Cohen, Philippa Jane (2013) ***The contribution of locally managed marine areas to small-scale fisheries and food security - a Solomon Islands case study*****. PhD thesis, James Cook University.**

The contribution of locally managed marine areas to small-scale fisheries and food security - a Solomon Islands case study -

PhD thesis submitted by
Philippa Jane Cohen
BSc (Hons)
February 2013

For a degree of Doctor of Philosophy
Australian Research Council Centre of Excellence for Coral Reef Studies
James Cook University
Townsville, Queensland 4811
Australia

Statement of Access

I, the undersigned, author of this work, understand that James Cook University will make this thesis available for use within the University library via the Australian Theses Network, or by other means allow access to users in other approved libraries.

I understand that as an unpublished work, a thesis has significant protection under the Copyright Act and beyond this, I do not wish to place any restriction on access to this thesis

11th February 2013

______________________________ ______________________

Signature, Philippa Cohen Date

Statement of sources declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been duly acknowledged in the text and a list of references given.

11th February 2013

_____________________________ _____________________

Signature, Philippa Cohen Date

Statement of Contribution of Others

Research funding

Australian Discovery Grant	$40 000
Coral Reef Initiatives of the Pacific	$10 000
Australian National Network in Marine Science	$ 5 000
Australian Post-graduate Award Research Scholarships (stipend for 3.5 years)	$70 000

Thesis Committee

Dr. Simon Foale: Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University

Dr. Louisa Evans: Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University

Professor Terrence Hughes: Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University

Editorial support

Dr. Simon Foale
Dr. Louisa Evans
Dr. Morena Mills
Dr. Joshua Cinner
Dr. Timothy Alexander
6 anonymous reviewers of my published chapters

Permits

Research clearance was provided by the Solomon Islands government and human ethics clearance was provided by James Cook University (H-3337). Prior to each interview or focus group informed consent was obtained verbally from each respondent (verbal consent was used in preference to written due to literacy levels).

Ethics

This research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research, 2007. The proposed research study received human research ethics approval from the JCU Human Research Ethics Committee Approval Number H3337.

Acknowledgements

Over the last three years I have received guidance, support and encouragement from a great many people. Thank you firstly to Simon Foale for allowing me to start on this journey. You have provided me with a balance of freedom, support, and encouragement that has made this a very fulfilling experience. Louisa Evans - thank you for providing me with such sound guidance, and helping me navigate new ground. Thanks Terry Hughes for your words of wisdom and on-going support. Thanks also to Josh Cinner for being so generous with your time and assistance. I have also been lucky enough to receive advice from Rhondda Jones, Morena Mills, Örjan Bodin, Mike Fabinyi, and Tim Alexander.

I am truly grateful for the postgraduate atmosphere and to my fellow post-graduate students – this has been such a supportive and inspiring environment in which to be embedded. Thanks also to the staff who make the place tick; David, Jenny, Janet, Olga, Rose-Marie and Louise.

I have really valued the support offered to me by all staff at the WorldFish Center in Solomon Islands - I am particularly grateful to Anne-Maree Schwarz and Neil Andrew. The heavy field component of this research would not have been possible without the assistance of S. Sibiti, Z.Hilly, R. Posala, A. Tewaki, E. Rauba, A. Rikio, S. Bitia, W. Lea'amana, W. Zeke, J. Keba, E. Maelulu, D. Evan, C. Daokalia, T. Inipitu, P. Koso and M. Durai. Elton and Alec in particular - what an absolute pleasure it was to work with you! I am grateful also to all the many fishers who participated in my research, and shared meals and stories during my time in Solomon Islands.

My dear friends; Louisa, Chris, Al and Kirsty – your friendship, mentoring and laughter has really solidified this into a fantastic experience. Swim squad, bike rides, 'fun' runs and family dinners with Nick, Chris, Jake, Fin, Lou, Dave, Mike, Sarinda, Kirsty, Paul, Pete, Lynne, Esme, Tom and Al have made life outside of PhD so much fun – I look forward to so much more with you!

Finally, thanks to my family and friends for all your kind words, encouragement, and especially for all the fun escapes and adventures in Tasmania!

Abstract

Small-scale fisheries support the livelihoods and food security of millions of people worldwide, and if well managed can make significant contributions to socio-economic development. Coastal populations in developing countries can be highly reliant on coastal resources as small-scale fisheries provide an important source of income generation, are an important source of food, and in many areas often provide the primary source of dietary protein and micronutrients. However the sustainability of small-scale fisheries and the benefits they provide are under increasing pressure as populations grow, markets develop, technologies change and environments become degraded. Community-based and collaborative strategies (i.e., co-management) emerge as an important strategy to address challenges faced in managing small-scale fisheries. By engaging small-scale fishers in management, co-management can more effectively sustain benefits provided by fisheries. In so doing, co-management can support the three pillars of food security i.e., by protecting resource *availability* and *access*, the role of fisheries in *nutrition* may be sustained or improved.

The expansion of co-management initiatives is particularly apparent in the Indo-Pacific where centralised approaches have typically had low levels of success in managing subsistence and domestically-marketed fisheries. In this region co-management initiatives combine scientific information and conventional approaches to marine resource management, with local knowledge and institutions; a model referred to as *locally managed marine areas* (LMMAs). There are now hundreds of coastal communities with LMMAs in which a range of resource-use rules are developed and implemented at the community level, often with support from government or non-government organisations (NGOs). However, despite widespread arguments that such models of co-management can result in sustainable fisheries, empirical studies that systematically demonstrate benefits to fisheries and to food security are lacking. My thesis presents a case study of Solomon Islands to address the overarching question; do locally managed marine areas contribute to sustainable small-scale fisheries, and what are the implications for food security? I address this question by examining local fisheries governance arrangements and outcomes in Chapters 2, 3 and 4, and national level governance support structures and outcomes in Chapter 5.

LMMA initiatives frequently promote the re-establishment or re-invention of customary periodically-harvested marine closures as a measure to regulate marine resource use. Periodically-harvested closures are touted as being a successful, traditionally based measure for marine management, and often emerge as the principle management measure within LMMAs. Although periodically-harvested closures confer fisheries benefits for some taxa in western fisheries management contexts, there is little evidence that they are effective for the sustainable management of the many types of small-scale fisheries important in the Indo-Pacific. In Chapter 2 I systematically review cases from across the

Indo-Pacific region to explore the opening and closure cycles, concurrent harvest control measures, and fisheries objectives, and outcomes of periodically-harvested closures as they are employed in practice. I find that harvesting and closure regimes are highly variable, with some areas remaining predominantly closed and subjected to irregular one day harvests, while others are harvested for periods extending to weeks or months. Periodically-harvested closures are commonly placed over reef habitats, and are most frequently employed to manage trochus fisheries. I found few reports of restrictions being placed on periodic harvests, and few reports of concurrently employed restrictions on marine resource use in the broader fisheries area. This review clearly illustrated that there has been a lack of systematic research exploring the fisheries outcomes and potential limitations of periodically-harvested closures.

To address the knowledge gap identified in Chapter 2, I conducted an interdisciplinary study of periodically-harvested closures as a measure to control fishing effort, and to maintain and improve catch rates and yields. In Chapter 3 I aimed to determine whether fishing pressure (both in terms of effort and yield) was alleviated by implementing periodically-harvested closures, and whether resultant levels of harvesting were sustainable. I also aimed to understand how implementing periodically-harvested closures altered access to resources, and if their implementation resulted in displacement of fishing effort to other areas. In Chapter 3 I documented cycles of opening and closure applied in four periodically-harvested closures, decisions driving those cycles, access rights to closures through time and by different sectors of the local communities, and the broader management frameworks that influenced exploitation and management outcomes. I found duration and frequency of openings was highly variable, with open periods ranging from a single night to one month in duration, and occurring between one and 15 times per year. Fishing during openings was permitted for entire fishing communities in some cases, and only for specific rights-holding families in others. Decisions to harvest closures tended to be based on immediate social or economic needs. Harvesting during openings was restricted to a single taxon and single method in some cases, or unrestricted multi-species, multi-method harvesting in others. Periodically-harvested closures were the main form of management in use at all case study locations. In examining patterns of fishing pressure I found that fishing effort (mean fisher hours per day) during openings was relatively intense (between four and 60 times higher) compared to average daily effort on reefs continuously open to fishing. However over a full year, total effort and total harvested biomass from closures was low to moderate compared to open reefs. I found that effort was not significantly displaced onto open fishing grounds due to closures, likely because of the small size of closed areas relative to continuously open and accessible fishing grounds.

In Chapter 4 I examined the characteristics of catch to test hypotheses that emerged from the review in Chapter 2 i.e., that in periodically-harvested closures (a) catch rates (catch per unit effort; CPUE) are higher, (b) short lived, fast growing, sedentary taxa are more abundant, and (c) finfish and invertebrates are larger, compared to harvests from reefs continuously open to fishing. I compared catch rates and catch composition from periodic harvests to harvests of continuously-open fishing grounds, and also examined changes in catch rates throughout the opening period to look for depletion effects. I found that CPUE was significantly higher from periodically-harvested closures for gleaning, but not for spear and line fishing. In one periodically-harvested closure where data were sufficient for analysis of catch rates throughout the periodic harvest, I did not find quantitative evidence of significant fisheries depletion indicated by declines in CPUE for line and spear fishing. However catch rates from gleaning for invertebrates declined throughout the periodic harvest; CPUE was significantly higher in the early stages of the periodic harvest compared with open reefs, but not in the later stages of the harvest. This evidence, alongside reports from fishers and declines in effort (particularly for gleaning), suggests there was substantial localised depletion of invertebrate stocks. Family level catch composition was similar to open reefs for two closures. The small amount of dissimilarity in catches was due to relatively higher abundances of families of high rebound potential i.e., Strombidae, Acanthuridae and Balistidae. Six out of the eight species analysed were larger when harvested from periodically-harvested closures than those harvested from open reefs, but only *Lutjanus rufolineatus* was significantly larger. Trochus (*Trochus niloticus*) was significantly smaller from closures than those harvested from open reefs, which may be due to the effect of prior harvests.

To summarise the local fisheries governance arrangements and outcomes presented in Chapters 2, 3 and 4; periodically-harvested closures are a socially acceptable management measure, frequently implemented within co-management frameworks across the Indo-Pacific. My research indicates periodically-harvested closures can achieve at least short-term benefits by bolstering catch rates of invertebrates, and leading to catches with slightly larger fish in some species. However, harvesting during periodic harvests was intense, and there was evidence that this led to substantial localised depletion of invertebrate stocks. Further, as social and economic needs (rather than ecological knowledge and indicators) often drive decisions to open areas to harvest, the short-term fisheries benefits may be threatened by rising demand, and heavier and more frequent fishing events in the medium to long-term. There is a need for future studies to address long-term fisheries benefits of periodically-harvested closures. I found that periodically-harvested closures were the main form of management employed by communities with LMMAs. However, achieving nation-wide sustainable fisheries management will require marine resource governance to be comprehensive and widespread, requiring more than the currently localised and small scale advances. In response to this challenge, environmental governance is increasingly focused on connecting local management to higher scales of policy and planning. Governance networks are suggested as institutions that can foster cross-scale relations between actors for collective purposes. In Chapter 5 I present my analysis of a governance network explicitly established to strengthen and extend outcomes of local management efforts to hasten advancement towards national goals of widespread and effective fisheries governance.

In Chapter 5 I used quantitative social network analysis to examine patterns of collaborative and knowledge-exchange relations amongst NGOs, government agencies and local communities involved in co-management of small-scale fisheries and coastal ecosystems in Solomon Islands. I examined network structure alongside qualitative data to understand the potential of the network to facilitate co-ordination and learning among management actors. I identified an active social network that transcends the formal membership of the governance network. Cross-scale analysis highlighted that network members were the only functional pathway for cross-scale knowledge-exchange and higher level representation of local issues. I found mid-scale managers (e.g., provincial governments) were poorly connected, yet were identified as the target actors in policies and planning for improving decentralised management. The governance network also provided the primary means for knowledge-exchange between agencies, and was important for multi-actor learning about best practice for co-management. Yet I identified geographic, logistical and institutional barriers and trade-offs to multi-actor and cross-scale coordination and learning – and therefore significant obstacles to the ultimate objective of widespread and effective co-management.

My thesis highlights that periodically-harvested closures are a prominent feature of the small-scale fisheries co-management model employed widely across the Indo-Pacific region. Within periodically-harvested closures fisheries can be maintained at proposed sustainable targets in coastal regions where fishing pressure and populations densities are relatively low. Catch rates for invertebrates and fish size are bolstered by periodically-harvested closures. However, I found that in these particular coastal regions only a small proportion of fishing grounds are influenced by any LMMA or national management measures at all. Long-term successful fishery management will require periodically-harvested closures to be embedded within functional co-management frameworks in which a diversity of context specific, socially acceptable and fisheries appropriate rules are implemented and adapted. This presents an ongoing challenge to community managers and their partner agencies. Cross-scale institutional and knowledge exchange linkages, via partnerships with NGOs or government agencies, can guide and bolster local management institutions to address this challenge in the face of increasing pressures. Cross-scale, cross-institutional relationships are supported by a formal governance network designed to promote learning and collaboration. However maintaining these relationships in a manner that ensures equitable representation, and realises objectives of effective and widespread management, will continue to be fraught with challenges.

The success of co-management of small-scale fisheries has implications for three food security pillars; availability (i.e., sufficient amounts of food), access (i.e., ability to obtain sufficient food), and consumption (i.e., meeting nutritional needs). Small-scale fisheries provide the primary source of protein and are an important source of micronutrients to coastal populations, and across the Indo-Pacific alternatives are often limited. My thesis worked on the premise that the nutritional role fisheries plays would be threatened if *availability* and *access* were problematic, and that co-management can play a role in supporting these pillars. My thesis suggests that periodically-harvested closures can, in some cases, enhance availability of stocks, and act as a 'bank in the water' by stock piling resources for when needs are high. Yet the flexibility to harvest and lack of concurrent fisheries management measures may mean that modest gains in abundance or biomass are insufficient to meet future food needs and demands. The cases I examined showed that periodically-harvested closures present only short-term access restrictions to relatively small areas, and therefore fishers suffer only a minor loss of access to fisheries resources. However, in one of four cases I found evidence of elite capture, where direct benefits from harvesting accrued mainly to the Chief and his family, whereas previously the reef had been accessible to all fishers in adjacent communities. As competition for resources intensifies, it is increasingly important to consider equitable access and distribution of benefits in co-management initiatives. Finally, projections suggest that with current consumption patterns, coastal fisheries will not meet the needs of populations in 2030, even if reefs are well managed. Nevertheless, improving management of small-scale fisheries can help to minimize this shortfall. While the 137 LMMAs established in Solomon Islands represent a substantial advance in managing coastal ecosystems and small-scale fisheries, these areas account for only a very small proportion of coastal waters, human populations and small-scale fishing activities; mechanisms to expand and improve management are critical.

Publications associated with this thesis

Publications

Cohen, P. and S. Foale, (2013) Sustaining small-scale fisheries with periodically harvested marine reserves. Marine Policy 37:278-287. (Chapter 2)

Cohen, P., J. Cinner and S. Foale. Fishing patterns associated with periodically harvested marine closures. Global Environmental Change, *In Review.* (Chapter 3)

Cohen, P. and T. Alexander. Catch rates, composition and fish size from reefs managed with periodically-harvested closures. PLoSONE, *In Review*. (Chapter 4)

Cohen, P., L. Evans, and M. Mills, (2012) Social networks supporting governance of coastal ecosystems in Solomon Islands. Conservation Letters 5:376-386. (Chapter 5)

Reports

Cohen, P. and S. Foale, (2011) Fishing Taboos: Securing Fisheries for the future? SPC Traditional Marine Resource Management and Knowledge Information Bulletin 28: 3-13

Cohen, P. (2011). Social networks to support learning for improved governance of coastal ecosystems in Solomon Islands. ARC Centre of Excellence for Coral Reef Studies and Secretariat of the Pacific Community, Noumea, pp. 34.

Ratner, B.D., Barman, B., **Cohen, P**., Mam, K., Nagoli, J. and Allison, E.H. (2012) Strengthening governance across scales in aquatic agricultural systems. Working Paper. The WorldFish Center, Penang, Malaysia. AAS-2012-10.

Govan, H., Rupeni, E., Chenet, A., Troeng, F., Heaps, L., **Cohen, P**., Dupré, C., Bambridge, T., Herrenschmidt, J.-B., (2009) Governance & Management issues of Marine Managed Areas, Conférence régionale Pacifique des Aires Marines, Moorea, pp 14.

Conference presentations

Cohen, P., S. Foale and J. Cinner. Sustaining small-scale fisheries with periodically harvested marine reserves. 12th International Coral Reef Symposium, 9-13 July 2012, Cairns, Australia.

Cohen, P. Local Management of Marine Resources Securing Fisheries for the Future? 6th International Conference on Environmental Future, 18-22nd July 2011, Newcastle, UK.

Cohen, P. Periodic Harvesting in Solomon Islands; Securing Fisheries for the Future? People and the Sea VI: 'Bridging Science and Policy for sustainable coasts and seas'. July 6-9th 2011 in Amsterdam, The Netherlands.

Cohen, P. Periodic Closures - Securing Pacific Fisheries for the Future? Third Australian National Network in Marine Science Conference, Marine science in tropical, temperate and southern oceans. 29 November–1 December 2011, Perth, Australia.

Other publications produced during my candidature

Publications

Foale, S., **P. Cohen**, S. Januchowski-Hartley, A. Wenger, M. Macintyre (2010). Tenure and taboos: origins and implications for fisheries in the Pacific. Fish and Fisheries. 12:357-69.

Foale, S., D. Adhuri, P. Aliño, E. Allison, N. Andrew, **P.Cohen**, L. Evans, M. Fabinyi, P. Fidelman, C. Gregory, N. Stacey, J. Tanzer, N. Weeratunge (2013) Conserving biodiversity for food security: putting people at the centre of the Coral Triangle Initiative. Marine Policy 38, 174–183.

Ratner, B.D., **P. Cohen,** B. Barman, M. Kosal, J. Nagoli, and E.H. Allison. Governance of aquatic agricultural systems; analyzing representation, power and accountability. Ecology and Society, *In Review.*

Christie, P., C. Hicks , **P. Cohen**, J. Cinner, T. McClanahan, R. Pollnac. Understanding people and the sea: Progress toward marine social ecological interdisciplinary science. Book Chapter. Cambridge University Press, *In Review.*

Mills, M., J. Álvarez-Romero, K. Vance-Borland, **P. Cohen**, H. Ernstson, R. Pressey, A. Guerrero, H. Ernstson. Social network analysis for systematic conservation planning. Biological Conservation, *In Review*.

Reports

Cohen, P. and D. Mills 2012. Global lessons and information to assist with monofilament gill net management in Ghana. WorldFish Center. P.12

Table of Contents

List of Tables

List of Figures

Thesis objectives

The overarching objective of my thesis is; *to understand how locally managed marine areas contribute to small-scale fisheries, and food security*. I achieve this by answering a series of sub-questions (outlined below, and the thesis outline in the subsequent section) designed to address specific gaps identified in the literature, or hypotheses proposed by existing studies. In examining the LMMA governance arrangements and outcomes, I particularly focus on periodically-harvested closures because it was apparent from my preliminary scoping studies (and verified by data presented in Chapters 2 and 3) that this was the dominant or, frequently, only resource management measure employed in the LMMA model. To address my objective and answer my research questions, I use a Solomon Islands case study, and employ an interdisciplinary approach by integrating social research methods such as household surveys, interviews, focus groups, and social network analysis, with ecological methods such as fish catch and effort surveys.

- *How are periodically-harvested closures applied in contemporary contexts, and under what conditions do they deliver fisheries benefits?*

In Chapter 2 I systematically review cases from across the Indo-Pacific region to explore the opening and closure cycles/patterns, concurrently employed fisheries regulatory measures, and the objectives and outcomes of periodically-harvested closures as they are employed in practice.

- *Is effort reduced and/or displaced by implementing periodically-harvested closures?*

In Chapter 3 I aim to determine whether fishing pressure (both in terms of effort and yield) is alleviated by implementing periodically-harvested closures, and whether resultant levels of harvesting are sustainable. I investigate how implementing periodically-harvested closures alters access (temporally and socially) to resources, and if their implementation results in the displacement of fishing effort to other areas. I also aim to understand the factors that influence decisions driving harvesting and closure cycles, and how the broader LMMA frameworks and regulations might influence patterns of exploitation and management outcomes.

- *Are catches improved by periodically-harvested closures?*

In Chapter 4 I examine the characteristics of catch to test hypotheses that emerged from the review in Chapter 2, i.e., that in periodically-harvested closures (a) catch rates (catch per unit effort; CPUE) are higher, (b) short lived, fast growing, sedentary taxa are more abundant, and (c) finfish and invertebrates are larger, compared to harvests from reefs continuously open to fishing. I compare catch rates and catch composition to that from continuously-open fishing grounds, and examine changes in catch rates throughout the opening period to look for depletion effects.

- *How can the effectiveness of co-management be improved?*

In Chapter 5 I take a broader perspective of co-management as a national strategy for small-scale fisheries governance. I examine the structure of a governance network established to support fisheries co-management efforts in Solomon Islands. I aim to understand the governance network's role in promoting learning, collaboration and coordination between agencies involved in co-management, including how the network facilitates representation of local managers and local issues in higher levels of governance. I explore then how the network may help to strengthen and extend outcomes of co-management to hasten advancement towards national goals of widespread and effective fisheries governance.

Thesis outline

This thesis is presented as a series of chapters written for publication in peer-reviewed journals and reformatted to fit in a thesis structure. Figure 1 shows the overall structure of the thesis. Chapters 2, 3 and 4 examine local fisheries governance arrangements and outcomes for fisheries and food security. The fifth chapter takes a broader perspective - looking at a governance network established explicitly to support co-management as a national strategy for small-scale fisheries governance. I designed this research, and collected and analysed all the data. Authorship of chapters for publications is shared with members of my thesis committee; Simon Foale (Chapter 2, 3) and Louisa Evans (Chapter 5), as well as several contributing co-authors Joshua Cinner (Chapter 3), Timothy Alexander (Chapter 4) and Morena Mills (Chapter 5). Tables and figures are shown throughout the thesis, and additional supporting methods and figures are provided in the appendices. I have also co-authored four journal articles (i.e., two published, two in review) that are directly relevant to this thesis, and they are also provided in the appendices.

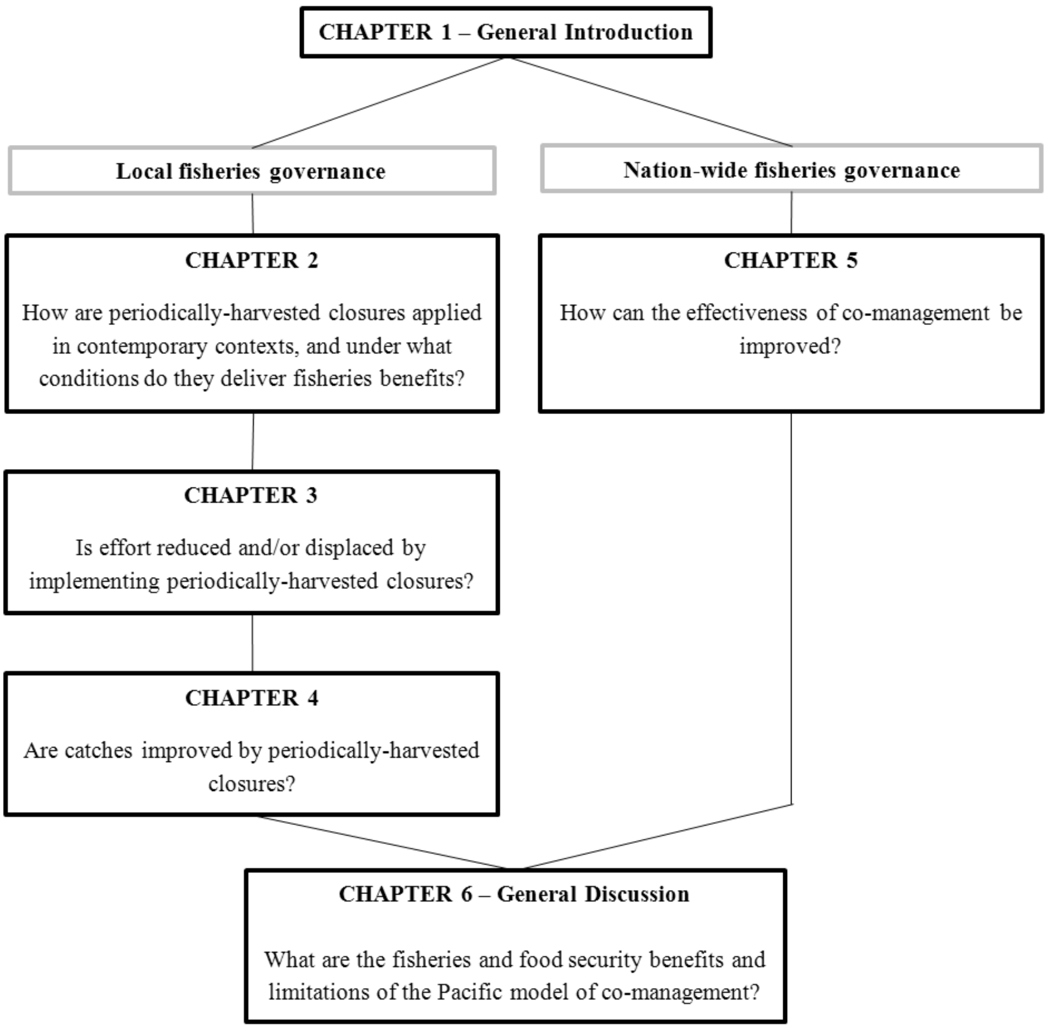


Figure 1 Thesis outline and structure

Chapter 1 provides an introduction of the concepts and frameworks employed for the thesis. It highlights the gaps in understanding of co-management outcomes for small-scale fisheries in general, and for the Pacific in particular. It also outlines the food security framework through which thesis findings are discussed.

Chapter 2 seeks to answer the overarching question; *how are periodically-harvested closures applied in contemporary contexts, and under what conditions do they deliver fisheries benefits?* I conduct a review of literature on the use of periodically-harvested closures in the Indo-Pacific and identify specific gaps in research on the applications and outcomes of periodically-harvested closures for small-scale fisheries. I developed the concept for the review, conducted the review and wrote the chapter. Simon Foale assisted with editing the chapter. The chapter was originally based on Pacific literature only and published by the Secretariat of the Pacific Community. It was subsequently re-written to include literature from Indonesia, and a geographically and conceptually broader paper was published in Marine Policy (with permission from both journals).

Publications:

Cohen, P., Foale, S. (2011) Fishing Taboos: Securing Pacific Fisheries for the future? SPC Traditional Marine Resource Management and Knowledge Information Bulletin 28, 3-13.

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

Chapter 3 seeks to answer the overarching question; i*s effort reduced and/or displaced by implementing periodically-harvested closures?* I compare fishing effort and yield on reefs continuously open to fishing and on periodically-harvested closures. This chapter analyses the distribution of fishing effort in time and space, and presents the social and economic drivers for opening periodically-harvested closures. I developed the concept for this chapter, designed data collection, coordinated and conducted the data collection (with research assistants), analysed data and wrote the chapter. Joshua Cinner assisted in structuring the paper, provided advice on analysis and editing the chapter. Simon Foale provided advice on concept development, data analysis, and assisted with editing the chapter.

Publication:

Cohen, P., Cinner, J., Foale, S. *In review.* Fishing patterns associated with periodically harvested marine closures. Global Environmental Change

Chapter 4 seeks to answer the overarching question; *Are catches improved by periodically-harvested closures?* I examine catch rates, fish size and catch composition from reefs continuously open to fishing and periodically-harvested closures. I developed the concept for this chapter, designed data collection, coordinated and conducted the data collection (with research assistants), analysed data and wrote the chapter. Timothy Alexander provided advice on analysis and assisted with editing the chapter.

Publication:
Cohen, P. and T. Alexander. *In review*. Catch rates, composition and fish size from reefs managed with periodically-harvested closures. PLoSONE

Chapter 5 seeks to answer the overarching question; *How can the effectiveness of co-management be improved?* I examine a governance network established explicitly to support co-management as a national strategy for small-scale fisheries governance. Using quantitative social network analysis to examine patterns of collaborative and knowledge-exchange relations among agencies, alongside qualitative data collection, this chapter examines the role of the governance network for strengthening and extending outcomes of co-management. I developed the concept for this chapter, designed data collection, conducted the interviews and observations, analysed data and wrote the chapter. Louisa Evans provided advice on the interpretation of results, and assisted with paper structuring and editing. Morena Mills provided advice in initial concept development, on the presentation of results, and assisted with editing the paper.

Publication:
Cohen, P., Evans, L., Mills, M. (2012) Social networks supporting governance of coastal ecosystems in Solomon Islands. Conservation Letters 5, 376–386.

Chapter 6 provides a summary of the previous chapters and discusses the results for small-scale fisheries co-management in the context of the concepts introduced in Chapter 1. In particular, it explores the implications of my findings for food security. In this chapter I also reflect on the limitations of my research, and discuss opportunities for addressing remaining research gaps.

Chapter 1 General Introduction

Protecting the food and livelihood benefits provided by small-scale fisheries presents an important challenge in developing countries. Active participation of small-scale fishers and fisheries-reliant communities is now seen as integral to addressing this challenge. In this chapter I introduce the concepts of co-management, the welfare model of small-scale fisheries management, and food security. I outline Pacific fisheries and food security situations and projections, with specific details for Solomon Islands as the case study for this thesis. I discuss the limitations of the body of literature that seeks to evaluate co-management of small-scale fisheries.

1.1 The small-scale fisheries management challenge

Small-scale fisheries support the livelihoods and food security of millions of people worldwide, and if well managed can make significant contributions to socio-economic development (Mills et al., 2011, Pauly, 2006). Small-scale fishers are "*those operating from the shore or from small fishing vessels in coastal or inland waters*" (Allison and Ellis, 2001: 377). Small-scale fisheries are characterised as having decentralised fishing activities, relatively low capital investment, operating at the household or community level, and being dynamic in the use of space, time and technology (Mills et al., 2011). In practice this represents fishing activities that span large geographic areas, land catch at numerous and highly dispersed sites, employ a wide array of vessels and gears, target a range of taxa, and engage large numbers of fishers who operate independently or in small groups, and who may move in and out of the sector as needs and opportunities arise. The characteristics of small-scale fisheries have presented a substantial challenge to management. Centralised management models have often had low levels of success in effectively managing small-scale fisheries due to limited capacity relative to the scope of the fisheries, and a tendency to focus on target species, rather than on ecological, social and economic factors that interact with resource status and drive resource use patterns (Ruddle, 1998, World Bank, 2004). As human populations rise and markets develop, pressures on small-scale fisheries intensify. It is widely acknowledged that the sustainability of coastal, and particularly reef, resources that support small-scale fisheries are threatened by overexploitation and other anthropogenic pressures (Hughes et al., 2003, Polunin and Roberts, 1996). Effective management solutions are required, and these must balance preservation of resources with maintaining or optimising livelihoods and food benefits for coastal populations (Bell et al., 2006, Foale et al., 2013, Whittingham et al., 2003).

Overall, fisheries contributions to national economies of Pacific countries lag behind those of other sectors such as mining, agriculture and foreign aid (FAO, 2013, Foale, 2008). However the importance of fisheries to economic development and well-being of Pacific Island Countries is recognised in national and international policies (such as the Vava'u Declaration, Leaders of the Pacific Islands Forum, 2007). Throughout the Pacific, pelagic, tuna-focused fisheries dominate contributions made to national economies and the volume of fish harvested (Gillett, 2009), and have resultantly captured much of the political attention that fisheries receive. The role of small-scale fisheries has historically been overlooked and poorly quantified. Pacific small-scale fisheries are suggested to account for around 12 percent of the region's total fisheries production; comprised of coastal subsistence fisheries (70%) and commercial fisheries (30%) (Gillett, 2009). Pacific populations commonly demonstrate high levels of participation in small-scale fisheries, and nutritional surveys show that locally sourced fresh fish provide the major contribution to protein intake (Bell et al., 2009). Although cash-based economies are expanding, in many Pacific Island countries where human development is low, the subsistence economy, including small-scale fisheries, plays an important role in human well-being (Lane, 2006).

1.2 Managing small-scale fisheries

As mentioned, the importance of small-scale fisheries to economies, livelihoods and food security has historically been undervalued, resulting in the sector being neglected in policy and planning at national and international levels (Mills et al., 2011). The attention that small-scale fisheries have received has focused on investment in development via enhanced technology (Gillett, 2010), and resource management that employed single species, bio-economic models aimed at maximising yield and economic gains (e.g., Maximum Sustainable Yield and Maximum economic Yield) (McClanahan and Castilla, 2008). With these models as a reference, Cunningham et al. (2009) presented a 'wealth based' model of fisheries management, arguing that small-scale fisheries can and should function as an engine of economic development by enhancing economic efficiency through restricted participation, maximizing resource rent and increasing contributions to national economies. However in coastal developing countries, the food security and pro-poor functions of small-scale fisheries are increasingly recognised as critical to prevent and alleviate poverty, and to progress broader development goals (Béné et al., 2007, Whittingham et al., 2003). Small-scale fisheries can provide an essential role as a food security and employment safety net (Béné et al., 2010). These pro-poor functions are optimised by maintaining participation at high levels and retaining fishers' flexibility to enter or leave the sector as opportunities arise – the 'welfare-based' model of fisheries management. Béné et al. (2010) argue that in developing country contexts, the wealth-based model of management will result in accumulation of wealth to few, and that the development of policies and procedures necessary to redistribute economic gains to the poor will lag behind, leaving poor people even more vulnerable due to exclusion from the fishery. My thesis therefore employs the underlying assumption that, in the absence of governance and economic institutions to support a wealth-based approach, food security at the community and household level will be best served by the welfare-model of management. Community-based and collaborative management arrangements (henceforth co-management) implicitly support the welfare-based model of fisheries management; encouraging protection of the resource base for flexible subsistence and small-scale commercial exploitation (Allison, 2011).

1.3 Co-management

In 1968, Garrett Hardin famously asserted that privatisation or state control of natural resources was necessary to prevent *tragedy* i.e., degradation and ultimate destruction of resources where use was shared (such as is common for fisheries). More recently, the work of Elinor Ostrom has highlighted that solutions to managing use of multiple stakeholders can be (and have been historically) successfully engineered locally (e.g., Ostrom et al., 1999, Ostrom, 1990). Concurrently, there has been a growing realisation that resource status and exploitation are driven by social and economic factors, and therefore that management will be more effectively addressed when resource users are actively involved in designing and implementing management (Pomeroy, 1995). As a result, community-based and co-management strategies are now a mainstream approach to managing many natural resources, including those utilised by small-scale fisheries (Evans et al., 2011). The philosophy behind co-management is that those who are affected by management (e.g., fishers and other resource users) should be involved in making management decisions (Berkes, 2009). Resource-user involvement supports social justice, equity and empowerment, and legitimizes management, which can lead to enhanced compliance (Pomeroy, 1995, Berkes, 2009). Fisheries co-management is defined as a relationship between a resource-user group (e.g., local fishers) and another entity (e.g., government agency or non-government organisation) in which management responsibilities and authority are shared (Pomeroy and Berkes, 1997, Evans et al., 2011). Co-management models often seek to combine scientific information and conventional marine resource management approaches, with local knowledge and governance institutions (Govan, 2009a, Johannes, 2002, Ruddle, 1998). Compliance and enforcement are often tasked to communities via local governance institutions (such as Chiefly systems or newly formed committees), but may be reinforced through relationships with partner organisations or formal legal structures (Ostrom et al., 1999). A range of resource measures may be employed under co-management frameworks, including customary resource use controls, national fisheries regulations or new rules developed in consultation between resource users and the supporting partner (World Bank, 2004). Co-management is recognised for its potential to reconcile social and ecological objectives, and is also proposed as a useful tool to support or promote ecosystem-based approaches to fisheries management (Berkes, 2012).

In developing country contexts, engaging with local-level knowledge systems and governance institutions is now seen as critical for effective resource management (Berkes, 2012, Pomeroy, 1995). In the Pacific, customary tenure institutions have been recognized by some scholars as one of these solutions, for their potential or even necessary role in contemporary resource management (Bell et al., 2006, Baines, 1990, Johannes, 2002). Customary tenure is a common or group property rights system (Ostrom et al., 1999), where different clans hold the primary rights to land areas or coastal waters (i.e., commonly reef or mangrove areas), and based on those rights can create rules about who can access resources and how resources can be used (Macintyre and Foale, 2007). Rights are established through genealogy and through complex exchanges initiated by historical area-use patterns or feasting, for example. Rights claims can also emerge in response to increased interest in an area when resources within it become commodities e.g., trochus, sea cucumber, baitfish (Akimichi, 1991, Otto, 1997). Tenure arrangements (i.e., the people who hold rights, the nature of those rights, and the areas to which rights are held) are dynamic and informal (i.e., in the sense that they are not written down) (Baines, 1990). The clarification of local tenure rights in order to sell resources, or to establish formalised resource management arrangements, is not without challenges - such as protracted negotiations, disputes and conflict (McDougall, 2005, Macintyre and Foale, 2007). Yet, it is argued that improving resource management will ultimately entail strengthening governance of local tenure regimes to provide a mechanism to exclude outsiders, and provide a framework under which resource use can be regulated and a sense of stewardship can be nurtured (Bell et al., 2008, Govan, 2009a). The ability of tenure and other customary institutions (e.g., customary fisheries closures) to lead to sustainable fisheries practices in contemporary, competitive resource-use contexts is questioned by some scholars (Foale et al., 2011, Polunin, 1984). In Foale et al., (2011) we argue that customary institutions are more likely to support sustainable fisheries practices where scientific and local knowledge of economic, social and ecological factors are accounted for in decisions about resource use and regulation. Integration of knowledge sources and governance institutions are explicitly supported and promoted by co-management.

Fisheries co-management initiatives are proliferating in the developing world (Govan, 2009b, Weeks et al., 2010). This expansion is particularly apparent in the Pacific where there are reportedly over 500 co-managed areas covering over 12 000 km^2 of coastal waters (Govan, 2009a). The co-management model frequently employed in the Pacific is referred to as a locally managed marine area (LMMA); "*a locally managed marine area is an area of nearshore waters and coastal resources that is largely or wholly managed at a local level by the coastal communities, land-owning groups, partner organizations, and/or collaborative government representatives who reside or are based in the immediate area*" (Govan, 2009b: 28). LMMAs are most commonly established with direct support from a non-government organisation (NGO), or less commonly by a government agency. Within the Pacific LMMAs are based on, or strengthen local customary tenure systems, and also engage with and employ local governance institutions. As with co-management more broadly, a suite of management measures may be employed within an LMMA, including access restrictions, size limits, gear restrictions, species bans, and permanent or periodically-harvested closures (Govan, 2009b).

Permanent no-take marine reserves are a popular tool to manage at an ecosystem level to prevent marine biodiversity loss, and are a widely promoted strategy to conserve fisheries resources (Hilborn et al., 2004). Marine reserves are expected to deliver benefits when protection from fishing improves habitat and stocks status within the reserve, leading to export of adults ("spillover") and propagules ("larval export") to sustain fisheries operating outside of the area i.e., to the extent of over-compensating for lost access to resources within the reserve (Abesamis and Russ, 2005, McClanahan and Mangi, 2000). However, there is still conjecture as to whether permanent reserves will deliver these benefits to fisheries in the range of contexts in which they are employed (Hilborn et al., 2006, Russ, 2002, Roberts and Polunin, 1993, Graham et al., 2011). As coral reefs support exceptionally high levels of biodiversity (Roberts et al., 2002), and the majority of reefs are located in developing countries where they are relied on by small-scale fishers (Donner and Potere, 2007), progress towards biodiversity conservation and food security objectives is often sought in combination. In developing countries where alternative sources of income and nutritional equivalents of fish can be limited, permanent closures/marine reserves are not always a feasible option, due to the (at least initial) cost fishers incur from lost access to resources (Foale and Manele, 2004, Christie, 2004). While there are permanent no-take marine reserves in the Pacific, there is a higher preference for and prevalence of other marine resource-use regulations, particularly periodically-harvested closures, employed under co-management frameworks (Govan, 2009a).

Area taboos or periodically-harvested closures (Foale et al., 2011), have emerged as important or even primary management measures within LMMAs, and in other forms of contemporary co-management across the Indo-Pacific (Govan, 2009a, McLeod et al., 2009). Periodically-harvested closures have been traditionally employed throughout the Indo-Pacific, and fall under customary institutions of *sasi laut* in eastern Indonesia (Evans et al., 1997), and *taboos* throughout the Pacific (Johannes, 1982). In customary form, objectives and patterns of harvesting (e.g., harvesting or closing an area) are socially driven e.g., to mark the death of a community member, to harvest for a celebratory feast, or protect a sacred site (Foale et al., 2011). The protection of ecological functions and long-term benefits for fisheries resulting from these practices are suggested to be unintended and minimal if any (Foale et al., 2011, Polunin, 1984). Yet, the *potential* of periodically-harvested closures for contemporary resource management is recognised, as long as the parameters of closures and openings are appropriately tailored to the fishery. It is expected that stocks will recover and build within the area during the closed period, to be directly and periodically exploited. While there may be secondary effects of spill-over and larval export, these have not been examined for periodically-harvested closures. Levels of fishing effort and yield during area openings, and overall relief from fishing pressure during closures are key factors determining the fisheries outcomes of periodically-harvested closures (Russ and Alcala, 1996, Game et al., 2009, Kaplan et al., 2010). Modelling and empirical evidence suggests that periodic harvesting strategies are more suited to the management of fast-growing, short-lived taxa, sedentary or sessile taxa (Jennings et al., 1999b, Russ and Alcala, 1998b). Yet, in co-management models periodically-harvested closures are commonly used for multi-species fisheries. There is however, relatively little information about cycles of opening and closure, levels of fishing and concurrent regulations employed in practice, and few studies have examined the outcomes for multi-species fisheries when periodically-harvested closures are used.

