-Leste Country Brief*.

Wheeler, T., and J. Von Braun. 2013. Climate change impacts on global food security. *Science* 341:508–513.

White, S. C. 2009. *Bringing Wellbeing into Development Practice*.

Whittingham, E., J. Campbell, and P. Townsley. 2003. *Poverty and reefs*. Page *Dfid–Imm–Ioc/Unesco*.

Wieland, R., S. Ravensbergen, E. J. Gregr, T. Satterfield, and K. M. A. Chan. 2016. Debunking trickle-down ecosystem services: The fallacy of omnipotent, homogeneous beneficiaries. *Ecological Economics* 121:175–180.

Wilbanks, T. J. 2006. 2. How Scale Matters: Some concepts and findings. Pages 20–126 *in* W. V. Reid, F. Berkes, D. Capistrano, and T. J. Wilbanks, editors. *Bridging Scales and Knowledge Systems : Concepts and Applications in Ecosystem Assessment*. Island Press, Washington, DC.

Winterhalder, B. 1986. Diet choice, risk, and food sharing in a stochastic environment. *Journal of Anthropological Archaeology* 5(4):369–392.

Winterhalder, B. 1990. Open field, common pot: Harvest variability and risk avoidance in agricultural and foraging societies. Pages 67–87 *Risk and Uncertainty in Tribal and Peasant Economies*.

Wong, P. P., I. J. Losada, J.-P. Gattuso, J. Hinkel, A. Khattabi, K. McInnes, Y. Saito, and A. Sallenger. 2014. Coastal Systems and Low-Lying Areas. Pages 361–409 *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

World Bank. 2016. *Poverty in Timor-Leste 2014*.

World Bank. 2018. *Timor-Leste Systematic Country Diagnostic*. Page *Timor-Leste Systematic Country Diagnostic*.

World Bank, FAO, and WorldFish. 2012. *The Hidden Harvests. The Global Contribution of Capture Fisheries*. World Bank, Washington, DC.

Yang, W., T. Dietz, W. Liu, J. Luo, and J. Liu. 2013. Going Beyond the Millennium Ecosystem Assessment: An Index System of Human Dependence on Ecosystem Services. *PLoS ONE* 8(5).

Yin, R. K. 2009. *Case study research: design and methods*. Fourth. SAGE.

Zoderer, B. M., E. Tasser, S. Carver, and U. Tappeiner. 2019. Stakeholder perspectives on ecosystem service supply and ecosystem service demand bundles. *Ecosystem Services* 37:100938.

APPENDICES

APPENDIX A: SUPPLEMENTARY MATERIAL FOR CHAPTER 2

APPENDIX A.1. PANEL SURVEY – SUBSET OF QUESTIONS USED TO COLLECT DATA ON DAILY FISHING AND CATCH USE

Household panel survey

Fishing activities

Did anyone in your household go fishing yesterday? (select one):

(●) Yes ( ) No

» Catch information

How many fish did they catch?

» » How many of the fish caught were used in each way?

Eaten fresh by the household	Sold fresh	Dried to be eaten by the household	Dried to be sold	Shared with friends/family

APPENDIX A.2. KEY INFORMANT INTERVIEW QUESTIONS FOR DIFFERENT LIVELIHOOD ACTIVITIES

Fishing

1. Typical months of fishing seasons:

    a) Good season?

    b) Bad season?

    c) Moderate season?

2. In each season:

    a) How often do you go fishing? How do you decide when to fish? (preference, need, weather)

    b) How long do you spend fishing? What determines time spent? (preference, time limitation, catch, weather)

    c) Where do you go fishing? What determines where you go fishing?

    d) What fishing methods do you use? How do you decide which fishing method to use?

    e) What are the main catch species? What determines the type of fish you catch? (season, location, gear)

    f) How much fish do you catch on a typical trip? Do you catch enough fish?

    g) What is catch used for? (selling fresh/dry, eating fresh/dried, gifting) How do you decide how to use catch?