Despite widespread arguments that co-management of marine resources can result in sustainable fisheries, empirical studies that systematically demonstrate these benefits, and how they can be achieved in different contexts, are lacking (Gutierrez et al., 2011, Evans et al., 2011). Studies have largely focused on co-management *processes* of participation and conflict resolution, which are assumed to be positively correlated with fisheries benefits. In the relatively few cases that assess *outcomes*, co-management generally results in positive trends in household income, household well-being, resource status, fishery yield, and resource access. But overall outcomes are highly variable between cases (Evans et al., 2011). Outcomes for fisheries and well-being can preferentially benefit (Cinner et al., 2012) or disadvantage (Béné et al., 2009) certain sectors of society due to inequitable distribution of benefits or access to resources. And although benthic and demersal fisheries appear to benefit from co-management in some cases, success is less evident for multi-species fisheries, potentially due to a mismatch of scales of stock distribution, and the scale at which stock-recruitment processes and management operate (Gutierrez et al., 2011). Cases demonstrating fisheries benefits (particularly for multi-species fisheries), cases from the Pacific and critical evaluations that report negative or no outcomes are lacking.

Although co-management is a mainstream approach for managing small-scale fisheries (Evans et al., 2011, Govan, 2009a), comprehensive assessments of the ecological and social benefits that co-management can deliver for fisheries are relatively rare. As a result, the effectiveness of co-management and embedded resource-use regulations for delivering or securing fisheries benefits is not well understood. Yet, co-management is confidently promoted for addressing small-scale fisheries concerns, particularly by NGOs in the Pacific (e.g., Leisher et al., 2007). I suggest that this promotion is based on what co-management *could* achieve, and not on what co-management *is* achieving. Enthusiasm for the approach may be driven by the success NGOs observe in the process of management uptake, or the interest communities display in engaging with an externally funded project that might deliver development benefits (Foale, 2001, Filer, 2004). While community engagement in designing and implementing management is considered critical to successful co-management, it will not necessarily lead to sustainable fisheries outcomes. My thesis therefore addresses this knowledge gap and concentrates on critically examining co-management outcomes for small-scale fisheries (Chapters 2, 3 and 4). In Chapter 6, I go on to explore the implications of these outcomes for food security.

As discussed, understandings of co-management measures and resource-use regulations that lead to improved outcomes for fisheries are limited globally. Learning how to make co-management work for small-scale fisheries objectives can be supported by the generation and sharing of knowledge across institutional and geographic scales (Bell et al., 2006, Berkes, 2009). Due to the complex and dynamic nature of fisheries systems, it is unlikely that a single agency will have sufficient capacity or knowledge to address the challenge of designing and implementing management (Berkes, 2009). Effective co-management will also require strengthening the accountability, capacity and representation of historically marginalised resource users in decision making and knowledge generation (Bell et al., 2006, Ratner et al., in review). Practical experience and guidance on ways to achieve enhanced inter-agency knowledge generation and learning, alongside local level representation are however limited (Berkes, 2009). Increasingly, social networks and formal governance networks are suggested as mechanisms that can promote learning between actors for collective purposes, such as for improving governance of small-scale fisheries or coastal ecosystems (Newig et al., 2010, Lebel et al., 2005, Vance-Borland and Holley, 2011). Across the Asia-Pacific, NGOs, government agencies and local communities involved in co-management have been connected under the umbrella of the *locally managed marine areas network* (LMMA, 2011). The LMMA network was established explicitly to: (1) promote learning and collaboration amongst agencies involved in co-management, and; (2) enhance representation of small-scale fishers and community managers in higher levels of governance. In Chapter 5 I explore, the structure and function of the Solomon Islands branch of this network to understand the role it plays in promoting learning and coordination amongst co-management actors. I discuss implications for advancing the ultimate objective of strengthening co-management and improving small-scale fisheries and coastal ecosystem management outcomes.

1.4 Food security

Alongside goals for the sustainable management of marine resources, social objectives such as food security are also leading objectives of co-management (Allison, 2011, Pomeroy, 1995). Food security is fundamental to poverty alleviation and sustainable economic development, and is recognised as a major international concern (United Nations Department of Economic and Social Affairs, 2010). Food security exists when all people at all times have economic, social and physical access to sufficient nutritious and safe food to meet dietary needs and preferences (FAO, 1996). The World Health Organisation (2010) suggests that food security is built on three pillars; availability, access and consumption (Figure 2). The availability pillar refers to consistent and sufficient quantities of food, and is threatened for example when crops fail or resources are depleted. Access refers to people's economic, legal, logistic and technical ability to obtain appropriate and sufficient foods, and may be threatened, for example, when people do not have the fiscal means to purchase food, or when food supplies cannot reach them due to transport or trade barriers. Consumption refers to appropriate use of basic nutrition and care, which is supported when people have knowledge and behaviours that result in a balanced nutritional intake, and also requires that people have clean water and sanitation adequate to prepare food safely (World Health Organisation, 2010).

In my thesis I employ food security as a framework by which to qualitatively discuss the outcomes and implications of fisheries co-management. While fisheries can contribute indirectly to food security via incomes, licence fees and taxes, I focus on the direct contribution of subsistence fisheries to diets (i.e., nutritional security) through animal protein, essential fatty acids and micronutrients (Kawarazuka and Bene, 2010). Fish is a particularly important source of nutrition due to its affordability, availability and cultural acceptability (Kawarazuka and Bene, 2010). The importance of the direct contribution of fisheries to food security is enhanced in contexts where redistribution of profits and wealth, distribution of food and accessing alternative sources of equivalent nutrition, are problematic.

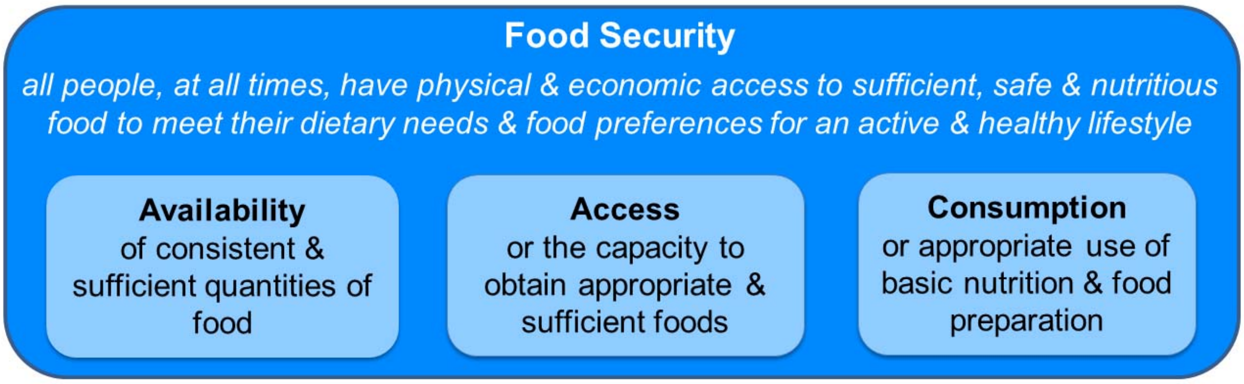


Figure 2 The food security framework (WHO 2010)

In terms of fisheries, *availability* translates to plenty of harvestable fish[1] in the sea, rivers or ponds. Therefore, interventions or management measures that enhance or maintain harvested fish stocks[2] can contribute to food security. Fisheries regulations such as size limits, licences, quotas, marine reserves etc., are used to promote sustainable fishing practices which will maintain or improve fish stocks and yields. While local or community-based design, implementation and enforcement of fisheries regulations is increasingly common (Johannes, 2002, Govan, 2009a), the nature of management measures actually employed in contemporary developing country situations, and their impacts on yields and fish stocks, has rarely been systematically documented. Particularly rare are assessments that go on to examine these outcomes for food security.

---

[1] In this thesis I employ the term 'fish' to account for any living product harvested from the sea, and therefore includes for example marine finfish, invertebrates, algae, reptiles and coral.
[2] I acknowledge the future potential role of aquaculture, however in this thesis I concentrate on fisheries production systems as they are currently in the Pacific, and therefore focus on small-scale fisheries for wild-caught fish.

The access pillar of food security refers to the capacity to obtain appropriate and sufficient foods. It is proported that at a global scale, food insecurity is not an issue of insufficient quantities of food, but is a result of factors that restrict or prevent access (Sen, 1983). Factors that affect access can include financial capacity, distribution mechanisms, technical or physical capacity to harvest food, or access restrictions imposed through licences, property rights or social relations (Ribot and Peluso, 2003). In the Pacific fisheries context, access can be affected by customary tenure arrangements, which can dictate rights to harvest resources or rights to the resources once harvested (Carrier, 1987, Macintyre and Foale, 2007). Fisheries management arrangements, such as marine reserves or periodically-harvested closures, can vary geographic and temporal access to resources, which may affect entire communities or differentially affect certain sectors of society. In addition to affecting access, management institutions can also influence the sustainability of resource use, and thus the availability of stocks (Bayliss-Smith, 1991). The effects of co-management on resource *access* and on *availability* have rarely been studied concurrently, and I address this research gap with the studies I present in Chapters 3 and 4.

The consumption pillar refers to basic nutrition and safe food preparation. Consumption is sufficiently addressed when people have access to sufficient and appropriate foods to meet nutritional requirements. Fisheries provide a particularly important contribution to the consumption pillar via the direct contribution to dietary animal protein, essential fatty acids and micronutrients (Kawarazuka and Bene, 2010). In many poor communities around the world the affordability, availability and cultural acceptability of fish makes is a particularly important source of nutrition (Kawarazuka and Bene, 2010). And in many contexts, sourcing alternatives is economically, logistically or culturally challenging. For example, in coastal communities across the Pacific, the nutritional contributions of small-scale fisheries to diets is considered to be critical to preserve given the lack of alternatives, and the transformations required to create alternatives in the future (Weeratunge et al., 2011).

Bell and colleagues (2009) explored the relationship between small-scale fisheries and future food security across the Pacific. Using current consumption rates, population growth projections and near-shore fisheries productivity estimates (based on reef area) they suggest that 11 countries, including Papua New Guinea and Solomon Islands, will face a food security shortfall by 2030 (Bell et al., 2009). Bell et al. argue that the shortage of fish cannot be met by reef fisheries alone due to limits to productivity, and that alternative fish and protein sources will be required to meet needs. The food security shortfall would however be worsened if coastal fisheries were poorly managed and reef habitats were degraded. My thesis works on the premise that the nutritional role that fisheries plays would be threatened if *availability* and *access* were problematic. While I do not examine *consumption* and nutrition explicitly, the protection of the nutritional function of small-scale fisheries via the availability and access pillars, underpins this thesis.

1.5 Solomon Islands and local case studies

Solomon Islanders predominantly (80%) reside in rural areas, and 90 percent of the rural population live on or near the coast (World Resources Institute, 2007). Up to 83 percent of all households participate in some form of fishing activity (Oreihaka, 1997), and the majority of protein consumed is from fresh fish, derived from subsistence fishing or local markets (Bell et al., 2009, Solomon Islands Statistics Office, 2006). While most reef habitats and coastal ecosystems are considered to be in a good condition currently (Green et al., 2006), the Solomon Islands government considers that there are threats to coastal and reef fisheries from climate change, habitat impacts from logging, a rapidly growing human population and developing export markets (MFMR, 2008). In the face of these pressures, maintaining the role of subsistence fishing and farming sectors is nationally recognised;

> *"…the self-sufficiency of the subsistence community is an asset that must not be overlooked or undermined. We have a degree of self-sufficiency that provides an important protection from the risk of vulnerability."*
>
> Prime Minister of Solomon Islands, The Hon Dr Derek Sikua (MFMR, 2008: 1)

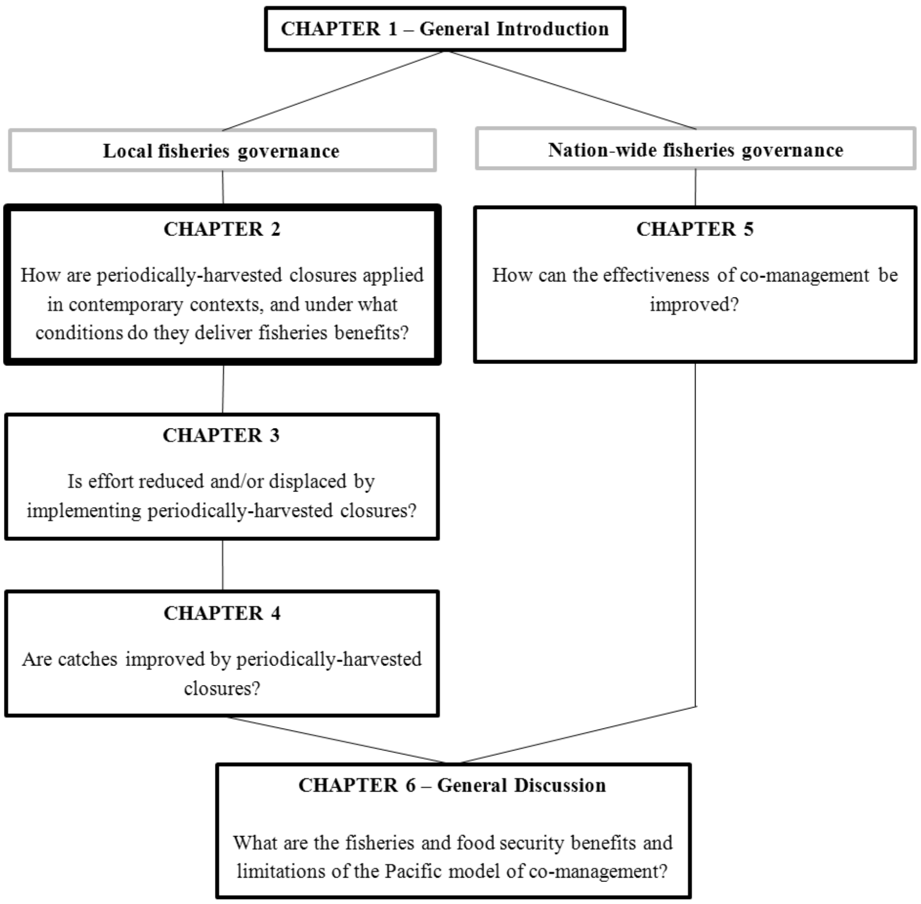
Coastal ecosystems and fisheries are governed by the state through environment and fisheries legislation, alongside customary land and marine tenure systems that are recognised in the constitution (Lane, 2006). The national government has met with challenges in managing small-scale fisheries, in part due to low capacity and enhanced by difficulties in aligning state and customary regulation of resource access and use (e.g., in some areas customary law is legally recognised to preclude state controls such as fisheries regulations) (Johannes, 1998a, Baines, 1990, Lane, 2006). The current national strategy for the management of small-scale or inshore fisheries and marine resources recognizes the central role of community-based initiatives (MFMR, 2008). The strategy lays out ten principles which emphasise that management must be adaptive, flexible to different community contexts, low cost, people-centred, ecosystem-based, supported by peer-to-peer learning, embedded within multi-sectoral engagements and supported by legal and institutional frameworks.

Over the last 10 years, initiatives to establish fisheries management and marine conservation have established 137 co-managed marine areas or LMMAs (Govan 2009). Similar to observations made of the global literature (Evans et al., 2011), I found there was a lack of critical, bias-free, and systematic appraisals of co-management outcomes for Solomon Islands. However, positive outcomes have been suggested, including that; co-managed permanent closures do not adversely affect, and may potentially enhance, local nutrition and health (Aswani and Furusawa, 2007); co-managed periodically harvested areas can enhance shellfish biomass (Aswani and Weiant, 2004), and; where co-management is employed, incomes and health can be improved (Leisher et al., 2007).

Solomon Islands was selected as a case study because; (1) it is one of the 11 countries for which there is anticipated to be a food security shortfall from fisheries by 2030 (Bell et al., 2009), (2) the use of LMMAs is supported as being a dominant strategy for the management of small-scale fisheries (MFMR, 2008), (3) it was safe and logistically feasible to conduct field work, and (4) I had existing professional relationships with organisations that supported, and could facilitate, my critical appraisal of management arrangements and outcomes. I selected three case study locations within Solomon Islands to explore management in a range of rural and coastal community contexts. The communities were situated within three regions; (1) Malaita Province (2) Central Province, and (3) Western Province. Community names are not provided because of confidentiality arrangements. In these locations management via LMMAs was anecdotally reported to be established and active, meaning I could document the types and forms of management measures actually implemented (and compare implemented management to management plans). Management engaged three to five villages working together in each location. These clusters of villages meant that there were smaller management units, or replicates, within sites. In each location, management was supported by one known NGO partner; either the Foundation for Peoples of the South Pacific International, or WorldFish. These agencies were willing to support my independent research at these locations in terms of facilitating access to communities (e.g., introducing me to community leaders and resource owners), and assisting with initial transport and logistical arrangements.

Chapter 2 Sustaining small-scale fisheries with periodically-harvested closures

In western fisheries management contexts, periodically-harvested closures have been shown to be beneficial for the management of some taxa. Periodically-harvested closures are widely employed and promoted as an effective strategy, with a traditional basis, to contribute to fisheries management within co-management models employed throughout the Indo-Pacific. However, there is little evidence that they are effective for the sustainable management of the many types of small-scale fisheries important in the region. In Chapter 2 I review cases from across the Indo-Pacific region to explore the opening and closure periodicities, concurrent harvest control measures, and fisheries objectives and outcomes of periodically-harvested closures as they are employed in practice. In Chapter 2 I illustrate that there has been a lack of systematic and critical evaluations of the outcomes and limitations of periodically-harvested closures as a fisheries management strategy. In this chapter I develop a framework to assess the fisheries management outcomes of periodically-harvested closures for controlling fishing effort, and maintaining and improving catch rates and yields. I use this framework to guide the analysis I present in Chapters 3 and 4.



2.1 Introduction

Spatial marine closures are widely employed and advocated for marine resource management and conservation. The main expected fisheries function of permanent marine reserves is the export of adults ("spill-over") and propagules ("larval export") to sustain fisheries operating outside of the area (Russ, 2002). Permanent reserves will accrue greater ecological benefits to populations and habitats within their boundaries than areas subjected to some level of fisheries exploitation (Lester and Halpern, 2008). However population increases inside a permanent reserve will take time to deliver benefits to fishers (Hilborn et al., 2004). In certain contexts non-permanent closures are employed in preference to permanent reserves. Temporal, non-permanent, rotational or periodically harvested area closures (henceforth periodically-harvested closures) are expected to build stocks within the closed area that are directly and periodically exploited. There may be secondary effects of spillover and larval export (Abesamis and Russ, 2005, McClanahan and Mangi, 2000) however these are beyond the scope of this chapter.

In a Western management context, periodically-harvested closures have mainly been proposed and tested as a management strategy for sedentary and sessile benthic invertebrates; urchins (Botsford et al., 1993, Pfister and Bradbury, 1996), scallops (Hart, 2003, Valderrama and Anderson, 2007), abalone (Caddy and Seijo, 1998, Sluczanowski, 1984), trochus (Nash et al., 1995), lobster (Gendron and Brethes, 2002) and coral (Caddy, 1993). Few studies have tested periodically-harvested closures as a management strategy for fish (De Klerk and Gatto, 1981, Game et al., 2009) or for multi-species fisheries. Some studies indicate that net fisheries gains from a strategy of periodically-harvested closures will be marginal (Kaplan et al., 2010), or that the strategy is useful for maintaining population size but will be accompanied by a decrease in yield comparable to a strategy of continuous fishing (Pfister and Bradbury, 1996), while other studies find that maintaining both yield and population size is possible (Botsford et al., 1993, Myers et al., 2000). Modelling of rotation (i.e., closure and harvesting) periods broadly conclude that for long-lived species longer periods of closure are required for building stocks, while for shorter-lived and fast-growing species shorter rotation periods can achieve optimal biomass and yield (Caddy and Seijo, 1998). In general it is anticipated that periodic harvesting is a more suitable management strategy for short-lived and fast-growing taxa than for those that are longer lived and slower growing (Jennings et al., 1999b, Russ and Alcala, 1998b).

The recovery of exploited stocks and habitats when a fishing ground is closed to fishing is a complex process (Jennings, 2001). While there are few empirical data about recovery specifically during periodic closures, the permanent no-take reserve literature is instructive (Jennings, 2001, Russ and Alcala, 2003, Russ and Alcala, 2004). Rates of stock recovery or replenishment will be *site specific,* *time period specific* and *species specific* (Russ et al., 2005), dependent on stock status at the commencement of closure, and are influenced by hydrodynamics and larval supply (Jennings, 2001, Mills et al., 2011). Patterns of depletion during reserve opening can be equally complex and are driven by fisher behaviour, catchability of target taxa and the conditions of opening - such as its duration and regulations imposed on harvesting. Imposing periods of closure is an indirect mechanism to reduce fishing effort within an area (Botsford et al., 1993). Yet patterns of fishing outside closed areas are just as important to consider for fisheries management goals (Hilborn et al., 2006), and can also be affected by the implementation of periodically-harvested closures (e.g., via the displacement of effort) (Kaplan et al., 2010).

In tropical zones most forms of management are challenged by the characteristics of small-scale fisheries; multi-species, multi-gear fisheries with large numbers of dispersed landing sites and high numbers of participants harvesting for subsistence and commercial purposes (Johnson, 2006). Area closures hold potential to manage multi-species fisheries as they control access and exploitation at the ecosystem level rather than species or fisher level (Polunin and Roberts, 1996). Despite the range of factors that will dictate the fisheries outcomes of periodically-harvested closures, closing an area to fishing can be a relatively simple management action, particularly within community-based management or co-management arrangements, or where data to inform management is limiting (Hilborn et al., 2004, Johannes, 1998a). In fact, periodically-harvested closures have become an important or even primary tool in many community-based and co-management arrangements across the Indo-Pacific (Govan, 2009a, McLeod et al., 2009). Yet there is a striking scarcity of empirical evidence that the closure-opening cycles and harvesting patterns employed in practice can achieve sustainable management of the range of taxa exploited by small-scale fisheries in the region. As a result managers and policy makers are challenged to find or provide guidance for designing and implementing periodically-harvested closures to address fisheries concerns.

This chapter focuses on the application of periodically-harvested closures for the objectives of sustainably managing fisheries by: (1) maintaining or improving yield; and (2) maintaining stocks of target invertebrates and fish. The factors that influence the success of *implementing* and *governing* periodically-harvested closures themselves are not discussed here (but see Harkes and Novaczek, 2002, Cinner et al., 2007, Foale et al., 2011). The aim of this review is to highlight current knowledge that must be considered by managers and policy makers to maximise the effectiveness, and plan for the limitations, of periodically-harvested closures for managing fisheries. This chapter develops a theoretical framework from permanent reserve and periodic closure literature to illustrate the factors that contribute to fisheries management outcomes from periodically-harvested closures. This framework is used to assess periodically-harvested closures employed for tropical small-scale fisheries, focusing on case studies from the Indo-Pacific. Critical issues and knowledge gaps to be addressed by future work are discussed.

2.2 Traditional origins and contemporary use of periodically-harvested closures

Throughout the Pacific there is a rich diversity of customary institutions for managing marine resource use (Ruddle and Akimichi, 1984). Customary controls include tenure systems that define access and fishing rights, bans on sectors of society consuming or fishing certain species and temporary closures placed over fishing grounds (Johannes, 1978, Johannes, 1982). These periodically-harvested closures fall under customary institutions of *sasi laut* in eastern Indonesia (Evans et al., 1997) and *taboos* throughout the Pacific (Carrier, 1987, Johannes, 1978). Periodic fisheries closures have long been practised in the Indo-Pacific as a mark of respect for the death of prominent community members, to protect sacred sites, affirm rights and control access to fishing grounds, or as part of preparation (i.e., allowing the replenishment of stocks) for customary feasting (Allan, 1957, Hviding, 1998, Johannes, 1978, Thorburn, 2000). While customary closures controlled use of resources and access to them, the main motivation for their use was socially and culturally driven and was less likely motivated by the need or intent to manage resources sustainably (Ruttan, 1998, Zerner, 1994, Foale et al., 2011). Conservation and fisheries management benefits may have resulted from the use of customary closures in some cases. However, anecdotal evidence suggests that in other cases customary closures did not result in resource management or conservation outcomes in any practical sense (Carrier, 1987, Polunin, 1984).

Co-management is currently expanding across the Indo-Pacific embrace a hybrid model that combines conventional approaches to marine resource management with traditional governance systems, calling upon scientific, traditional and local knowledge (Govan, 2009a, Johannes, 2002, Ruddle, 1998, Pannell, 1997). These approaches have found traction in addressing small-scale fisheries management challenges where centralised management institutions have had less success due to lack of capacity and difficulties resolving state and traditional controls (Alcala and Russ, 2006, Arifin et al., 1998, Ruddle, 1998). Community-based marine resource management has been met with enthusiasm in the literature and in practice. There are now hundreds of coastal communities throughout the Indo-Pacific employing a range of rules and resource-use regulations that have been developed in consultation with partner support agencies, including government and non-government organisations (NGOs) (Govan, 2009a, LMMA, 2011).

Many co-management initiatives have promoted the re-establishment or re-invention of periodically-harvested closures as a key measure for regulating marine resource use (Govan, 2009a, Johannes, 1978, McLeod et al., 2009). In many areas where the traditional use of closures had declined or ceased, contemporary closures have been newly established (Harkes and Novaczek, 2002, Johannes, 1978, Johannes, 1998b). In the Indo-Pacific periodically-harvested closures can cover areas of reef, mangrove or shoreline and are generally small in size (Harkes and Novaczek, 2002); for example, in Fiji 179 areas had a median area of 1 km^2 (Govan, 2009b) and in Vanuatu areas were as small as 0.02 km^2 (Johannes, 1998b). Govan (2009a) reports that there are a total of 595 area closures in the Pacific covering over 1000 km^2 in total. These areas may be predominantly opened and "periodically closed" to harvesting, predominantly closed and "periodically harvested", closures that rotate between reefs, or relatively few "permanent" no-take marine reserves (Figure 3) (Govan, 2009b, Thorburn, 2000, McLeod et al., 2009). Fishing restrictions within closures may apply to a single species (e.g., trochus) (Evans et al., 1997, Foale, 1998b), or concurrently to commercially harvested invertebrates (e.g., sea cucumbers, oyster, green snail) but not fish (McLeod et al., 2009, Harkes and Novaczek, 2002), or apply to the entire area and all species within it (Bartlett et al., 2009b, Cinner et al., 2006) (Table 1).

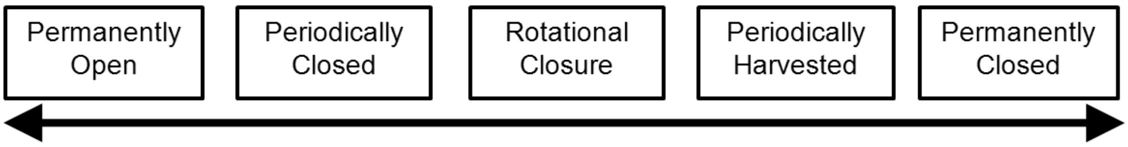


Figure 3 The spectrum of marine area closure and opening regimes practised in the Indo-Pacific

Periodically-harvested closures are touted by NGOs and some scientists as being a successful strategy, with a traditional basis, to contribute to small-scale fisheries management and marine conservation in the Indo-Pacific. NGO enthusiasm for this tool may be due to the relative eagerness with which it is employed by the communities they work with. Community enthusiasm, at least in part, arises from its similarities with customary practice (Williams et al., 2006) alongside maintaining their ability to access and exploit resources in the area (Foale and Manele, 2004) and their observations of stock replenishment or increased catchability after the closure is lifted (pers. comm. A. Schwarz 2009, Cinner et al., 2006). The traditional basis of periodically-harvested closures in the Indo-Pacific is beyond the scope of this review, yet could influence their implementation and resultant success for fisheries management. In summary it is important to understand that the management of social relationships, rather than ecological sustainability, was in many cases the primary incentive for the use of periodically-harvested closures traditionally (Thorburn, 2000, Foale et al., 2011, Carrier, 1987).

Table 1 Cases of periodically-harvested closures from the Indo-Pacific; the key attributes of the closure, harvesting and broader management strategies that will influence the fisheries management outcomes are highlighted for each case. 'NR' indicates data have not been reported.

Reference	Country	Site	Opening-closure cycle	Restriction	Harvesting details	Controls on harvest	Concurrent management
Arifin et al., 1998	Indonesia	Run, Hatta, Saparua, Kai Islands, Maluku Province	Saparua: 1967-1984 closure 3-4 years then shortened 1-2 years, opened 1-2 weeks. Run & Hatta: closed 2 years, open 1 week	Trochus	1 tonne per year, after 1984 0.5 tonnes per year	Minimum size limit 6cm. Saparua: daylight harvest only, village residents >15 years old. Run & Hatta Island: village residents only	Nation-wide ban on harvest of trochus
Bartlett et al., 2009a,b	Vanuatu	Nguna, Pele & Emao Islands, North Efate	Single day harvest ≤ twice per year	NR – (assume total ban on extraction)	NR	Only some men in the villages participated in a day-long harvest (average 15 people). Intensity & frequency of harvest controlled - but specific regulatory measures NR	Customary tenure over shoreline & associated fringing reefs. Two villages had tenure-wide bans on giant clam harvest
Cinner et al., 2006	Indonesia	Kakarotan, Sangihe-Talaud Archipelago, North Sulawesi	Each year 1of 9 reef areas closed - site selection & duration decided by village traditional leaders	All fishing activities	NR	NR	NR
Cinner et al., 2006	PNG	Muluk village, Karkar Island, Madang Province	Closed 2-3 times per decade for 1-2 years	NR – (assume total ban on extraction)	NR	NR	NR
Cinner et al., 2005	PNG	Ahus Island	Predominantly closed 0-3 openings per year	Spears & nets banned, hook & line permitted. Invertebrate harvest is severely limited.	One opening e.g. approx 3 hours of fishing intensively with a monofilament gill net, canoes & swimmers driving fish to nets.	NR	NR
Evans et al., 1997	Indonesia	Kei Islands, Maluku Province	Opening periods varied from a few days to 2 months between October-March.	Trochus, sea cucumber, seaweed & green snail.	Trochus, sea cucumber, seaweed & green snail were also harvested only at this time	All men > 15 years old participated in the harvest	60mm min size limit for trochus
Evans et al., 1997	Indonesia	Tulehu & Tengah-Tengah villages, Ambon Island Maluku Province	Closed March-May	Trochus (only 2 of 15 villages performed closures on finfish)	NR	Small trochus not harvested (but rule believed to be broken) & reports of harvesting during closures	Villages permitted no access to their area, or may allow some exploitation (invertebrates e.g. holothurians) subject to fees
Ferraris et al., 2005	New Caledonia	Abore Reef reserve, Noumea Lagoon	Fishing banned on entire reef 1990–1993, then permitted on two-thirds of the reef August 1993-August 1995, then re-closed.	NR – (assume total ban on extraction)	In the first 2 weeks of lifting the ban the number of boats & fish yield in the area reached levels previously observed over an entire year	NR	NR
Foale, 1998	Solomon Islands	Sandfly Island,West Ngella, Central Province	Serial ban on harvesting trochus, punctuated by harvests. Closure re-installed immediately or after several months	Trochus	3 or more days (depending on stock density & reef size) of intensive harvesting by reef owners, then area opened to wider community	No set catch limits. National size limit not adhered to	NR

Reference	Country	Site	Opening-closure cycle	Restriction	Harvesting details	Controls on harvest	Concurrent management
McLeod et al., 2009	Indonesia	Tomolol, Misool, Raja Ampat	Restricts harvest of specific marine resources for 6 months (April - September).	Can include sea cucumber, turtle, shellfish, shrimp, & shark - not a total fishing ban	NR	Prohibitions on species harvested & gear used – specific restrictions NR	NR
McLeod et al., 2009	Indonesia	Fafanlap, Misool, Raja Ampat	From 1 to 3 months during the stormy season & conducted 1-2 per year	Can include sea cucumber, turtle, shellfish, shrimp, & shark- not a total fishing ban	NR	No restrictions on yield	Restrictions against cyanide & dynamite fishing (combination of government & local laws)
Nash et al., 1995	Cook Islands	Aitutaki	Closure to trochus fishing with approximately annual harvest. Opening durations vary 1 day - 15 months	Trochus	Participation in all men Women & children had participated in previous harvests.	A quota system (since 1990), & minimum & maximum size limits (80-110mm). Recorded harvest was unusual i.e. no quota & increased maximum size to 120mm after 3 days	NR
Ruttan, 1998	Indonesia	Ohoirenan village, Kei Besar Island	NR	Trochus, not finfish	NR	Only men from the village can harvest. The shoreline divided into 4 sections, one area opened at a time for trochus harvest. Each area fished twice over 8 days, approximately 2 hours per day. SCUBA banned	Spearfishing allowed in area only after trochus harvested. In 1994 two new rules were made 1. divers not allowed to bring canoe attendants 2. minimum size limit roughly 50-60mm
Ruttan, 1998	Indonesia	Ohoi El village, Kei Besar Island	NR	Trochus, not finfish	In 1994 300 to 400 individuals dove for trochus - including people from neighbouring villages	No size restrictions on trochus, no SCUBA used	NR
Thorburn, 2000	Indonesia	Ohoirenan village, Kei Islands, Southeast Maluku	Opened usually only 2 or 3 days, at intervals ranging from yearly to once every 3-5 years. Reef divided into 4 equal zones & sequentially harvested	Trochus	Harvests average 7-10 tons per opening. All village males dive for trochus	Only men & teenage boys dive for trochus	Some villages ban goggles except during the area opening. Some ban fishing nets. Many ban poison. Trochus cultivation, harvest & transport is regulated nationally
Weiant and Aswani, 2006	Solomon Islands	Baraulu & Bulelavata, Roviana Lagoon, Western Province	Closed for 8 months (September–April) & harvested for 4 months (May–August) each year	*Anadara granosa* & *Polymesoda* sp.	Women & children, gleaning mainly	No limits on harvest	Alternative livelihood project (sewing) to minimise effort displacement
Williams et al., 2006	USA	Waikiki-Diamond Head Fishery Management Area, Oahu, Hawaii	2 years closure - 2 years harvesting cycle for 10 years, followed by 1 years closure, 1 years harvesting cycle for next 10 years.	All fishing activities	NR	In earlier years some openings only permitted hook & line fishing. In later years all forms of fishing except gillnetting & night-spearing were permitted	NR
Jupiter et al., 2012	Fiji	Kia Island, Macuata Province	Informally protected, then in 2005 formally closed. Opened in 2008 for 5 weeks, closure reinstated.	NR – (assume total ban on extraction)	Fishers harvested *in shifts over 24 hour periods* 6 days per week – initially for fundraising from sales of fish & invertebrates. Mainly spears & hook & line used.	NR	This was one of 9 closures forming an MPA network. Communities *did not have a well-developed management plan*
Holland 1994	Solomon Islands	Ongtong Java, Malaita Province	Every ‘even’ year open (e.g. 1990, 1992 etc), every odd year closed	All sea cucumber harvesting	NR	Harvesting concentrated on two species in particular – white teatfish and a second species that was chosen based on relative abundance.	NR

2.3 Opening and closure periodicities

Modelling of rotational or periodic harvesting demonstrates that the periodicity of the harvesting and closure cycle is a key factor influencing the resultant fisheries management efficacy (Gerber et al., 2003). It is therefore critical to understand the duration, frequency and drivers of opening and closing areas to harvesting in practice. Throughout the Indo-Pacific region, the scheduling and duration of openings and closures are generally under the control of the local community, clan or family that has tenure to the area (Foale and Macintyre, 2000, Hviding, 1996, McLeod et al., 2009). Timing of openings may also be influenced by a supporting agency such as an NGO or government partner (Bartlett et al., 2009a, Nash et al., 1995), however the extent and nature of that influence is difficult to discern in reported cases. Reviewed case studies suggest opening-closing cycles employed in practice are highly variable (Table 1); they can be fixed or dynamic, are generally driven by community decision makers and are harvested to meet subsistence, commercial, cultural or ceremonial needs.

Periodicities of harvesting and closure appear in some cases to be aimed at achieving medium- to long-term goals of fisheries management or conservation. For example, in Maluku province of Indonesia, area openings varied from a few days to two months, where the timing and duration of opening and closure were dictated by the village council based on their assessment of stocks and conserving them for future exploitation (Evans et al., 1997). The Aitutaki trochus fishery was managed for long-term goals of sustainability and optimising economic return, with decisions on harvest duration and timing based on western stock assessment methods (Nash et al., 1995). In communities in the North Efate region of Vanuatu, closures were subject to single-day harvest events, no more than twice per year for subsistence or celebration purposes (Bartlett et al., 2009a). Here the most commonly cited reason for establishing periodically-harvested closures was to halt the decline of resources (Bartlett et al., 2009b). In Roviana lagoon in Solomon Islands, closures prohibited harvesting of the shellfish *Anadara granosa* and *Polymesoda* sp. were implemented to address overexploitation (Weiant and Aswani, 2006). These communities committed to a more rigid schedule of opening and closure with areas closed from September to April and then harvested from May to August each year. In Ongtong Java in Solomon Islands, cycles of opening and closing an area to sea cucumber harvesting were also rigid; harvesting occurred every 'even' year and closure every 'odd' year – the factors that influenced the decisions to use this cycle are not however described (Holland, 1994).

Many communities may use periodically-harvested closures to ensure a ready supply of fish and invertebrates and therefore base the timing of openings on occasions when need is high (e.g., fundraising or celebratory feasts) rather than on explicit goals of longer-term sustainable management

(Govan, 2009b). On Ahus Island, Papua New Guinea (PNG), reserve openings were instigated for ceremonial events between zero to three times per year (Cinner et al., 2005). In Muluk, PNG, 50 ha of reef were closed two to three times in a decade for one to two years each time (Cinner et al., 2006). The objective of the closure was to make fish easier to catch, and the decisions about where, when and for how long to place the closure were made considering ecological indicators (i.e., closing the area when fish catch declined until fish become "tame"). A review of Vanuatu cases indicated that periods of closure varied from between one to five years, to areas that were closed indefinitely or opened only when *the area is ready* (Johannes, 1998b). In Kei Islands, southeast Maluku province, reserves were opened usually for only two or three days at intervals of between one and five years. The decision to open the areas was made by community elders who based the timing usually on an immediate village-level economic need (Thorburn, 2000).

These examples highlight two additional fisheries related objectives for implementing periodically-harvested closures: (1) to increase the efficiency of harvests via biomass gains and/or fish becoming easier to catch due to behavioural changes (Feary et al., 2011, Cinner et al., 2006); and (2) to use periodically-harvested closures as a saving instrument where withdrawals are made only when needed by fishers or the broader community (Govan, 2009b). Dependant on factors outlined in the following sections, these objectives may or may not align with longer term sustainability objectives; nevertheless they address legitimate and immediate concerns of Indo-Pacific fishers.

2.4 Recovery and replenishment during closure

Rates of replenishment of fish and invertebrates after cessation of fishing depend on many factors including biological attributes of species, the physical environment (currents, etc.), ecosystem conditions and the size of local and distant adult populations. Evidence varies suggesting that recovery can be rapid e.g., one to three year recovery in abundance after fishing ceases (Halpern and Warner, 2002), or that full recovery of predatory fish may take 30 to 40 years (McClanahan et al., 2007, Russ and Alcala, 2004). Species recover at different rates and recovery through time is non-linear (McClanahan et al., 2007), adding to the complexity of managing multi-species fisheries with periodically-harvested closures. In practice fishers' expectations to open areas for harvest, or the levels of exploitation during openings (discussed in section 2.5), may not coincide with sufficient replenishment of some species. To achieve a goal of medium- to long-term sustainable fisheries management the duration of closure and mechanisms of recovery are critically important to consider.

Periodic harvesting may be more suitable for short-lived and fast-growing taxa than those that are longer lived and slower growing (Jennings et al., 1999b, Russ and Alcala, 1998b). *Trochus niloticus* (trochus) are relatively short-lived and fast-growing and are arguably the species most commonly managed with periodically-harvested closures in the Indo-Pacific (Table 1). The strategy is perceived by some communities as successful for trochus management due to observable recoveries during closure (pers. comm. A-M. Schwarz 2009, Foale and Day, 1997) and due to a history of stable trends in catches (Evans et al., 1997). However, evidence from case studies is variable, highlighting that a range of factors are at play, particularly patterns of harvesting. In West Nggela closures were commonly placed on reefs to control trochus harvests. However Foale (1998b) observed that trochus populations were low when compared to "well managed" stocks and suggested that the fishery performed poorly where periodically-harvested closures were the main tool for management. In a multi-species closure in Vanuatu, trochus were also observed to be vulnerable to the periodic harvesting strategy (Bartlett et al., 2009a). In Aitutaki in Cook Islands, it was demonstrated that with adequate pre-fishing biomass, a combination of size limits and quota restraints and short harvest periods were a successful management strategy for trochus (Nash et al., 1995).

Higher trophic level species, such as predatory fish, are frequently of high economic and social value and thereby preferentially targeted by fishers (Jennings and Polunin, 1995). However, these species are often slow growing, long lived and exhibit slower rates of population increase (Cheung et al., 2005), and are predicted to be less likely to be managed effectively with periodically-harvested closures (Jennings et al., 1999b, Russ and Alcala, 1998b). Yet there have been cases with low fishing pressure where periodically-harvested closures have had fisheries management benefits over strategies of continuous fishing for species deemed vulnerable to exploitation. In North Efate higher abundances and biomass, including of tridacnid clams and fish with vulnerable life histories, were observed in periodically-harvested closures compared with continuously fished areas (Bartlett et al., 2009a). In Muluk three families of long-lived fish with low population doubling times, as well as the mean trophic level of fish communities, appeared to respond positively to a strategy of periodic harvesting compared with continuous fishing (Cinner et al., 2006).

In cases of higher fishing pressure, benefits of periodically-harvested closures are less evident. In the Waikiki-Diamond Head Fishery Management Area (FMA) in Hawaii overall declines in target-species, including predatory fish, indicated that the one to two year closure periods were too short for compensatory growth and reproduction (Williams et al., 2006). Cinner (2005) examined three periodically harvested areas on Ahus Island and observed that the average size of reef fish, but not fish abundance, was greater in periodically-harvested closures compared with adjacent openly fished areas, indicating there was growth but not population recovery. In two fish reserves in the Philippines a biomass increase of predatory fish was detected only three to four years after a fishing event (Russ et al., 2005) and density and biomass were still increasing after nine years of protection in one reserve, and 18 years in the other (Russ and Alcala, 2003). The Philippines case is an example of population recovery after a lapse in compliance with permanent reserves, and where no legitimate controls were placed on access or fisheries extraction. This situation may vary from periodically-harvested closures employed within community based or co-management frameworks, yet the example is illustrative of replenishment times after high levels of fishing.

The ability of marine closures to confer fisheries benefits is affected by the size of the closure and the scale at which ecosystems function (Nowlis and Roberts, 1999). In the Indo-Pacific periodically-harvested closures (and broader marine tenure) operate on relatively small scales (Foale and Manele, 2004). Species with sedentary habits and with short-lived or demersal larvae may be well protected and display population increases within small reserves. Impressive evidence for this comes from Fiji, where a small three year closure designated to rebuild *Anadara* spp. stocks displayed a 13-fold increase within the closed areas and a fivefold increase in adjacent fished areas, where fishers also experienced a doubling in catch per unit effort (Tawake and Aalbersberg, 2002). Conversely species that have larger home ranges and long-lived or widely dispersing larvae would be less likely to be significantly protected or to self-recruit to small reserves (Ferraris et al., 2005, Roberts et al., 2001b, White and Costello, 2011). Such species are, however, still of importance to small-scale fishers and this emphasizes the importance of employing management strategies alternative to or in conjunction with closures (discussed in section 2.6).

Fertilisation success, larval dispersal and resultant recruitment at a site are species specific; depending on oceanographic and habitat conditions, and population densities at the source and settlement sites (Roughgarden et al., 1988, Levitan et al., 1992). Recruitment is highly variable both spatially and temporally, making it difficult to predict how a species will recover in an area closed to fishing. For example in the Philippines, over a 17-year period Sumilon Island reserve experienced two grouper recruitment pulses that resulted in 200% and 300% increases in density, whereas no such recruitment pulses were observed at nearby Apo Island reserve over that period (Russ and Alcala, 2003). If a stock has been very heavily fished the rate of population recovery will be slower than if only lightly depleted. The ability of populations to rebuild can become reduced or even lost when densities of mature adults are very low i.e., due to the Allee affect where recruitment declines at low population density, probably mediated through low fertilisation success (Stephens et al., 1999). In these situations the population can continue to decline even if not fished; examples from Pacific nations include sea cucumbers (Bell et al., 2008) and green snail (Ramohia, 2006). For sluggish species, closures may allow time for individuals to aggregate in sufficient densities for spawning, or where there is an Allee effect, allow sufficient increases in densities of spawning adults to prevent recruitment overfishing, as demonstrated for North American red sea urchins (Botsford et al., 1993). However Pfister and Bradbury’s (1996) model for the same urchin species demonstrated that with an Allee effect the population would continue to decline for all tested fishing rotation rates and pressures.

Where populations are particularly low, local fishing closures or national moratoria would need to be prolonged, or may even be insufficient to recover populations (e.g., Hawes et al., 2011, Friedman et al., 2011). In some cases manual aggregation of mature adults have been proposed to accelerate recruitment rates through increased fertilisation success (Bell et al., 2008).

In the Indo-Pacific periodically-harvested closures are seen to have potential for fisheries management (Cinner et al., 2006) and conservation of habitats and biodiversity (McLeod et al., 2009). Habitat recovery after an area is closed (e.g., increased coral cover due to less breakage by fishers) may increase the potential of some fish or invertebrate populations to replenish (Wilson et al., 2010, Wild et al., 2004). Food webs and habitat dynamics will have indirect effects on the recovery of populations, i.e., recovery rates of one species (e.g., a predator) may be influenced by or be dependent on the abundance of another species (e.g., prey) (Russ et al., 2005). However, there is little evidence from the region that periodically-harvested closures will confer greater benefits to habitats or biodiversity than a strategy of continuous fishing. For example, no differences were observed in fish species richness and coral diversity between periodically-harvested closures and openly fished sites in Muluk (Cinner et al., 2006). On Ahus Island species richness, live coral cover and coral diversity did not vary significantly between three periodically-harvested closures and nearby control areas that were open year-round (Cinner et al., 2005). Conversely anecdotal evidence from a periodic closure in Vanuatu suggested there were increases in biodiversity (Bartlett et al., 2009b). Unregulated fishing events in two reserves in Philippines caused a decline in fish species richness in one reserve but not the other (Russ and Alcala, 1998a). Considering that some managers may have biodiversity and habitat conservation objectives, and that ecosystem health may impact upon fisheries performance, there is a paucity of research on biodiversity and habitat responses to periodic harvesting strategies.

2.5 Harvesting and stock depletion

The effects of harvesting via multi-species fisheries will differ between taxa depending on fishers' targets alongside inter-and intra-species variations in catchability. In Fiji, harvesting of a closure caused significant depletions of the primary fishing targets: Acanthuridae, Carangidae, Lutjanidae and Serranidae (Jupiter et al., 2012). Fishing after the removal of reserve status of Abore reef, New Caledonia, led to greatest declines in lethrinids and siganids (Ferraris et al., 2005). Populations of herbivores, piscivores and macrocarnivores all significantly declined yet effects were variable between families within these functional groups. Taxa vary in their susceptibility to exploitation i.e., cryptic species such as trochus are less susceptible to overexploitation, whereas large or conspicuous taxa such as giant clam are more susceptible. Fish and invertebrates also display seasonal or biological variations in catchability which can impact on the efficiency of harvests, making the timing of area openings and closures critical to fisheries management outcomes. For example, harvesting grouper or other fish species during spawning aggregations can rapidly deplete stocks (Hamilton and Matawai, 2006). Fishers often possess extensive knowledge about optimal times to fish (Weiant and Aswani, 2006, Foale, 1998b), and openings are in some cases planned to correspond with these times. In Ohoirenan trochus harvests were planned for easy diving conditions i.e., when there were low neap tides and prior to the east monsoon (Ruttan, 1998). While harvesting at times or in areas of high catchability results in efficient returns for fishers, the impact on populations and potential for over-harvesting increases. Conversely, timing closures to protect spawning stocks, such as reported in Maluku (Thorburn, 2000), will optimise protection afforded by the period of closure. Between-taxa or temporal variation in catchability should be considered in the planning of area openings and closures, alongside accounting for the overall intensity of fishing.

The intensity of fishing and the taxa targeted during area openings are as critical to fisheries management outcomes as patterns of recovery during closures. Implementing a periodic closure reduces the opportunity to fish an area. Yet 'pulse-fishing' when areas become open is variable, but may be intense, particularly when fishers anticipate higher catch rates and yields, or social demands and needs are high (Murawski et al., 2005, Russ and Alcala, 1998b). An opened reserve in Fiji was intensely harvested for 5 weeks resulting in significant declines of large bodied fish; declines that were still evident after one year of re-closure (Jupiter et al., 2012). Periodically-harvested closures experiencing levels of effort and exploitation higher than or equivalent to openly fished areas would be less likely to accrue benefits to fisheries (Russ and Alcala, 2003). For example during the first two weeks of opening Abore reef reserve, fishing effort and yield in the area reached levels which had previously been observed over an entire year (Ferraris et al., 2005). On Ahus Island, underwater visual census did not detect an impact on biomass after the removal of 5-10 percent of fish biomass by a one-day harvest event of a periodically closed area (Cinner et al., 2005). However a key question remains for these cases: was the recovery of biomass during the closure greater than or equal to the biomass extracted by fishing? In Hawaii and the Philippines this was not the case. The Waikiki-Diamond Head FMA experienced a cycle of equal periods of opening and closure where increases in fish biomass during closed periods were less than the declines during open periods (Williams et al., 2006). In fishing reserves in the Philippines, increases of predatory fish had occurred slowly during closure, yet unregulated fishing during reserve openings rapidly eliminated density and biomass gains (Russ and Alcala, 2003).

The Philippines and Hawaii cases capture a critical point; that harvesting must at most match but not exceed replenishment occurring during closure to achieve long-term fisheries sustainability (Figure 4A). Where fisheries depletion is greater than recovery an unsustainable situation would be expected (Figure 4B), as observed in Hawaii (Williams et al., 2006). This highly simplified model is complicated by the many factors discussed in this paper. In summary, the same pattern of fishing in the same area will have different effects on different species. Similarly, opening-closure cycles and fishing patterns will have different effects between areas. But also, in most cases fishing patterns and opening-closure cycles in any one area will likely be dynamic and flexible and change with need, opportunity and local social and ecological conditions.

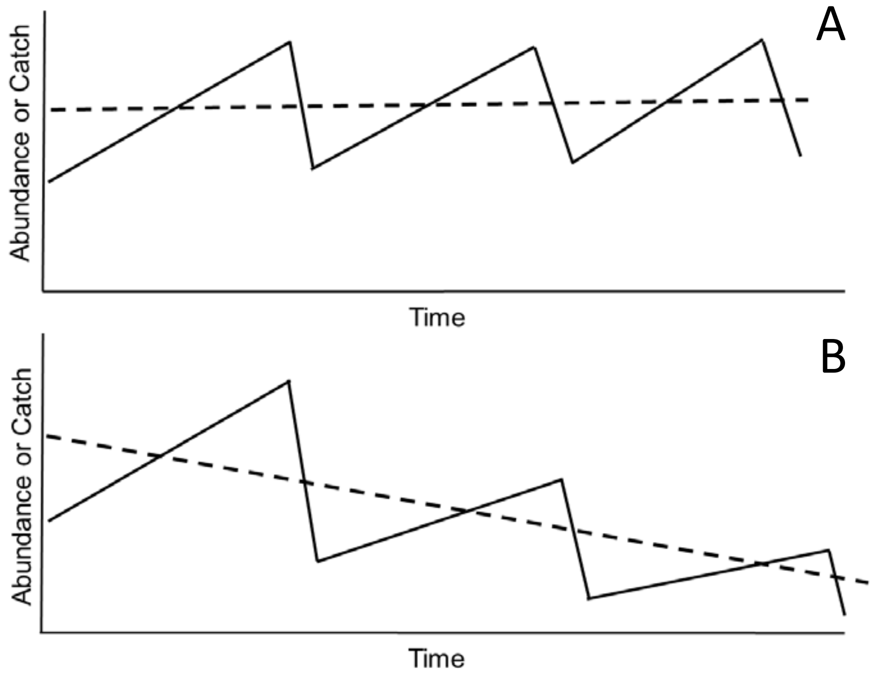


Figure 4 A schematic of the stock or catch response to a closure/harvesting cycle. (A) Represents a sustainable scenario and (B) represents an unsustainable scenario. The time and abundance/catch scales are subjective, dependent upon standing stock, frequency and duration of harvesting, fishing pressure, susceptibility of stock to harvesting and capacity of stock to recover.

2.6 The broader fisheries and management system

2.6.1 *Shifting effort in time, space and sectors of society*

Implementing periodically-harvested closures will likely force a shift in fishing patterns in both time and space. The positive effects of a rotational fishing strategy that were observed by Game et al. (2009) were due to the overall removal of fishing effort from the system, rather than the rotational strategy itself (Kaplan et al., 2010). Cinner et al. (2006) suggested that the positive fisheries effects they observed (particularly on more vulnerable species) may have been due to an overall lower or reduced fishing pressure inside that area compared to continuously fished areas. However, in practice closing an area to fishing can shift and intensify effort onto other fishing grounds if total fishing effort (e.g., of a community in their broader fishing grounds) is not reduced (Hilborn et al., 2004). Women from communities in Roviana lagoon in Solomon Islands observed that when two areas were closed to harvesting, open areas were more heavily exploited and impacted (Weiant and Aswani, 2006).

Periodically-harvested closures are less likely to achieve overall fisheries benefits if effort is simply shifted from one place to another. However, if effort is not reallocated to another ground, or open grounds are inferior, there may be a short- to medium-term decline in catch (McClanahan and Mangi, 2001). A decline in catch or the increased effort required to maintain catches (e.g., longer travelling time to open fishing grounds) imposes a cost on food security and livelihoods of fishing communities. However, where closures are small relative to total accessible fishing grounds these effects may be minimal (Leisher et al., 2007).

Closing or altering the accessibility to fishing grounds may differentially affect or exclude some sectors of society (e.g., women or migrants). Nearshore areas proximate to villages are preferentially selected for closures for easy surveillance (Govan et al., 2008), and it is in nearshore and near-village mangrove and reef areas that women tend to glean invetebrates (Kronen and Vunisea, 2009). Where traditional tenure systems operate, migrants may have fewer rights to access and use of land and marine areas, and can therefore be vulnerable in subsistence settings when access restrictions are strong (Koczberski et al., 2006). These factors should be considered in planning, particularly when the goals of management relate to well-being or food security (Vunisea, 2008). Investigating how fishers respond, including the redistribution of fishing effort when fishing grounds are periodically closed and opened, represents a critical knowledge gap and important area for research (see Chapter 3).

2.6.2 Closures in combination

Combining periodic harvesting with other strategies or other resource use controls can reduce the effect of concentrating effort into pulse-fishing events or re-distributing effort to other fishing grounds. Further, alternative livelihood strategies have been used to minimise the economic impacts of immediate declines in catch due to closures (e.g., Weiant and Aswani, 2006). Fishing or management activities (such as size limits or effort restrictions) outside of closures can significantly influence the fisheries benefits of the closure itself (Gerber et al., 2003, Hilborn et al., 2006). Many NGOs and supporters of community-based and co-management approaches in the Indo-Pacific have emphasized that a whole-area management approach is required for successful fisheries management, with periodically-harvested closures as just one within a suite of management tools employed (Govan et al., 2008). Reviewed cases highlight some examples of concurrently employed resource-use controls, including limited access, size limits, species bans, catch limits and gear restrictions (Table 1).

Community-based and co-management approaches utilise or sometimes reaffirm customary tenure boundaries and traditional governance institutions (Govan, 2009a). Holders of tenure (clan, chief or family) have mechanisms for limiting access and controlling the use of resources. In fact intact tenure is a likely prerequisite for the use of community managed closures (Cinner et al., 2006, Foale and Macintyre, 2000, Ruttan, 1998, Evans et al., 1997, Harkes and Novaczek, 2002). However Polunin (1984) points out that restricting participation in a fishery will not necessarily change the volume harvested, just who harvests it. While fisheries participation may or may not be effectively limited via tenure, many cases report that there are no limits on the total quantity harvested during reserve openings (Foale, 1998b, Weiant and Aswani, 2006, Thorburn, 2000, Harkes and Novaczek, 2002, McLeod et al., 2009) and only one case reported explicit harvest limits (Nash et al., 1995). In sites in Vanuatu, frequency and intensity of harvests were regulated to ensure that ecological gains were not lost during harvests, although the regulatory measures and the factors contributing to their design were not stated (Bartlett et al., 2009a).

Size limits and gear restrictions can minimise the impacts of fishing and may better ensure sustainable harvests from closures or from continuously open areas. In West Nggela, where periodically-harvested closures were employed to manage the trochus fishery, trochus populations were observed to be low. Population models demonstrated that both yield and egg production could be significantly increased with enforcement of the (then un-enforced) official minimum size limit of 8cm (Foale and Day, 1997). In Indonesia, Arifin et al. (1998) recommended an increase in size limit from 6cm to 8cm with a two-year closed season to ensure an adequate adult population to maintain recruitment, and that reducing the closed season to one year without a further increase in size limit would endanger stocks. The use of size limits in conjunction with periodically-harvested closures is often reported for trochus fisheries (Evans et al., 1997, Arifin et al., 1998, Johannes, 1998b), but rarely reported for other fished taxa (Johannes, 1998b). Some communities employing periodically-harvested closures in Vanuatu concurrently applied regulatory measures to harvesting gears or methods: these included bans on night spear fishing, commercial gillnetting, and breaking corals while gleaning (Johannes, 1998b). Some Indonesian communities employing periodically-harvested closures also banned the use of goggles (except when the areas were opened for trochus harvest), while others banned nets, local poisons, cyanide and dynamite fishing (Thorburn, 2000, McLeod et al., 2009).

The successful management of the Aitutaki trochus fishery via periodically-harvested closures demonstrates the value of quantitative assessment of stock condition prior to harvest to decide on sustainable catch limits (Nash et al., 1995). However, the reality is that other fisheries can be more challenging to assess. and the level of effort and technical expertise required to accurately determine quotas may not be feasible (Johannes, 1998a). Managers face trade-offs in selecting a strategy for monitoring periodically-harvested closures. Quantitative participatory research provides an option for monitoring and assessment of stocks, but to date community-based, low-cost and minimal training underwater visual census techniques appear to be low in accuracy and precision and may be subjective (Leopold et al., 2009). Village-level perceptions of recovery and decline e.g., the Chiefs in Muluk (Cinner et al., 2006) may be more appropriate. However, perception-based assessments can also be unreliable (Dulvy and Polunin, 2004, Roberts and Polunin, 1993). For example, Bartlett et al., (2009b) found that community members provided perceptions of the success of periodically-harvested closures based on assumption, as opposed to observation, in 90 percent of cases. While long-term detailed monitoring datasets may be prohibitively expensive and logistically demanding to obtain, there can be limitations with interpreting shorter term monitoring data. A review found that studies using short-term monitoring tended to report rapid rates of response to protection, whereas longer term studies indicated slower average rates of recovery as they accounted better for variability (Russ, 2002). Using relatively recent baselines for either quantitative or qualitative monitoring can be misleading. For example, observers may detect increases when comparing pre- and post-closure abundance, and local perceptions could accurately account that “there are more fish”. However, this analysis would fail to highlight that the long-term trend is a decline (Figure 4B). To further complicate monitoring, removing disturbance by fishers affects fish behaviour making them tamer (Feary et al., 2011) and may also lead to “spill-in” of fish to low-disturbance areas and “bail-out” in response to rapid increases in fishing pressure (Jupiter et al., 2012). Consequently, monitoring may overestimate recovery after a period of closure or underestimate stocks after periods of fishing. Monitoring catch from harvesting events may aid in ensuring sufficient breeding stocks remain (Jupiter et al., 2012), however practical guidance for such assessments is currently lacking.

2.7 Conclusion

There is still conjecture as to whether, and the conditions in which, permanent no-take marine reserves might deliver fisheries benefits (Hilborn et al., 2006, Russ, 2002, Sale et al., 2005, Kearney et al., 2012). Nonetheless a permanent reduction of fishing grounds may be something that some fishing communities are unable or unwilling to bear. Throughout the Indo-Pacific permanent no-take marine reserves tend to fit poorly with social, economic and consumptive needs of communities, and tend to receive lower levels of compliance and acceptance than closures that will at some point be harvested (Cinner et al., 2007, Foale and Manele, 2004, McClanahan et al., 2006). Periodically-harvested closures appear to be met with relative enthusiasm, provide regular access to resources and have potential, under the right conditions, to contribute to certain fisheries management objectives.

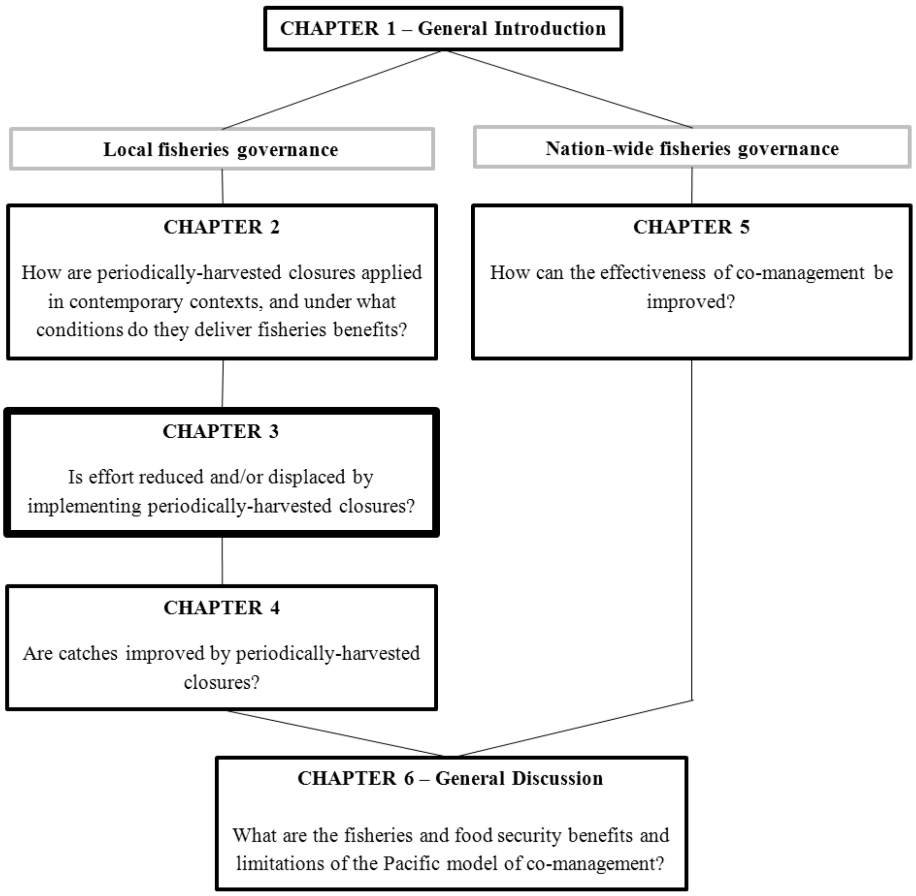
Periodically-harvested closures are now a widely employed and relied upon tool in co-management approaches for marine resources in the Indo-Pacific. Contemporary periodically-harvested closures can resemble customary closures, they can be governed via local institutions, and they have been embraced as a management tool by governments, NGOs and communities alike. However achieving compliance with a closure or limits placed on harvesting is an ongoing challenge, even where traditional governance is intact and social capital is high (Evans et al., 1997). Success in implementing and governing this tool is critical to achieving any potential for managing fisheries. However, success in implementation does not necessarily equate to sustainable fisheries management.

Generalizing about the success, failure or potential of periodically-harvested closures is problematic due to variability in ecological conditions and harvesting strategies applied; namely the period of closure, harvesting intensity, harvesting frequency and target species, all of which vary greatly between sites and times. The root causes of overfishing will continue to challenge community-based and co-management approaches, and fisheries management tools such as periodically-harvested closures. The Indo-Pacific region potentially faces declining respect for traditional or local authority, escalating fishing intensity driven by increasing reliance on the sector, growing and urbanising populations, advances in fishing technology and developing commercial markets, alongside potential climatic impacts on ecosystems. It will be critical to understand the form periodically-harvested closures will take and their effectiveness as social, economic and ecological contexts change.

Maintaining the governance structures that support periodically-harvested closures (i.e., via co-management or community based management) can convey a variety of benefits not directly associated with fisheries (Govan, 2009b) and may increase the success and potential for further developing fisheries management institutions (Harkes and Novaczek, 2002, Thorburn, 2000). However studies to date have not confirmed whether periodically-harvested closures can maintain or improve fisheries yields and sustain stocks for the small-scale fisheries that contribute to food security and livelihoods in the Indo-Pacific. A failure in meeting expectations of “more fish” or “fish for the future” by using periodically-harvested closures could lead to disillusionment and a squandered opportunity to harness community enthusiasm. Applying best available local and scientific knowledge to periodically-harvested closures, accounting for the tools’ limitations, and addressing fisheries management in broader practice and policy are all necessary to manage the regions’ small-scale fisheries.

Chapter 3 Fishing patterns associated with periodically-harvested closures

The effectiveness of periodically-harvested closures for managing fisheries is greatly influenced by the periodicity of harvesting cycles and intensity of fishing during harvests. The literature review presented in Chapter 2 found no detailed attempts to document patterns of fishing, or quantify fishing effort overall, or during openings of customary or contemporary periodically-harvested closures. In Chapter 3 I report on four periodically-harvested closures in Solomon Islands. I examine the duration and frequency of openings, participation in fishing when areas are opened, decisions to harvest, and restrictions placed on harvests in terms of participation, gear use and species. I also quantify fishing effort during opening periods, and compare this to levels of effort observed on nearby continuously-open fishing grounds. I also use quantitative fishing effort data, alongside qualitative data to determine whether implementation of periodically-harvested closures results in the displacement of fishing effort to other areas.



3.1 Introduction

Small-scale fisheries support the livelihoods and food security of millions of people worldwide, and if well managed can make significant contributions to socio-economic development (Béné et al., 2010). Community-based and collaborative strategies (henceforth co-management) are increasingly emerging to address challenges in managing small scale fisheries (Gutierrez et al., 2011). The expansion of co-management is particularly apparent in the Indo-Pacific where centralised management has typically had low levels of success (Alcala and Russ, 2006, Arifin et al., 1998, Ruddle, 1998). Co-management initiatives combine scientific information and conventional approaches to marine resource management, with local knowledge and governance systems (Govan, 2009a, Johannes, 2002, Ruddle, 1998). There are now hundreds of coastal communities in the Indo-Pacific employing a range of resource-use rules that have been developed at the community level, often with support from government or non-government organisations (NGOs) (Govan, 2009a). However, despite widespread arguments that co-management of marine resources can result in sustainable fisheries, empirical studies that systematically demonstrate these benefits, and how they can be achieved in different contexts, are lacking (Gutierrez et al., 2011, Evans et al., 2011). An ongoing challenge to co-management initiatives is to identify socially acceptable and locally implementable controls on marine resource use that will result in long-term and effective management of small-scale fisheries.

Co-management frameworks in the Indo-Pacific frequently promote the re-establishment or re-invention of customary periodically harvested marine closures as a measure to regulate marine resource use (Johannes, 1978, McLeod et al., 2009). Such periodically-harvested closures are now a prominent feature of many co-management initiatives and are touted as being a successful, traditionally based measure for marine management. In a western fisheries context non-permanent, rotational or periodically-harvested closures are also recognised for their fisheries management potential, mainly for sedentary invertebrates (Botsford et al., 1993, Sluczanowski, 1984, Nash et al., 1995). However, the effectiveness of periodically-harvested closures as a management strategy for fish (De Klerk and Gatto, 1981, Game et al., 2009), or for multi-species fisheries, remains poorly understood.

While periodically-harvested closures can contribute to sustainable fisheries, there are a range of factors that will determine if fisheries benefits are realized (Chapter 2). Factors relate firstly to ecological conditions, particularly pre-harvest stock levels and the demography of species, and secondly to the patterns of harvesting. The intensity of harvesting during openings, and the overall relief from fishing pressure during closure, are key factors influencing fish recovery and management outcomes (Russ and Alcala, 1996, Game et al., 2009, Kaplan et al., 2010). In practice, 'pulse-fishing' can be intense when areas are opened, particularly under open access scenarios or where governance institutions are weak, or because fishers anticipate improved catch rates, or demand and needs are high (Russ and Alcala, 1998b, Murawski et al., 2005, Jupiter et al., 2012). However, few studies have examined the levels of fishing during openings where periodically-harvested closures are employed within functional co-management frameworks.

Modelling of rotational or periodic harvesting demonstrates that the periodicity of opening and closure cycles is also a key factor influencing outcomes (Gerber et al., 2003). Throughout the Indo-Pacific region, the scheduling and duration of openings and closures is generally under the control of the local community, clan or family that has tenure to the area (McLeod et al., 2009, Hviding, 1996). Given the importance to fisheries outcomes, there are surprisingly few studies that have documented the duration, frequency and drivers of opening and closing areas to harvesting. Additionally, no studies have compared the overall levels of effort and catch between periodically and continuously harvested areas. My study in this chapter has four objectives to address this knowledge gap. Firstly, to determine how fishing pressure, in terms of both yield and effort, compares between periodically-harvested closures and reefs that are continuously open to fishing. Secondly, I aim to determine whether closures cause the displacement of effort to other fishing grounds. Thirdly, I aim to describe the cycles of opening and closure applied in practice, and to understand factors considered in decisions driving those cycles. Finally, I seek to understand how closures are exploited in terms of fishing gears and methods used, and how broader management frameworks influence exploitation. I examine four periodically-harvested reef closures in Solomon Islands, where marine areas are increasingly co-managed by communities with the support of NGO partners.

3.2 Methods

3.2.1 Study location

In Solomon Islands communities and their partner NGOs have established over 100 co-managed marine areas (also referred to as locally managed marine areas, or LMMAs) in response to concerns over resource sustainability. Most co-managed marine areas employ some type of area closure, most often rotational, periodically harvested or indefinitely closed until circumstances change and needs arise (Govan, 2009a).

Four periodically harvested marine closures were examined in two community clusters in Solomon Islands (Figure 5). Community cluster one in Central province had one closure, the second community cluster in Western province had three closures, in which all extractive activities were banned during periods of closure. Each community cluster comprised of three separate, but geographically proximate, communities (i.e., within four and six km from each other, respectively). I recorded catch landings from all three communities within each cluster to account for potentially overlapping fishing grounds. Fishers from these communities had primary fishing rights to the closed areas and other nearby fishing grounds, and fishing by 'outsiders' was reported in pilot surveys to be minimal. Community names are not provided because of confidentiality arrangements.

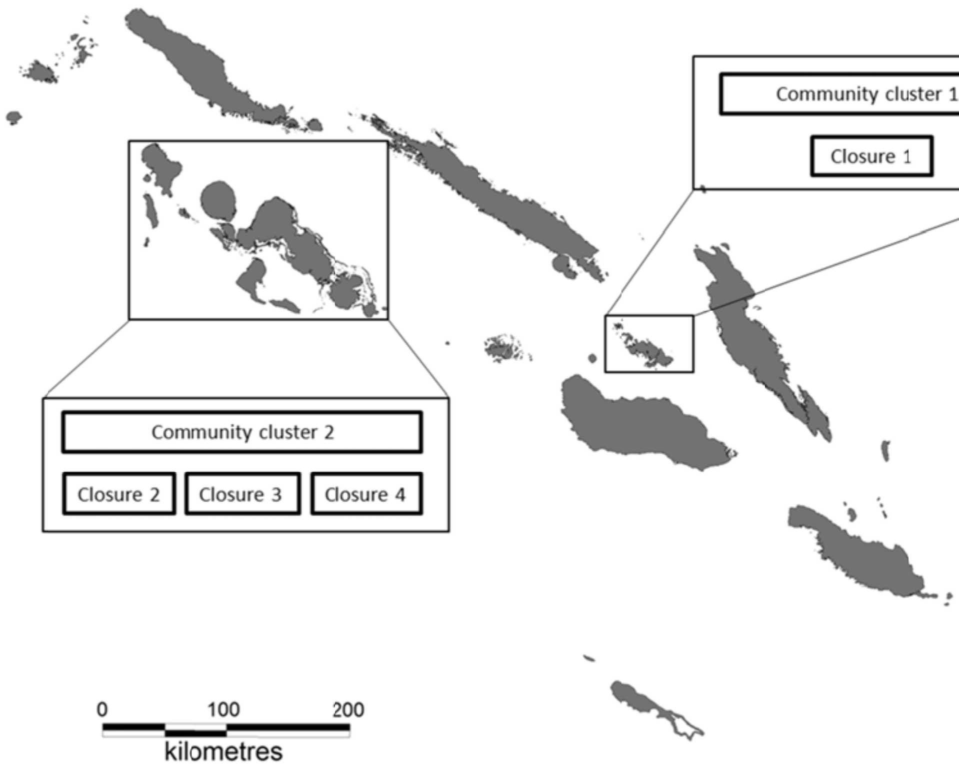


Figure 5 Location of case study closures in Solomon Islands. Embedded schematics represent the sampling design where six communities, within two clusters, were landing sites/sampling locations.

Population density in community cluster one was moderately high (26-50 people per km^2), whereas density was low in community cluster two (less than 10 people per km^2) (Solomon Islands National Statistics Office, 1999). Food and livelihoods were supported predominantly by small-scale forestry, agriculture, remittances from relatives in towns and cities, and fishing. Fisheries predominantly focussed on reefs (reef fishing represented 73% of trips, mangrove/lagoon zones accounted for 8%, and pelagic zones 17% of fishing trips, with 2% of trips to two or more zones or in rivers). Commercial fisheries focussed on trochus (*Trochus niloticus*), and previously on sea cucumber (at the time of this study there was a long-term national moratorium on commercial sea cucumber harvest). Communities in cluster one also sold reef fish to the national capital market. Periodic closures lasting around three months had historically been used, mainly as a mark of respect for the death of a community member or in preparation for feasting, and closures of indefinite length had been used to replenish and limit access to trochus stocks.

All communities were engaged in NGO-supported resource management initiatives involving the formation and commitment to management plans which incorporated resource-use rules and education, compliance and monitoring strategies. Resource use rules committed to paper included national fisheries regulations and additional community-based regulations including size limits, gear restrictions, bans on harvesting spawning aggregations and specified closed periods and reefs subject to periodic harvesting. Closure 1 was established in 2005, and Closures 2, 3 and 4 were established in 2008. These four periodically-harvested closures represented at most 5 percent of reef area observed to be fished during sampling. There were also two indefinitely closed reserves (i.e., one in each community cluster) that represented 2 percent of all fished reef area.

3.2.2 Qualitative Data

To understand recent site history and the co-management approach at each site, I reviewed written management plans and conducted preliminary unstructured interviews with staff of the partner NGOs. At case study sites, I conducted participant observations, informal interviews, semi-structured interviews (n=77) (see Appendix 1 – Local governance fisher and key informant interview) and focus groups (n=20) (see Appendix 2 – Local governance focus group) with between two and six men, women or youth fishers. I conducted all interviews in Solomon Islands pijin and hand wrote responses *in situ*. I asked the reasons for opening closures to harvesting, the duration and frequency of opening events over the previous 12 months, controls placed on harvesting from closures and other fishing grounds, and compliance with those controls. To triangulate information on fishing trip sample sizes, I conducted household surveys (Appendix 8 - Household survey) in 50 percent of all households in each community asking (amongst other things), “how many times do people in this household go fishing in a week?”

3.2.3 Landing site sampling

Sampling coincided with community-planned openings of periodically-harvested closures; in July 2011 for Closure 1, and in December 2010 for Closures 2, 3 and 4. I attempted to record details of all fishing trips at all six communities during the full period of openings, and for at least two weeks during closures. At least one trained research assistant was posted in each community to record landings (see Appendix 3 – Catch record sheet). Details of the research programme had been provided in community meetings in each community prior to the commencement of sampling, and community leaders also assisted in personally informing fishers of the data collection programme. Research assistants recorded daily observations of numbers of people sighted fishing, or leaving for fishing, and any disparities with the number of landings they recorded. They also recorded weather and events in the community that affected fishing activities.

I returned six months later to record fishing patterns in communities in cluster two to account for seasonal variation. I was unable to return to community cluster one, however pilot study interviews indicated my sampling was within the period of calmest weather and highest overall fishing activity. A total of 239 fishing trips were directly recorded from periodic harvesting of closures, and 720 trips were recorded from grounds continuously open to fishing (Table 1). I also documented the catch and effort of an additional 31 trips that had been recorded by community members, and I used interview data that described number of fishers, methods used and/or quantities harvested, to reconstruct catch and effort of a further 21 fishing trips that took place in minor opening events over the previous 12 months.

Research assistants and I asked fishers to recall details of their fishing trip as soon as they returned to shore. Details included: time of departure and time of return, number of fishers on the trip, gear(s) used, name of fishing location(s), fished area description(s) (i.e., reef, mangrove, lagoon, pelagic), and the management regime in operation (i.e., continuously open to fishing or periodically-harvested closure). Trips were classified into three types according to target taxa; finfish, non-finfish, or mixed (i.e., both finfish and non-finfish were targeted on the same trip). The total wet weight of the catch was measured using hanging fishing scales (either a 10 kg/5g digital scale or 22kg/250g analogue scale, depending on the size of the catch) and recorded. Larger catches were separated for weighing and then weights summed. Local names of species were used to categorise finfish and non-finfish for counting and recording purposes (Foale, 1998a: WorldFish Center, unpublished data).

Where fishers were not immediately encountered at the landing location and their catch already cooked, consumed or sold, research assistants and I used a 'recall' method (n=207 of the 959 fishing trips recorded in total) in which the fisher was asked to provide the details of the fishing trip (as per the descriptors above) and to recall the number and estimate the 'average' total length of each type of finfish or non-finfish in the catch. Fishers indicated total length using their hands and we used a ruler to measure the size indicated. Recalled catches were translated to weight using recalled numbers and the standard expression $W=aL^b$ to convert lengths to weight with species specific length-weight (L-W) relationships from FishBase (Froese and Pauly, 2012). Before biomass estimation, I used length–length conversion factors from FishBase to change total length to fork length or standard length as the L-W relationship required. I preferentially selected L-W relationships derived from large samples and from the Indo-Pacific region, respectively. Where local nomenclature incorporated several species I used the unweighted mean L-W coefficient to represent that grouping, and where it incorporated an entire family or genus I used the L-W co-efficient of the species I most frequently observed in catches. For species for which there was no L-W coefficient available I used that of another species of the same genus with similar gross morphology.

3.2.4 Characterising fishing grounds

I asked experienced fishers to name and identify reef fishing grounds on nautical charts and satellite images (Landsat 7 ETM+). The areas of fishing grounds were calculated from reef delineations derived from satellite imagery (Andréfouët et al., 2006). Where several fishing locations were identified by fishers, but indiscernible on a single reef complex, I combined data from those fishing locations and used a single area estimate. Analysed satellite imagery failed to detect two coastal reefs, and I estimated their areas using a combination of raw satellite imagery, nautical charts and fisher-drawn maps. I used MapInfo 11.0 to calculate distances between each fishing ground and its respective community or communities.

3.2.5 Data standardisation

I used a two-way analysis of variance (ANOVA) to test whether the recall and direct observation data collection methods varied in terms of trip duration and catch weight, and whether this varied by fishing method. Because the number of observations was unequal between each combination of data collection method and fishing method, I used type III sums of squares. Trip duration data were square root transformed and catch data were reciprocal transformed to conform with assumptions of homogeneity of variances and normality, which were assessed by inspecting residual plots. Average trip duration recorded via the direct observation method (4.70 ± 0.11 hours, n = 681) and recall method (4.00 ± 0.18 hours, n= 207) did not vary significantly overall ($F_{1, 873}$= 1.9, P = 0.172), and there was no interaction with fishing method ($F_{6, 873}$= 1.5, P = 0.175). I excluded trips harvesting with explosives from comparison of catch weights due to the low sample size and uncertainty in catch weights (i.e., explosives yielded catches too large to weigh, and catches were often distributed amongst many fishers, hindering in most cases, accurate reconstruction of total catch from a single event). As I was interested in the comparability of catch weight only, I excluded trips with nil catch. Mean catch weight varied significantly ($F_{1, 841}$ = 12.6, P <0.001) between data collection methods (standard method 4.52kg ± 0.25, n = 675 and recall method 5.28kg ±1.10, n= 179), but there was no interaction between data collection method and fishing method ($F_{5, 841}$= 0.9, P = 0.505). Accordingly, I adjusted all catch weights derived from the recall method by –14%. There was no systematic bias in the use of the recall method for the direct observation method of recording catch data.

For comparison of annual yields, catch weights from trips collecting both finfish and non-finfish were divided and allocated equally between finfish and non-finish yield data. To allow comparison of annual fishing patterns on periodically-harvested closures and continuously fished reefs, I used a weighted average to scale up catch and effort per fishing ground per year; weighting was based on the number of sampling days relative to the duration in one year that reefs were closed or opened. Additionally, I used two methods (i.e., household surveys and research assistant observations of fishing) to determine appropriate scaling of my catch and effort sample (i.e., because I did not record 100% fishing trips within the sampling period). Household survey responses provided an estimate of total fishing trips per community per week, and indicated that my sampling rate was between 10-22 percent in community cluster one, and 33-45 percent in community cluster two. Whereas observations recorded by research assistants suggested that recording rates were nearer to 40 percent and 60 percent respectively. I made an adjustment considering both estimates, and used a scaling up factor of three for catch and effort data from community cluster one, and a factor of two for data from community cluster two.

I compared daily fishing effort standardised by area on periodically-harvested closures to fishing effort on a subset of continuously-open reefs. Because travelling time was included in total effort (i.e., fisher hours), I limited the comparison of each closure to reefs that were a similar distance from communities (i.e., excluding reefs further than an arbitrary 2 kilometres from each closure). Secondly, I compared each closure only to reefs that were fished by the same community, or communities. I was forced to exclude trips of unknown duration (n=74), or trips to reefs of unknown or questionable area (n=36) from these analyses.

3.2.6 Data analysis

I compared average daily fishing effort on closures and on reefs continuously open to fishing, and looked for any evidence of effort displacement; testing the hypothesis that fishing effort increases in open fishing areas due to closures. Daily fishing effort data were exceptionally non-normal due to the relatively high proportion of days with nil effort, and it was not possible to find a transformation to resolve normality. I therefore used a Kruskal-Wallis rank sum test to look for differences in daily effort per km^2 on closures compared to open reefs. Due to the pairing of closures with a particular sub-set of open reefs for comparison, I analysed the response to each closure separately. I also used Kruskal-Wallis rank sum tests to examine daily fishing effort on all open fishing grounds (i.e., pelagic, mangrove/lagoon and continuously open reef) fished by communities in each cluster, during periods when closures were closed versus open. I used Games-Howell post hoc-tests to examine where differences lay for each of the four closure comparisons, and each of the two community clusters.

3.3 Results

3.3.1 Comparison of yield

I estimated total annual yield for individual reefs, and compared these to yields suggested by other studies to be sustainable (Figure 6). I included all fishing trips where a reef was identified as the fishing location, and therefore loosely reef-associated or semi-pelagic finfish were included in yield estimates. I observed that 39 percent of reefs (including Closure 1) had higher finfish yields than the 5000 kg/km^2 maximum sustainable yield estimate presented by Newton et al (2007), and 28 percent (again including Closure 1) above the range observed by Jennings and Polunin (1995) to be sustainable. Finfish catches from the remaining reefs, including the three other closures, were lower than sustainable yield estimates. The proportion of non-finfish (i.e., mainly molluscs, but including other invertebrates, seaweed, and turtles) in total yields was variable between reefs - some reefs only being harvested for non-finfish, many for both (including Closures 1, 2 and 4) and others only finfish (including Closure 3) (Figure 7). Overall, annual yields of non-finfish from closures were moderate to low in comparison with yields from reefs continuously open to fishing.