3. What is the selling price of fish? What determines price and how does price vary (season, location)?

4. What is the money earnt from fishing used for? (daily needs, savings, reinvested)

5. Gifting fish - to who/what type of fish/when, how often/why/reciprocity

6. Do you go fishing alone or with other people? Who do you fish with?

7. What rules are there about fishing and who decides the rules about fishing?

8. What do you enjoy about fishing?

9. What are the key challenges you face in fishing?

10. Have you ever experienced a time when the fishing was much worse than usual? (situation, response, implications)

11. Have you ever experienced a time when the fishing was much better than usual? (situation, response, implications)

12. During your lifetime, have you noticed changes in fishing conditions or fish catches?

Gleaning

1. Typical months of gleaning seasons:

    a) Good season?

    b) Bad season?

    c) Moderate season?

2. In each season:

a) How often do you go gleaning? How do you decide when to glean? (preference, need, weather)

b) How long do you spend gleaning? What determines time spent? (preference, time limitation, catch, weather)

c) Where do you go gleaning? What determines where you go gleaning?

d) What gleaning methods do you use? How do you decide which gleaning method to use?

e) What are the main species you collect? What determines what you collect? (season, location, gear)

f) How much do you collect on a typical trip? Do you find enough?

g) What is catch used for? (selling fresh/dried, eating fresh/dried, gifting) How do you decide how to use catch?

3. What is the selling price of gleaned species? What determines price and how does price vary (season, location)?

4. What is the money earnt from gleaning used for? (daily needs, savings, reinvested)

5. Gifting glean - to who/what type/when, how often/why/reciprocity

6. Do you go gleaning alone or with other people? Who do you glean with?

7. What rules are there about gleaning and who decides the rules about gleaning?

8. What do you enjoy about gleaning?

9. What are the key challenges you face in gleaning?

10. Have you ever experienced a time when the gleaning was much worse than usual? (situation, response, implications)

11. Have you ever experienced a time when the gleaning was much better than usual? (situation, response, implications)

12. During your lifetime, have you noticed changes in gleaning conditions or glean catches?

Crop farming

1. Typical months of farming seasons:

a) Peak harvest?

b) Some harvest?

c) Planting?

d) Land clearing?

2. What crops do you farm? (harvest months and key uses of crop types)

3. In each season:

a) How often do you do farming? What determines when you do farming? (preference, need, weather)

b) How long do you spend farming? What determines time spent? (preference, time limitation, catch, weather)

4. Where are your crop fields? How do you decide where to plant different crops?

5. How much do you harvest in a normal year?

6. Do you farm crops alone or with other people? Who do you farm with?

7. What defines a good year for crop farming?

8. What defines a bad year for crop farming?

9. What factors affect crop farming and how?

10. What is the selling price for crops? What determines price and how does price vary (season, location)?

11. What is the money earnt from crops used for? (daily needs, savings, reinvested)

12. Gifting crops - to who/what type of fish/when, how often/why/reciprocity

13. What do you enjoy about crop farming?

14. What are the key challenges you face in farming?

15. Have you ever experienced a time when farming was much worse than usual? (situation, response, implications)

16. Have you ever experienced a time when farming was much better than usual? (situation, response, implications)

17. During your lifetime, have you noticed changes in farming conditions or harvests?

Livestock

1. Typical months of livestock seasons:

    a) Healthy?

    b) Sick?

    c) Trading?

    d) Gifting?

2. What livestock do you have? (numbers of adult/young and key uses)

3. What do you feed livestock, how often do you feed them and how long does it take to collect/prepare feed?

4. What determines how and when you use livestock?

5. What is the selling price of livestock? What are the determines price and how does price vary (season, location)?

6. What is the money earnt from livestock used for? (daily needs, savings, reinvested)

7. Do you owe anybody livestock? (what, why, when)

8. Does anyone owe you livestock? (what, why, when)

9. Gifting livestock - to who/what type of fish/when, how often/why/reciprocity

10. What rules are there about livestock and who decides the rules about livestock?

11. What do you enjoy about livestock rearing?

12. What are the key challenges you face in livestock rearing?

13. Have you ever experienced a very bad time for livestock? (situation, response, implications)

14. Have you ever experienced a very good time for livestock? (situation, response, implications)

15. During your lifetime, have you noticed changes in livestock? (health, price, numbers)

APPENDIX A.3. HARD-FORMAT ADAPTATION OF THE DIGITAL HOUSEHOLD SURVEY.