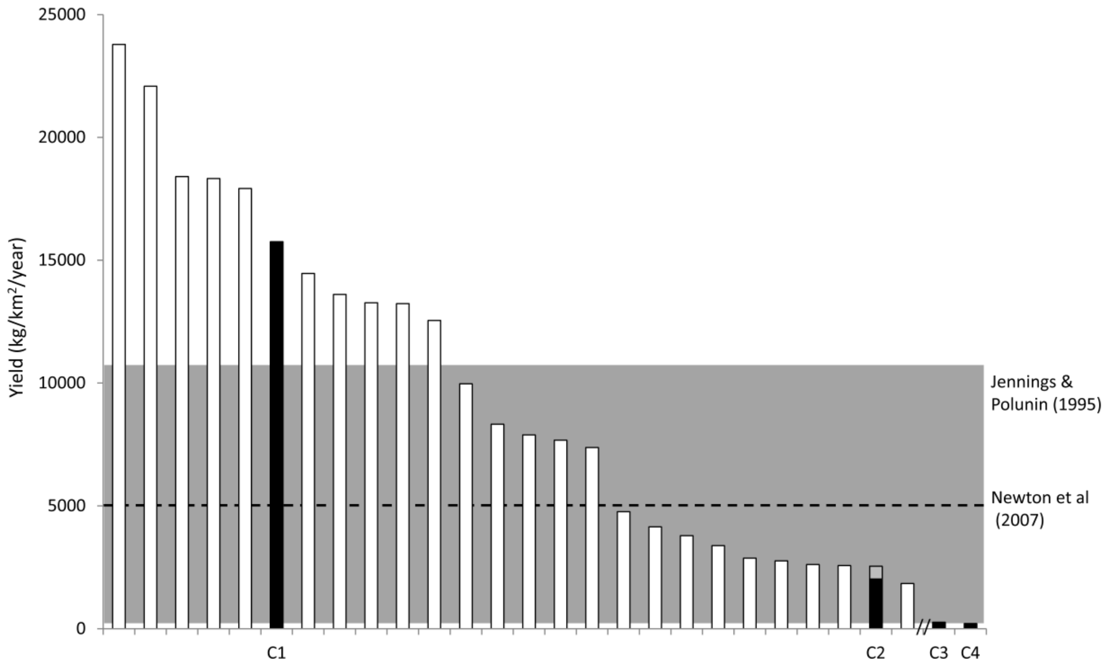


Figure 6 Estimated annual yields of finfish from individual reef fishing locations; reefs continuously open to fishing (white bars) and major harvests of periodically-harvested closures (black bars C1, C2 C3, C4). Yield from minor harvests of closures is indicted in light grey (C2 only). The dark grey shaded area indicates the range of fish yields observed to be sustainable in Fiji (Jennings and Polunin, 1995). The dashed line indicates a maximum value for sustainable finfish yield from reefs (Newton et al., 2007). In addition to C3 and C4, there were 15 other reefs with total finfish harvests of less than 1000 kg per km^2 year that are not presented here (i.e., to the right of the break //).

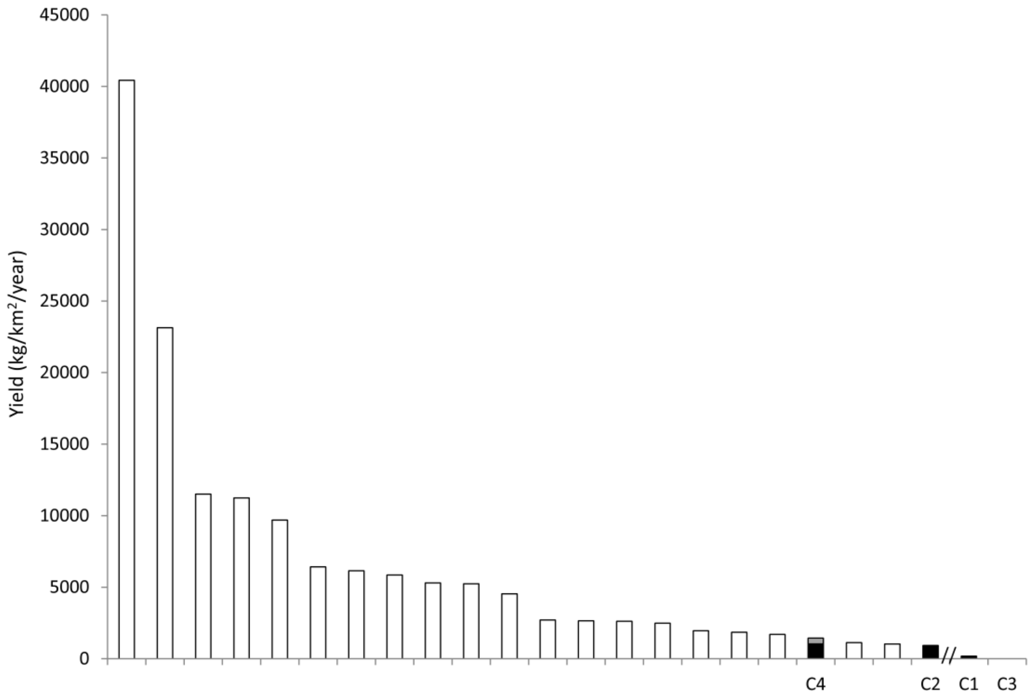


Figure 7 Estimated annual yields (inclusive of shell weights) of non-finfish from all reef fishing locations; reefs continuously open to fishing (white bars) and major openings of periodically-harvested closures (black bars C1, C2, C3 and C4). Yield from minor harvests of closures is indicted in grey (i.e., C4 only); live coral harvests of C1 are not represented here. In addition to C1 and C3, there were 14 reefs where total non-finfish harvests was less than 1000 kg per km^2 year that are not presented here (i.e., to the right of the break //).

3.3.2 Comparison of effort and effort displacement

I scaled effort to a full year (i.e., to account for closure periods where closures receive no effort, yet other reefs are open to continuous fishing) and found that across a full year Closures 2 and 4 were fished moderately and Closures 1 and 3 lightly, compared to reefs continuously opened to fishing (Figure 8). Fishing effort data that were reconstructed, through community records and interviews, indicated that effort from minor harvests throughout the previous 12 months accounted for 22 percent (Closure 1), 6 percent (Closure 2) and 7 percent (Closure 4) of total annual fishing effort; the remainder being accounted for by the major harvesting events I recorded directly.

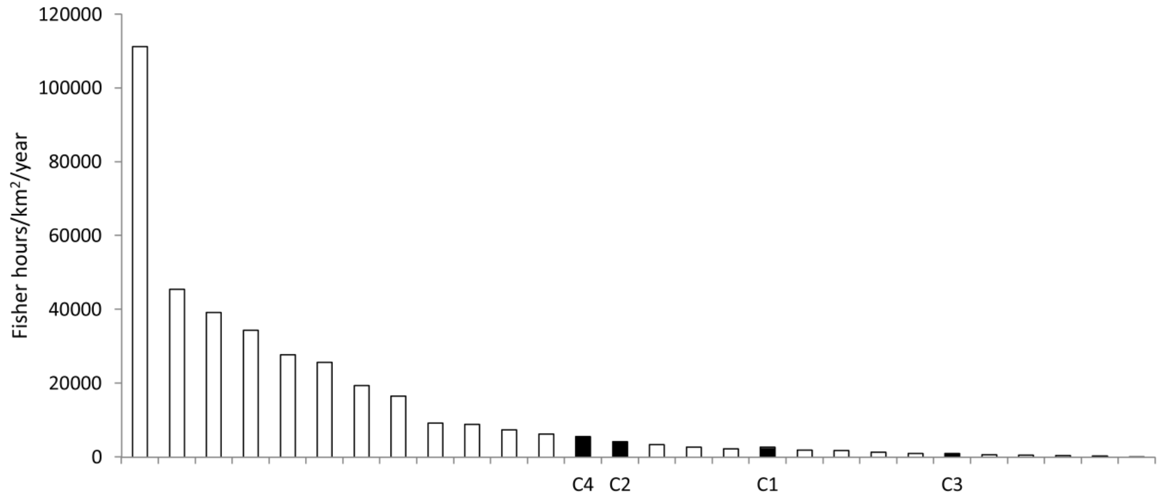


Figure 8 Annual (scaled-up) total fishing effort (fisher hours per km^2) on individual reefs (white bars) within a 2km range of periodically harvested closure (solid black bars). Effort of minor harvests of closures (C1, C2 and C4) that occurred throughout the previous 12 months is indicted in grey.

While annual fishing effort on closures was low to moderate, on the days that closures were opened to fishing, effort was considerably higher, but highly variable, compared to that on reefs continuously open to fishing (Figure 9). I found no significant difference between, effort on reefs continuously open to fishing during periods when closures were opened or closed and effort of harvesting of Closure 1 ($\chi^2_{(2, n=220)} = 1.3$, $P = 0.523$) or Closure 4 ($\chi^2_{(2, n=46)} = 1.5$, $P = 0.461$). I did find effort varied significantly amongst comparisons for Closure 2 ($\chi^2_{(2, n=66)} = 12.0$, $P = 0.003$), where post-hoc tests revealed that effort was significantly higher during periodic harvests of Closure 2 than on open reefs in both periods. I observed significant heterogeneity in the comparison of effort for Closure 3 ($\chi^2_{(2, n=70)} = 30.6$, $P < 0.001$), but that clearest differences lay between open reefs during periods of opening (i.e., effort lower) and periods of closure (i.e., effort higher), yet not to a level of statistical significance ($P = 0.083$). Overall therefore I did not find clear evidence of displacement of effort onto other reefs due to any of the closures, as fishing effort did not vary significantly on comparable, continuously open reefs between 'closure-closed' and 'closure-opened' periods.

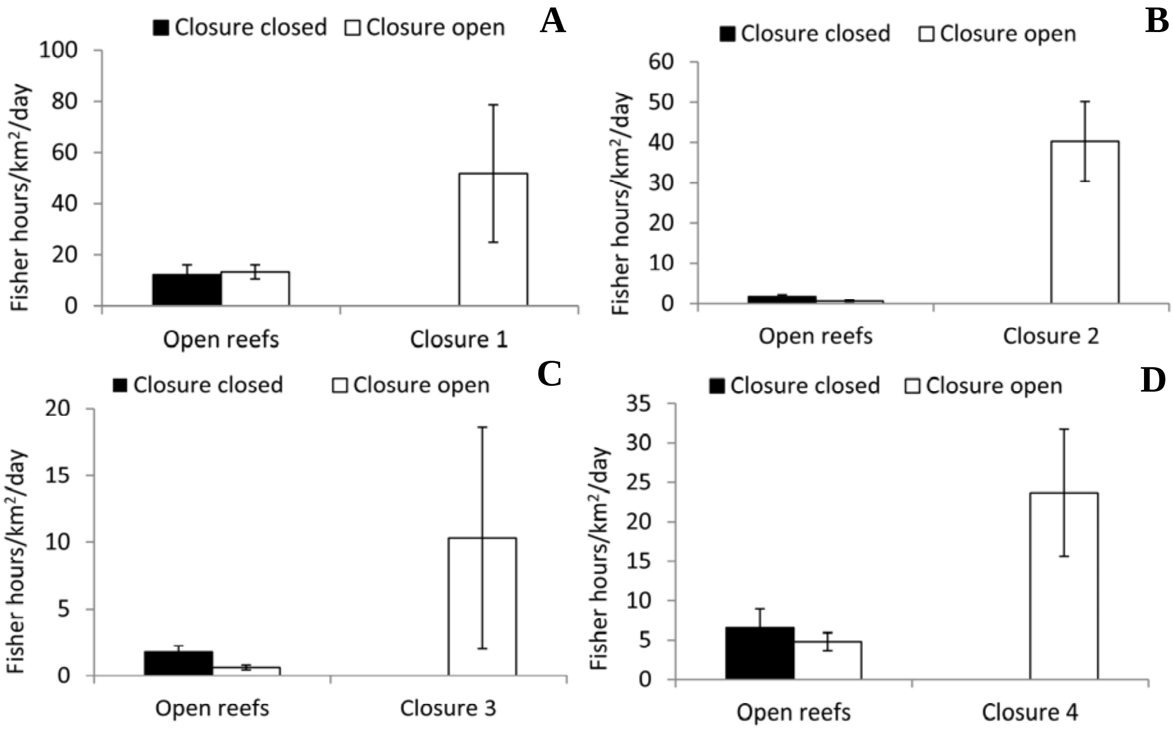


Figure 9 Mean daily fishing effort (±SE) per km^2 of reef, for closure and reefs continuously open to fishing within a 2km range of each closures, in periods when the closure remained closed and when they were opened; (A) Closure 1; (B) Closure 2; (C) Closure 3, and (D) Closure 4.

I also found no substantial evidence of effort displacement onto all open fishing zones (i.e., reef, pelagic and mangrove/lagoon) fished by communities in both clusters (Figure 10). Daily fishing effort did not differ significantly on open grounds fished when closures were open or when they were closed in community cluster one ($\chi^2_{1,27} = 0.5$, $P = 0.494$) or in community cluster two ($\chi^2_{1,48} = 2.7$, $P = 0.099$).

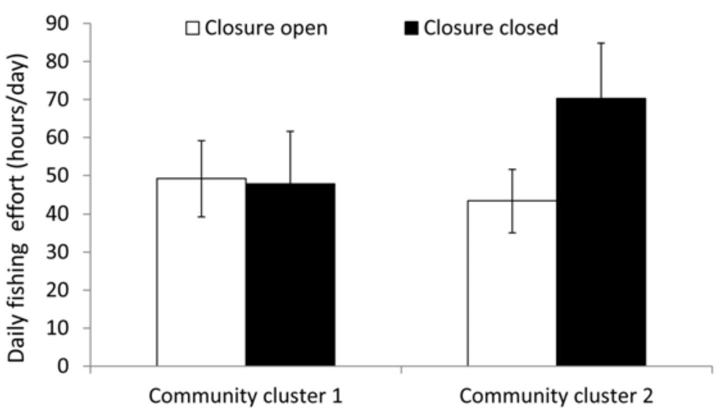


Figure 10 Average daily fishing effort (±SE) for all fishing locations (i.e., data from open reef, pelagic, and mangrove/lagoon zones pooled) in periods when closures were closed and when they were opened.

To examine patterns of effort on closures more closely, I observed total effort on each day closures were opened, and found that effort was generally higher in the earlier stages of the opening period than the latter (Figure 11). Closure 3 was an exception receiving only four trips relatively late in the open period. Closure 3 also had a very high proportion of days on which it received no effort at all. Informal interviews failed to conclusively confirm the reason for low levels of interest in fishing Closure 3, but suggested that it was a relatively poor fishing ground.

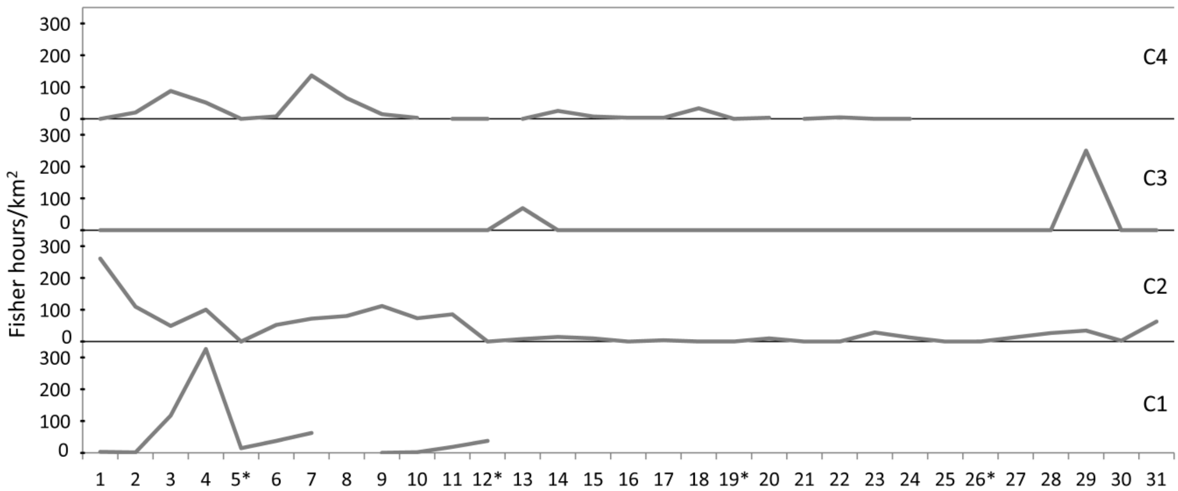


Figure 11 Daily fishing effort (fisher hours) per km^2 throughout the opening period of each closure (C1-4). Horizontal axis indicates the day count from the first day of opening. * indicates Sundays during openings of Closures 2, 3 and 4 where there was no fishing activity at all. Closure 1 was re-closed on day 13. Blanks during periods of opening indicate days that were not sampled.

3.3.3 Drivers of opening and closure periodicities

Across all closures, opening frequencies varied from once to 15 times per year (Table 1). Openings were most frequent on Closure 2 where harvest periods varied from a single major opening lasting one month to 14 minor events of only a single night (Figure 12). In the four closures, there were three distinct harvesting patterns: 1. harvesting as needs arose, with no prescribed opening schedule (Closure 1); 2. following a prescribed opening schedule (Closure 3); and 3. following a prescribed schedule but occasionally allowing for harvests to meet economic and social needs (Closures 2 and 4). For example, the one month openings of Closures 2, 3, and 4 were regular annual events scheduled for December, reportedly a period of high demand for cash (e.g., for school fees) and food (e.g., for Christmas celebrations). The decisions about these major openings had been made at the time of agreeing management norms at the community level, and had been committed to in a formal management plan with the assistance of the supporting NGO. The more spontaneous minor openings throughout the previous 12 months were not accounted for in the management plan, but had occurred in response to requests from community members to harvest for money or food for fundraising or celebrations (Table 2).

Table 2 Details of periodically-harvested closures including areas, periodic harvesting schedules applied over a 12 month period (prior to, and including, the period of study), reasons for harvesting, harvesting methods permitted, access restrictions and the number of trips recorded.

Closure	Area (km^2)	Period of opening (days)	Opening date	Reason for opening	Methods used	Access restrictions	# trips recorded
1	0.044	12	18th - 29th June 2011	Church fundraising	mixed	permitted family members only	24
		7	Various 2011	Family financial needs	coral harvesting	permitted family members only	7 [b]
2	0.63	31	1st - 31st Dec 2010	Scheduled	mixed	community-wide	175
		14	Various 2010	Birthdays, weddings	spear fishing	4-5 permitted spear fishers only	14 [b]
3	0.03	31	1st - 31st Dec 2010	Scheduled	mixed	community-wide	4
4	0.37	31	1st - 31st Dec 2010	Scheduled	mixed	community-wide	36
		2	27th - 28th Sep 2010	Clinic fundraising	trochus gleaning	community-wide	24 [a]

Trips recorded via community records [a] or reconstructed from interviews [b]

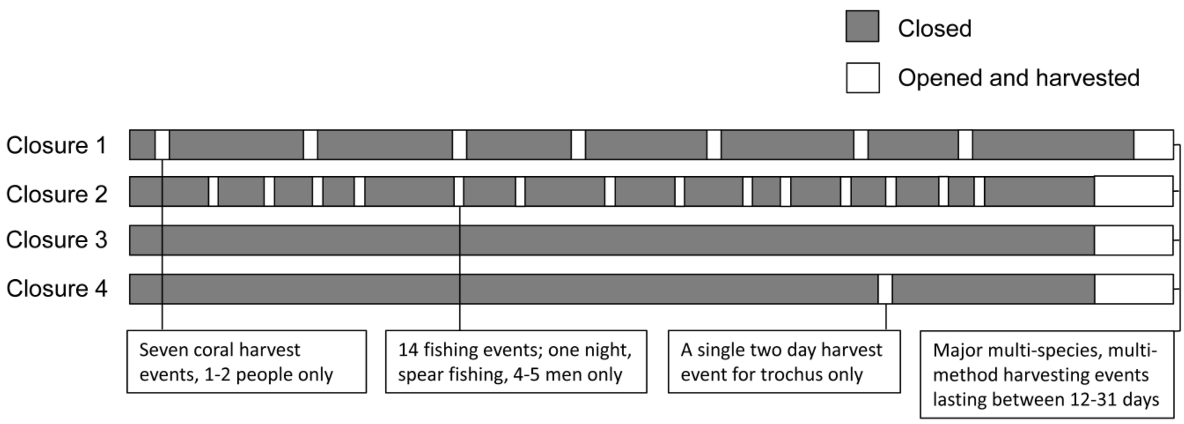


Figure 12 A schematic representing the harvesting and closure regimes employed in periodically-harvested closures over the 12 month period prior to, and including, the period of study.

3.3.4 Exploitation and management

To harvest finfish and non-finfish from reefs, fishers used several types of fishing gear and methods, which for the purpose of this study have been grouped into the six main categories (Figure 13). I observed the use of explosives only in Closure 1, and on reefs fished by communities within cluster one. Periodic harvesting was conducted mainly by spear fishing and gleaning on Closures 2 and 4. The opening events I observed directly were multi-method harvests (Closure 3 was an exception receiving only four handline trips), whereas spontaneous minor harvests of closures throughout the previous 12 months were recalled to be single method harvests (i.e., only gleaning, or only spear fishing).

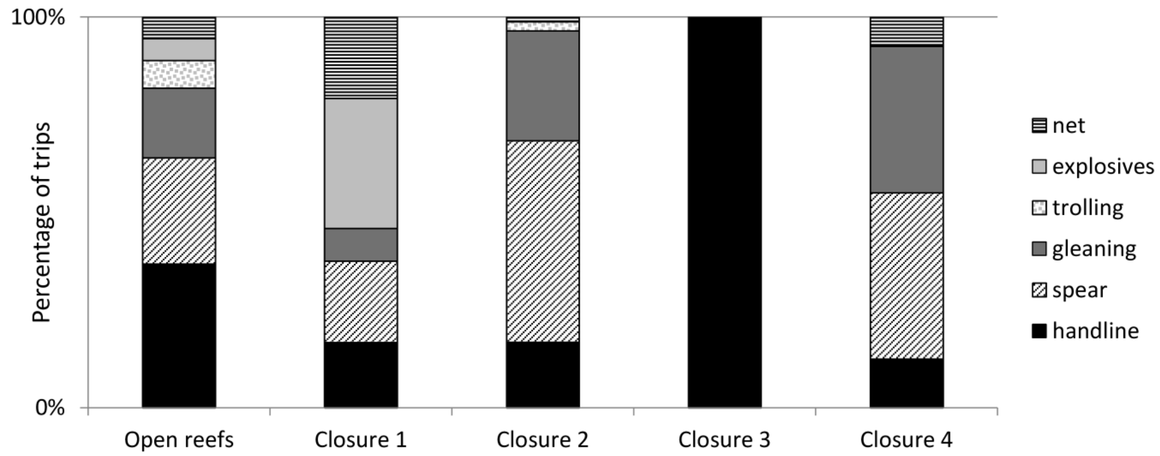


Figure 13 Fishing methods used to harvest closures, and reefs continuously open to fishing.

In addition to the duration of openings, there were two forms of restrictions placed on certain harvests. Firstly there were limitations on harvesting methods and targets during the minor harvests of Closure 1 (i.e., coral harvesting only), Closure 2 (i.e., spear fishing only) and Closure 4 (i.e., gleaning for trochus only). Secondly, access restrictions were imposed for minor openings of Closure 2, and for all harvesting events of Closure 1. The authority to harvest Closure 1 was controlled by one person as the reef owner, whose extended family could harvest if they had gained his explicit permission. My qualitative data suggest that fishing effort of those community members who had previously fished at that location prior to closure implementation (i.e., prior to 2005) had been displaced to other fishing grounds.

I observed a limited set of other fisheries restrictions placed on harvesting closures and other fishing grounds. It was locally prohibited to harvest tridacnid clams from Closures 2, 3 and 4; catch and qualitative data indicated that this restriction was well complied with. Communities recognized and followed nationally legislated size limits on trochus (between 8 and 12 cm), bans on commercial harvesting of sea cucumber, and on the use of explosives (however there were observed exceptions to this). There was an understanding in all communities that harvesting 'small fish' (specific size limits were not indicated) was not permitted, yet catch and qualitative data suggested that this was not well complied with. Fishing activities from communities in cluster one took place on all days of the week, whereas there were no fishing activities on Sundays (due to Church restrictions) from communities in cluster two. I did not record any other fishing restrictions on continuously open fishing grounds. There were two indefinitely closed reserves; one in the region of community cluster one (implemented 2005) and the other in the region of community cluster two (implemented 2008).

General observation and interview data indicated the number of fishing trips from a community increased when closures became open, or to prepare for celebratory feasts or for a trip to market. Conversely fishing activities would decline during community celebrations or events (e.g., new year, Christmas, church feasts or death of a community member), or when there was gambling or gaming in the community, or due to illness, poor weather, fatigue (e.g., after an episode of intense fishing for a trip to market) or other agricultural activities such as copra preparation or timber milling. Fishing patterns were also observed to be affected by lunar cycles, and were reported to be affected by season.

3.4 Discussion

Fishing patterns associated with periodically-harvested closures have received little research attention to date, despite their prevalence as a fisheries co-management measure. My study illustrates that total annual fishing effort and yield on periodically-harvested closures can be low to moderate compared to reefs continuously open to fishing. Yet, I also observe that fishing pressure can be relatively intense during periods of opening. There is insufficient evidence to confirm that fishing effort is substantially displaced from small periodically closed areas to adjacent open fishing grounds. Harvesting frequency of closures is variable, but almost always flexible, and largely driven by local social and economic needs. Patterns of harvesting, including participation and gears used, are constrained by management measures applied to some opening events, while no constraints are placed on others.

3.4.1 Comparison of yields

Within co-management frameworks across the Indo-Pacific, a pressing question for managers is *how much can be sustainably harvested when closures are opened?* While confidence in yield and sustainable yield estimates is challenged by multiple factors, particularly for multi-species coral reef fisheries (Russ, 1991, Larkin, 1977), they can provide a useful basis for comparison. In cases of single species harvests, such as trochus fisheries, quantitative assessments of stock condition prior to harvests have successfully informed sustainable catch limits (Nash et al., 1995). However, multi-species harvests are significantly more challenging to assess, and within co-management frameworks, even single species quota determination through stock assessments is likely beyond capacity available (Johannes, 1998a). In general, periodically-harvested closures would be less likely to accrue fisheries benefits when total exploitation levels are higher than, or equivalent to, levels in areas continuously open to fishing (Russ and Alcala, 2003). However, more specific guidance for community managers on harvest limits is currently lacking.

Three of the four periodically-harvested closures I observed were harvested below finfish yields that previous studies have suggested might be sustainable (Newton et al., 2007, Jennings and Polunin, 1995). One closure appeared to be harvested above measures of sustainable yield, largely due to the dominant use of efficient methods (i.e., explosives and nets) to harvest loosely reef-associated fish (mostly scads) from a relatively small area of reef. When loosely reef-associated scads are excluded from catch data, the recalculated annual yield estimate falls to around 8000 kg per km^2. Therefore, all reef-associaed finfish yields from periodically-harvested closures are low to moderate compared with reefs continuously open to fishing. While non-finfish yields from periodically-harvested closures are also low to moderate compared to yields from reefs continuously open to fishing, I find no multi-species estimates to indicate whether these levels of non-finfish harvesting might be sustainable.

The sustainability of catch levels will be highly variable among target species, due to wide variation in life history traits (growth rate, longevity, fecundity, age at maturity, etc.), which confer differing levels of vulnerability to fishing (Cheung et al., 2005, Pauly et al., 1998). Periodic harvesting strategies are thought to be more suitable for short-lived and fast-growing taxa than those that are longer lived and slower growing (Jennings et al., 1999b, Russ and Alcala, 1998b, Foale and Manele, 2004). However, comparisons of fish biomass inside and outside of closed areas in Vanuatu, Papua New Guinea, and Indonesia suggest that periodically-harvested closures have had benefits over strategies of continuous fishing for species deemed vulnerable to exploitation (Bartlett et al., 2009a, Cinner et al., 2006). For certain species in temperate fisheries, particular cycles of closure and harvesting can in fact marginally increase sustainable yields compared to continuous harvesting strategies (Hart, 2003); yet for tropical species this information is not as yet available. To better understand the fisheries management efficacy of periodic harvesting strategies, more research is needed into the taxonomic composition of catches from harvests (Chapter 4), and the taxa-specific and secondary ecological responses to patterns of periodic harvesting.

3.4.2 Comparison of effort and effort displacement

Implementing periods of closure reduces fishers' opportunity to harvest, and can act as an indirect measure to reduce overall fishing effort expended in a given area. Positive fisheries effects (i.e., comparatively high standing stocks) of periodically harvested or rotational closures that have been observed and modelled may result primarily from reduced fishing pressure inside closures (Game et al., 2009, Cinner et al., 2006, Kaplan et al., 2010). Over a 12 month period, I observed periodically-harvested closures to be fished at light to moderate effort levels compared to reefs fished year-round. While there is flexibility to open closures more than once within a 12 month period, the major opening events account for the majority of effort and catch in all cases. All four closures were geographically closer to communities than over 50 percent of comparable reefs. As proximate fishing grounds tend to receive proportionally more fishing effort than those more distant (Daw, 2008, Caddy and Carocci, 1999), it might be expected that if continuously open, these areas would be some of the most heavily fished reefs. While I lack pre-implementation effort data to confirm whether overall effort has been reduced by closure periods, my comparison of effort across 12 months lends support to the hypothesis that implementing periodically-harvested closures lowers effort.

Yet, while I observed annual effort in closures to be relatively low, fishing effort during openings can be intense (i.e., daily average effort was between four and 60 times higher on closures than on reefs continuously open to fishing), and is particularly intense early in the opening period. The phenomenon of elevated fishing intensity in 'pulse-fishing' when areas are newly opened has been observed elsewhere when fishers' anticipate higher catch rates and yields, and when economic and social demands are high (Russ and Alcala, 1998b, Murawski et al., 2005). Fishers are ostensibly benefiting from increases in growth or abundance that have accrued during closure, however intense fishing could potentially deplete stocks beyond levels of replenishment. In cases of high fishing pressure, particularly in open access fisheries, benefits of periodically-harvested closures are less evident. For example, during the first two weeks of opening a reef closure in New Caledonia, fishing catch and effort reached levels that had previously been observed over an entire year (Ferraris et al., 2005). Periodic harvests in Hawaii resulted in overall declines of target-species populations, indicating that the one to two year closure periods were too short for compensatory growth and reproduction (Williams et al., 2006). Similarly, unrestrained harvests of two fish reserves in the Philippines rapidly depleted finfish biomass, whereas subsequent recoveries were slow (Russ and Alcala, 2003). High ambient fishing pressures, combined with a lack of restraint during harvests, reduce the chance of realising fisheries benefits from periodic harvesting strategies. This emphasises the importance of embedding periodically-harvested closures within functional co-management frameworks, or more generally where other mechanisms to limit fishing effort exist.

Implementing periodically-harvested closures shifts fishing effort in time, and potentially also in space. While periods of closure allow for closed areas to replenish, other areas can become more impacted if broader management has failed to remove net effort from the system (Hilborn et al., 2004). This will be particularly apparent in regions where fishing pressure is high, or alternative fishing grounds are minimal. My qualitative data suggest that upon implementation of Closure 1, the fishing activities of those who had previously fished at that location were displaced to other grounds. Yet, I observe no spatial effort displacement due to the closed or open status of Closure 1; this is not surprising given that fishers affected (post-implementation) by the closed or open status, represent only a very small proportion all people fishing open grounds. I found no evidence that effort is significantly displaced onto open fishing grounds due to any of the closures, likely due to the relatively small size of closures, and relatively low ambient fishing pressures in Solomon Islands, particularly compared to coastal areas of Asia for example (Newton et al., 2007). I identified a range of other factors that change participation or intensity of fishing e.g., celebrations, preparation of agricultural exports or high wind weather conditions temporally reduced the intensity of fishing, whereas when weather was fair or there were preparations for a celebratory feast, fishing intensity could be elevated. These factors are also important to understand and integrate into management that seeks to reduce fishing effort with closures, or other strategies.

3.4.3 Drivers opening and closure periodicities

The periodicity of closure and harvesting events is critical to determining the fisheries management efficacy of periodically-harvested closures (Gerber et al., 2003). I observe planned management arrangements to vary between indefinite periods of closure with the flexibility to open as needs arise, and more strictly scheduled closures and openings. Opening and closure cycles are in fact more similar in practice than in planning, with areas being opened as needs arise in three of the four cases. Decisions about when to harvest closures are largely based on increased economic (similar to Thorburn, 2000, Foale, 1998b) or social needs (similar to Bartlett et al., 2009a, Cinner et al., 2005), as opposed to ecological observations or assessments (as reported by Nash et al., 1995, Cinner et al., 2006). This flexibility to open areas fits well with meeting social objectives, but potentially increases vulnerability of fisheries to increasing demands on resources. Socially driven decisions to harvest areas may not, in practice, coincide with sufficient replenishment of some species. As such, to meet longer term fisheries management goals, management must seek to address the balance between social, economic and ecological indicators used to influence decisions to harvest. In scenarios of low ambient fishing pressure the need to refer to ecological indicators may not be so pressing, but in increasing or high fishing pressure scenarios the importance of resource monitoring, concurrent controls on harvesting and adaptive management institutions is elevated.

3.4.4 Exploitation and management

To harvest from reefs, fishers use a range of gears with differential selectivity and habitat impact. In one case I observed the use of explosives; a highly non-selective and efficient method that can cause substantial and lasting habitat damage when used directly on coral reefs (Russ and Alcala, 1998b). Spears and gill nets can also damage corals directly, whereas methods such as line fishing have relatively low impacts (Mangi and Roberts, 2006). Few studies have considered habitat recovery or habitat impacts of periodic harvests, however where it has been studied, species richness, live coral cover and coral diversity did not to vary significantly between periodically-harvested closures and areas open year-round (Cinner et al., 2005). In addition to the amount of effort or biomass removed by periodic harvesting, the methods and gears employed will impact upon conservation and fisheries outcomes. The concurrent use of gear and spatial fisheries controls has benefited tropical fisheries in other regions (McClanahan, 2010), yet it appears the effective implementation of gear restrictions presents a challenge in at least one of these cases where compliance with existing gear controls was weak. The relative frequency of use of different fishing methods and the selectivity of gears for large, small, vulnerable or resilient taxa will ultimately influence the sustainability of any particular level of yield. As such, in multispecies, multi-gear harvests the life history characteristics of the resultant catch will be a critical factor influencing the efficacy of periodically-harvested closures for fisheries management.

Similar to many studies of periodically-harvested closures in the Indo-Pacific (Chapter 2), I find no limits placed on the volume or numbers of fish/invertebrates harvested during openings. I do find evidence of taxa-specific limits during minor harvests and compliance with a total ban on harvesting tridacnid clams from three closures. The clam ban is not accounted for in the management plan, and appears to be a useful adaption of management that accounts for relatively slow recovery rates for that genus in relation to closure times. Fisher participation in harvesting is limited implicitly to community residents, with more explicit limits on participation applying in certain cases. While limiting access is a fundamental mechanism to manage fisheries, restricting participation will not necessarily change the volume harvested, just who harvests it (Polunin, 1984). This distinction will become increasingly evident in scenarios of increasing or high population pressure, and commercialisation of fisheries.

In one of the four cases I find evidence of “elite capture”, where direct benefits from harvesting the closure accrued only to the Chief and his family, whereas prior to closure implementation that reef area had been accessible to all fishers in adjacent communities. Elite capture refers to the disproportionate flow of benefits, often towards more powerful interests, who have exercised their existing positions or powers to secure those benefits. Many co-management initiatives aim to improve community-wide well-being, however elite capture or inequitable benefit distribution at the local level are common unintended consequences of decentralisation initiatives working within customary governance structures (Béné et al., 2009). In the case I observed, community members appear to have been only marginally disadvantaged by the implementation of the closure due to its small area relative to other accessible fishing grounds. Yet, as competition for resources intensifies, scenarios of elite capture, or inequitable benefit distribution, will almost certainly become more common (for analogous scenarios in Philippines, see also Cabral and Alino, 2011, Fabinyi et al., 2010), and with greater implications for non-elite or marginal groups. Equitability of benefit distribution therefore needs to become a serious consideration in fisheries co-management initiatives.

Despite comprehensive written management plans that included a diversity of resource-use rules, I found that locally formed and *implemented* rules were less comprehensive. There was widespread awareness and compliance with the nationally legislated trochus, sea cucumber and explosives restrictions. However other agreed-to local rules appeared less conducive to community level implementation than periodically-harvested closures. Community enthusiasm for closures, at least in part, arises from similarities with customary practice (Williams et al., 2006), maintaining fishers' ability to access and exploit resources in the area (Foale and Manele, 2004), and observations of stock replenishment, or increased catchability, after closures are lifted (Cinner et al., 2006). However implementing a range of regulations within co-management frameworks is reported to increase the likelihood of improved outcomes for fisheries (Gutierrez et al., 2011).

In my case studies, reefs represent the dominant habitat for fishing, although fishers also utilized pelagic, lagoonal, and mangrove areas. While other resource-use rules may influence fishing in a range of habitats, most periodically harvested marine closures in the Indo-Pacific are placed over coral reefs (Chapter 2). Periodically-harvested closures and indefinitely closed reserves represent less than 7 percent of fished reefs, and are the most prominent form of resource-use control in the cases I studied. Closed reefs therefore represent a very small proportion of all fishing grounds and displaced effort is therefore highly dispersed amongst open fishing grounds. However, I find then that only a very small proportion of fishing grounds are influenced by any management practices at all. Long-term successful fishery management will likely require periodically-harvested closures to be embedded within functional co-management frameworks in which a diversity of context specific, socially acceptable and fisheries appropriate rules are implemented and adapted (Gutierrez et al., 2011). Assuming a common objective is in fact sustainable fisheries practices; attaining more comprehensive resource management within co-management frameworks presents an ongoing challenge to community managers and their support agencies.

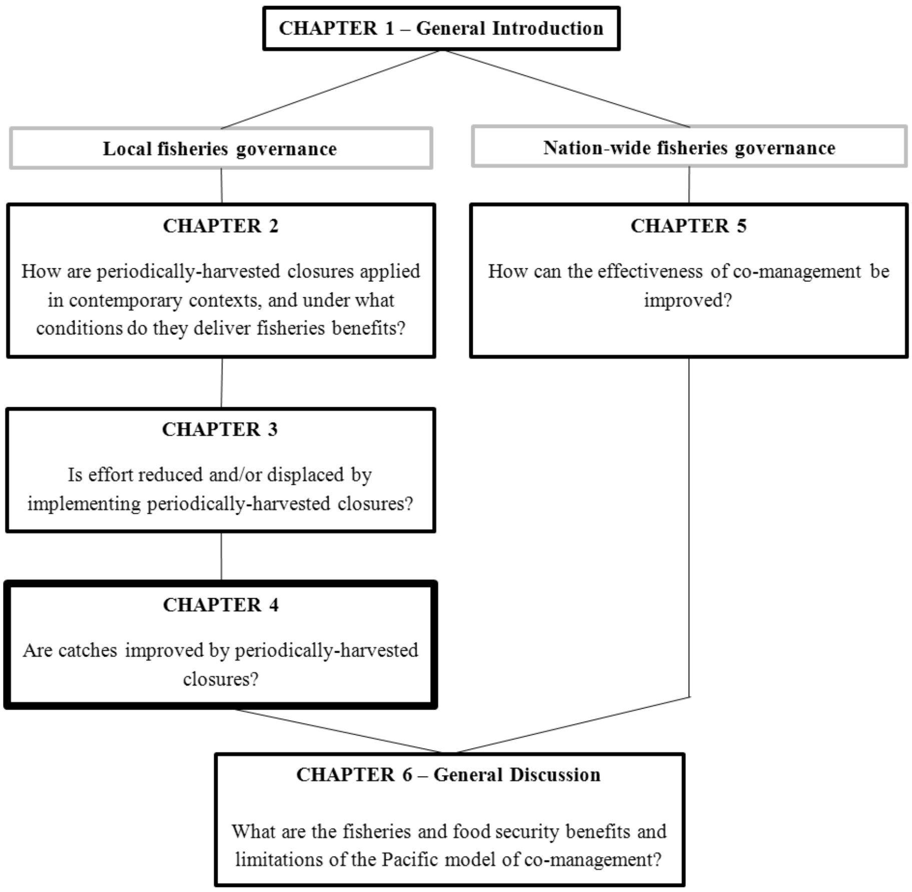
3.5 Conclusion

My research suggests that periodically-harvested closures may help to maintain fisheries at proposed sustainable targets for multi-species reef fisheries. Yet, I recognise that confidently determining sustainable limits for multi-species fisheries is an ongoing agenda for research. Emerging research has begun to identify alternative sustainability targets for multi-species reef fisheries using relatively simple techniques (e.g., McClanahan et al., 2011, Graham et al., 2005) which may prove globally useful once tested and refined for other geographies and circumstances. However to support co-management, including measures such as periodically-harvested closures, broadly applicable rules of thumb or context specific targets must also be workable considering co-management capacity and resource owners objectives. Due to the dynamic nature of social and ecological aspects of small scale fisheries, *adaptive* forms of co-management are increasingly promoted. Embedded institutions for learning and response could enhance the fisheries outcomes from co-management (Olsson et al., 2004) where for example, periodic harvesting levels and opening-closure periodicities can remain flexible, but decisions about when, how, how much and what to harvest are based on local observations, and improved understandings of resource and ecosystem dynamics

Co-management arrangements that feature periodically-harvested closures have proliferated in the Asia-Pacific region over the past decade (Jupiter et al., 2012, Bartlett et al., 2009a). Yet, tropical fisheries, and their management institutions, face increasing demands from commercialisation and factors operating outside of the fisheries sector, including population growth (Bruno and Selig, 2007, Bell et al., 2006, Schwarz et al., 2011). While the flexibility to harvest closures is of social and economic importance, increasing demands may lead to increased frequency of openings and elevated intensity of harvests, resulting in net overall declines in stocks. Customary management institutions (i.e., the origins of periodically-harvested closures and the foundations of co-management in the Indo-Pacific) are not necessarily robust to factors such as population growth, export market penetration and economic modernisation (Ruddle, 1994, Polunin, 1984). However within co-management frameworks, cross-scale institutional and knowledge exchange linkages, via partnerships with NGOs or government agencies, may guide and bolster local institutions in the face of increasing pressures (see Chapter 5) (Thorburn, 2000, Cudney-Bueno and Basurto, 2009). Recognising the importance of periodically-harvested closures in the Indo-Pacific, future research should inform practical guidance to retain closures as community governed institutions that meet shorter term social and economic needs, but that also enhance progress toward longer term fisheries goals. While a suite of strategies is likely required to address contemporary fisheries concerns in the Indo-Pacific, co-managed periodically-harvested closures form foundations to build upon.

Chapter 4 Catch rates, composition and fish size from reefs managed with periodically-harvested closures

By employing periodically-harvested closures, fishers potentially benefit from increases in abundance and growth accrued during periods of closure. Periodic harvesting is likely to be a more suitable long-term management strategy for short-lived, fast-growing and sedentary taxa than for longer lived, slower growing taxa, or those with home ranges that extend beyond the boundaries of the closure. While commonly employed within co-management models or LMMAs to manage multi-species fisheries, the effectiveness of periodically-harvested closures as a management strategy for fish, or for multi-species fisheries, is poorly understood - as illustrated in my review in Chapter 2. In Chapter 4 I examine the characteristics of catch to test hypotheses that emerged from this review i.e., that in periodically-harvested closures (a) catch rates (catch per unit effort; CPUE) are higher, (b) short lived, fast growing, sedentary taxa are more abundant, and (c) finfish and invertebrates are larger, compared to harvests from reefs continuously open to fishing. Due to the relatively high intensity of periodic harvests, as noted in Chapter 3, I also examine CPUE throughout the opening to look for stock depletion effects. I discuss these results in terms of short-term objectives of enhanced efficiency, and in terms of long-term sustainability objectives.



4.1 Introduction

In many developing country contexts permanent no-take reserves are not always a feasible option to manage small-scale fisheries (Foale and Manele, 2004, Christie, 2004), and in many cases closures that are periodically harvested are preferred. As discussed in Chapter 2, in the Indo-Pacific periodically-harvested closures have customary origins (Johannes, 1978, Carrier, 1987), and emerge as important, or even primary management measures within many contemporary community-based and co-management (Govan, 2009a, McLeod et al., 2009). In a Western management context, rotational closures or periodically-harvested closures have been used as a management strategy mainly for single-species invertebrates fisheries; scallops (Hart, 2003, Valderrama and Anderson, 2007), abalone (Caddy and Seijo, 1998, Sluczanowski, 1984), lobster (Gendron and Brethes, 2002), sea urchins (Pfister and Bradbury, 1996) and coral (Caddy, 1993). Reported outcomes for invertebrate fisheries vary, suggesting that periodic harvesting strategies can; (1) maintain population size, but will result in a decrease in yield (Pfister and Bradbury, 1996), (2) maintain both population size and yield (Botsford et al., 1993, Myers et al., 2000), or (3) modestly improve biomass-per recruit and yield-per recruit, and decrease the risk of recruitment and growth overfishing, relative to strategies of continuous harvesting (Hart, 2003).

Fewer studies have tested periodically-harvested closures as a management strategy for fish, or for multi-species fisheries. Modelling of rotational closures suggests that for herbivorous fish, biomass and reef resilience can be improved (Game et al., 2009), but when effort displacement is accounted for, net fisheries gains will be marginal (Kaplan et al., 2010). Empirical field studies of multi-species fisheries suggest that periodic harvesting can lead to depletion of stock that is greater or more rapid than recovery (Williams et al., 2006, Jupiter et al., 2012), although other cases find increased abundance and size of some fish within the area (Cinner et al., 2005, Cinner et al., 2006, Bartlett et al., 2009a).

The success of periodically-harvested closures for managing fisheries broadly relies on growth and abundance increases within the area during periods of closure to be greater than or equal to levels of depletion during harvests. While increased abundance may lead to some secondary benefits, such as spill-over of adults and export of larvae to fisheries operating outside of the area, the marine reserve literature suggests that these benefits are slow to be realised, even where protection from fishing is permanent (Abesamis and Russ, 2005). The recovery of exploited stocks and habitats when a fishing ground is closed depends on species demographics, site characteristics, the duration of the closure, hydrodynamics and larval supply (Russ et al., 2005, Jennings, 2001). In the marine reserve literature reported recovery rates vary from rapid and substantial increases in abundance as soon as one to five years after the cessation of fishing (Halpern and Warner, 2002, Roberts et al., 2001a), to reports that relatively long periods of closure are required to build abundance and biomass of longer-lived, slower-growing fish species, and also that recovery is dependent on unpredictable pulses of recruitment (Russ and Alcala, 2003, Russ and Alcala, 2004). Modelling of closure and harvesting cycles for periodically-harvested closures suggests that relatively short cycles can build biomass to enhance yields of shorter-lived, fast-growing and sedentary species (Caddy and Seijo, 1998). In general, periodic harvesting is predicted to be a more suitable strategy to maintain or enhance catches and stocks of sedentary, short-lived and fast-growing taxa (i.e., those of high rebound potential) than longer lived and slower growing species, or those with home ranges extending beyond the boundaries of the closure (Jennings et al., 1999b, Russ and Alcala, 1998b).

In order for periodic-harvesting to be beneficial for fishers in the long term, overall yield must be sustainable at greater levels than could be achieved by a continuous harvesting strategy. In the short-term, implementing periodically-harvested closures can enhance catch efficiency, which is an important objective for communities and fishers (Cinner et al., 2006, Foale et al., 2011, Gelcich et al., 2010). Elevated catch rates may result from increased abundance of fast growing taxa, or reduced flight distance in finfish targeted by spear-fishers (Feary et al., 2011). Whether short term improvements to catch efficiency correspond with overall gains in sustainable yield in the longer term is an important question for managers. For long-term objectives, patterns of depletion during harvesting events are equally important as recovery trajectories. Fishing patterns and resultant levels of depletion are driven by fisher behaviour, catchability of target taxa, gear selectivity and any restrictions placed on harvesting during the open period (and closed periods if bans are not complete or not fully complied with) (Chapter 2) . Exploitation patterns that result from a closure-harvesting cycle may lead to yield gains or stable populations of certain taxa, but might result in yield losses or depleted populations of others. To date there has been little research attention given to understanding the short-term and long-term consequences of periodic-harvesting for multi-species fisheries.

This chapter examines the potential of periodically-harvested closures as a management strategy to sustainably manage fisheries. I test whether the strategy can maintain or improve catch rates and yields. In four periodically-harvested closures I examine multi-species catch rates (catch per unit effort; CPUE), relative abundance of finfish and invertebrates in catches, and compare the length of eight frequently-harvested finfish and one invertebrate species. I use CPUE to examine changes in the fishery for three reasons. Firstly, fisheries independent data collection methods can be contentious (e.g., experimental fishing), or difficult and expensive in remote settings (e.g., underwater visual census). Secondly, CPUE provides a measure of the fishers' actual experiences of cost (time spent) relative to benefit (weight of catch). Thirdly, CPUE can provide a proportional index of abundance, and therefore changes in CPUE can reflect changes in abundance – with some notable caveats (Beverton, 1957, Harley et al., 2001, Maunder et al., 2006) that are detailed in the discussion.

I compare observations of CPUE, composition and fish and invetebrate length from periodically-harvested closures with catches from the same group of fishers exploiting reefs that are continuously open to fishing. I tested the hypotheses that when periodically-harvested closures are open to fishing: (1) catch rates are higher; (2) short lived, fast growing taxa are relatively more abundant; and, (3) finfish and invertebrates are larger, compared to harvests from reefs continuously open to fishing. In the case of one periodically-harvested closure where adequate data were available (i.e., due to a high frequency of trips), I also examine changes in CPUE and effort throughout the opening period to measure the impact of stock depletion.

4.2 Methods

4.2.1 Study location

In this chapter I examined the same four periodically-harvested closures that I studied in Chapter 3 (i.e., referred to as Closures 1-4). Communities are again referred to as community cluster one (CC1) and community cluster two (CC2). As established in Chapter 3, fishers from these communities predominantly targeted reef areas, and exploited pelagic zones and mangroves to a lesser extent. All communities had engaged in NGO-supported co-management initiatives that formed management plans which incorporated resource-use regulations and education, compliance and monitoring strategies. As part of co-management arrangements, periodically-harvested closures were established over selected reefs. Reefs were generally selected by communities based on uncontested ownership and proximity to the village which allowed for easy monitoring and access. CC1 had one periodically-harvested closure, and CC2 had three, in which all extractive activities were banned during periods of closure. I established in Chapter 3 that these periodically-harvested closures were all small (Closure 1: $0.044km^2$, Closure 2: $0.63km^2$, Closure 3: $0.03km^2$ and Closure 4: $0.37km^2$), and accounted for less than five percent of the fished reef area (i.e., the total area of 59 reefs observed to be used for fishing during the study period). The closure at CC1 was established in 2005 and since then, until the harvesting event I observed, had reportedly been closed to all fishing activities, aside from the removal of coral that had been planted in the area. Closures 2, 3 and 4 at CC2 were established in 2008, and since that time had been closed for 11 months from January to November, and subjected to one month-long harvests every December (Chapter 3).

4.2.2 Sampling design and landing site sampling

Data collection followed the same basic procedure detailed in Chapter 3, however although fishing took place in pelagic and mangrove areas, in this chapter I only consider data from reef fishing grounds used by the same community of fishers who were exploiting the four periodically-harvested reefs (n=518 fishing trips to reefs). Sampling coincided with community-planned openings of periodically-harvested closures (i.e., Closure 1 was harvested for 11 days in July 2011 and Closures 2, 3 and 4 were harvested for 31 days in December 2010). In the same manner detailed in Chapter 3, fishers were asked to provide details of their fishing trip as soon as they returned to shore. In addition to recording total weights of catches, for this chapter I also counted the number of fish and invertebrates in each landed catch. Again, local nomenclature was used for counting and recording purposes (Foale, 1998a, WorldFish Center, unpublished). In 73 fishing trips, catches of the molluscs *Strombus luhuanus*, *Nerita polita* and *Polymesoda erosa* were too large to allow total enumeration of the catch. In these instances I sub-sampled the catch and extrapolated to the full sample. In 86 fishing trips (of the 518 total reef fishing trips observed) fishers were not immediately encountered at the landing location and their catch was already cooked, consumed or sold. In these cases I used a 'recall' method to describe the landed catch – this method is also detailed in Chapter 3.

I excluded data from incomplete trip records, and from trolling trips due to low number of trips to periodically-harvested closures (Table 3). I also excluded data from trips using dynamite and nets because catches were distributed amongst many fishers, and so total catch weight from single netting or dynamiting events could not be reliably reconstructed. Note that the use of nets and dynamite were relatively infrequent, and their use in periodically-harvested closures was of similar frequency their use on open reefs. Taking into account excluded data a total of 191 fishing trips were recorded from the four periodically-harvested closures, and 327 trips from 55 reefs continuously open to fishing (henceforth 'open reefs'), representing a total of 2 903 fisher hours (Table 4). I recorded 19 159 finfish and 19 043 invertebrates in total. A total of n=213 (i.e., <1%) of individual finfish or invertebrates were unidentified, and therefore excluded from the catch composition analysis.

Table 3 Data excluded from analysis of reef fishing catch rates. Note that the number of dynamite and netting trips refers to the number of fishers returning with catch from those events, and does not indicate the number of netting or dynamiting events.

Trip data excluded	n (trips)
Incomplete record (i.e., missing trip duration, catch weight, method)	33
Dynamite	19
Nets	33
Trolling	76

Table 4 Sampling periods, and fishing trips and hours analysed in each periodically-harvested closure and in reef fishing grounds in each study region.

Reef area type	Days sampled	Fishing trips	
		# trips	# fishing hours
Closure 1	11	10	16
Closure 2	31	146	947
Closure 3	31	3	6
Closure 4	21	32	93
Open reefs CC1	23	130	765
Open reefs CC2	54	197	894

For length measurements, the catch was photographed on a gridded sheet of plastic using a 12 megapixel camera. I measured and analysed length data for eight species of finfish (Table 6) and the invertebrate *Trochus niloticus* (trochus). These species were selected because they were numerically abundant in catches from both periodically-harvested closures and open reefs. Although abundant in catches I did not measure acanthurids as growth in adults is hard to detect (Choat and Axe, 1996). While data were originally recorded using local language names, images were used to identify fish to species level. Total lengths of finfish, and basal diameter of trochus, were determined through analysis of images using Image J (Rasband, 1997-2012). In each image, all fish or trochus of interest were measured, and the data recorded against the corresponding trip details.

4.2.3 Data standardisation

Prior to pooling data collected by the recall method with data recorded directly, I repeated a similar procedure to that detailed in Chapter 3 – however in this case for only this sub-sample of reef fishing trips. I used a two sample t-test to determine whether the data collection methods varied in terms of trip length and catch weight. Trip time and catch weight were square root transformed to improve normality which was assessed by inspecting residual plots. There was no significant difference ($t = 0.03$, $df = 516$, $p = 0.787$) between the average trip duration for those trips observed directly (313 ± 13 minutes, $n = 432$), and those recorded using the recall method (314 ± 28 minutes, $n= 86$). As I was interested in the comparability of the recall and standard methods for estimating catch weight, I excluded trips where nothing was caught. Using a Welch modified two-sample t-test to account for unequal variances, I found there was a significant difference ($t=-3.14$, $df = 95$, $p = 0.002$) between catch weight from trips observed directly (4.03 kg ± 0.30, $n = 423$), and those collected using the recall method (5.09 kg ± 1.92, $n = 86$). There was no systematic bias in the use of the recall method for collecting data from any fishing method or any harvested strategy (i.e., continuous or periodic). Accordingly, I adjusted catch weights from the recall method with a correction factor of 0.8. Subsequent analyses were run with and without data collected with the recall method, and this did not vary the main findings.

Catch rate (CPUE) was calculated per trip using kilograms per fisher hour. To standardize catch rate for reef fishing I estimated and removed travel time to and from reefs, so that the time component of effort accounted for active fishing only. In each community, I asked experienced fishers to estimate travelling times (i.e., via canoe as this was the only boat type used for fishing on reefs) to fishing grounds they were familiar with. I calculated distances to these fishing grounds using MapInfo 11.0 and then calculated a median paddling speed (9 minutes km^{-1}) to infer travelling times for all other reef fishing grounds. Subsequently, according to the distance between the fishing ground and landing location of each trip, I determined actual time spent fishing by subtracting paddling times from total trip time.

4.2.4 Data analysis

To compare the difference in CPUE between harvesting strategies (i.e., periodic versus continuous harvesting) I used a linear mixed effects model (Pinheiro and Bates, 2000) using S+ (version 8.2). Harvesting strategy and fishing method were treated as fixed factors, and I tested for interaction effects (i.e., harvested strategy x fishing method). The model contained two random factors; region (i.e., CC1 or CC2) and fishing ground (i.e., the 55 open reefs and the 4 periodically harvested reefs), which was nested within region. CPUE data were strongly skewed; a reciprocal transformation (i.e., 2-(1/CPUE+0.5)) improved normality. I examined residual plots to confirm data were normally distributed, and equal variances were confirmed using Levene's test.

In Closure 2 there were sufficient trips through the cycle of opening to allow an analysis of trends in CPUE from the commencement of harvesting until the end. The comparison of CPUE from open reefs was restricted to only those reefs in the same region as Closure 2 (i.e., CC2 open reefs). CPUE averaged over each week of the opening period were initially visually inspected because the sporadic timing of fishing trips, and uneven distribution of effort between open reefs and the periodically-harvested closure, meant that it was difficult to conduct formal statistics. Based on this visual inspection and the relatively low frequency of fishing trips in the later stages (i.e., final three weeks) of the harvesting period, I categorised trips into those occurring in the early (i.e., first seven days) or the late (i.e., final 24 days) stages of the periodic harvest. I ran a two-way ANOVA with harvesting strategy-time (i.e., ‘periodic harvest-early, periodic harvest-late or ‘open reef’), and gear as independent variables; I used Tukey’s post-hoc test to identify where difference lay.

All catch composition analyses were conducted in PRIMER (Clarke and Gorley, 2006) following the methods described in Clarke and Warwick (2001). Catch composition data were first standardised by effort, dividing the total number of individual fish and/or invertebrates caught at each particular fishing location by the total number of fishers hours sampled at that location (summarised in Table 4). A few families (e.g., Strombidae and Acanthuridae) were particularly abundant in catches. Therefore standardised catch composition data were square root transformed so as to increase the sensitivity to detect differences driven by families of intermediate abundance. Non-metric multidimensional scaling (MDS) based on Bray-Curtis similarity measures was used to examine variability in catch composition between sites. Due to the high stress of the two dimensional MDS, I also consulted the three dimensional version of the plot to confirm that patterns were not being misrepresented in two dimensions. ANOSIM was used to test whether the catch composition was significantly different between periodically-harvested closures and open reefs, and SIMPER analysis identified the families important in driving the trends for each fishing method. I analysed all fishing methods together, and also examined results from analyses conducted separately for gleaning for invertebrates, spear fishing for finfish, and line fishing for finish. Where periodic harvests spanned several weeks (i.e., Closures 2 and 4) I visually examined catch composition through time. I characterised fish families in the catches as having a low, medium or high potential to recover from fishing (referred to henceforth as ‘rebound potential’). Rebound potential was based on the species-specific index for resilience to fishing reported by FishBase and SeaLifeBase (Froese and Pauly, 2012, Palomares and Pauly, 2012), and the index of a particular species if it was dominant in catches.

I restricted analysis of fish and trochus size to Closures 2, 3, and 4, in comparison to open reefs in CC2; I did not examine Closure 1 due to the few replicates of most species in catches relative to fishing on adjacent open reefs. Length data for the eight finfish species (n=1 216) and for trochus (n=312) were analysed separately. Data were log-transformed to improve normality, and variances tested with Levene’s test were found to be equal. I used a one-way ANOVA to examine the effect of periodic versus continuous harvesting strategies on the length of trochus, and each of the eight finfish species. Finally, length-weight relationships ($W=aL^b$) were used to calculate the difference in weight of average size fish caught on open reefs compared to average size fish from periodically-harvested closures. Species specific growth parameters were retrieved for finfish from FishBase (Froese and Pauly, 2012), and for trochus from Nash et al. (1995). Where parameters were not available for a particular species, I used those provided for the family (Froese and Pauly, 2012).

4.3 Results

4.3.1 Catch rates

Catch rates varied significantly between fishing methods ($F_{2, 455} = 18.13$, $P < 0.001$). Catch rates were significantly higher from periodically-harvested closures than from reefs continuously open to fishing ($F_{1, 455} = 156.13$, $P = 0.002$) (Figure 14), yet this varied significantly between fishing methods ($F_{2, 455} = 3.03$, $P = 0.049$). Due to the significant interaction effect, I re-ran the analysis for each fishing method separately. Catch rates from gleaning were twice as high from periodically-harvested closures, as from reefs continuously open to fishing ($F_{1, 91} = 8$, $P = 0.007$), catch rates from spear fishing ($F_{1, 167} = 1.31$, $P = 0.254$) and line fishing ($F_{1, 160} = 0.01$, $P = 0.923$) did not differ significantly, but the trend was the same.

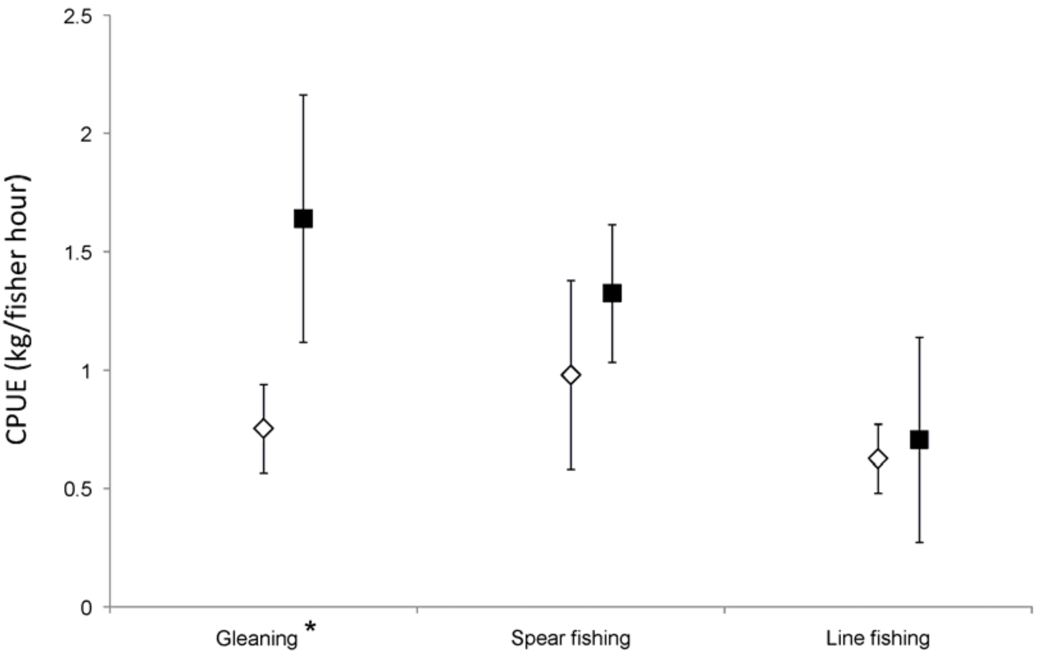


Figure 14 Catch rates (untransformed CPUE) from commonly used methods of harvesting in periodically-harvested closures (closed symbols) and continuously open reefs (open symbols). Error bars indicate 95% confidence intervals. * indicates a significant difference at $\alpha = 0.05$.

In Closure 2 there were sufficient trips through the cycle of opening to examine the constancy with which catch rates were bolstered relative to a continuous harvesting strategy, and to determine whether catch rates declined during the harvest. Visual inspection of the data (Figure 15A) indicated that relatively high catch rates for gleaning and line fishing declined after the first week of harvesting, whereas spear fishing catch rates were variable throughout the harvest period.

CPUE varied significantly between fishing methods ($F_{2, 344} = 19.78$, $P < 0.001$), but did not vary between harvesting strategy-times; i.e., early in the periodic harvest, late in the periodic harvest or harvesting from open reefs ($F_{2, 344} = 1.54$, $P = 0.216$). Due to a near-significant interaction between harvesting strategy-time and fishing method ($F_{4, 344} = 2.11$, $P = 0.079$), I examined each of the three methods separately. CPUE for gleaning, but not for line fishing and spear fishing, significantly varied between harvesting strategy-time (Table 5). Tukey post-hoc tests revealed that for gleaning, CPUE was significantly higher in the early stages of periodic harvesting compared to open reefs, but not in the later stages. Visual examination of total fishing effort applied throughout the opening period (Figure 15B) suggested that effort was particularly high on the first day of opening, remained high for the first 11 days, then declined and remained relatively low through the remaining 20 days of the open period.

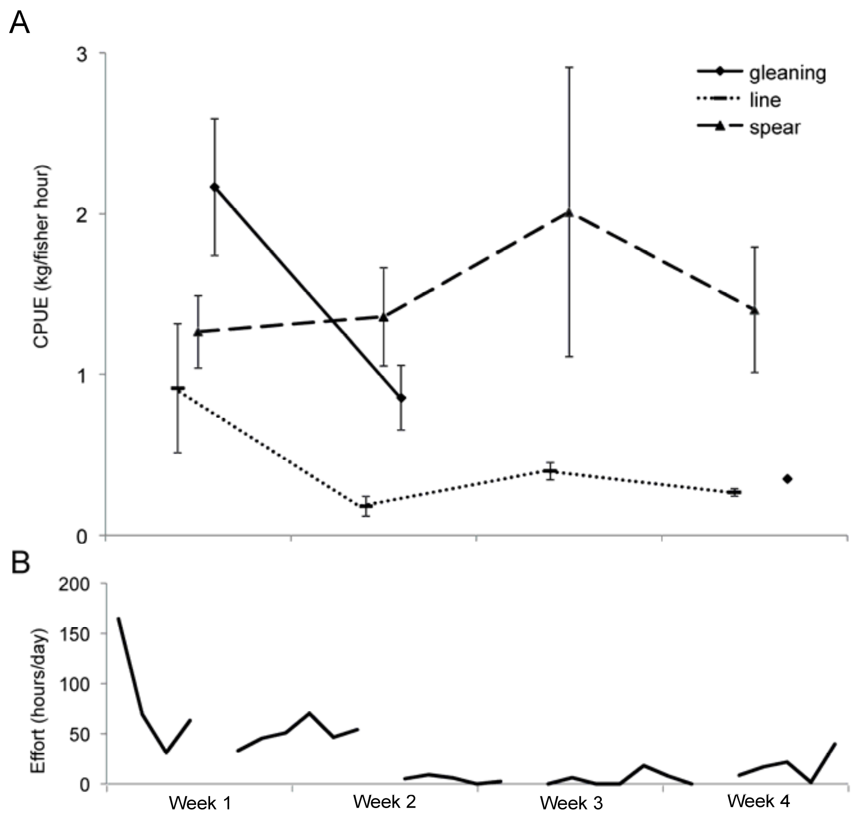


Figure 15 Each week of the one month harvest period of Closure 2 (A) Mean weekly CPUE (± SE) (B) Daily fishing effort (total fisher hours per day) applied throughout the harvest period. Gaps in effort data represent Sundays when no fishing took place for social reasons.

Table 5 Mean CPUE and ANOVA results of CPUE in the early and the late stages of the periodic harvest of Closure 2, and CPUE from open reefs in the same region (i.e., CC2). CPUE is catch per unit effort measured in kilograms per fisher hour. Bold text indicates statistical significance at the level α =0.05.

	Continuously open reef		Early periodic harvest		Late periodic harvest		ANOVA	
	Mean ± SE	n	Mean ± SE	n	Mean ± SE	n	F	P
All harvesting	0.84 ± 0.10	197	1.51 ± 0.20	73	1.19 ± 0.18	73	1.54	0.216
Spear fishing	1.42 ± 0.44	33	1.27 ± 0.22	28	1.45 ± 0.24	53	0.34	0.714
Line fishing	0.67 ± 0.09	142	0.91 ± 0.40	15	0.28 ± 0.04	11	1.02	0.363
Gleaning	1.03 ± 0.24	22	2.17 ± 0.43	25	0.80 ± 0.19	9	3.71	**0.031**

4.3.2 Catch composition

I recorded the capture of 36 families of finfish, 15 families of invertebrates, and five other families (e.g., seaweed). I examined family level composition of catches from all methods combined, and then separately for spear fishing and line-fishing for finfish, and gleaning for invertebrates in the four periodically-harvested closures and 55 open reefs. Considering reefs as replicates, MDS plots suggested no clear differentiation between catches from open reefs and periodically-harvested closures for all methods combined (Figure 16), or for each of the three dominant fishing methods.

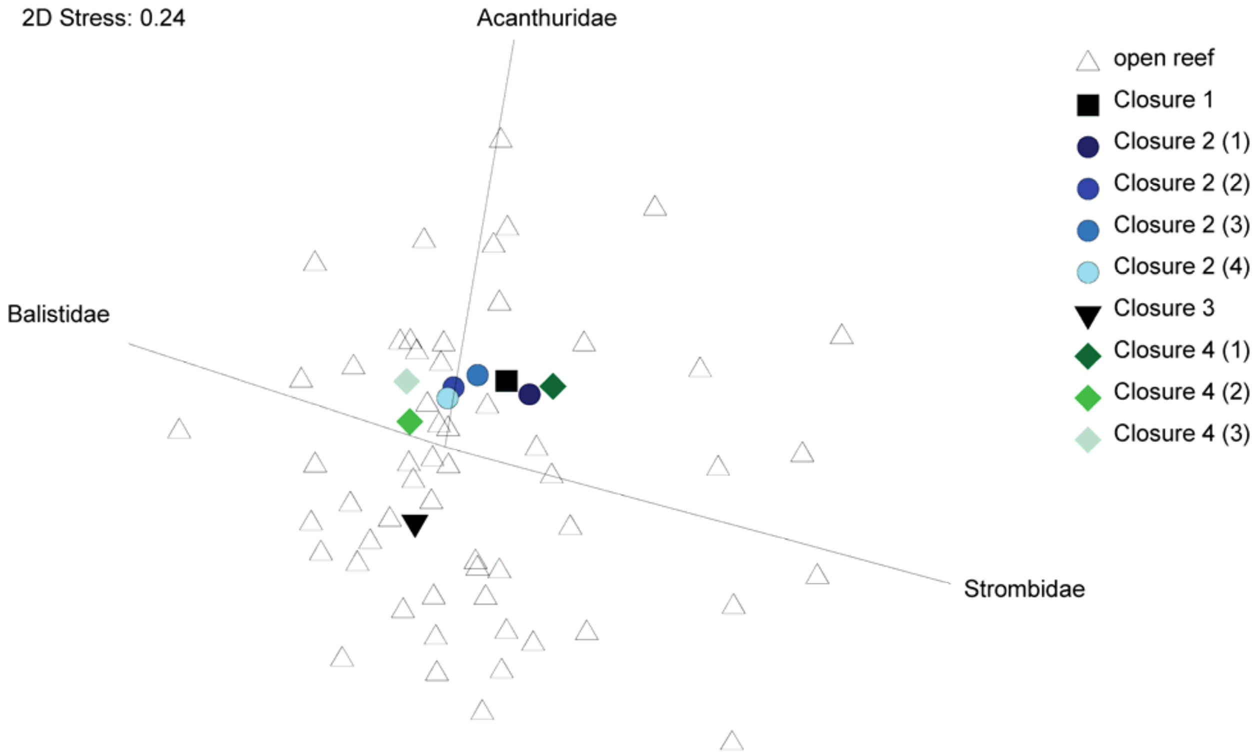


Figure 16 Non-metric multi-dimensional scaling plot of counts from families comprising catches from all fishing methods, from individual open reefs (open symbols) and periodically-harvested closures (closed symbols), with overlaid vectors of three families contributing most to observed variation between reefs. For Closures 2 and 4 (i.e., where periodic harvests spanned several weeks), the number in brackets indicates the week of harvesting (i.e., first to fourth week).

ANOSIM results confirmed that family level composition of catches from periodically-harvested closures and open reefs did not vary significantly for all three fishing methods combined (R = -0.141, p = 0.79), or for gleaning (R = -0.023, p = 0.531), spear fishing (R = -0.248, p = 0.60), or line fishing (R = 0.046, p = 0.39) when analysed separately. SIMPER results indicated that any dissimilarity that did occur between composition of catches was driven mainly by relatively higher abundances of Strombidae (for gleaning), Acanthuridae (for spear fishing), and Balistidae (for line fishing) in catches from periodically-harvested closures (Table 6). These three families have intermediate to high potential to rebound from fisheries exploitation (Froese and Pauly, 2012, Palomares and Pauly, 2012).

Table 6 Results from SIMPER analysis for the families that contribute most to dissimilarity in composition of catches from each fishing method from open reefs compared to periodically-harvested closures. Rebound potential from fisheries exploitation is based on the life history characteristics of each family (Palomares and Pauly, 2012, Froese and Pauly, 2012)

Fishing method	Family	Average number of individuals per fisher hour		% contribution to dissimilarity	Rebound potential
		Open reefs	Periodically-harvested closures		
Gleaning	Strombidae	1.77	5.15	45.85	high
Spear fishing	Acanthuridae	1.21	2.46	15.98	intermediate-high
Line fishing	Balistidae	0.10	1.00	16.91	intermediate

4.3.3 Fish and trochus lengths

One way ANOVAs for each species identified that only *Lutjanus rufolineatus* was significantly larger ($F_{1, 195} = 7.97$, P = 0.005) from periodically-harvested closures than fish harvested from open reefs (Figure 17). Observed differences in length translated to an average difference of 11.5 % in weight (Table 7). Trochus were significantly smaller in catches from periodically-harvested closures compared to those harvested from open reefs ($F_{1, 310} = 5.9425$, P = 0.015). The observed difference in length translated to a -21% difference in weight per individual.

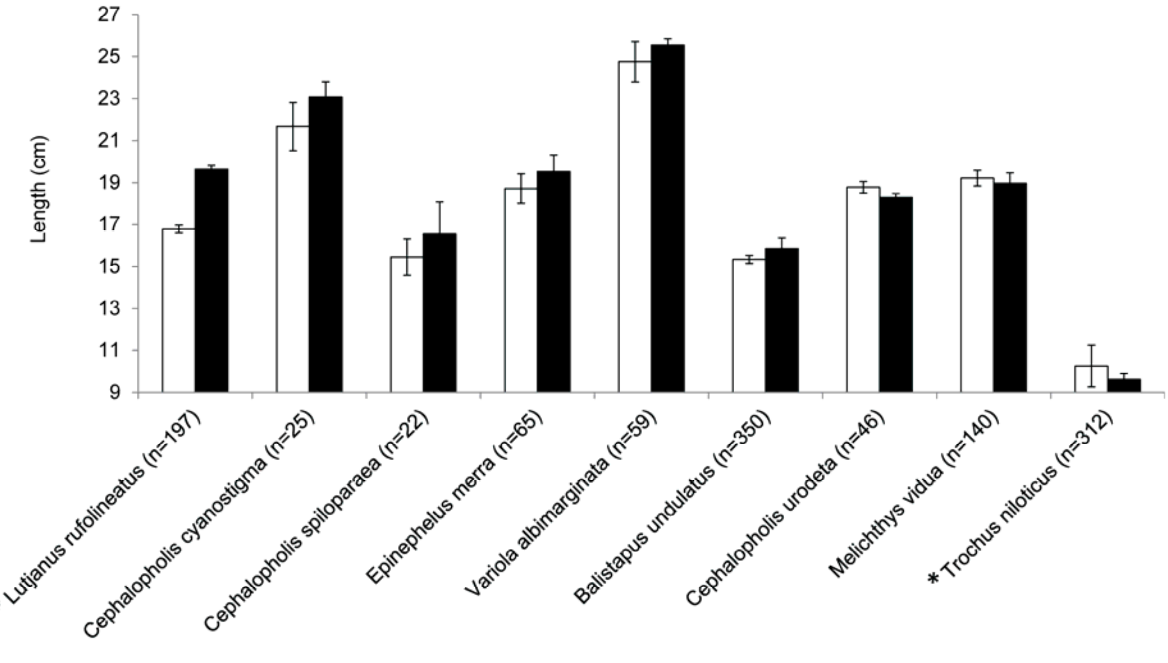


Figure 17 Average lengths of finfish and trochus harvested from open reefs (white bars) and periodically-harvested closures (black bars). Error bars indicate standard error. * indicates a significant difference between length of fish or trochus caught from periodically-harvested closures compared with open reefs.

Table 7 Observed differences in length of fish and trochus caught from periodically-harvested closures compared to open reefs. Mean % weight difference is calculated from the mean average length difference and using the standard expression W=aLb. * indicates lengths were significantly different between periodically-harvested closures and open reefs.

Species	Mean observed length difference (cm)	Mean % weight difference
Lutjanus rufolineatus	2.86 *	37.23
Cephalopholis cyanostigma	1.41	18.21
Cephalopholis spiloparaea	1.10	20.08
Epinephelus merra	0.82	11.93
Variola albimarginata	0.80	9.06
Balistapus undulatus	0.50	9.25
Cephalopholis urodeta	-0.49	-8.80
Melichthys vidua	-0.25	-4.82
Trochus niloticus	-0.34 *	-20.79

4.4 Discussion

Periodically-harvested closures are an important component of co-management in the Indo-Pacific (Govan, 2009a, Johannes, 2002). Communities and their partner agencies expect that periodically-harvested closures will deliver short-term gains by improving catch rates, and long-term benefits by improving or sustaining yields. However, empirical evidence of these benefits, and the circumstances in which they can be realised, has been lacking (Chapter 2). During the periodic harvesting events I observed, catch rates for gleaning of invertebrates were higher than those from continuously-open reefs. Catch rates for fish were not elevated, but fish caught from periodically-harvested closures were slightly larger than those caught from open reefs. While enhanced catch rates and larger fish are important short-term benefits for fishers, the long-term benefits and sustainability of the strategy will depend on levels of exploitation during periodic harvests. The relatively intense harvesting I noted in Chapter 3 probably caused localised depletion of sedentary invertebrate stocks. My observation of elevated catch rates for gleaning support the prediction that periodic harvesting is better suited for managing fast growing, short-lived, sedentary or sessile taxa. In these cases, I did not find evidence that the strategy was beneficial for the management of multi-species fin-fisheries.

4.4.1 Are catch rates improved in periodically-harvested closures?

By employing a periodic harvesting strategy, fishers potentially benefit from increases in growth and abundance accrued during periods of closure. From an ecological perspective, the extent of recovery during closed periods will depend on the status of the stock and condition of the habitat when the closure commences, the life history characteristics and scales of movement of target species, alongside patterns of larval dispersal and recruitment that are influenced by hydrodynamics and stock status in surrounding areas (Jennings, 2001). Recovery will also depend on the patterns of opening and closure (in terms of duration and frequency), effort, and gears used, which are determined by social factors. An important social objective of implementing periodically-harvested closures is that resources are stockpiled for harvesting in times of high demand (Thorburn, 2000, Cinner et al., 2005). In line with this, the harvesting events I studied were initiated when communities had elevated social (e.g., celebratory feasts) and economic (e.g., fundraising) needs for marine resources (Chapter 3). The higher catch rates I observed for gleaning suggest that in some situations, periodically-harvested closures can meet with social and economic objectives, allowing fishers to harvest more efficiently and address their immediate and elevated needs for marine produce. However, where populations are critically low, even fast growing, highly fecund species, and particularly sedentary taxa, may not recover during periods of closure due to reduced fertilisation success (i.e., the Allee effect; Allee et al., 1949, Stoner and Ray-Culp, 2000, e.g., Bell et al., 2008). Where elevated catch rates are achieved, this may, or may not, correspond with longer term objectives of maintaining or improving yield – the characteristics of harvesting will mediate long term outcomes.

Examining catch rates (i.e., CPUE) can also provide a proportional index of abundance, and therefore changes in CPUE are anticipated to reflect changes in abundance – with some notable caveats (Beverton, 1957, Harley et al., 2001, Maunder et al., 2006). As my sampling is geographically and temporally discrete, I largely avoid confounding factors such as seasonal variation in fishing and population dynamics, effort creep (i.e., technological and knowledge advances that increase efficiency), or the movement of fishing activities to 'new' grounds and stocks. Additionally, I account for variability in fishing efficiency by stratifying data by gear type. However, there are several other factors that may influence catchability, and therefore complicate the relationship between catch rates and abundance . These factors include variations in fisher skill, fish behavioural responses, target switching (i.e., when fishers change their target taxa) or changes in catchability that are due to changes in abundance (Maunder et al., 2006). I will discuss predicted effects of behavioural responses in more detail later. Based on observation I can be confident in assuming that fisher skill level was randomly distributed within sampling times and locations, and therefore unlikely to confound observed catch rate trends. The variation in fishers' targets is invariably difficult to disentangle from catch rates in a multi-species fishery. However, as I found no significant difference between catch composition from open reefs and periodically-harvested closures, I assume difference in targets is not driving catch rate trends. In general, these factors can either accentuate or dampen the decline or increase in catch rates relative to a decline or increase in abundance. However, as I was unable to collect fisheries independent measures of abundance to establish this relationship, in this chapter I use catch rates as an indication of changes in abundance, but also as a sound measure of fisher efficiency.

Improved catch rates were not evident for line or spear fishing. This suggests that closure periods were short relative to the time required for fish to rebuild from previous harvesting events. Even for sedentary stocks, modelling of optimal harvesting cycles and harvesting levels suggests the benefits of periodic harvesting will be modest (Hart, 2003). Further, harvesting during closure periods (e.g., due to rule infringements) may mean that benefits for fishers during the scheduled periods of opening are reduced, or not realised at all. In fact, in all of the four closures I studied there were low levels of harvesting (through both non-compliance, and limited approved harvest events) during the intended periods of closure (Chapter 3). In addition to changes in biomass and abundance, patterns of fishing and protection can also influence catch rates via changes in fish behaviour i.e., fish become less fearful of fishers after periods of protection (Feary et al., 2011, Januchowski-Hartley et al., 2011). In some cases this short-term elevation of catchability is the explicit objective of implementing periodically-harvested closures (Cinner et al., 2006). However, neither increased abundance and biomass, nor behavioural changes were reflected by elevated catch rates of fish in these cases.

Pulses of fishing can be intense when closures are opened, particularly where participation in harvesting is unrestricted, governance institutions are weak, fishers anticipate improved catch rates, or when demand and needs are high (Russ and Alcala, 1998b, Murawski et al., 2005, Jupiter et al., 2012). During the harvesting events I observed, average daily effort was between four and 60 times higher than effort on nearby open reefs (Chapter 3). Declines in catch rates from gleaning between the early and the late stages of the harvesting of Closure 2, suggest that harvesting led to substantial localised depletion of invertebrates. A similar decline in catch rates was apparent but not significant for line fishing. Evidence of the periodic harvest depleting invertebrate stocks was further supported by anecdotal reports from fishers, and a decline in effort (for gleaning in particular) throughout the periodic harvest (Figure 15B). The significantly higher catch rates for gleaning in periodically-harvested closures overall were therefore likely due to a few days of good catches at the commencement of openings, rather than consistently good catch rates throughout. These trends are probably accentuated for gleaning where conspicuous individuals are quickly removed, and subsequently more time must be spent locating and harvesting remaining cryptic individuals. Observations of stock depletion from other periodically-harvested closures in the Indo-Pacific region vary, due in part to differing opening and closure cycles. In Papua New Guinea for example, a one day harvest caused no significant impact on biomass (Cinner et al., 2005). Yet in Hawaii, declines in abundance of target-species indicated that the one to two year closure periods were too short for growth and reproduction to compensate for depletion during the one to two year-long openings (Williams et al., 2006). Where depletion of stocks during opening periods exceeds recovery, such as observed in Hawaii, periodically-harvested closures will not meet long term sustainability objectives. In situations where fishing can be intense, restrictions on frequency, duration and intensity of periodic harvests may be necessary to realise long-term fisheries goals.

Applying a range of regulations will increase the likelihood of positive fisheries outcomes from co-management (Gutierrez et al., 2011). The co-management arrangements within which the four periodically-harvested closures I studied were embedded, proposed a range of fisheries regulations (e.g., size limits, gear restrictions etc.) in management plans. Few of these were implemented and enforced in practice (Chapter 3). Similarly, the use of other fisheries regulations to complement periodically-harvested closures was infrequently reported in cases from across the Indo-Pacific (Chapter 2). In high fishing pressure contexts, and where harvesting is effectively unrestricted, depletion can be substantial when marine closures are opened to fishing (e.g., Kulbicki et al., 2007, Russ and Alcala, 2003). Additionally, periodically-harvested closures in the Indo-Pacific are often very small (Chapter 2); the areas I studied were all less than 0.1 km^2, and accounted for less than 5 percent of all reef area fished by nearby communities (Chapter 3). Even where periodically-harvested closures can improve fisheries within their boundaries, given escalating pressures from growing populations and developing markets, a diversity of strategies is required to effectively manage fisheries in the spaces between closures (McClanahan and Cinner, 2008, Foale et al., 2013).