Date		Interview number		Village	

1. Consent

Read the following statement to the respondent: *This survey is part of the research activities of Miss Ruby Grantham. During the interview you will be asked about the livelihood activities that your household carries out, household consumption and gifting and trading activities. All data collected will beanonymous. The information will be used to support research that will be presented in scientific publications and social media. The survey will take 30-60 minutes. If you agree to participate, you are able to withdraw at any point. Do you have any questions? Please sign the form provided to indicate you are willing to participate.*

Signed

2. Household head

	Gender			**Age**					**Education**			
	Male	Female		Child <11	Youth 11-17	Adult 18-60	Elderly >60		None	Primary	Second.	Tertiary
✓ (1)			✓ (1)					✓ (1)				

3. Household socio-demographics

Household members (n)		**Livelihood activities**	✓	**House material**	✓(1)
Children (<11 yrs)		Crop farming		Wood	
Female youth (11-17 yrs)		Livestock rearing		Brick	
Male youth (11-17 yrs)		Fishing		Combined	
Female adults (18-60 yrs)		Gleaning			
Male adults (18-60 yrs)		Seaweed farming		**Assets**	✓
Female elderly (>60 yrs)		Fish processing		Phone	
Male elderly (>60 yrs)		Fish trade		Solar panel	
Total (sum and confirm)		Labour		Generator (access)	
		Kiosk		TV	
Livestock (n)		Boat transportation		Remittances	
Pigs		Tourism		Savings	
Goats		Salary			
Dogs		Other (specify)			
Chickens					
Ducks					
Other					
Land (n)		What is the most important livelihood activity for this household?			
Sm. fields					
Big fields					

4. Fishing activities

4.A. In the CALM SEASON...		**4.B. In the ROUGH SEASON...**	
How often does anyone in this household fish? ✓ (1)		**How often does anyone in this household fish? ✓ (1)**	
Multiple times a day		Multiple times a day	
Once a day		Once a day	
Multiple times a week		Multiple times a week	
Once a week		Once a week	
Less than once a week		Less than once a week	
Never (skip to rough season fishing 4.B.)		Never (skip to gleaning 5)	

In the CALM SEASON:

Who fishes ✓

Children <11 yrs	Youth 11-17yrs		Adults 18-60 yrs		Elderly >60 yrs	
	Female	Male	Female	Male	Female	Male

Travel time to fishing locations ✓

In the village		Far (30-120 mins)	
Close (< 30 mins)		Distant (>120 mins)	

Typical time spent fishing ✓ (1)

< 30min	< 90min	< 3 hrs	< 6 hrs	> 6 hrs

Habitats fished ✓

Reef		Drop-off		Sea/other	

Methods used ✓

Gillnet	Spear	Spear (night)	Trap	Line	Other

Catch groups

	Fusilier	Reef fish	Pelagic fish	Octopus	Other
✓					
Main ✓(1)					

Typical pieces ✓ (1)

<5	5-10	11-20	21-40	41-60	61-100	>100

Rate catch ✓ (1)

V. bad	Bad	Okay	Good	V. good

Uses ✓

Eat fresh	Eat dry	Sell fresh	Sell dry	Share

In the ROUGH SEASON:

Who fishes ✓

Children <11 yrs	Youth 11-17yrs		Adults 18-60 yrs		Elderly >60 yrs	
	Female	Male	Female	Male	Female	Male

Travel time to fishing locations ✓

In the village		Far (30-120 mins)	
Close (< 30 mins)		Distant (>120 mins)	

Typical time spent fishing ✓ (1)

< 30min	< 90min	< 3 hrs	< 6 hrs	> 6 hrs

Habitats fished ✓

Reef		Drop-off		Sea/other	

Methods used ✓

Gillnet	Spear	Spear (night)	Trap	Line	Other

Catch groups

	Fusilier	Reef fish	Pelagic fish	Octopus	Other
✓					
Main ✓(1)					

Typical pieces ✓ (1)

<5	5-10	11-20	21-40	41-60	61-100	>100

Rate catch ✓ (1)

V. bad	Bad	Okay	Good	V. good

Uses ✓

Eat fresh	Eat dry	Sell fresh	Sell dry	Share

5. Gleaning activities

5.A. In the CALM SEASON…

How often does anyone in this household glean? ✓ (1)

Multiple times a day	
Once a day	
Multiple times a week	
Once a week	
Less than once a week	
Never (skip to rough season fishing 4.B.)	

In the CALM SEASON:

Who gleans ✓

Children <11 yrs	Youth 11-17yrs		Adults 18-60 yrs		Elderly >60 yrs	
	Female	Male	Female	Male	Female	Male

Travel time to gleaning locations ✓

In the village		Far (30-120 mins)	
Close (< 30 mins)		Distant (>120 mins)	

Typical time spent gleaning ✓ (1)

< 30min	< 90min	< 3 hrs	< 6 hrs	> 6 hrs

Habitats gleaned ✓

Tidal flats		Shallows	

Catch groups

	Shells	Crabs	Eels	Tiny fish	Fish	Octopus
✓						
Main ✓(1)						
Other						

Typical basket level ✓ (1)

Low (1/4)	Mid (1/2)	High (3/4)	Full

Rate catch ✓ (1)

V. bad	Bad	Okay	Good	V. good

Uses ✓

Eat fresh	Eat dry	Sell fresh	Sell dry	Share

5.B. In the ROUGH SEASON…

How often does anyone in this household glean? ✓ (1)

Multiple times a day	
Once a day	
Multiple times a week	
Once a week	
Less than once a week	
Never (skip to gleaning 5)	

In the ROUGH SEASON:

Who gleans ✓

Children <11 yrs	Youth 11-17yrs		Adults 18-60 yrs		Elderly >60 yrs	
	Female	Male	Female	Male	Female	Male

Travel time to gleaning locations ✓

In the village		Far (30-120 mins)	
Close (< 30 mins)		Distant (>120 mins)	

Typical time spent gleaning ✓ (1)

< 30min	< 90min	< 3 hrs	< 6 hrs	> 6 hrs

Habitats gleaned ✓

Tidal flats		Shallows	

Catch groups

	Shells	Crabs	Eels	Tiny fish	Fish	Octopus
✓						
Main ✓(1)						
Other						

Typical basket level ✓ (1)

Low (1/4)	Mid (1/2)	High (3/4)	Full

Rate catch ✓ (1)

V. bad	Bad	Okay	Good	V. good

Uses ✓

Eat fresh	Eat dry	Sell fresh	Sell dry	Share

6. Seafood consumption

6.A. In the CALM SEASON…

How often does this household eat these types of seafood in a typical week

Fresh fish	
Dry fish	
Shells	
Other seafood	

Where does seafood eaten by this household come from?