4.4.2 Does the composition of catch vary from periodically-harvested closures?

Although frequently applied to manage multi-species fisheries, few studies have critically compared the outcomes of periodically-harvested closures for different taxa (Cinner et al., 2006, but see Bartlett et al., 2009a). I observed no significant differences in the familial composition of catches from continuously harvested reefs or from periodically-harvested reefs. To allow more generalised observations of responses to closure and fishing I also refer to categories of rebound potential, which are based on indices of vulnerability and resilience (Froese and Pauly, 2012, Cheung et al., 2005). These categorisations use life history and ecological characteristics to predict relative rates of decline or recovery from fishing. These measures do not however, capture the nuances of prior stock levels, habitat condition, ecological interactions or elements of fishing impact due to targeting certain species or sizes. Nonetheless, such measures have provided a useful basis for comparison between predicted and observed responses to pulse fishing (Russ and Alcala, 1998b) and periodic harvesting (Cinner et al., 2006); the results of which I will discuss in turn. In my study, the small amount of dissimilarity that did exist between catches from the two harvesting strategies was mainly driven by relatively higher counts of invertebrates or fish from families with intermediate or high rebound potential.

In the two periodically-harvested closures where there were sufficient data to study catch composition through time, strombids were somewhat more abundant in catches from newly opened areas compared to catches from open reefs. As harvesting continued, I observed a weak signal of catches becoming more similar to those from open reefs as the relative abundance of strombids in catches decreases (Figure 16). This further supports my observation that invertebrate gleaners profit most from increases of faster growing invertebrates, but that these benefits are reaped mainly in the early stages of the harvest.

While my observations of elevated catch rates provide some evidence that stocks of short lived, fast growing taxa can build during periods of closure, and therefore may be suited to management with periodically-harvested closures, other cases from across the Indo-Pacific demonstrate a variety of outcomes. Trochus have a high rebound potential, but were observed at relatively low abundance in a closure in Vanuatu, and were therefore considered to be vulnerable to the periodic harvesting strategy applied there (Bartlett et al., 2009a). In Solomon Islands, trochus catches had declined from historical levels and populations were relatively low where periodically-harvested closures were employed, and harvests were only minimally restricted (Foale, 1998b, Foale and Day, 1997). Whereas higher, sustained abundances of trochus in Cook Islands were attributed partly to management with a combination of scientifically informed size limits, quotas and harvesting cycles (Nash et al., 1995). There are also observations that periodic harvesting can benefit species vulnerable to exploitation (such as larger, longer-lived taxa) in circumstances where fishing pressure is low during harvest periods, or where total effort has been reduced because of the decreased opportunity to harvest. For example, in Vanuatu relatively higher abundance and biomass of tridacnid clams and fish with vulnerable life histories were observed inside periodically-harvested closures (Bartlett et al., 2009a), and in Papua New Guinea there were relatively higher abundances of families of long-lived fish with long population doubling times (Cinner et al., 2006). In some cases the preferential selection of a productive fishing ground for periodic closure may enhance the differences observed in abundance or catches between continuously-fished areas and periodically-harvested closures. Also, for species with home ranges that extend beyond the boundaries of the closure, or that have highly dispersing larvae, fishing practices, and migration and recruitment from outside, can be as influential on population changes in an area as the direct effects of closure and periodic harvesting - particularly when closures are small (Jennings, 2001, Russ and Alcala, 2003). Fisher and community expectations of what might be achieved for their fisheries by implementing periodic harvesting strategies should be tempered by the variability of these outcomes.

4.4.3 Are fish larger from periodically-harvested closures?

Reducing or temporarily removing fishing pressure in an area may enhance yield per recruit by permitting continued growth and accumulation of larger individuals (McCallum, 1988, Myers et al., 2000). I observed that finfish from periodically-harvested closures were slightly larger than those of the same species harvested from open reefs. *Lutjanus rufolineatus* was the only species that was significantly larger, yet had a relatively moderate (i.e., fourth highest) growth rate compared to the other seven species I analysed. This highlights that average fish size on any particular reef is not simply a function of growth rate, but is also influenced by historical fishing patterns (Dulvy et al., 2004). As most fishing methods are size selective towards large individuals (Jennings et al., 1999a), ceasing fishing in an area can change the size spectra of fish communities so that large fish are relatively more abundant. This effect was observed in Papua New Guinea where fish on reefs that had been harvested two to three times per year were larger on average than fish in continuously fished areas (Cinner et al., 2005). The periodically-harvested closures where fish were captured for my study, had been predominantly closed for 11 months of each of the three years prior to sampling (i.e., since management was implemented). Since implementation the areas had likely experienced low to moderate fishing pressure compared to open reefs (Chapter 3). Given these harvesting levels, the closure period may have been insufficient to lead to significant growth recovery of many fish species; extending the closure while maintaining the same levels of fishing pressure may allow for greater growth gains. Even slightly longer fish can benefit fishers substantially in terms of yield (e.g., *L. rufolineatus* taken from periodically-harvested closures were on average 40% heavier). In addition to the direct benefits of harvesting larger fish, there may also be secondary benefits (such as enhanced reproductive output) from the short term protection of larger fish, particularly when periods of closure are longer (e.g., Devlaming et al., 1982).

Across the Indo-Pacific, periodically-harvested closures are employed most commonly for trochus fisheries management (Chapter 2). Trochus is arguably the most important commercially harvested marine product contributing to livelihoods of rural communities in the Indo-Pacific (FAO, 2010), however there are concerns about overexploitation of stocks throughout the region (Nash, 1993). Periodically-harvested closures are perceived in some cases as a successful strategy for managing trochus fisheries due to observable recoveries during closure (Foale and Day, 1997), and a history of stable catches in some areas where the strategy is employed (Evans et al., 1997). As a fast growing, sedentary invertebrate, trochus would be expected to be suited to management by periodic harvesting strategies (Jennings et al., 1999b, Russ and Alcala, 1998b). However, if adult populations have been substantially depleted by periodic harvests, relatively long-term closures (2-3 years) may be required for cryptic juveniles to emerge and new recruits to settle (Nash, 1993, Lincoln-Smith et al., 2006). The prior-reported observations of high effort (Chapter 3), the decline in gleaning CPUE observed here, and anecdotal reports from fishers suggests that the pressure on trochus stocks during periodic harvests can be intense. When trochus fishing grounds are predominantly closed, harvesting intensity may be elevated as fishers take advantage of the window of opportunity to harvest this valuable commodity.

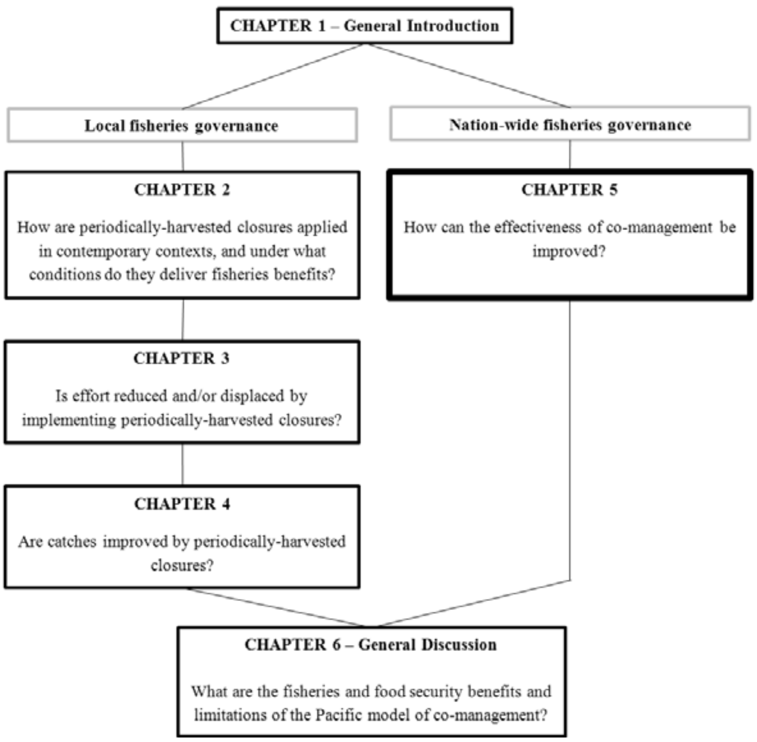
The significantly smaller trochus caught from periodically-harvested closures probably reflects the impacts of previous harvests, and removal of larger (legal) size classes. Although unlikely in wild populations and for relatively short closure periods, there is also evidence that at high stocking densities, trochus shell growth is inhibited (Amos and Purcell, 2003, Clarke et al., 2003). While the mechanism leading to small sized trochus requires further investigation, these harvests would have had negative implications in terms of benefits for fishers as small trochus yield less meat for human consumption, and small shells will fetch a lower market price (Richards et al., 1994). The combination of enforced size limits, harvest quotas and periodic harvesting strategies has been shown to vastly improve trochus yield over the long term (Foale and Day, 1997, Nash et al., 1995). This again reinforces that periodically-harvested closures may be more likely to achieve long-term fisheries objectives when restrictions on periodic harvests are concurrently applied.

4.5 Conclusion

Periodically-harvested closures are a socially acceptable and locally-implementable strategy, frequently employed in co-management models across the Indo-Pacific region. Although widely used as a management measure for multi-species fisheries, there have been few studies of their fisheries outcomes. I find that for multi-species fisheries, periodically-harvested closures may bolster catch rates of invertebrates, and lead to catches with slightly mean sizes for some species, thereby meeting with short-term community goals. Although effort during multi-species periodic harvests was much higher than for continuously fished reefs, conclusive evidence of short-term depletion was only found for invertebrate stocks, which are more likely than longer-lived fish to rebuild during closure periods. For long-term fisheries objectives, it is important to consider that in their current form, periodically-harvested closures in the Indo-Pacific; (1) may be applied in isolation to other effective resource-use regulations, (2) may only benefit taxa of high rebound potential, unless overall fishing pressure is substantially reduced, and (3) any benefits such as elevated catch rates or larger fish are realised only in a very small proportion of fishing grounds (even if spill-over and larval export were to occur). The variability and flexibility of cycles of harvesting and closure applied in practice provide a mechanism for management to adapt and account for changed ecological conditions. However, this flexibility may potentially leave fisheries vulnerable to high levels of depletion when demand for marine resources is high. Data-intense or prescriptive management measures are poorly suited to co-management in developing countries. However, there is a need to complement local ecological knowledge with appropriate forms of monitoring, and new knowledge generation to reassess, readjust and regulate periodic harvests. As demand for marine resources intensify, the application of complementary management measures in adjacent fishing grounds will become increasingly important.

Chapter 5 Social networks supporting governance of coastal ecosystems and small-scale fisheries

Chapters 2, 3 and 4 have shown the mixed outcomes of periodically-harvested closures for fisheries. While there may be benefits for fisheries targeting invertebrates, for managing the range of small-scale fisheries important in Solomon Islands, ecological factors contributing to recovery need to be considered to a greater degree in patterns of harvesting. More broadly than this, achieving nation-wide sustainable management of small-scale fisheries will require small-scale fisheries governance to be effective and widespread. Learning how to make co-management work better for small-scale fisheries can be supported by the generation and sharing of knowledge across institutional and geographic scales. Cross-scale connections can also strengthen local management efforts by enhancing local-level representation in higher scales of policy and planning. In Solomon Islands, a governance network of NGO, government agency and local community management actors, was established explicitly to strengthen and extend outcomes of LMMAs, and enhance representation of small-scale fishers and community managers. In Chapter 5 I employ quantitative social network analysis to examine patterns of collaborative and knowledge-exchange relationships among network members. I examine network structure alongside qualitative data to understand the potential of the network to facilitate co-ordination and learning among management actors, and for facilitating local-level representation. I discuss the implications of network structure and function for progressing the ultimate objective of widespread and effective co-management of small-scale fisheries and coastal ecosystems.



5.1 Introduction

In the face of increasing threats to biodiversity and pressures on natural resources, effectively governing coastal ecosystems is an urgent but challenging imperative, particularly for developing countries (Bellwood et al., 2004). Research and action in contemporary environmental governance are increasingly focused on connecting local environmental management (hereafter management) to higher scales of policy and planning and vice versa (Pressey and Bottrill, 2009, Berkes, 2009). This aims to improve the effectiveness of current management, and duplicate effective management in new areas; *strengthening* and *extending* outcomes. The challenge is achieving this in ways that avoid blue-print approaches or panacea (Ostrom et al., 2007).

Adaptive co-management is a governance framework, which can improve social and environmental management outcomes while retaining a flexible approach tailored to specific places and situations (Olsson et al., 2004). Adaptive co-management embodies the collaborative and cooperative functions of co-management, and the learning and adjustment characteristics of adaptive management (Armitage et al., 2008) (Table 1A). Gaps in our knowledge about management practices that can be accepted and led by local communities, while also delivering conservation and livelihood benefits, highlight that learning and sharing such lessons is integral to developing best practice for conservation (Knight et al., 2006). In contexts where human, technical and financial resources for management are scarce, adaptive co-management can promote collaboration and the sharing of these resources, and facilitate knowledge-exchange, learning and shared understandings, allowing coordination for more cost-effective management (Cochrane et al., 2011). Such approaches have wide appeal for managers, and forms of adaptive co-management of coastal ecosystems are proliferating in the developing world (Govan, 2009a, Weeks et al., 2010). However, managers are challenged to find practical ways to implement adaptive co-management to deliver greater than localised biodiversity conservation and fisheries management outcomes (Pajaro et al., 2010).

Governance networks are social networks that are explicitly formed to foster relations between different actors for collective purposes – in this study, coastal ecosystem governance (Newig et al., 2010). The resulting network forms a relatively stable (as opposed to spontaneous) institution for information transmission, learning and coordination (Newig et al., 2010). Networks of actors that cross geographical and administrative scales can be particularly important for *strengthening* and *extending* management outcomes (Lebel et al., 2005, Pressey and Bottrill, 2009). For example, local actors and localised actions may be better positioned to respond to ecological and social conditions at sites (Ernstson et al., 2010), but can also be linked to actors in other geographic areas or within national and inter-sectoral policy arenas, thereby facilitating access to new information and increasing their involvement in environmental policy (Olsson et al., 2004, Pajaro et al., 2010, Cudney-Bueno and Basurto, 2009).

Social network analysis (SNA) provides methods to systematically quantify: (1) relations between actors, and; (2) resultant network structures (Degenne and Forsé, 1999, Borgatti et al., 2009). In the context of environmental governance, characteristics of social network structure, relations and actors are linked in theory to governance processes and outcomes, including learning and coordination (e.g., Bodin and Crona, 2009, Sandström and Rova, 2010, Newig et al., 2010). Empirical work on social networks for environmental governance has considered the influence of emergent local networks (e.g. Cudney-Bueno and Basurto, 2009, Crona and Bodin, 2010) and the match between social networks and ecological processes at landscape levels (e.g. Ernstson et al., 2010). Few studies have analysed purpose-built governance networks for environmental management (Newig et al., 2010). This study is one of few to address governance networks for adaptive co-management (Marin and Berkes, 2010, Sandström and Rova, 2010). My focus on a developing country is particularly important; in this context diverse social-ecological systems necessitate context-sensitivity, and scarce financial and technical resources call for efficient, coordinated approaches to achieve management goals.

Using SNA, GIS and qualitative methods I examined the structure and function of two configurations of a governance network constructed explicitly to improve adaptive co-management of coastal ecosystems in Solomon Islands. The first configuration describes collaborative relationships among stakeholders in implementing management. The second configuration captures the knowledge-exchange relationships that facilitate learning among stakeholders and adaptation. Both collaboration and learning are critical to management coordination (Table 8).

I analyse the structural attributes of the resultant networks against those theorised to influence governance processes. I then analyse members' perceptions of the barriers to more effective collaboration, learning and coordination. I discuss the potential of the governance network to support adaptive co-management that *strengthens* governance by maintaining a flexible, responsive approach and *extends* management outcomes by connecting local actors in different areas, and actors across administrative scales.

Table 8 (A) Adaptive co-management framework; definitions, relevant relationships and outcomes (B) Questions used to determine SILMMA members' relationships of collaboration and knowledge exchange for adaptive co-management.

A	Co-management	Adaptive
Definition	Resource-users, government agencies, non-government organisations and research institutes share responsibility and authority, which can legitimize management processes, improve joint problem solving, and strengthen compliance (Berkes 2009; Bodin & Crona 2009)	Actors facilitate knowledge-sharing and learning about environmental change and how to address it effectively and legitimately, thereby making conservation and resource management more responsive to social and environmental feedback (Olsson *et al.* 2004).
Relationship	Collaboration human, technical and financial resources for the implementation of environmental management	Information and knowledge exchange significant information and knowledge about environmental management
Outcomes	Cooperation Co-ordination	Learning

B		
Interview Question	Which agencies do you collaborate with when implementing marine resource management and conservation?	From which agencies have you received new ideas and influential information regarding marine resource management and conservation?

5.2 Methods

5.2.1 Case Study

Solomon Islands' coastal ecosystems and small-scale fisheries are governed by the state through environment and fisheries legislation, but also to a large extent by communities who have customary marine tenure (Lane, 2006). Lack of capacity and difficulties resolving state and customary marine resource controls have limited the application of centralised management. The national fisheries agency now actively promotes adaptive co-management of coastal ecosystems. Communities and their partner agencies have established 137 co-managed areas or sites where governance arrangements and specific fisheries and coastal resource management rules are developed, implemented and tested.

The national fisheries agency coordinates a network of non-governmental organisations (NGOs), government agencies, and communities that engage directly in co-management - called the Solomon Islands Locally Managed Marine Area Network, henceforth SILMMA (MFMR, 2008). SILMMA was established in 2003 by the national fisheries agency with NGOs; it now operates with formal rules of membership such as fees and reporting requirements. Under SILMMA, members gather once or twice a year for meetings and workshops. They also share information via technical reports and informally (e.g., in-person, via email). SILMMA forms one of the most enduring institutions for promoting collaboration, learning and coordination amongst actors to improve coastal ecosystem governance (its explicit objectives). The adaptive co-management framework encompasses SILMMA members' emphasis on co-management, monitoring, and learning.

5.2.2 Network Structure

I pre-identified the ten agencies that were SILMMA members (SILMMA, 2009). I conducted 22 interviews with employees of those agencies who were selected according to their experience and knowledge (Supporting Information 1.1 and 1.2). To gather network data, I presented respondents with a table of agencies involved in coastal ecosystem governance in Solomon Islands, including the 9 other SILMMA members and 20 other agencies identified in pilot analysis (Supporting Information 1.3). Blank spaces allowed respondents to add agencies. The boundaries of the network were therefore delimited by the relationships SILMMA members identified to these 20 agencies and any added agencies, and I refer to all these agencies and SILMMA members as the 'extended network'. For analysis, agencies were categorized by their main 'scale' of operation and by agency 'type' (Table 9).

Table 9 Agencies identified as members of the SILMMA governance network and other non-member agencies (indicated by the number in brackets) implementing or supporting coastal ecosystem governance in Solomon Islands. * International NGOs and the university that are SILMMA members have national offices and programmes of work and are considered on the national scale for the purpose of analysis. † In total four community-based organisations were identified in my pilot analysis, however informal community groups involved in co-management are more numerous and represented by co-managed sites in this study.

	Type of agency				
Scale	Development agency	NGO	Government agency	University	Private enterprise
International	(2)	(6)	(4)	(7)	-
National*	-	4 (4)	2 (4)	1	(2)
Provincial	-	-	(9)	-	-
Local†	-	3 (1)	-	-	-

Respondents characterized relationships between their agency and each other agency in the list as either strong, weak or absent in response to two separate questions (Table 8B). In the collaboration network the relations represent flows of human, financial and technical resources for implementation of management. In the knowledge-exchange network, relations represent flows of significant information about management. In these networks, agency was used as the actor/node.

Using Ucinet version 6.288 (Borgatti et al., 2002) two centrality measures were calculated: (1) in-degree, which measures the number of relations running to an agency from other agencies, and; (2) betweenness which measures the number of shortest paths that run through an agency, representing the importance of an agency for connecting other agencies that would otherwise be disconnected or more distantly connected (Degenne and Forsé, 1999). To understand the relative density of strong relations, network analysis was run twice; dichotomising relations firstly to absent or present (weak and strong combined), and secondly to weak (weak and absent combined) or strong. I conducted bootstrap t-tests of in-degree centrality to compare the number of collaboration and knowledge-exchange relations between SILMMA members and to non-members (Hanneman & Riddle 2005). I ran bootstrap paired t-tests of network densities i.e., the number of existing relations divided by all possible relations (Degenne and Forsé, 1999), to determine differences in the density of collaboration and knowledge-exchange relations and between strong and weak relations. I used quadratic assignment procedure (Hanneman and Riddle, 2005) to correlate the presence of collaboration and knowledge-exchange relations among the same sets of agencies.

I mapped agency engagements onto co-managed (local level) sites using SILMMAs' database of 131 sites updated with a further six sites (Lipsett-Moore et al., 2010, S. Albert, pers.com.) (Figure 18). I did not map provincial government engagements with co-managed sites, but they are perceived to be very rare (A-M Schwarz, pers.com.).

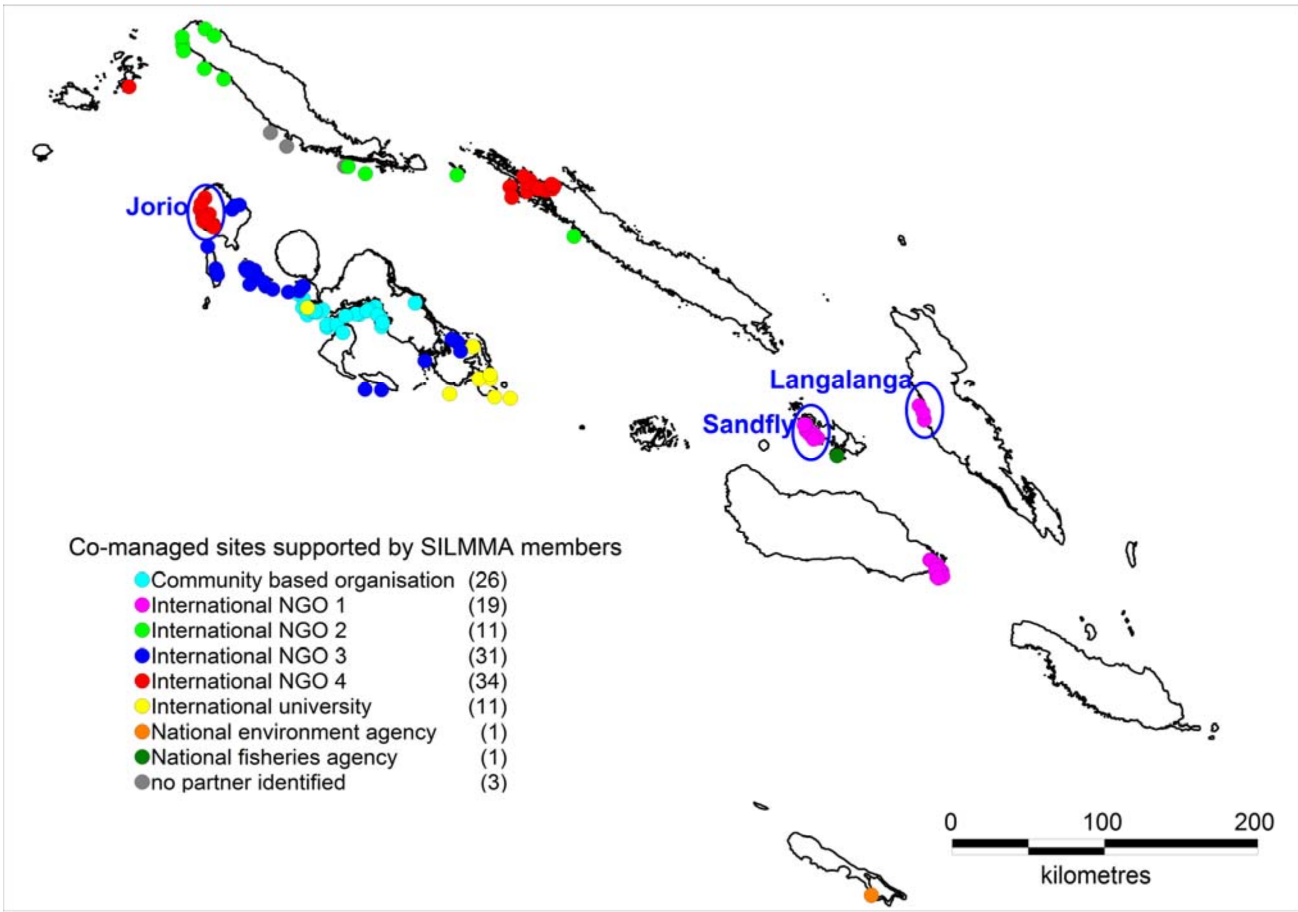


Figure 18 Sites with established co-management of coastal ecosystems (co-managed sites, N = 137) indicated by dots colour-coded by partner agencies. This map only illustrates one partner agencies per site, however 10% of sites are supported by two SILMMA members in collaboration. Co-managed sites where interviews were conducted are indicated by blue circles.

5.2.3 Network Function

To understand network function I collected qualitative information through interviews with SILMMA members and a focus group discussion at SILMMA's 2010 annual general meeting (Supplementary Methods 1.4). I asked respondents to reflect on the adequacies and barriers to inter-agency collaboration and knowledge-exchange. I also attended three SILMMA meetings (2009 – 2010) to gather information on coordinated activities.

Interview questions (see Appendix 4 – National social networking qualitative interview and Appendix 5) regarding learning focused on: (1) the importance of SILMMA for facilitating knowledge-exchange between agencies relative to other means, and; (2) the role of SILMMA in facilitating knowledge transfer across scales. Respondents ranked (1 = most used to 5 = least used) their use of five arenas for learning about successes or failures of co-management. These included learning: (1) within their own agency (a) nationally or (b) internationally; (2) with other agencies (a) nationally or (b) internationally, and; (3) learning-by-doing at sites. Respondents also categorised their usage (regularly rely on/sometimes use/unaware of/aware of but don't use) of ten information exchange strategies (e.g., SILMMA, routine meetings, email lists) and tools (e.g., databases) - identified in a pilot study. They similarly ranked modes of exchanging information with other SILMMA members: (a) workshops and meetings, (b) written reports, (c) informal personal communication, (d) scientific publications and (e) websites.

Finally, to understand the relations for knowledge-exchange and technical support between SILMMA members and co-managed sites from a 'site' perspective, I conducted key informant interviews at three sites (Figure 18) where informants identified the agencies that provided support for their co-management initiatives (see Appendix 6 – Social networking local partner interview)

5.3 Results

5.3.1 Network Structure

Bootstrap (R = 5 000) node level t-tests of in-degree show that SILMMA members collaborated and exchanged knowledge significantly more with other members than with non-members ($P = 0.0002$, $P = 0.0004$). However, in-degree measures of some non-member agencies were greater or equal to those of some members (Figure 19A and B, Table S1 in Appendix 7). The highest in-degree measures were attributed to the national fisheries and environment agencies for collaboration, and to the national fisheries agency and an international NGO for knowledge-exchange. In both network configurations betweenness measures indicated that the national fisheries agency was most important for connecting agencies that would otherwise be distantly connected or disconnected (Figure 19C and D, Table S1 in Appendix 7).

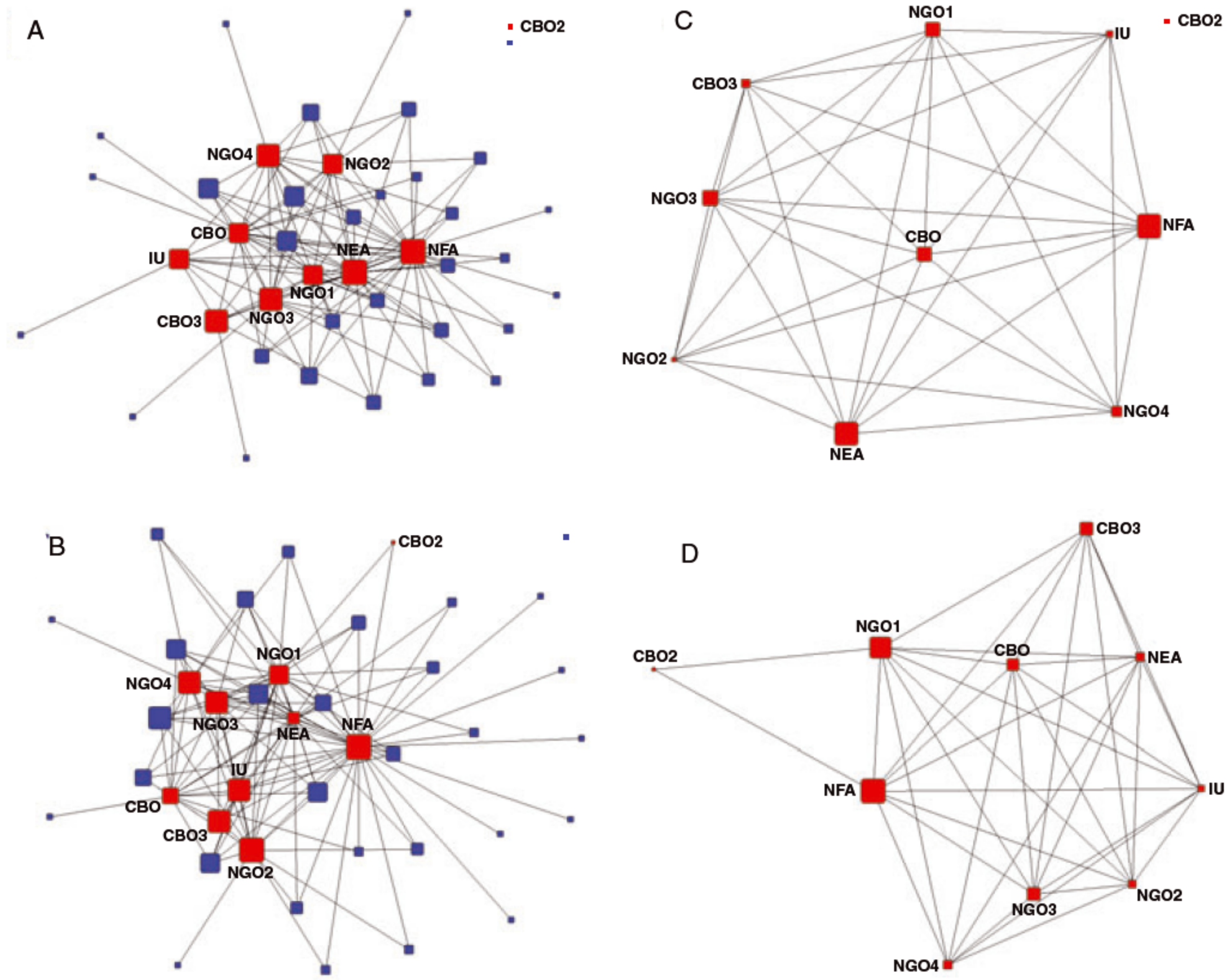


Figure 19 Network maps (drawn in Netdraw, Ucinet) based on multidimensional scaling (MDS) ordination, illustrating relations (represented by lines) between SILMMA members (represented by red boxes, N = 10) and other non-member agencies (blue boxes, N = 31) involved in coastal ecosystem management in Solomon Islands. The size of the box is scaled to the centrality measure and lines represent relationships. Agencies are labelled as community based organisation (CBO), international NGO (NGO), international university (IU), national fisheries agency (NFA) and national environment agency (NEA). (A) In-degree centrality based on collaborative relations. Respondents did not identify any relationships to one member and one non-member agency (B) In-degree centrality based on knowledge-exchange relations. Respondents did not identify any relationships to one non-member agency (C) Betweenness centrality based on collaborative relations. Respondents did not identify any relationships to one member agency (D) Betweenness centrality based on knowledge-exchange relations.

Despite slight differences in the distribution of relations in each configuration, bootstrap (R = 5 000) t-tests revealed that the density of collaboration versus knowledge-exchange relations within SILMMA and the extended network were not significantly different (SILMMA $P = 0.302$, extended network $P = 0.419$, Table 10Table 10). Where a collaborative relationship was present, a knowledge-exchange relationship was present in 81 percent of cases within SILMMA (simple match coefficient 0.811, $P = 0.001$) and 97 percent of cases in the extended network (simple match coefficient 0.965, P

= 0.001). Within SILMMA and the extended network the density of strong relations was significantly lower than weak relations for collaboration (SILMMA $P = 0.001$, extended network $P = 0.0014$) and knowledge-exchange (SILMMA $P = 0.0002$, extended network $P = 0.001$).

Table 10 Densities of collaborative and information exchange relations (weak and strong) within the SILMMA governance network and the extended network. Extended network densities are relatively low due to research design, that is, SILMMA non-members did not report their relations and there are, by design, no links between them, therefore formal versus extended network densities have not been compared.

	Density of weak relationships		Density of strong relationships	
	Collaboration	Information exchange	Collaboration	Information exchange
Formal network	0.6778	0.6444	0.3667	0.2778
Extended network	0.0960	0.0808	0.0349	0.0255

Most relationships were among SILMMA members operating at the national level (Figure 20A,Table 11) and then between SILMMA members and non-member international agencies (Figure 20C). There were fewer relationships between SILMMA members and provincial agencies (Figure 20B). The database of sites indicated that over 80 percent of co-managed sites were supported by one SILMMA member, 10 percent by two members in collaboration, and 10 percent by no partner agency. Certain regions had many co-managed sites, with agencies tending to have regions of focus (Figure 18, Figure 20A).

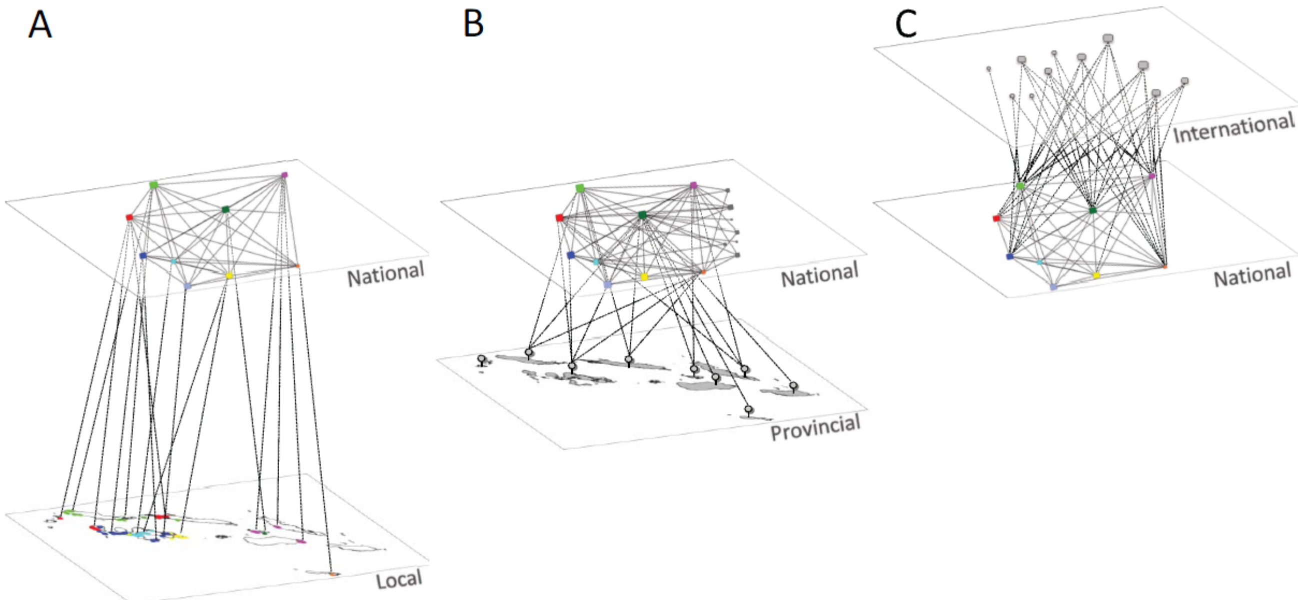


Figure 20 Cross scale social network for adaptive co-management of marine resources in Solomon Islands. SILMMA is depicted in the national layer where individual member agencies are represented by coloured squares; the size of square represents in-degree centrality. (A) All SILMMA members (*N* = 10) have direct relationships (indicated with a line to single sites or clusters of sites) with co-managed sites (depicted as coloured symbols on the local layer, *N* = 137). Agency colour corresponds with the colour of co-managed sites they provide support to. (B) Cross scale networking (determined through social network analysis) of agencies involved in supporting co-management. The national level depicts SILMMA members (coloured squares, *N* = 10) and non-member national agencies (grey squares, *N* = 8) and relations between them (solid black lines). The national and provincial layers depict relationships (dashed black lines) between SILMMA members and provincial agencies (grey circles situated within each province, *N* = 9). (C) The national and international layers depict relationships between SILMMA members and non-member international agencies (grey squares, *N* = 19).

Table 11 The proportion of relationships held by SILMMA governance network members with agencies operating within the national level and with agencies operating at provincial and international levels.

	Percentage (%) of relations of SILMMA members across scales	
	Collaboration	Information exchange
Formal network agencies	41	39
National non-member agencies	17	16
Provincial agencies	19	13
International agencies	22	27

5.3.2 Network function

The dominant arena for agencies to obtain information about co-management experiences was 'learning-by-doing' at their co-managed sites, followed by learning from within their own agency or with other agencies based in Solomon Islands (Figure 21). Face-to-face meetings and workshops were ranked the most important modes of information-exchange, and SILMMA was identified as the most important strategy for exchanging information between agencies: alternatives were largely unutilised (Figure 22). Yet, two thirds of interview respondents observed failures in collaboration and knowledge-exchange between agencies in general, and around half remarked that SILMMA was operating sub-optimally for facilitating learning and coordination. Focus groups identified a range of constraints to knowledge-exchange relationships and learning outcomes (Table 12).

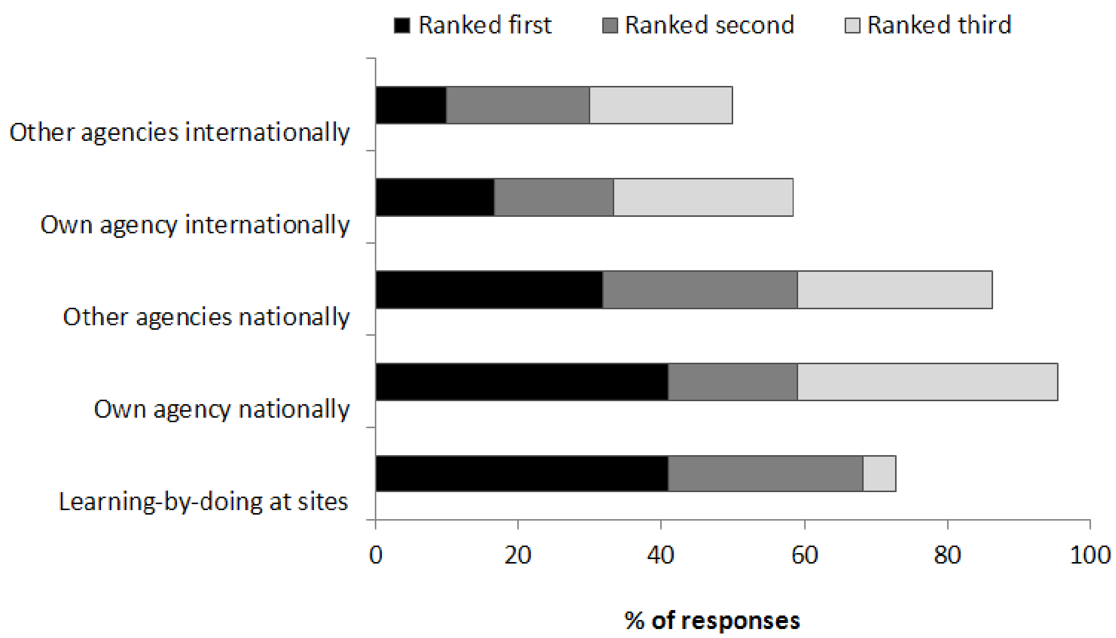


Figure 21 Top three rankings for arenas used for learning about factors of success or failure of co-management approaches.

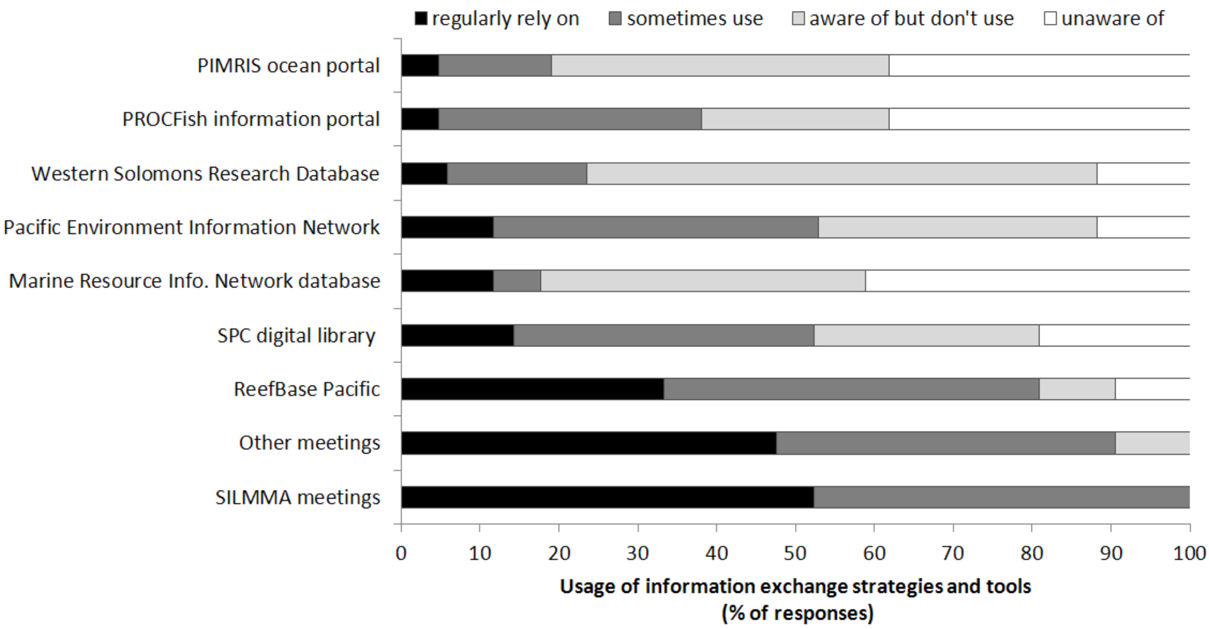


Figure 22 Figure 22 SILMMA members usage of strategies and tools for gaining information to facilitate learning and support for co-management initiatives.