	✓	Main ✓(1)
Caught by household		
Bought		
Gifted from another household		

6.B. In the ROUGH SEASON…

How often does this household eat these types of seafood in a typical week

Fresh fish	
Dry fish	
Shells	
Other seafood	

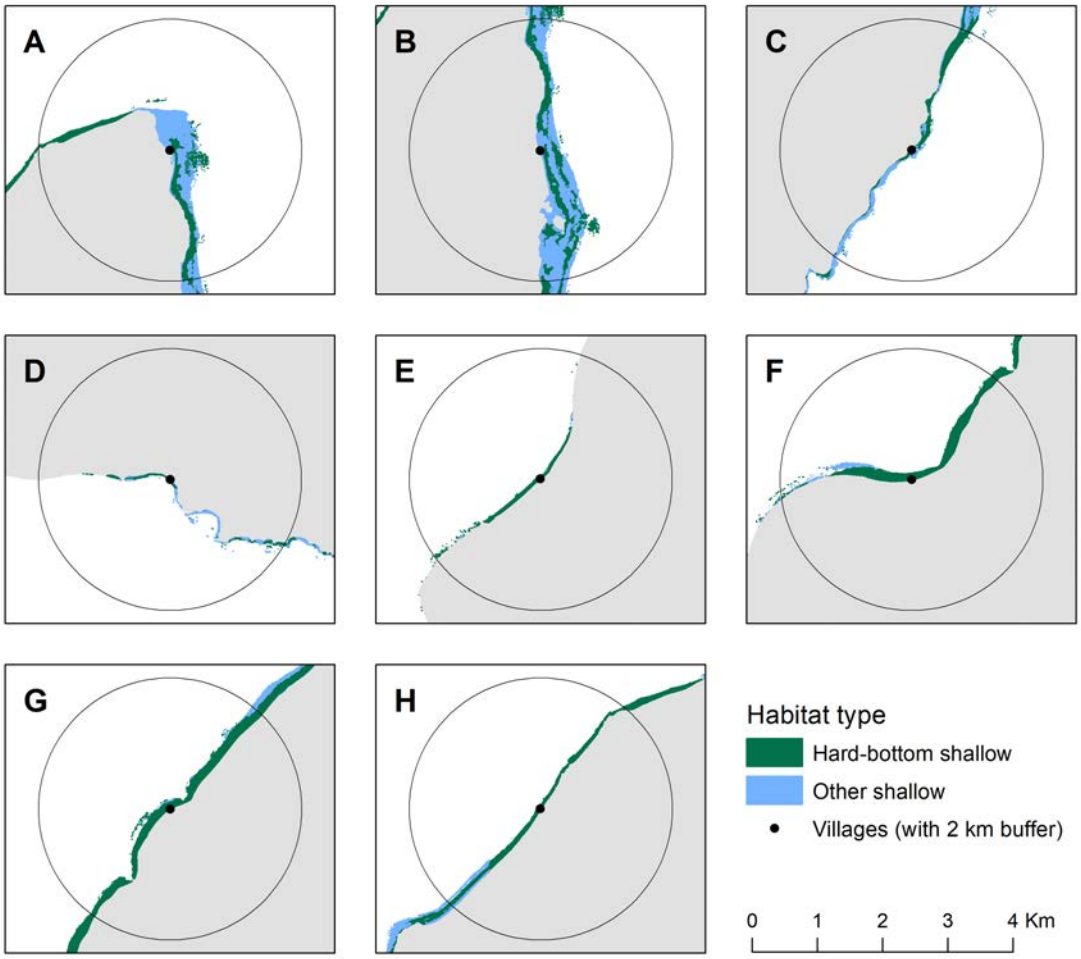
Where does seafood eaten by this household come from?

	✓	Main ✓(1)
Caught by household		
Bought		
Gifted from another household		

Notes:

APPENDIX B: SUPPLEMENTARY MATERIAL FOR CHAPTER 3

APPENDIX B.1. PANELS SHOWING SHALLOW COASTAL HABITAT TYPES AND 2 KM BUFFER FOR EACH COMMUNITY AND SUMMARY OF SPATIAL DATA FOR NEARSHORE HABITATS PROXIMATE TO STUDY COMMUNITIES



	Within 2km radius of community:							
Habitat type	A	B	C	D	E	F	G	H*
Hard-bottom shallow habitat (ha)	21.62	35.06	10.89	2.64	5.73	29.11	35.59	14.03
Other shallow habitat (ha)	42.32	65.81	9.73	3.30	0.06	2.18	1.94	1.89
Model variables								
Area (ha) (Sum of hard and other shallow habitats)	63.94	100.87	20.62	5.94	5.90	31.29	37.53	15.92
Hard (%) (Hard-bottom shallow habitat/shallow habitat)	33.81	34.76	52.82	44.46	97.10	93.03	94.84	88.09

* The authors observed a habitat classification error in the north-western region of the island proximate to community H. The misclassification was reported and recognised by NOAA, however it was not possible for the original images to be reprocessed. NOAA provided data with reclassified habitat variables in the region, which addressed some inaccuracies but it likely still contains some areas of misclassification.

APPENDIX B.2: MODEL OUTPUTS OF SEAFOOD CONSUMPTION STABILITY AND SEASONAL GLEANING AND TABLE SHOWING PAIRWISE COMPARISONS

	Consumption stability		
Predictors	**Estimates**	**CI**	**p**
Intercept	0.38	0.24 – 0.51	**0.001**
Never glean	-0.06	-0.22 – 0.09	0.430
Glean in rough season	0.37	0.18 – 0.56	**<0.001**
Glean year round	0.29	0.17 – 0.41	**<0.001**
Random Effects			
σ^2	0.07		
$\tau_{00\ village}$	0.00		
$\tau_{00\ fish}$	0.00		
ICC	0.10		
N_{fish}	3		
$N_{village}$	8		
Observations	128		
Marginal R^2 / Conditional R^2	0.252 / 0.328		
AIC	62.806		

Paired comparison	Estimate	SE	df	t ratio	p value
Calm only - Never	0.06	0.08	109	0.76	0.872
Calm only – Rough only	-0.37	0.11	64	-3.49	**0.004**
Calm only – Year round	-0.29	0.07	109	-4.36	**0.000**
Never – Rough only	-0.43	0.11	54	-3.77	**0.002**
Never – Year round	-0.35	0.08	71	-4.37	**0.0002**
Rough only – Year round	0.08	0.09	88	0.84	0.836

APPENDIX B.3: MODEL OUTPUTS EXPLAINING SEASONAL GLEANING USING DATA EXCLUDING COMMUNITY H (A), INCLUDING ALL COMMUNITIES (B), AND ONLY INCLUDING SEASON AND SPATIAL HABITAT VARIABLES, EXCLUDING COMMUNITY H (C).

	Model A			*Model B*			*Model C*		
Predictors	**Log-Odds**	**CI**	**p**	**Log-Odds**	**CI**	**p**	**Log-Odds**	**CI**	**p**
Intercept	1.31	0.04 – 2.58	**0.043**	1.27	0.35 – 2.20	**0.007**	1.52	0.70 – 2.34	**<0.001**
Adults (calm)	-0.05	-0.84 – 0.74	0.904	0.20	-0.35 – 0.76	0.478			
Adults (rough)	-0.42	-1.15 – 0.30	0.252	-0.46	-0.99 – 0.06	0.084			
Women (calm)	1.14	0.09 – 2.20	**0.034**	0.86	0.20 – 1.53	**0.011**			
Women (rough)	-0.26	-0.96 – 0.43	0.456	-0.03	-0.49 – 0.43	0.895			
Brick (calm)	-0.72	-2.54 – 1.10	0.438	-0.11	-1.25 – 1.03	0.845			
Brick (rough)	-1.16	-2.73 – 0.41	0.147	-0.78	-1.81 – 0.26	0.142			
Diversity (calm)	0.35	-0.53 – 1.23	0.437	0.00	-0.54 – 0.54	0.992			
Diversity (rough)	0.25	-0.46 – 0.96	0.496	0.35	-0.18 – 0.88	0.195			
Fishing (calm)	1.93	-0.19 – 4.05	0.074	0.79	-0.73 – 2.30	0.309			
Fishing (rough)	1.64	-0.07 – 3.35	0.061	1.22	0.15 – 2.29	**0.026**			
Area (calm)	2.99	0.71 – 5.27	**0.010**	2.49	0.96 – 4.01	**0.001**	1.57	0.41 – 2.74	**0.008**
Area (rough)	3.47	1.30 – 5.63	**0.002**	2.31	1.13 – 3.49	**<0.001**	3.08	1.53 – 4.62	**<0.001**
Hard (calm)	0.10	-1.46 – 1.67	0.898	-0.23	-1.38 – 0.92	0.693	0.32	-0.49 – 1.12	0.440
Hard (rough)	2.07	0.74 – 3.40	**0.002**	1.90	1.04 – 2.75	**<0.001**	1.88	0.88 – 2.88	**<0.001**
Area:Hard (calm)	-1.15	-3.08 – 0.77	0.239	-0.88	-2.30 – 0.54	0.225	-0.68	-1.70 – 0.35	0.198
Area:Hard (rough)	2.10	0.61 – 3.59	**0.006**	1.37	0.47 – 2.27	**0.003**	1.97	0.87 – 3.07	**<0.001**
Random Effects									
σ^2	3.29			3.29			3.29		
τ_{00}	$3.09_{\text{hh\_id:village}}$			$0.51_{\text{hh\_id:village}}$			$1.87_{\text{hh\_id:village}}$		
	0.00_{village}			0.00_{village}			0.00_{village}		
ICC	0.48			0.13			0.36		
N	$110_{\text{hh\_id}}$			$128_{\text{hh\_id}}$			$110_{\text{hh\_id}}$		
	7_{village}			8_{village}			7_{village}		
Observations	220			256			220		
Marginal R^2 / Conditional R^2	0.704 / 0.847			0.684 / 0.726			0.483 / 0.670		