Table 12 Constraints and barriers to establishing or strengthening information and knowledge exchange relationships, and constraints and barriers to learning outcomes, as identified by SILMMA members in a focus group at the 2010 SILMMA annual general meeting.

Constraints and barriers to information and knowledge exchange	Constraints and barriers to learning, i.e., applying new knowledge or adapting approaches based on information received
• A lack of trust between actors • Insufficient time • Intellectual property concerns • No clear common purpose for 'sharing' • Prioritization of personal or agency agendas • A lack of financial resources to bring people together from across the geographic expanse that members operate • Inadequate mechanisms and procedures for information sharing	• Agencies' commitments to donors • Agency mandates • Project design • Momentum with existing approaches or activities

Nevertheless, SILMMA members (90 % of respondents) believed that information shared between agencies involved in coastal ecosystem governance in Solomon Islands led to improvements in management applied at local levels. Several examples were provided of information from one agency influencing the approach of another, such as methods for engaging with provincial governments or employing the ecosystem approach to fisheries management. Over three quarters of key informants from co-managed sites (19 of 22) indicated that their partner agencies (a SILMMA member) were the exclusive channel for external information and technical support for co-management.

At SILMMA meetings members committed to a common strategic plan, produced a common resource-monitoring protocol, and started developing a plan to prioritise and schedule assistance to communities requesting support for co-management.

5.4 Discussion

My analysis of the SILMMA governance network revealed important insights into the relationships that have emerged for collaboration and knowledge-exchange between agencies involved in coastal ecosystem governance in Solomon Islands. First, most co-managed sites are partnered by agencies that are members of SILMMA, suggesting there is a pathway for local actors and issues to be represented at the national level. Second, SILMMA members themselves recognise the value of the governance network for facilitating flows of resources and information among agencies and between scales and sites. While learning-by-doing through co-management partnerships at sites was the most important learning arena in general, SILMMA members identified the governance network as the most important strategy for knowledge-exchange *between* agencies.

Within SILMMA, the national fisheries agency displayed the highest betweenness centrality demonstrating the importance of this agency, and its role as coordinator, for connecting different agencies and scales. However, in-degree measures indicated that this agency shared the position of most highly connected node with the national environment agency for collaboration and an international NGO for knowledge-exchange. This highlights that the governance network has evolved to some degree from its construct, which suggests that SILMMA is now somewhat less vulnerable to fragmentation if the connecting role of the national fisheries agency is lost or ineffective (Borgatti and Foster, 2003).

However, my analysis also showed a much broader social network of agencies influencing coastal ecosystem governance than formal membership of the governance network encompassed i.e., SILMMA members identified 31 other agencies as important partners for implementation and knowledge-exchange. Network density was highest amongst SILMMA members but in-degree measures indicated that certain non-members were as connected as some members. Membership requirements help constrain the size of governance networks, which is valuable for fostering strong relationships leading to trust and lower transaction costs of interaction (Pretty and Ward, 2001, Schneider et al., 2003, Newig et al., 2010). Yet, 'bridging' relations with non-members can facilitate access to new expertise, innovations and opportunities (Reed et al., 2009) and may become particularly valuable in contexts of uncertainty and change (Crona and Bodin, 2006, Olsson et al., 2006). Formal membership requirements force a trade-off between stronger relations among a restricted number of members and relations with a wider diversity of agencies; yet my data also indicated that spontaneous or historical relationships with non-members can still emerge or be maintained.

While network density was highest among SILMMA members, I observed a low density of strong ties, which illustrates this trade-off between investment in relationships and outcomes (Bodin and Crona, 2009, Newig et al., 2010, Sandström and Rova, 2010). Strong ties are said to emerge between individuals sharing similarities (McPherson et al., 2001) and it is feasible that certain similarities also lead to stronger relations between agencies, while others lead to competition. SILMMA members all supported localised co-management for coastal ecosystem governance, yet their mandates varied between biodiversity conservation and fisheries management; objectives that can be conflicting (Rice and Garcia, 2011). A high density of strong relations facilitates collective action and consensus (McPherson et al., 2001, Bodin and Crona, 2009), whereas heterogeneity can increase the capacity for innovation (Folke et al., 2005). Such trade-offs are inherent in network structure and function (Bodin et al., 2006) and there is unlikely to be an ideal network structure for governing complex systems (Vance-Borland and Holley, 2011). In my study, respondents identified factors such as geography and lack of trust, time and finances as constraints to developing new or stronger relations. These factors are inherent to multi-stakeholder approaches and may be constraints that are difficult to overcome in contexts of scarce technical and financial resources (Cochrane et al., 2011).

My analysis also examined the relationships of SILMMA members across geographical and administrative scales. Emerging management policies and literature highlight the importance of multi-scale integrated policy and action (Lebel et al., 2005, Pajaro et al., 2010), in particular the importance of mid-scale mangers or scale-crossing brokers (Ernstson et al., 2010). While Solomon Islands' provincial government agencies are situated as mid-scale managers and have been identified as the most appropriate unit to support decentralised and long-term environmental governance (Lane, 2006), I pinpointed a weakness in their connectivity to SILMMA. The relatively few relationships between provincial agencies and SILMMA members or local communities implied their low capacity to influence and participate in management. Improving their capacity and integration would be required for their potential role to be realised; this could be facilitated in-part through membership of SILMMA.

Local communities are connected to other geographical and administrative scales through direct partnerships with SILMMA members. The generation of knowledge via learning-by-doing through such partnerships is fundamental to successful adaptive co-management (Ostrom et al., 2007, Armitage et al., 2008). Place-specific learning can mean that knowledge generated and lessons learned are highly context-specific and cannot be generalised. Replication and isolation of learning may be exacerbated by agencies' regions of focus (Figure 18), a high preference for learning within one's own agency (Figure 21), and by weak or lacking relations between agencies. Therefore where information generated at local levels is more broadly relevant, strong knowledge-exchange relationships would be important to facilitate learning across agencies, scales or sites (Lebel et al., 2005, Bodin et al., 2006). A learning theme particularly relevant to this network would be improving understandings of factors of success and failure of periodically-harvested closures for improving fisheries; as 80 percent of sites described by interviewees employed the strategy as a management measure. However, the nine SILMMA members also act as scale-crossing brokers and provide the only functional pathway for local lessons to reach national and international forums. This presents a trade-off for SILMMA members, between investing in the transfer of knowledge that is valuable to higher scales or other sites, and ensuring sufficient time and resources are still available to support essential 'learning-by-doing' at local scales. Community groups at co-managed sites often rely on their partners' support for co-management activities and representation at higher scales, meaning SILMMA partners are in a powerful position to control flows of information and resources (Ratner et al., in review).

Coordinated approaches are emerging from collaboration and learning among agencies in Solomon Islands, which is critical to strengthening and expanding management outcomes (Berkes, 2009). Examples to-date include a commitment to a common strategic plan and the development of a shared monitoring protocol. However, members noted there is further potential and need for coordination, for example in scheduling assistance to new areas, which would be aided by strengthened relations between SILMMA members. Strengthening the role of the coordinator might promote a more centralised governance network to facilitate a higher degree of coordination.

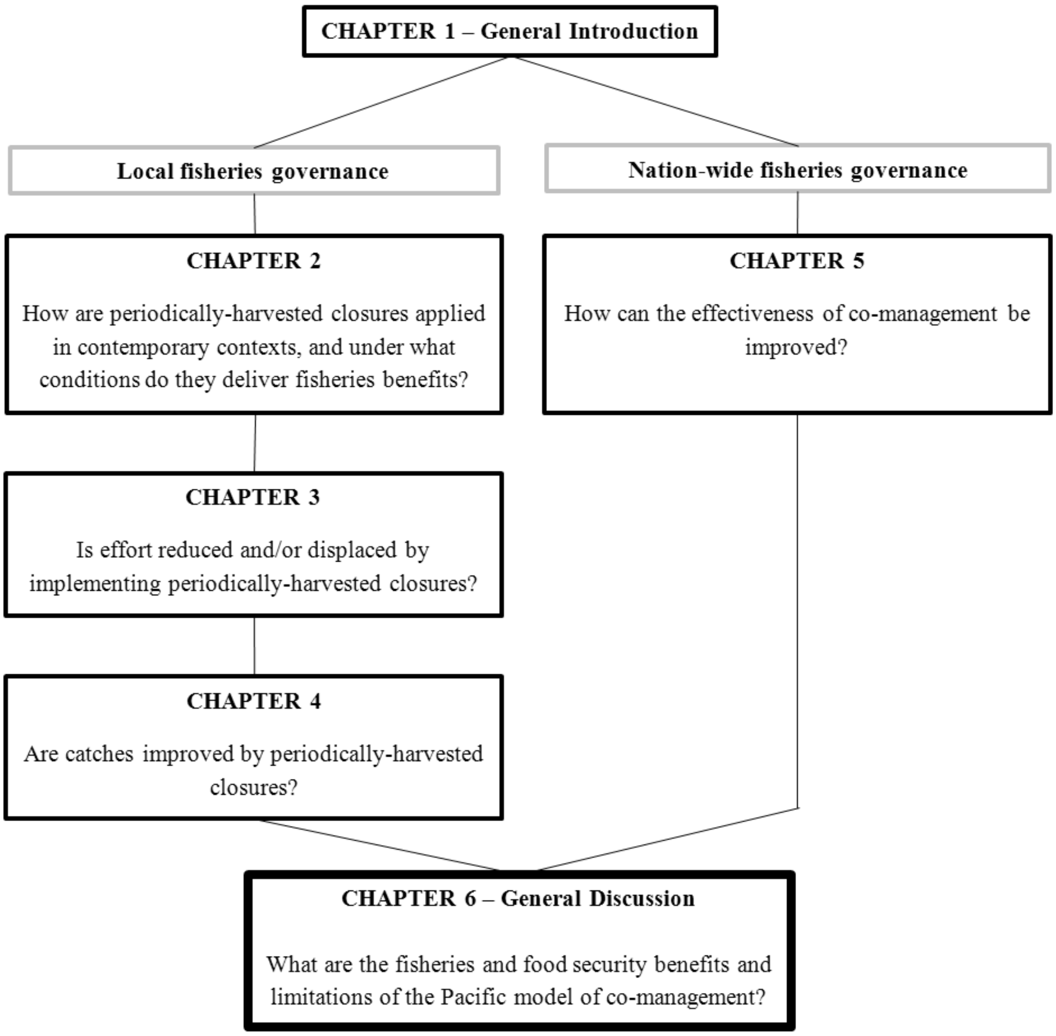
5.5 Conclusion

Governance networks can enhance collective action for management but are not a panacea, as highlighted by the benefits and trade-offs I identified. My findings indicate that partnerships between communities and NGOs remain central to co-management actions and continued learning-by-doing.

SILMMA members are in a powerful position as scale-crossing brokers; often the only pathway for local knowledge, interests and actions to be represented at other scales. The relationships among SILMMA members enhance coordination, whilst agency relationships to sites retain the ability for localised learning and context-appropriate action. Consequently SILMMA plays an important role as a bridging organisation by facilitating collaboration, learning and coordination among agencies that span local, national and international levels; functions that are critical to *strengthening* and *extending* management. Yet the barriers I identified present ongoing challenges to sustained or improved network function. In practice, efforts to form effective governance networks would benefit from reflexive, iterative approaches to learn what level of investment in networks is sustainable whilst delivering sufficient added value to adaptive co-management itself.

Chapter 6 General Discussion

In Chapter 6 I summarise the key findings of my thesis and discuss how my thesis contributes to the scientific basis for assessing co-management, and for understanding outcomes of co-management for small-scale fisheries and food security. I discuss the management and policy implications of these results for Solomon Islands, the Pacific region, and co-management in general. I also discuss limitations of this study, remaining knowledge gaps and directions for future research.



Chapter 6 General Discussion

6.1 Locally managed marine areas; small-scale fisheries outcomes

Managing small-scale fisheries effectively has presented a challenge globally, but this challenge is critical to address for the livelihoods and food security of millions of people worldwide (Béné et al., 2010). Co-management is now a mainstream approach to tackle the small-scale fisheries management challenge. It is therefore important that systematic and critical appraisals can demonstrate the benefits of co-management for fisheries and for food security, and determine the contexts in which these are achieved. However, to date research has largely failed to do so. Specific issues and gaps identified in reviewed literature include a lack of studies that provide bias-free assessments, provide appraisals of outcomes for fisheries and human well-being, investigate co-management in the Pacific region (Evans et al., 2011), demonstrate co-management benefits for multi-species fisheries (Gutierrez et al., 2011), and address issues of equitability of access and benefit distribution (Cinner et al., 2012). My thesis has directly responded to these research gaps, by answering the overarching question; can co-managed marine areas (termed LMMAs in the Pacific) contribute to small-scale fisheries sustainability, and future long-term food security?

Customary institutions of many societies, particularly in the Pacific, have been regarded as having a resource management function (Colding and Folke, 2001, Johannes, 1978, Ruddle, 1998). The use of customary institutions (such as seasonal or species taboos) in contemporary co-management is widely advocated (Ruddle, 1998, Govan, 2009a). However, the robustness and fisheries performance of customary institutions in contemporary contexts is not assured simply due to their continued use by some societies (Foale et al., 2011, Ruddle, 1994, Polunin, 1984). Therefore contemporary applications of customary institutions are worthy of investigation, and in particular research on area taboos, or periodically-harvested closures is needed given their importance in the Indo-Pacific model of co-management. However, studies from across the Indo-Pacific have often failed to fully described the ways in which periodically-harvested closures are being applied, and evidence of fisheries benefits is scant and far from conclusive (Chapter 2).

The review presented in Chapter 2, illustrated that periodically-harvested closures are commonly employed for trochus specifically (i.e., eight out of eighteen cases), but also for restricting multiple methods and managing multiple species in many cases (e.g., Williams et al., 2006, Cinner et al., 2006). Restrictions on amounts harvested were reported in only one case (Nash et al., 1995), and the concurrent use of other restrictions on periodic harvests, or the application of fisheries regulations in broader fishing grounds, were infrequently reported. Openings of periodically-harvested closures were reportedly driven by economic and social needs, but only rarely by ecological assessments or indicators (i.e., in only two of eighteen cases). Some cases supported hypotheses that periodic harvesting strategies are beneficial for the management of short-lived and fast-growing taxa (e.g. Evans et al., 1997). However stock declines for long-lived taxa, or for a range of taxa when harvesting was intense, were also observed (e.g. Williams et al., 2006). The overarching questions unanswered by these studies were; can periodically-harvested closures (a) control or reduce fishing effort, and (b) maintain or improve catch rates and yields? The specific information gaps highlighted by the review, and hypotheses proposed by authors, provided a framework for the analyses presented in Chapters 3 and 4.

The intensity of harvesting during area openings, and the overall relief from fishing pressure during closures are key factors influencing management outcomes from periodically-harvested closures (Russ and Alcala, 1996, Game et al., 2009, Kaplan et al., 2010). Due to short periods of closure relative to fishing intensity during openings, it was postulated that customary periodically-harvested closures may not achieve resource management or conservation outcomes (Carrier, 1987, Polunin, 1984). Despite this long standing hypothesis, and the fact that controlling effort is a critical determinant of fisheries success, the literature review presented in Chapter 2 found no detailed attempts to quantify fishing effort overall, or during openings of customary or contemporary closures. Similarly, there were few systematic descriptions of the cycles of closure and opening, and the social, economic and ecological factors that influenced those cycles. Chapter 3 addressed these gaps.

In Chapter 3 I found that total yield from periodically-harvested closures was low to moderate compared to reefs continuously open to fishing, and that many reefs (whether continuously open or periodically harvested) were harvested within sustainable limits proposed in the literature (Newton et al., 2007, Jennings and Polunin, 1995). In the cases I examined, these sustainable levels of harvesting are partly explained by relatively low population densities (Foale et al., 2011) and reasonable distances to markets (Brewer et al., 2009). The duration and frequency of openings of the four periodically-harvested closures was highly variable. In all cases decisions to harvest were made at the community level, and were generally based on elevated social or economic needs; supporting the findings of others (Foale, 1998b, Bartlett et al., 2009a, Cinner et al., 2005, Thorburn, 2000). I found no substantial evidence of ecological factors influencing decisions (cf. Nash et al., 1995, Cinner et al., 2006), although one NGO partner had intended results from monitoring to be factored into the decision-making processes. Results in Chapter 3 supported observations of other studies, that 'pulse-fishing' can be intense when areas are opened as fishers anticipate improved catch rates, or demand and needs are high (Russ and Alcala, 1998b, Murawski et al., 2005, Jupiter et al., 2012). However when total effort was examined across a full year, I found it to be low to moderate in periodically-harvested closures compared to continuously open reefs, and probably lower than expected for reefs so close to villages. This result suggests that in practice, periodically-harvested closures can reduce overall effort applied to an area (Botsford et al., 1993). This then lends support to the hypothesis that positive fisheries benefits observed in periodically-harvested closures elsewhere may be attributable to overall reduced effort due to the decreased opportunity to harvest (Cinner et al., 2006, Kaplan et al., 2010).

Periodic harvesting is likely to be a more suitable long-term management strategy for short-lived, fast-growing, sedentary and sessile taxa than for those that are longer lived, slower growing or with home ranges extending beyond the boundaries of the closure (Jennings et al., 1999b, Russ and Alcala, 1998b). The effectiveness of periodically-harvested closures as a management strategy for fish, or for multi-species fisheries, emerged from Chapter 2 as being particularly poorly understood. The differential impacts of periodic harvesting on species targetted by multi-species and multi-gear fisheries have been examined in a few cases (e.g., Cinner et al., 2006, Bartlett et al., 2009a, Williams et al., 2006), but warrant investigation in a range of management and ecological scenarios representative of the Pacific. In Chapter 4 I found that catch composition did not vary significantly between open reefs and periodically-harvested closures. I did find however, that the small amount of dissimilarity that did exist between catches from periodically-harvested closures and open reefs was driven by relatively higher abundances of families with intermediate and high rebound potential. While taxonomic differences in catch were not overt in these cases, in general it would be expected that when periodically-harvested closures are employed for multi-species fisheries, the closure-harvesting cycle, and the fishing pressure during openings may result in sustainable patterns exploitation of some taxa, but may lead to the depletion of others. To account for these differences, the concurrent use of harvesting restrictions, such as the ban on the slow-growing and fisheries-susceptible tridacnid clams (reported in Chapter 3), will likely be useful, or even necessary for sustainabiilty.

Alongside objectives of long term sustainabilty, Chapter 2 highlighted that community goals of implementing periodically-harvested closures also include increasing the efficiency of harvests via biomass gains and/or behavioural changes of fish (i.e., where species are harvested by spear) (Feary et al., 2011, Cinner et al., 2006). While some authors have argued that these objectives can be met (Cinner et al., 2006), there are few studies that have tested the impact of periodic harvesting strategies on catch rates. In Chapter 4 I found that catch rates (i.e., CPUE) for invertebrate gleaning were higher than gleaning CPUE on open reefs. Yet benefits of the strategy for spear and line fisheries were not demonstrated in elevated catch rates, but marginal benefits were evident as fish were slightly larger than those caught from open reefs. I found however, that trochus were significantly smaller from periodically-harvested closures, perhaps due to the impacts of previous, relatively intense harvests. The higher catch rates I observed for gleaning may have been attributable to a build-up of biomass due to reproduction and growth since the cessation of fishing, the emergence of cryptic juveniles (as in the case of trochus) and/or due to the overall lower fishing effort imposed on the area since the implementation of the periodic harvesting strategy. I did not find quantitative evidence of significant fisheries depletion indicated declines in CPUE through the opening period for line and spear fishing. However for gleaning, CPUE was significantly higher in the early stages of the periodic harvest compared to open reefs, but not at the end. Alongside reports from fishers, and declines in effort (particularly for gleaning) this evidence led me to conclude that the localised depletion of some invertebrate species was substantial. It was not possible from these results to determine if depletion was greater than biomass gains during the closure, as was the case in Hawaii (Williams et al., 2006). However, understanding depletion compared to recovery is clearly important for future, longer term studies to address.

At the commencement of my research I intended to investigate co-management arrangements, and periodically-harvested closures, in three regions: Central Province, Western Province and in Malaita. Initial information provided by partner NGOs suggested that management was active in all three regions; however a field trip to Malaita revealed that resource management was largely absent, and periodically-harvested closures were no longer implemented. The interviews and observations I conducted in Malaita provided a critical insight into challenges faced in managing small-scale fisheries via co-management. Resources in the research location in Malaita are heavily depleted, due partly to relatively high population densities on the coast and market pressures (Foale et al., 2011), alongside the historically prevalent use of explosives for fishing (Green et al., 2006). In an attempt to address resource declines, the Foundation for Peoples of the South Pacific International supported three communities to establish three area closures and a committee to manage the areas. After less than a year however, in an infringement of the closures, the areas were dynamited and fish harvested. Since that time the closures have not been re-established, the committee reportedly disbanded, and attempts to manage fisheries through local level regulations have been abandoned. These results highlight that co-management is not a panacea (Ostrom et al., 1999), and is not feasible in all situations or locations, in part due to a lack of social capital, and also due to the lack of alternate productive fishing grounds and livelihood opportunities (Bell et al., 2006). My findings at Malaita highlight that strategies alternative to co-management and periodically-harvested closures will be necessary to address small-scale fisheries management in certain circumstances.

To meet objectives, managers and co-management structures must accommodate the differing and dynamic social and ecological contexts that characterise small-scale fisheries (Ostrom, 2007). Designing and implementing management for complex and dynamic fisheries systems is challenging, and a single agency is unlikely to have sufficient capacity or knowledge to address this challenge alone (Berkes, 2009). Additionally, it is increasingly recognised that effective co-management is promoted by management being *adaptive*. Adaptive management relies upon learning and knowledge development that guides alterations to management to suit different situations or changing conditions (Armitage, 2007). Adaptive co-management therefore refers to flexible resource management tailored to specific places and situations with significant participation of resource users and various organizations at different levels (Olsson et al., 2004). Learning how to make co-management work, and implementing co-management for small-scale fisheries, is therefore supported by relationships amongst a range of actors. In many parts of the world, marine resource management actions and outcomes have been restricted to the local scale, realising only localised impacts. The failure to achieve more widespread or greater impacts has been reinforced by a lack of effective cross-scale networking (Pajaro et al., 2010). In theory, cross-scale networks (i.e., linking actors across geographical and administrative scales) can be particularly important for learning, and for strengthening and extending management outcomes (Lebel et al., 2005, Pressey and Bottrill, 2009, Newig et al., 2010). Perhaps unsurprisingly, there are some serious challenges in putting this theory into practice. To date, there are only limited lessons on ways to improve inter-agency knowledge generation, learning and cooperation in practice (Berkes, 2009).

The governance network (i.e., SILMMA) that was examined in Chapter 5 was explicitly established to facilitate learning between sites and agencies engaged in co-management in Solomon Islands. The qualitative results from my research demonstrated that the network provided the primary means for knowledge-exchange between agencies, and was important for building knowledge about best practice for co-management. However, I identified geographic, logistical and institutional barriers to multi-actor and inter-site learning which present obstacles to improving the effectiveness of current co-management practices, and to facilitating the 'roll-out' of the co-management model to new areas. Additionally, policies and planning for decentralised management in Solomon Islands identify provincial governments as a primary vehicle for mid-scale management (Lane, 2006, Govan et al., 2011). However quantitative social network analysis in Chapter 5 highlighted that these actors are poorly connected, and investment in relationships and capacity would be necessary to foster their role in supporting co-management into the future.

Effective co-management will also require strengthening capacity and representation of historically marginalised resource users in decision-making and knowledge generation (Bell et al., 2006, Ratner et al., in review). Chapter 5 highlighted that the SILMMA network members were the only functional pathway for cross-scale knowledge-exchange and higher-level representation of local fisheries issues. However, significant obstacles remain to enhance the direct representation of local stakeholders in higher levels of governance. For example, local level participants in the governance network were often reliant on their NGO partner for support for management activities, and for direct engagement in the governance network (e.g., travel to meetings and workshops from remote places). Therefore, mechanisms are needed to ensure that local representatives are adequately autonomous, and that community interests are not subordinated to partner agendas (Ratner et al., in review). While there are ongoing challenges to improving representation, the governance network examined in Chapter 5 provides an important mechanism by which local fisheries or food security concerns can be represented in national and international spheres.

While inclusive and participatory co-management processes are commonly reported to lead to positive outcomes for governance, and community and resource user empowerment (Evans et al., 2011, Cox et al., 2010), culture and power relationships can mean that participatory processes can fail in achieving equitable representation of all those affected by management (Eder, 2005, Béné et al., 2009). The case of elite capture, discussed in Chapter 3, highlights that although there is local-level engagement in co-management, partner agencies must be careful that processes support the opportunity for all sectors of communities to be fairly represented at local and higher scales (Béné et al., 2009, Ratner et al., in review). In the Pacific context the views of women, youth and those with no local tenure rights (e.g., migrants) are often overlooked due to cultural conditions (Vunisea, 2008). Additionally, the representation of local levels in higher levels of governance via the network studied in Chapter 5, can also potentially be subverted by local power dynamics, which is an important consideration when seeking adequate and fair representation (Ratner et al., in review). The challenge of navigating culture and local power relationships, while pursing inclusive and participatory processes, remains a challenge for co-management initiatives (Eder, 2005, Foale et al., 2013). While co-management can provide an opportunity to build local capacity and empower fishers to influence management decisions, the equability of representation can ultimately be affected by processes of engagement and participation, and this should therefore be a concern to government or NGO partners facilitating these processes.

6.2 Locally managed marine areas; food security implications

Globally, many small-scale tropical fisheries are fully or over-exploited (Newton et al., 2007), and continued failures in management could lead to further resource decline and food security deficit (Garcia and Rosenberg, 2010). The projection that coastal fisheries will fall sort of demand in many Pacific Islands countries by 2030, highlights the importance of managing fisheries to minimise the gap between production and need (Bell et al., 2009). This projection also draws attention to the need to concurrently develop strategies for nutritional and employment alternatives. Co-management is a leading strategy to address small-scale fisheries management, and a preferred approach (i.e., in preference to centralised, commercialised or wealth-based management models) for protecting the welfare functions of fisheries, including for food security (Allison, 2011). However few studies to date have explored the benefits and limitations of co-management for food security objectives, particularly in the Pacific.

Food security is a critical concern in developing countries, and alongside sustainable fisheries management, can also be an important objective of co-management (Allison, 2011, Pomeroy, 1995). Fisheries can contribute to food security indirectly via income, licence fees and taxes that can increase individual to national level purchasing power to buy food. But, the direct contribution of fisheries to food security through animal protein, essential fatty acids and micronutrients, is particularly important in developing country contexts where redistribution of wealth, distribution of food, and sourcing alternatives with equivalent nutrition can be problematic (Kawarazuka and Bene, 2010). The results of my thesis have implications for each of the three food security pillars; availability, access and consumption (World Health Organisation, 2010) (Figure 23). In terms of the consumption pillar, small-scale fisheries provide an important source of micronutrients to coastal populations, and in many regions may provide the primary source of protein where alternatives may be difficult to access or are not preferred (Bell et al., 2009, Kawarazuka and Bene, 2010). In the communities I studied, household surveys (Appendix 8 - Household survey) indicated that most households participated in fishing, fishing was the second (to agriculture) most identified source of income, most meat consumed was fish or shellfish, and other forms of meat were rarely eaten. These high consumption rates are fairly typical of rural coastal communities across the Pacific, although consumption patterns, and the nutritional importance of fish can vary between ages, genders and geographic areas (Solomon Islands National Statistics Office et al., 2009). While small-scale fisheries do not contribute hugely to national gross domestic product in many countries, it is nevertheless vital to invest in improved management to support this welfare function. It is also one of the reasons why local management approaches that involve communities in decision-making (such as co-management) are necessary and appropriate. The *consumption* pillar relies on both *availability* of, and *access* to, sufficient fish to meet nutritional needs.

The availability pillar is addressed if there are consistent and sufficient quantities of food. This direct relationship is particularly strong in rural and remote areas, where globalisation and markets may have minimal effect - meaning there is a relatively tight link between sites of production and consumption (York and Gossard, 2004). In terms of fisheries, *availability* then refers to there being enough fish and invertebrates in accessible fishing grounds to meet dietary needs. In coastal areas the availability of marine resources is supported by sustainable fisheries practices. My thesis suggests that periodically-harvested closures can, in some cases, help to maintain or enhance the availability of stocks; by potentially reducing overall effort applied to an area, without leading to displacement of effort to other areas (Chapter 3), and by leading to elevated catch rates and larger fish (Chapter 4).

Closures appeared to effectively act as a 'bank in the water' by stock piling resources for when needs were high (Chapter 3).

Yet, the flexibility to harvest and lack of concurrent fisheries regulations (discussed in Chapter 2 and 3), may mean that gains in growth and abundance during closures are insufficient to meet ongoing, or growing, needs and demands. In Solomon Islands, and more broadly in the Pacific region, fishing pressure and depletion of fish stocks are anticipated to increase due to growing populations, improved market connections and economic development (Foale et al., 2013, Bell et al., 2009). As such, the ability of periodically-harvested closures to maintain sustainable yields in the long-term and in high fishing pressure situations, is worthy of further study. The lack of concurrent fisheries regulations implemented in continuously-open fishing grounds (Chapter 2 and 3), suggests that as fishing pressure intensifies, periodically-harvested closures could (at most) provide very small refuges from fishing effort and resource depletion. The importance of embedding periodically-harvested closures within functional co-management frameworks that employ a range of restrictions (discussed in Chapter 2, 3 and 4), and the need for co-management to be part of a larger scale network or management system (Chapter 5), again becomes clear here. Importantly, other fishing zones, such as pelagic areas, can also make an important contribution to quantities of food in rural areas. For example, in the communities where I conducted my research, although fishing trips to pelagic zones were proportionally low, the small pelagic Skip jack tuna (*Katsuwonus pelamis*) was in fact the most frequently caught fish. The ability of fishers to increase their use of pelagic zones (e.g., with Fish Aggregating Devices SPC, 2012, Bell et al., 2011), particularly where coastal areas become over-exploited, and the role of small-scale pelagic fisheries in food security, is also worthy of further study.

Access, or the capacity to obtain sufficient foods, is also a critical aspect of food security. On a global scale it is posited that there are sufficient quantities of food (availability pillar) to meet dietary needs (consumption pillar), but it is most often problems with access that result in food insecurity (Sen, 1983). On a global or national scale, logistical failures in distribution, lack of economic capacity and social and economic inequalities can restrict access to food. These challenges can be somewhat avoided in subsistence settings where there is a tight link between production and consumption, such as in Papua New Guinea and Solomon Islands where coastal populations are proximate to productive fishing grounds. However, within the local scale or within a particular community, several factors (some discussed below) can also influence access to fisheries resources.

In many developing countries, and those within the Coral Triangle region in particular, there is global attention and effort to conserve reef-associated biodiversity, alongside progressing human development goals (CTI Secretariat, 2009). Addressing food security and preventing biodiversity loss represents one of the greatest contemporary challenges facing marine resource managers and policy makers (United Nations Department of Economic and Social Affairs, 2010, Rice and Garcia, 2011). As coral reefs support exceptionally high levels of biodiversity (Roberts et al., 2002), and the majority of reefs are located in developing countries where they are relied on by small-scale fishers (Donner and Potere, 2007), progress towards food security and biodiversity conservation objectives is often sought in the same places. For example, in Papua New Guinea and Solomon Islands where coastal resource reliance through small-scale fisheries is high, human development is low and biodiversity is globally recognised as exceptional but threatened (CTI Secretariat, 2009), the synergies and conflicts between food security, economic development and biodiversity conservation come into sharp focus (Foale et al., 2013). Permanent no-take marine reserves are commonly promoted and used to conserve biodiversity and manage fisheries resources (Roberts et al., 2001a). Yet the assumption that marine reserves can contribute to both biodiversity conservation, and food security from fisheries, is problematic (Foale et al., 2013). Where alternative sources of income and nutritional equivalents of fish are limited, permanent closures are not always a suitable option, due to the (at least initial) cost incurred from lost access to resources (Foale and Manele, 2004, Christie, 2004). Across the Pacific, for cultural and access retention reasons, the use of locally managed periodically-harvested closures is preferred (Chapter 2) (Foale and Manele, 2004).

The process of establishing management via locally managed marine areas in general, or periodically-harvested closures in particular, can reinforce claims to tenure rights and provides a mechanism by which to restrict access (e.g., Fabinyi, 2008, Govan, 2009a). The ability to restrict access is a foundation of effective resource governance (Ostrom, 1990). In Chapter 3 I showed that periodically-harvested closures can restrict access to selected areas for a majority of the time (i.e., they are predominantly closed). Fishers, in my case studies, suffered only a minor loss of access to fisheries resources due to the small size of closures relative to other available fishing grounds. At the community scale, the loss of access to closed fishing grounds did not result in a detectable shift in fishing effort to other locations (Chapter 3). However within communities, certain sectors of society or individuals may have been differentially affected due to their previous resource-use patterns overlapping with the fishing ground selected for closure. For example, in one of four cases the periodically-harvested closure had previously been accessible to all fishers in adjacent communities, and since establishment of the closure, harvests were controlled by the Chief. This can be regarded as a case of ‘elite capture’, where direct benefits from harvesting accrued mainly to that Chief and his family. The risk of elite capture, and disparate distribution of benefits (Cinner et al., 2012) or disadvantages (Béné et al., 2009) between certain sectors of society has been demonstrated in the global co-management and anthropology literature (e.g., Eder, 2005, Fabinyi et al., 2010). As competition for resources intensifies, equitable distribution of co-management impacts and benefits need to become a central consideration in resource management policy and action.

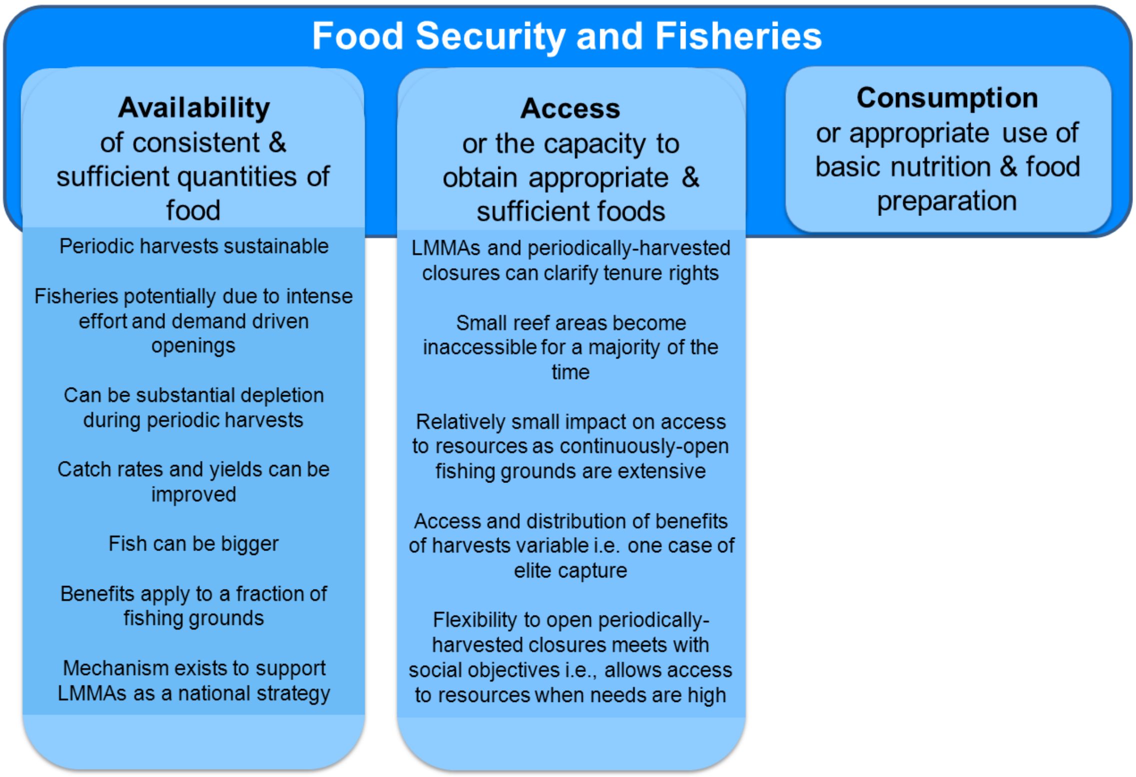


Figure 23 The implications of LMMAs and periodically-harvested closures for food security

6.3 General Conclusions

In Chapter 3 and 4, I found that in coastal areas that were reported to be managed via LMMAs, only a small proportion of fishing grounds were influenced by any management measures at all. Periodically-harvested closures were the dominant, or even arguably the only form of regulation implemented via co-management in these cases. A review of literature (Chapter 2) suggested that across the Indo-Pacific periodically-harvested closures were frequently implemented in isolation to other management measures. The fisheries benefits of the periodically-harvested closures I examined were limited to improved catch rates for gleaning, and slightly larger finfish. The flexibility with which periodically-harvested closures are harvested is important for the access pillar of food security but has implications for the availability pillar – because a socially and economically driven harvesting cycle may not give certain taxa or habitats sufficient time to recover from previous harvests. To meet longer term fisheries and food security goals, management of periodically-harvested closures must address this balance between social, economic and ecological factors, and consider all these in management decisions. Developing knowledge about how best to employ periodically-harvested closures is an important task to tackle, my thesis has highlighted that they not a panacea.

Successful long-term fisheries management will require periodically-harvested closures to be embedded within functional co-management frameworks in which a diversity of context specific, socially acceptable and fisheries appropriate regulations are implemented and adapted (Gutierrez et al., 2011). This presents an ongoing challenge to community managers and their support agencies. Cross-scale institutional and knowledge exchange linkages, via partnerships with NGOs or government agencies (Chapter 5), can guide and bolster local management institutions to address this challenge in the face of escalating pressures. However, planning and policies that support co-management as a national strategy for small-scale fisheries, must recognise and address the geographic, logistical and institutional barriers identified in Chapter 5, to advance the ultimate objective of widespread and effective co-management.

While co-management may strengthen and expand effective management of small-scale fisheries, the approach is ultimately limited. In some rural areas non-compliance with co-management rules, perhaps due to a lack of social capital, and poor opportunities for alternative food and livelihood strategies, presents potentially insurmountable challenges to co-management approaches. Similarly, in urban and peri-urban areas where economic pressures and incentives of increasingly cash-based economies are high, customary tenure regimes have broken down, and social capital is potentially compromised, co-management will be more difficult. Further, environmental stressors such as pollution or climate change cannot be addressed substantially by local co-management efforts. Urbanisation, globalisation, developing markets and climate change place pressures on resources, and on resource users, that may be difficult to deal with using only localised management approaches (Hall, 2011, Gillett and Cartwright, 2010). While local-level experiences of these stressors may be better represented at higher levels thanks to structures and relationships facilitated by co-management (e.g., the SILMMA governance network studied in chapter 5), ultimately these issues require the attention of higher levels of governance.

Finally, projections suggest that with current consumption patterns, coastal fisheries will not meet the needs of many Pacific populations in 2030, even if near-shore small-scale fisheries are well managed (Bell et al., 2009). Improving management of small-scale fisheries can help to minimize this deficit in the Pacific, and more globally (Garcia and Rosenberg, 2010). While the establishment of 137 LMMAs in Solomon Islands represents a substantial advance in managing coastal ecosystems and small-scale fisheries, these areas account for only a very small proportion of coastal waters, human populations and small-scale fishing activities; mechanisms to expand and improve management are critical. To address food security in the longer term, co-management actions and policies must also be aligned with alternative strategies for protein and micro-nutrient production and distribution (e.g., aquaculture development is a hopeful but extremely challenging pathway). To address the small-scale fisheries management challenge, co-management must be strengthened and extended, but the limitations of the approach must also be explicitly acknowledged and addressed in broader policy and action.

6.4 Limitations and future directions

This study uses Solomon Islands as a broad case study, with three local case studies. As I used a case study approach there are limitations to conclusions that I can draw for LMMAs or co-management models in general. This thesis has however highlighted the variability in management models applied between cases, and that outcomes are also variable. In fact, this is a key finding. The range of social and ecological contexts in which periodically-harvested closures, and co-management models in general, are applied highlights the importance of the adaptive nature of management; that it is flexible to local context and responds to learning-by-doing while retaining the overall objectives. The variability in application and outcomes also highlights that general statements about what periodically-harvested closures can achieve for fisheries are problematic.

As a result of my literature review, informal interviews in pilot studies, and verification in local case studies, my thesis focused on periodically-harvested closures as the main fisheries regulation or management measure employed by co-management. However, there may also be less clear-cut outcomes from co-management initiatives, such as reinforcement of national fisheries regulations or the bolstering of customary tenure, which I did not explicitly examine. Additionally, education and awareness-raising delivered through the initiatives may have altered individuals' or communities' predisposition or ability to uptake, or more easily progress towards, a comprehensive suite of management measures. Understanding these indirect outcomes of management would require before-and-after intervention testing or longer term ethnographic work, which was not possible within the scope of this study, but is an important direction for future studies.

In the coastal regions where my research focused, there was relatively low overall fishing pressure compared to other areas of the Indo-Pacific i.e., where market access and opportunities are improved and population densities are higher. The findings of my thesis should be re-tested in high(er) fishing pressure situations. Further, this was a short-term study, and provided insights about management and outcomes from a snapshot in time. There is a global need for long-term studies investigating the outcomes of co-management. As discussed throughout my thesis, patterns of fishing pressure (including effort applied during openings, the frequency and duration of openings, and levels of non-compliance during closure periods), and the robustness of co-management institutions in general, must be examined over longer time scales – as this is where impacts from population pressure, resource degradation, improved technology and market expansion will really come into play.