APPENDIX C: SUPPLEMENTARY MATERIAL FOR CHAPTER 5

APPENDIX C.1: MODEL OUTPUTS FOR CATCH ALLOCATION ACCORDING TO LANDINGS AND SEASON SEPARATELY

	Landings			Season		
Predictors	Log-Mean	CI	p	Log-Mean	CI	p
Intercept	-0.19	-0.47 – 0.10	0.206	-0.52	-0.83 – -0.21	**0.001**
10-20 fish	-0.25	-0.69 – 0.20	0.280			
>20 fish	-0.81	-1.29 – -0.33	**0.001**			
Sold	-2.58	-3.13 – -2.02	**<0.001**	-0.52	-0.96 – -0.08	**0.019**
Shared	-1.97	-2.46 – -1.49	**<0.001**	-2.11	-2.59 – -1.63	**<0.001**
10-20 fish / Sold	1.37	0.62 – 2.11	**<0.001**			
>20 fish / Sold	2.76	1.98 – 3.53	**<0.001**			
10-20 fish / Shared	0.56	-0.14 – 1.26	0.116			
10-20 fish / Shared	1.27	0.54 – 2.00	**0.001**			
Lean season				0.33	-0.15 – 0.81	0.179
Harvest season				-0.01	-0.47 – 0.45	0.969
Lean season / Sold				-2.12	-2.87 – -1.38	**<0.001**
Harvest season / Sold				-0.71	-1.37 – -0.05	**0.035**
Lean season / Shared				0.39	-0.34 – 1.12	0.291
Harvest season / Shared				1.26	0.58 – 1.94	**<0.001**
Random Effects						
σ^2	1.00			1.00		
τ_{00}	0.00 $_{HH}$			0.00 $_{HH}$		
N	15 $_{HH}$			15 $_{HH}$		
Observations	537			537		
Marginal R^2	0.437			0.430		

APPENDIX C.2.1: PAIRED COMPARISONS OF CATCH USES BETWEEN LANDING GROUPS

Use	Landings	Est.	SE	t.ratio	p
Eat	<10 / 10-20	0.246	0.228	1.080	0.527
	<10 / >20	0.806	0.245	3.292	**0.003**
	10-20 / >20	0.560	0.262	2.135	0.083
Sell	<10 / 10-20	-1.119	0.305	-3.672	**0.001**
	<10 / >20	-1.952	0.309	-6.307	**0.000**
	10-20 / >20	-0.833	0.270	-3.084	**0.006**
Share	<10 / 10-20	-0.317	0.276	-1.148	0.484
	<10 / >20	-0.463	0.282	-1.639	0.229
	10-20 / >20	-0.146	0.278	-0.524	0.860

APPENDIX C.2.2: PAIRED COMPARISONS OF CATCH USES WITHIN LANDING GROUPS

Landings	Use	Est.	SE	t.ratio	p
<10 fish	Eat / Sell	2.576	0.282	9.145	**0.000**
	Eat / Share	1.974	0.246	8.009	**0.000**
	Sell / Share	-0.603	0.312	-1.933	0.129
10-20 fish	Eat / Sell	1.211	0.256	4.738	**0.000**
	Eat / Share	1.411	0.260	5.437	**0.000**
	Sell / Share	0.200	0.268	0.744	0.737
>20 fish	Eat / Sell	-0.181	0.276	-0.656	0.789
	Eat / Share	0.705	0.281	2.509	**0.032**
	Sell / Share	0.886	0.280	3.167	**0.004**

APPENDIX C.3.1: PAIRED COMPARISONS OF CATCH USES BETWEEN SEASONS

Use	Season	Est.	SE	t.ratio	p
Eat	Prep. / Lean	-0.329	0.245	-1.343	0.371
	Prep. / Harv.	0.009	0.233	0.039	0.999
	Lean / Harv.	0.338	0.253	1.338	0.374
Sell	Prep. / Lean	1.794	0.291	6.163	**0.000**
	Prep. / Harv.	0.720	0.244	2.945	**0.009**
	Lean / Harv.	-1.074	0.310	-3.468	**0.002**
Share	Prep. / Lean	-0.723	0.280	-2.578	**0.027**
	Prep. / Harv.	-1.251	0.258	-4.846	**0.000**
	Lean / Harv.	-0.529	0.277	-1.909	0.136

APPENDIX C.3.2: PAIRED COMPARISONS OF CATCH USES WITHIN SEASONS

Landings	Use	Est.	SE	t.ratio	p
Preparation	Eat / Sell	0.521	0.222	2.342	**0.050**
	Eat / Share	2.108	0.244	8.648	**0.000**
	Sell / Share	1.588	0.242	6.563	**0.000**
Lean	Eat / Sell	2.644	0.309	8.560	**0.000**
	Eat / Share	1.715	0.281	6.093	**0.000**
	Sell / Share	-0.929	0.324	-2.870	**0.011**
Harvest	Eat / Sell	1.231	0.254	4.846	**0.000**
	Eat / Share	0.848	0.248	3.418	**0.002**
	Sell / Share	-0.384	0.261	-1.472	0.304

APPENDIX C.4.1: SUMMARY OF P STATISTICS FROM CHI-SQUARE COMPARISON OF ACTUAL PROPORTION OF CATCH USED IN EACH WAY WITH EQUAL ALLOCATION ACROSS USES FOR EACH LANDING GROUP IN EACH SEASON

Landing group	Season	P value		
		Eat	Sell	Share
<10 fish	Preparation	**<0.0001**	**<0.0001**	**<0.0001**
	Lean	**<0.0001**	**<0.0001**	**<0.0001**
	Harvest	**<0.0001**	**<0.0001**	0.0784
10-20 fish	Preparation	**<0.0001**	0.062	**<0.0001**
	Lean	**<0.0001**	**<0.0001**	0.11
	Harvest	**0.0031**	1.000	**0.0015**
>20 fish	Preparation	**0.035**	**<0.0001**	**<0.0001**
	Lean	0.708	1.000	0.950
	Harvest	**0.00055**	**<0.0001**	0.13852

APPENDIX C.4.2: PAIRED COMPARISONS OF PROPORTION OF CATCH USED IN EACH WAY BETWEEN SEASONS FOR EACH LANDING GROUP

Landing group	Seasonal comparison	P value		
		Eat	Sell	Share
<10 fish	Prep. / Lean	**0.025**	**0.02632**	0.63274
	Prep. / Harv.	**<0.0001**	0.1431	**0.00011**
	Lean / Harv.	**<0.0001**	**0.00017**	**<0.0001**
10-20 fish	Prep. / Lean	**0.49238**	**<0.0001**	**<0.0001**
	Prep. / Harv.	**0.00044**	0.11	**0.0017**
	Lean / Harv.	**<0.0001**	**<0.0001**	**0.0264**
>20 fish	Prep. / Lean	**0.0051**	**<0.0001**	**<0.0001**
	Prep. / Harv.	**<0.0001**	**<0.0001**	**<0.0001**
	Lean / Harv.	0.4764	**<0.0001**	**<0.0001**