Fisheries also provide indirect (i.e., non-food) contributions to food security. In the Pacific licence fees, revenue, profits and incomes from commercial fisheries (i.e., particularly tuna fisheries) can increase purchasing power of households, communities and nations and are therefore also critical considerations for food security. However, my thesis has concentrated on the direct contributions of fish to food security given the importance of this role in rural communities. Significant economic and institutional transformation would be required to maximise food security benefits from the commercial fisheries sector, and to ensure the distribution of some benefits to rural, coastal communities and households. The indirect food security benefits from fisheries, and the transformation needed to support equitable delivery of those benefits presents another important area for future research.

References

ABESAMIS, R. A. & RUSS, G. R. 2005. Density-dependent spillover from a marine reserve: Long-term evidence. *Ecological Applications,* 15**,** 1798-1812.

AKIMICHI, T. 1991. Sea tenure and its transformation in the Lau of North Malaita, Solomon Island. *South Pacific Study,* 12**,** 7-22.

ALCALA, A. C. & RUSS, G. R. 2006. No-take marine reserves and reef fisheries management in the Philippines: A new people power revolution. *Ambio,* 35**,** 245-254.

ALLAN, C. H. 1957. Customary Land Tenure in the British Solomon Islands Protectorate. Honiara: Western Pacific High Commission.

ALLEE, W. C., PARK, O., EMERSON, A. E., PARK, T. & SCHMIDT, K. P. 1949. *Principles of Animal Ecology,* Philadelphia, W.B. Saunders Company.

ALLISON, E. H. 2011. Aquaculture, fisheries, poverty and food security. *Working paper 2011-65.* Worldfish Centre - Commissioned for OECD.

ALLISON, E. H. & ELLIS, F. 2001. The livelihoods approach and management of small-scale fisheries. *Marine Policy,* 25**,** 377-388.

AMOS, M. J. & PURCELL, S. W. 2003. Evaluation of strategies for intermediate culture of Trochus niloticus (Gastropoda) in sea cages for restocking. *Aquaculture,* 218**,** 235-249.

ANDRÉFOUËT, S., MULLER-KARGER, F., ROBINSON, J., KRANENBURG, C., TORRES-PULLIZA, D., SPRAGGINS, S. & MURCH, B. Year. Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. *In:* SUZUKI, Y., NAKAMORI, T., HIDAKA, M., KAYANNE, H., CASARETO, B. E., NADAOKA, K., YAMANO, H. & TSUCHIYA, M., eds. 10th International Coral Reef Symposium, 28 June-32nd July 2004 2006 Okinawa, Japan.

ARIFIN, Z., PRADINA, P. & PURNOMO, A. H. 1998. A case study of the traditional trochus (Trochus niloticus) fishery in the Maluku region, Indonesia. *Canadian Special Publication of Fisheries and Aquatic Sciences,* 125**,** 401-406.

ARMITAGE, D., MARSCHKE, M. & PLUMMER, R. 2008. Adaptive co-management and the paradox of learning. *Global Environmental Change-Human and Policy Dimensions,* 18**,** 86-98.

ARMITAGE, D. R. 2007. *Adaptive co-management: collaboration, learning, and multi-level governance,* British Columbia, University of British Columbia Press.

ASWANI, S. & FURUSAWA, T. 2007. Do marine protected areas affect human nutrition and health? A comparison between villages in Roviana, Solomon Islands. *Coastal Management* 35**,** 545-565.

ASWANI, S. & WEIANT, P. 2004. Scientific evaluation in women's participatory management: Monitoring marine invertebrate refugia in the Solomon Islands. *Human Organization,* 63**,** 301-319.

BAINES, G. B. K. 1990. A traditional base for inshore fisheries management in the Solomon Islands. *In:* RUDDLE, K. & JOHANNES, R. E. (eds.) *Traditional Marine Resource Management in the Pacific Basin: An Anthology.* Jakarta: UNESCO/ROSTSEA.

BARTLETT, C. Y., MANUA, C., CINNER, J., SUTTON, S., JIMMY, R., SOUTH, R., NILSSON, J. & RAINA, J. 2009a. Comparison of outcomes of permanently closed and periodically harvested coral reef reserves. *Conservation Biology,* 23**,** 1475-1485.

BARTLETT, C. Y., PAKOA, K. & MANUA, C. 2009b. Marine reserve phenomenon in the Pacific islands *Marine Policy,* 33**,** 673-678.

BAYLISS-SMITH, T. 1991. Food security and agricultural sustainability in the New Guinea Highlands: vulnerable people, vulnerable places. *Ids Bulletin-Institute of Development Studies,* 22**,** 5-11.

BELL, J. D., JOHNSON, J. E. & HOBDAY, A. J. (eds.) 2011. *Vulnerability of troptical Pacific fisheries and aquaculture to climate change,* Noumea: Secretariat of the Pacific Community.

BELL, J. D., KRONEN, M., VUNISEA, A., NASH, W. J., KEEBLE, G., DEMMKE, D., PONTIFEX, A. & ANDREFOUET, S. 2009. Planning the use of fish for food security in the Pacific. *Marine Policy,* 33**,** 64-76.

BELL, J. D., PURCELL, S. W. & NASH, W. J. 2008. Restoring small-scale fisheries for tropical sea-cucumbers. *Ocean & Coastal Management,* 51**,** 589-593.

BELL, J. D., RATNER, B. D., STOBUTZKI, I. & OLIVER, J. 2006. Addressing the coral reef crisis in developing countries. *Ocean & Coastal Management,* 49**,** 976-985.

BELLWOOD, D. R., HUGHES, T. P., FOLKE, C. & NYSTROM, M. 2004. Confronting the coral reef crisis. *Nature,* 429**,** 827-833.

BÉNÉ, C., BELAL, E., BABA, M. O., OVIE, S., RAJI, A., MALASHA, I., NJAYA, F., ANDI, M. N., RUSSELL, A. & NEILAND, A. 2009. Power Struggle, Dispute and Alliance Over Local Resources: Analyzing 'Democratic' Decentralization of Natural Resources through the Lenses of Africa Inland Fisheries. *World Development,* 37**,** 1935-1950.

BÉNÉ, C., HERSOUG, B. & ALLISON, E. H. 2010. Not by rent alone: analyzing the pro-poor functions of small-scale fisheries in developing countries. *Development Policy Review,* 28**,** 325-358.

BÉNÉ, C., MACFADYEN, G. & ALLISON, E. H. 2007. Increasing the contribution of small-scale fisheries to poverty alleviation and food security. *FAO Fisheries Technical Paper.* Rome: FAO.

BERKES, F. 2009. Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management,* 90**,** 1692-1702.

BERKES, F. 2012. Implementing ecosystem-based management: evolution or revolution? *Fish and Fisheries,* 13**,** 465-476.

BEVERTON, R. J., AND HOLT, S.J. 1957., 19: 533. 1957. *On the dynamics of exploited fish populations*, Great Britain Ministry of Agriculture, Fisheries and Food.

BODIN, O., CRONA, B. & ERNSTSON, H. 2006. Social networks in natural resource management: What is there to learn from a structural perspective? *Ecology and Society,* 11.

BODIN, Ö. & CRONA, B. I. 2009. The role of social networks in natural resource governance: What relational patterns make a difference? *Global Environmental Change-Human and Policy Dimensions,* 19**,** 366-374.

BORGATTI, S. P., EVERETT, M. G. & FREEMAN, L. C. 2002. Ucinet for Windows: Software for Social Network Analysis. Harvard, MA: Analytic Technologies.

BORGATTI, S. P. & FOSTER, P. C. 2003. The network paradigm in organizational research: A review and typology. *Journal of Management,* 29**,** 991-1013.

BORGATTI, S. P., MEHRA, A., BRASS, D. J. & LABIANCA, G. 2009. Network Analysis in the Social Sciences. *Science,* 323**,** 892-895.

BOTSFORD, L. W., QUINN, J. F., WING, S. R. & BRITTNACHER, J. G. Year. Rotating spatial harvest of a benthic invertebrate, the Red Sea urchin, *Strongylocentrotus franciscanus*. *In:* KRUSE, G., EGGERS, D. M., MARASCO, R. J., PAUTZKE, C. & QUINN, T. J., II, eds.

Alaska Sea Grant College Program Report, No. 93(2); International symposium on management strategies for exploited fish populations, 1993. 409-428.

BREWER, T., CINNER, J. E., GREEN, A. & PANDOLFI, J. M. 2009. Thresholds and multiple scale interaction of environment, resource use, and market proximity on reef fishery resources in the Solomon Islands. *Biological Conservation,* 142**,** 1797–1807.

BRUNO, J. F. & SELIG, E. R. 2007. Regional Decline of Coral Cover in the Indo-Pacific: Timing, Extent, and Subregional Comparisons. *PLoS ONE,* 2.

CABRAL, R. B. & ALINO, P. M. 2011. Transition from common to private coasts: Consequences of privatization of the coastal commons. *Ocean & Coastal Management,* 54**,** 66-74.

CADDY, J. F. 1993. Background concepts for a rotating harvesting strategy with particular reference to the mediterranean red coral, *Corallium rubrum Marine Fisheries Review,* 5**,** 10-18.

CADDY, J. F. & CAROCCI, F. 1999. The spatial allocation of fishing intensity by port-based inshore fleets: a GIS application. *ICES Journal of Marine Science,* 56**,** 388-403.

CADDY, J. F. & SEIJO, J. C. 1998. Application of a spatial model to explore rotating harvest strategies for sedentary species. *Canadian Special Publication of Fisheries and Aquatic Sciences,* 125**,** 359-365.

CARRIER, J. G. 1987. Marine tenure and conservation in Papua New Guinea: problems in interpretation. *In:* MCCAY, B. J. & ACHESON, J. M. (eds.) *The Question of the Commons: The Culture and Ecology of Communal Resources.* Tucson: The University of Arizona Press.

CHEUNG, W. W. L., PITCHER, T. J. & PAULY, D. 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. *Biological Conservation,* 124**,** 97-111.

CHOAT, J. H. & AXE, L. M. 1996. Growth and longevity in acanthurid fishes an analysis of otolith increments. *Marine Ecology-Progress Series,* 134**,** 15-26.

CHRISTIE, P. 2004. Marine protected areas as biological successes and social failures in southeast Asia. *In:* SHIPLEY, J. B. (ed.) *Aquatic Protected Areas as Fisheries Management Tools.*

CINNER, J., MARNANE, M. J., MCCLANAHAN, T. R. & ALMANY, G. R. 2006. Periodic closures as adaptive coral reef management in the Indo-Pacific. *Ecology and Society,* 11**,** 31.

CINNER, J. E., MARNANE, M. J. & MCCLANAHAN, T. R. 2005. Conservation and community benefits from traditional coral reef management at Ahus Island, Papua New Guinea. *Conservation Biology,* 19**,** 1714-1723.

CINNER, J. E., MCCLANAHAN, T. R., MACNEIL, M. A., GRAHAM, N. A. J., DAW, T. M., MUKMININ, A., FEARY, D. A., RABEARISOA, A. L., WAMUKOTA, A., JIDDAWI, N., CAMPBELL, S. J., BAIRD, A. H., JANUCHOWSKI-HARTLEY, F. A., HAMED, S., LAHARI, R., MOROVE, T. & KUANGE, J. 2012. Comanagement of coral reef social-ecological systems. *Proceedings of the National Academy of Sciences of the United States of America,* 109**,** 5219-5222.

CINNER, J. E., SUTTON, S. G. & BOND, T. G. 2007. Socioeconomic thresholds that affect use of customary fisheries management tools. *Conservation Biology,* 21**,** 1603-1611.

CLARKE, K. & GORLEY, R. 2006. PRIMER v6: User Manual/Tutorial. Plymouth: PRIMER E.

CLARKE, K. R. & WARWICK, R. M. 2001. Change in marine communities:an approach to statistical analysis and intepretation Plymouth: PRIMER-E.

CLARKE, P. J., KOMATSU, T., BELL, J. D., LASI, F., OENGPEPA, C. P. & LEQATA, J. 2003. Combined culture of Trochus niloticus and giant clams (Tridacnidae): benefits for restocking and farming. *Aquaculture,* 215**,** 123-144.

COCHRANE, K. L., ANDREW, N. L. & PARMA, A. M. 2011. Primary fisheries management: a minimum requirement for provision of sustainable human benefits in small-scale fisheries. *Fish and Fisheries,* 12**,** 275-288.

COLDING, J. & FOLKE, C. 2001. Social taboos: "Invisible" systems of local resource management and biological conservation. *Ecological Applications,* 11**,** 584-600.

COX, M., ARNOLD, G. & TOMAS, S. V. 2010. A Review of Design Principles for Community-based Natural Resource Management. *Ecology and Society,* 15.

CRONA, B. & BODIN, O. 2006. What you know is who you know? Communication patterns among resource users as a prerequisite for co-management. *Ecology and Society,* 11.

CRONA, B. & BODIN, Ö. 2010. Power Asymmetries in Small-Scale Fisheries: a Barrier to Governance Transformability? *Ecology and Society,* 15.

CTI SECRETARIAT 2009. Regional Plan of Action; Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF). Manado: Interim Regional CTI Secretariat.

CUDNEY-BUENO, R. & BASURTO, X. 2009. Lack of Cross-Scale Linkages Reduces Robustness of Community-Based Fisheries Management. *PLoS ONE,* 4.

CUNNINGHAM, S., NEILAND, A. E., ARBUCKLE, M. & BOSTOCK, T. 2009. Wealth-based Fisheries Management: Using Fisheries Wealth to Orchestrate Sound Fisheries Policy in Practice. *Marine Resource Economics,* 24**,** 271-287.

DAW, T. M. 2008. Spatial distribution of effort by artisanal fishers: Exploring economic factors affecting the lobster fisheries of the Corn Islands, Nicaragua. *Fisheries Research,* 90**,** 17-25.

DE KLERK, P. & GATTO, M. 1981. Some remarks on periodic harvesting of a fish population. *Mathematical Biosciences,* 56**,** 47-70.

DEGENNE, A. & FORSÉ, M. 1999. *Introducing Social Networks,* London, Sage Publications.

DEVLAMING, V., GROSSMAN, G. D. & CHAPMAN, F. 1982. On the use of the Gonosomatic index. *Comparative Biochemistry and Physiology a-Physiology,* 73**,** 31-39.

DONNER, S. D. & POTERE, D. 2007. The inequity of the global threat to coral reefs. *Bioscience,* 57**,** 214-215.

DULVY, N. & POLUNIN, N. 2004. Using informal knowledge to infer human-induced rarity of a conspicuous reef fish. *Animal Conservation,* 7**,** 365-374.

DULVY, N. K., POLUNIN, N. V. C., MILL, A. C. & GRAHAM, N. A. J. 2004. Size structural change in lightly exploited coral reef fish communities: evidence for weak indirect effects. *Canadian Journal of Fisheries and Aquatic Sciences,* 61**,** 466-475.

EDER, J. F. 2005. Coastal resource management and social differences in Philippine fishing communities. *Human Ecology,* 33**,** 147-169.

ERNSTSON, H., BARTHEL, S., ANDERSSON, E. & BORGSTROM, S. T. 2010. Scale-Crossing Brokers and Network Governance of Urban Ecosystem Services: The Case of Stockholm. *Ecology and Society,* 15.

EVANS, L., CHERRETT, N. & PEMSL, D. 2011. Assessing the impact of fisheries co-management interventions in developing countries: A meta-analysis. *Journal of Environmental Management,* 92**,** 1938-1949.

EVANS, S. M., GILL, M. E., RETRAUBUN, A. S. W., ABRAHAMZ, J. & DANGEUBUN, J. 1997. Traditional management practices and the conservation of the gastropod (Trochus niloticus) and fish stocks in the Maluku Province (eastern Indonesia). *Fisheries Research (Amsterdam),* 31**,** 83-91.

FABINYI, M. 2008. Dive tourism, fishing and marine protected areas in the Calamianes Islands, Philippines. *Marine Policy,* 32**,** 898-904.

FABINYI, M., KNUDSEN, M. & SEGI, S. 2010. Social Complexity, Ethnography and Coastal Resource Management in the Philippines. *Coastal Management,* 38**,** 617-632.

FAO. Year. Rome Declaration on World Food Security and World Food Summit Plan of Action. *In:* World Food Summit, 13-17 November 1996 1996 Rome.

FAO 2010. Marine fishery resources of the Pacific Islands. *In:* FAO (ed.). Rome.

FAO. 2013. *FAO Country Profiles* [Online]. Rome. [Accessed 13/01/2013 2013].

FEARY, D. A., CINNER, J. E., GRAHAM, N. A. J. & JANUCHOWSKI-HARTLEY, F. A. 2011. Effects of customary marine closures on fish behavior, spear-fishing success, and underwater visual surveys. *Conservation Biology,* 25**,** 341-349.

FERRARIS, J., PELLETIER, D., KULBICKI, M. & CHAUVET, C. 2005. Assessing the impact of removing reserve status on the Abore Reef fish assemblage in New Caledonia. *Marine Ecology-Progress Series,* 292**,** 271-286.

FILER, C. 2004. The knowledge of indigenous desire: Disintegrating conservation and development in Papua New Guinea. *In:* BICKER, A., SILLITOE, P. & POTTIER, J. (eds.) *Development and Local Knowledge: New approaches to issues in natural resources management, conservation and agriculture.* London: Routledge.

FOALE, S. 1998a. What's in a name? An analysis of the West Nggela (Solomon Islands) fish taxonomy. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin,* 9**,** 2-19.

FOALE, S., ADHURI, D., ALIÑO, P., ALLISON, E., ANDREW, N., COHEN, P., EVANS, L., FABINYI, M., FIDELMAN, P., GREGORY, C., STACEY, N., TANZER, J. & WEERATUNGE, N. 2013. Food security and the Coral Triangle Initiative. *Marine Policy,* 38**,** 174–183.

FOALE, S., COHEN, P., JANUCHOWSKI-HARTLEY, S., WENGER, A. & MACINTYRE, M. 2011. Tenure and taboos: origins and implications for fisheries in the Pacific. *Fish and Fisheries,* 12**,** 357-369.

FOALE, S. & DAY, R. 1997. Stock assessment of trochus (Trochus niloticus) (Gastropoda : Trochidae) fisheries at West Nggela, Solomon Islands. *Fisheries Research,* 33**,** 1-16.

FOALE, S. J. 1998b. Assessment and management of the trochus fishery at West Nggela, Solomon Islands: an interdisciplinary approach. *Ocean and Coastal Management,* 40**,** 187-205.

FOALE, S. J. 2001. 'Where's our development?' Landowner aspirations and environmentalist agendas in Western Solomon Islands. *The Asia Pacific Journal of Anthropology,* 2**,** 44-67.

FOALE, S. J. 2008. A preliminary exploration of relationships among fishery management, food security, and the Millennium Development Goals in Melanesia. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin,* 24**,** 3-8.

FOALE, S. J. & MACINTYRE, M. 2000. Dynamic and flexible aspects of property tenure at West Nggela, Solomon Islands: implications for marine resource management. *Oceania,* 71**,** 30-45.

FOALE, S. J. & MANELE, B. 2004. Social and political barriers to the use of Marine Protected Areas for conservation and fishery management in Melanesia. *Asia Pacific Viewpoint,* 45**,** 373-386.

FOLKE, C., HAHN, T., OLSSON, P. & NORBERG, J. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources,* 30**,** 441-473.

FRIEDMAN, K., ERIKSSON, H., TARDY, E. & PAKOA, K. 2011. Management of sea cucumber stocks: patterns of vulnerability and recovery of sea cucumber stocks impacted by fishing. *Fish and Fisheries,* 12**,** 75-93.

FROESE, R. & PAULY, D. 2012. *FishBase* [Online]. World Wide Web electronic publication. Available: www.fishbase.org [Accessed 10/2009].

GAME, E. T., BODE, M., MCDONALD-MADDEN, E., GRANTHAM, H. S. & POSSINGHAM, H. P. 2009. Dynamic marine protected areas can improve the resilience of coral reef systems. *Ecology Letters,* 12**,** 1336-1346.

GARCIA, S. M. & ROSENBERG, A. A. 2010. Food security and marine capture fisheries: characteristics, trends, drivers and future perspectives. *Philosophical Transactions of the Royal Society B-Biological Sciences,* 365**,** 2869-2880.

GELCICH, S., HUGHES, T. P., OLSSON, P., FOLKE, C., DEFEO, O., FERNANDEZ, M., FOALE, S., GUNDERSON, L. H., RODRIGUEZ-SICKERT, C., SCHEFFER, M., STENECK, R. S. & CASTILLA, J. C. 2010. Navigating transformations in governance of Chilean marine coastal resources. *Proceedings of the National Academy of Sciences of the United States of America,* 107**,** 16794-16799.

GENDRON, L. & BRETHES, J. C. 2002. Simulations of the impact of different temporal and spatial allocations of fishing effort on fishing mortality in a lobster (*Homarus americanus*) fishery. *Canadian Journal of Fisheries and Aquatic Sciences,* 59**,** 899-909.

GERBER, L. R., BOTSFORD, L. W., HASTINGS, A., POSSINGHAM, H. P., GAINES, S. D., PALUMBI, S. R. & ANDELMAN, S. 2003. Population models for marine reserve design: A retrospective and prospective synthesis. *Ecological Applications,* 13**,** S47-S64.

GILLETT, R. 2009. *Fisheries in the Economies of Pacific Island Countries and Territories,* Mandaluyong City.

GILLETT, R. & CARTWRIGHT, I. 2010. The Future of Pacific Island Fisheries. New Caledonia: Secretariat of the Pacific Community.

GILLETT, R. E. 2010. Fisheries centres in the Pacific Islands: Lessons learned? *SPC Fisheries Newsletter,* 133**,** 29-34.

GOVAN, H. 2009a. Achieving the potential of locally managed marine areas in the South Pacific. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin,* 25**,** 16-25.

GOVAN, H. 2009b. Status and potential of locally-managed marine areas in the South Pacific: meeting nature conservation and sustainable livelihood targets through wide-spread implementation of LMMAs. Suva.

GOVAN, H., AALBERSBERG, W., TAWAKE, A. & PARKS, J. E. 2008. Locally-managed marine areas: a guide to supporting community-based adaptive management. Suva: Locally-Managed Marine Area (LMMA) Network.

GOVAN, H., SCHWARZ, A.-M. & BOSO, D. 2011. Towards Integrated Island Management: Lessons from Lau, Malaita, for the implementation of a national approach to resource management in Solomon Islands. Honiara: WorldFish Center Report to SPREP.

GRAHAM, N. A. J., AINSWORTH, T. D., BAIRD, A. H., BAN, N. C., BAY, L. K., CINNER, J. E., DE FREITAS, D. M., DIAZ-PULIDO, G., DORNELAS, M., DUNN, S. R., FIDELMAN, P. I. J., FORET, S., GOOD, T. C., KOOL, J., MALLELA, J., PENIN, L., PRATCHETT, M. S. & WILLIAMSON, D. H. 2011. From microbes to people: tractable benefits of no-take areas for coral reefs. *In:* GIBSON, R. N., ATKINSON, R. J. A. & GORDON, J. D. M. (eds.) *Oceanography and Marine Biology: An Annual Review, Vol 49.*

GRAHAM, N. A. J., DULVY, N. K., JENNINGS, S. & POLUNIN, N. V. C. 2005. Size-spectra as indicators of the effects of fishing on coral reef fish assemblages. *Coral Reefs,* 24**,** 118-124.

GREEN, A., LOKANI, P., ATU, W., RAMOHIA, P., THOMAS, P. & ALMANY, J. 2006. Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. Brisbane: The Nature Conservancy.

GUTIERREZ, N. L., HILBORN, R. & DEFEO, O. 2011. Leadership, social capital and incentives promote successful fisheries. *Nature,* 470**,** 386-389.

HALL, S. J. 2011. Small-scale Fisheries Management : Frameworks and Approaches for the Developing World. *In:* POMEROY, R. S. & ANDREW, N. L. (eds.). Wallingford: CABI Publishing.

HALPERN, B. S. & WARNER, R. R. 2002. Marine reserves have rapid and lasting effects. *Ecology Letters,* 5**,** 361-366.

HAMILTON, R. & MATAWAI, M. 2006. Live reef food fish trade causes rapid declines in abundance of squaretail coralgrouper (*Plectropomus areolatus*) at a spawning aggregation site in Manus, Papua New Guinea. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin,* 16**,** 13-18.

HANNEMAN, R. & RIDDLE, M. 2005. *Introduction to social network methods; free introductory textbook on social network analysis,* Accessed 4 April 2011, Available from http://www.faculty.ucr.edu/~hanneman/nettext/.

HARDIN, G. 1968. The tragedy of the commons. *Science,* 162**,** 1243-1248.

HARKES, I. & NOVACZEK, I. 2002. Presence, performance, and institutional resilience of sasi, a traditional management institution in Central Maluku, Indonesia. *Ocean and Coastal Management,* 45**,** 237-260.

HARLEY, S. J., MYERS, R. A. & DUNN, A. 2001. Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Sciences,* 58**,** 1760-1772.

HART, D. R. 2003. Yield- and biomass-per-recruit analysis for rotational fisheries, with an application to the Atlantic sea scallop (*Placopecten magellanicus*). *Fishery Bulletin,* 101**,** 44-57.

HAWES, I., LASIAK, T., SMITH, M. L. & OENGPEPA, C. 2011. The status of silverlip pearl oyster (Jameson) (Mollusca, Pteridae) in the Solomon Islands after a 15-year export ban. *Journal of Shellfish Research,* 30**,** 255-260.

HILBORN, R., MICHELI, F. & DE LEO, G. A. 2006. Integrating marine protected areas with catch regulation. *Canadian Journal of Fisheries and Aquatic Sciences,* 63**,** 642-649.

HILBORN, R., STOKES, K., MAGUIRE, J. J., SMITH, T., BOTSFORD, L. W., MANGEL, M., ORENSANZ, J., PARMA, A., RICE, J., BELL, J., COCHRANE, K. L., GARCIA, S., HALL, S. J., KIRKWOOD, G. P., SAINSBURY, K., STEFANSSON, G. & WALTERS, C. 2004. When can marine reserves improve fisheries management? *Ocean & Coastal Management,* 47**,** 197-205.

HOLLAND, A. 1994. The beche-de-mer industry in the Solomon Islands: recent trends and suggestions for management. *South Pacific Commission Beche-de-mer Information Bulletin,* 6**,** 2-9.

HUGHES, T. P., BAIRD, A. H., BELLWOOD, D. R., CARD, M., CONNOLLY, S. R., FOLKE, C., GROSBERG, R., HOEGH-GULDBERG, O., JACKSON, J. B. C., KLEYPAS, J., LOUGH, J. M., MARSHALL, P., NYSTROM, M., PALUMBI, S. R., PANDOLFI, J. M., ROSEN, B. & ROUGHGARDEN, J. 2003. Climate Change, Human Impacts, and the Resilience of Coral Reefs. *Science,* 301**,** 929-933.

HVIDING, E. 1996. *Guardians of Marovo Lagoon: practice, place and politics in maritime Melanesia,* Honolulu, University of Hawaii Press.

HVIDING, E. 1998. Contextual flexibility: present status and future of customary marine tenure in Solomon Islands. *Ocean & Coastal Management,* 40**,** 253-269.

JANUCHOWSKI-HARTLEY, F. A., GRAHAM, N. A. J., FEARY, D. A., MOROVE, T. & CINNER, J. E. 2011. Fear of Fishers: Human Predation Explains Behavioral Changes in Coral Reef Fishes. *PLoS ONE,* 6.

JENNINGS, S. 2001. Patterns and prediction of population recovery in marine reserves. *Reviews in Fish Biology & Fisheries,* 10**,** 209-231.

JENNINGS, S., GREENSTREET, S. P. R. & REYNOLDS, J. D. 1999a. Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. *Journal of Animal Ecology,* 68**,** 617-627.

JENNINGS, S. & POLUNIN, N. V. C. 1995. Comparative size and composition of yield from six Fijian reef fisheries. *Journal of Fish Biology,* 46**,** 28-46.

JENNINGS, S., REYNOLDS, J. D. & POLUNIN, N. V. C. 1999b. Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life histories. *Conservation Biology,* 13**,** 1466-1475.

JOHANNES, R. E. 1978. Traditional marine conservation methods in Oceania and their demise. *Annual Review of Ecology and Systematics,* 9**,** 349-364.

JOHANNES, R. E. 1982. Traditional conservation methods and protected marine areas in Oceania. *Ambio,* 11**,** 258-261.

JOHANNES, R. E. 1998a. The case for data-less marine resource management: examples from tropical nearshore finfisheries. *Trends in Ecology and Evolution,* 13(6)**,** 243-246.

JOHANNES, R. E. 1998b. Government-supported, village-based management of marine resources in Vanuatu. *Ocean & Coastal Management,* 40**,** 165-187.

JOHANNES, R. E. 2002. The renaissance of community-based marine resource management in Oceania. *Annual Review of Ecology and Systematics,* 33**,** 317-340.

JOHNSON, D. S. 2006. Category, narrative, and value in the governance of small-scale fisheries. *Marine Policy,* 30**,** 747-756.

JUPITER, S. D., WEEKS, R., JENKINS, A. P., EGLI, D. P. & CAKACAKA, A. 2012. Effects of a single intensive harvest event on fish populations inside a customary marine closure. *Coral Reefs,* DOI 10.1007/s00338-012-0888-x.

KAPLAN, D. M., HART, D. R. & BOTSFORD, L. W. 2010. Rotating spatial harvests and fishing effort displacement: a comment on Game et al. (2009). *Ecology Letters,* 13**,** E10-E12.

KAWARAZUKA, N. & BENE, C. 2010. Linking small-scale fisheries and aquaculture to household nutritional security: an overview. *Food Security,* 2**,** 343-357.

KEARNEY, R., BUXTON, C. D. & FAREBROTHER, G. 2012. Australia's no-take marine protected areas: Appropriate conservation or inappropriate management of fishing? *Marine Policy,* 36**,** 1064-1071.

KNIGHT, A. T., DRIVER, A., COWLING, R. M., MAZE, K., DESMET, P. G., LOMBARD, A. T., ROUGET, M., BOTHA, M. A., BOSHOFF, A. F., CASTLEY, J. G., GOODMAN, P. S.,

MACKINNON, K., PIERCE, S. M., SIMS-CASTLEY, R., STEWART, W. I. & VON HASE, A. 2006. Designing systematic conservation assessments that promote effective implementation: Best practice from South Africa. *Conservation Biology,* 20**,** 739-750.

KOCZBERSKI, G., CURRY, G., WARKU, J. & KWAM, C. 2006. Village-based marine resource use and rural livelihoods, Kimbe Bay, west New Britain, Papua New Guinea. *TNC Pacific Island Countries Report No. 5/06.* Brisbane: The Nature Conservancy.

KRONEN, M. & VUNISEA, A. 2009. Fishing impact and food security – Gender differences in finfisheries across Pacific Island countries and cultural groups. *SPC Women in Fisheries Information Bulletin,* 19**,** 3-10.

KULBICKI, M., SARRAMEGNA, S., LETOURNEUR, Y., WANTIEZ, L., GALZIN, R., MOU-THAM, G., CHAUVET, C. & THOLLOT, P. 2007. Opening of an MPA to fishing: Natural variations in the structure of a coral reef fish assemblage obscure changes due to fishing. *Journal of Experimental Marine Biology and Ecology,* 353**,** 145-163.

LANE, M. B. 2006. Towards integrated coastal management in Solomon Islands: Identifying strategic issues for governance reform. *Ocean & Coastal Management,* 49**,** 421-441.

LARKIN, P. A. 1977. An epitaph for the concept of maximum sustainable yield. *Transactions of the American Fisheries Society,* 106**,** 1-11.

LEADERS OF THE PACIFIC ISLANDS FORUM 2007. Vava'u Declaration. *Vava'u Decisions on the Pacific Plan.*

LEBEL, L., GARDEN, P. & IMAMURA, M. 2005. The politics of scale, position, and place in the governance of water resources in the Mekong region. *Ecology and Society,* 10**,** 18.

LEISHER, C., VAN BEUKERING, P. & SCHERL, L. M. 2007. Nature's investment bank: how marine protected areas contribute to poverty reduction. Brisbane: The Nature Conservancy.

LEOPOLD, M., CAKACAKA, A., MEO, S., SIKOLIA, J. & LECCHINI, D. 2009. Evaluation of the effectiveness of three underwater reef fish monitoring methods in Fiji. *Biodiversity and Conservation,* 18**,** 3367-3382.

LESTER, S. E. & HALPERN, B. S. 2008. Biological responses in marine no-take reserves versus partially protected areas. *Marine Ecology-Progress Series,* 367**,** 49-56.

LEVITAN, D. R., SEWELL, M. A. & CHIA, F. S. 1992. How distribution and abundance influence fertilization success in the sea urchin *Strongylocentotus franciscanus*. *Ecology,* 73**,** 248-254.

LINCOLN-SMITH, M. P., PITT, K. A., BELL, J. D. & MAPSTONE, B. D. 2006. Using impact assessment methods to determine the effects of a marine reserve on abundances and sizes of valuable tropical invertebrates. *Canadian Journal of Fisheries and Aquatic Sciences,* 63**,** 1251-1266.

LIPSETT-MOORE, G., HAMILTON, R., PETERSON, N., GAME, E., ATU, W., KERESEKA, J., PITA, J., RAMOHIA, P. & SIOTA, C. 2010. Ridges to Reefs Conservation Plan for Choiseul Province, Solomon Islands. Honiara: The Nature Conservancy.

LMMA 2011. The Locally-Managed Marine Area Network 2010 Annual Report. *In:* TAN, W. & PARRAS, T. (eds.).

MACINTYRE, M. A. & FOALE, S. J. 2007. Land and Marine Tenure, Ownership and New forms of Entitlement on Lihir: Changing notions of property in the context of a goldmining project. *Human Organization,* 66**,** 49-59.

MANGI, S. C. & ROBERTS, C. M. 2006. Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin,* 52**,** 1646-1660.

MARIN, A. & BERKES, F. 2010. Network approach for understanding small-scale fisheries governance: The case of the Chilean coastal co-management system. *Marine Policy,* 34**,** 851-858.

MAUNDER, M. N., SIBERT, J. R., FONTENEAU, A., HAMPTON, J., KLEIBER, P. & HARLEY, S. J. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. *ICES Journal of Marine Science,* 63**,** 1373-1385.

MCCALLUM, H. I. 1988. Pulse fishing may be superior to selective fishing. *Mathematical Biosciences,* 89**,** 177-181.

MCCLANAHAN, T. & CASTILLA, J. C. (eds.) 2008. *Fisheries Management : Progress Towards Sustainability,* Oxford: Blackwell Publishing Ltd.

MCCLANAHAN, T. R. 2010. Effects of fisheries closures and gear restrictions on fishing income in a Kenyan coral reef. *Conservation Biology,* 24**,** 1519-1528.

MCCLANAHAN, T. R. & CINNER, J. E. 2008. A framework for adaptive gear and ecosystem-based management in the artisanal coral reef fishery of Papua New Guinea. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 18**,** 493-507.

MCCLANAHAN, T. R., GRAHAM, N. A. J., CALNAN, J. M. & MACNEIL, M. A. 2007. Toward pristine biomass: Reef fish recovery in coral reef marine protected areas in Kenya. *Ecological Applications,* 17**,** 1055-1067.

MCCLANAHAN, T. R., GRAHAM, N. A. J., MACNEIL, M. A., MUTHIGA, N. A., CINNER, J. E., BRUGGEMANN, J. H. & WILSON, S. K. 2011. Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries. *Proceedings of the National Academy of Sciences of the United States of America,* 108**,** 17230-17233.

MCCLANAHAN, T. R. & MANGI, S. 2000. Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery. *Ecological Applications,* 10**,** 1792-1805.

MCCLANAHAN, T. R. & MANGI, S. 2001. The effect of a closed area and beach seine exclusion on coral reef fish catches. *Fisheries Management and Ecology,* 8**,** 107-121.

MCCLANAHAN, T. R., MARNANE, M. J., CINNER, J. E. & KIENE, W. E. 2006. A comparison of marine protected areas and alternative approaches to coral-reef management. *Current Biology,* 16**,** 1408-1413.

MCDOUGALL, D. 2005. The unintended consequences of clarification: Development, disputing, and the dynamics of community in Ranongga, Solomon Islands. *Ethnohistory,* 52**,** 81-109.

MCLEOD, E., SZUSTER, B. & SALM, R. 2009. Sasi and marine conservation in Raja Ampat, Indonesia. *Coastal Management,* 37**,** 656-676.

MCPHERSON, M., SMITH-LOVIN, L. & COOK, J. M. 2001. Birds of a feather: Homophily in social networks. *Annual Review of Sociology,* 27**,** 415-444.

MFMR 2008. Solomon Islands national strategy for the management of inshore fisheries and marine resources. Honiara: Ministry of Fisheries and Marine Resources.

MILLS, D. J., WESTLUND, L., GRAAF, G. D., KURA, Y., WILLMAN, R. & KELLEHER, K. 2011. Under-reported and undervalued: Small-scale fisheries in the developing world. *In:* POMEROY, R. S. & ANDREW, N. L. (eds.) *Small-scale Fisheries Management : Frameworks and Approaches for the Developing World.* Wallingford: CABI Publishing.

MURAWSKI, S. A., WIGLEY, S. E., FOGARTY, M. J., RAGO, P. J. & MOUNTAIN, D. G. 2005. Effort distribution and catch patterns adjacent to temperate MPAs. *ICES Journal of Marine Science,* 62**,** 1150-1167.

MYERS, R. A., FULLER, S. D. & KEHLER, D. G. 2000. A fisheries management strategy robust to ignorance: rotational harvest in the presence of indirect fishing mortality. *Canadian Journal of Fisheries and Aquatic Sciences,* 57**,** 2357-2362.

NASH, W., ADAMS, T., TUARA, P., TEREKIA, O., MUNRO, D., AMOS, M., LEQATA, J., MATAITI, N., TEOPENGA, M. & WHITFORD, J. 1995. *The Aitutaki Trochus Fishery: A Case Study,* Noumea, South Pacific Commission.

NASH, W. J. 1993. Trochus. *In:* WRIGHT, A. & HILL, L. (eds.) *Nearshore Marine Resources of the South Pacific.* Suva: Institute of Pacific Studies, Forum Fisheries Agency, International Centre for Ocean Development.

NEWIG, J., GUENTHER, D. & PAHL-WOSTL, C. 2010. Synapses in the Network: Learning in Governance Networks in the Context of Environmental Management. *Ecology and Society,* 15.

NEWTON, K., CÔTÉ, I. M., PILLING, G. M., JENNINGS, S. & DULVY, N. K. 2007. Current and Future Sustainability of Island Coral Reef Fisheries. *Current Biology,* 17**,** 655-658.

NOWLIS, J. S. & ROBERTS, C. M. 1999. Fisheries benefits and optimal design of marine reserves. *Fishery Bulletin (Washington D C),* 97**,** 604-616.

OLSSON, P., FOLKE, C. & BERKES, F. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management,* 34**,** 75-90.

OLSSON, P., GUNDERSON, L. H., CARPENTER, S. R., RYAN, P., LEBEL, L., FOLKE, C. & HOLLING, C. S. 2006. Shooting the rapids: Navigating transitions to adaptive governance of social-ecological systems. *Ecology and Society,* 11.

OREIHAKA, E. 1997. Freshwater and Marine Aquatic Resources in Solomon Islands. Honiara: Fisheries Division, Department of Agriculture and Fisheries.

OSTROM, E. 1990. *Governing the Commons: the evolution of institutions for collective action,* Cambridge, Cambridge University Press.

OSTROM, E. 2007. A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America,* 104**,** 15181–15187.

OSTROM, E., BURGER, J., FIELD, C. B., NORGAARD, R. B. & POLICANSKY, D. 1999. Revisiting the Commons: Local Lessons, Global Challenges. *Science,* 284**,** 278-282.

OSTROM, E., JANSSEN, M. A. & ANDERIES, J. M. 2007. Going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America,* 104**,** 15176-15178.

OTTO, T. 1997. Baitfish royalties and customary marine tenure in Manus, Papua New Guinea. *Anthropological Forum,* 7**,** 667-690.

PAJARO, M. G., MULRENNAN, M. E. & VINCENT, A. C. J. 2010. Toward an integrated marine protected areas policy: connecting the global to the local. *Environment, Development and Sustainability,* 12**,** 945-965.

PALOMARES, M. L. D. & PAULY, D. 2012. *SeaLifeBase* [Online]. World Wide Web electronic publication. Available: www.sealifebase.org [Accessed].

PANNELL, S. 1997. Managing the discourse of resource management: The case of Sasi from 'Southeast' Maluku, Indonesia. *Oceania,* 67**,** 289-307.

PAULY, D. 2006. Major trends in small-scale marine fisheries, with emphasis on developing countries, and some implications for the social sciences. *Maritime Studies (MAST),* 4**,** 7-22.

PAULY, D., CHRISTENSEN, V., DALSGAARD, J., FROESE, R. & TORRES, F. 1998. Fishing down marine food webs. *Science,* 279**,** 860-863.

PFISTER, C. A. & BRADBURY, A. 1996. Harvesting red sea urchins: Recent effects and future predictions. *Ecological Applications,* 6**,** 298-310.

PINHEIRO, J. C. & BATES, D. M. 2000. *Mixed-eVects models in S and S-Plus,* New York, Springer.

POLUNIN, N. V. C. 1984. Do traditional marine "reserves" conserve? A view of Indonesian and New Guinean evidence. *In:* RUDDLE, K. & AKIMICHI, T. (eds.) *Maritime Institutions in the Western Pacific.* Osaka: National Museum of Ethnology.

POLUNIN, N. V. C. & ROBERTS, C. M. 1996. *Reef Fisheries,* London, Chapman and Hall.

POMEROY, R. S. 1995. Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. *Ocean & Coastal Management,* 27**,** 143-162.

POMEROY, R. S. & BERKES, F. 1997. Two to tango: The role of government in fisheries co-management. *Marine Policy,* 21**,** 465-480.

PRESSEY, R. L. & BOTTRILL, M. C. 2009. Approaches to landscape- and seascape-scale conservation planning: convergence, contrasts and challenges. *Oryx,* 43**,** 464-475.

PRETTY, J. & WARD, H. 2001. Social Capital and the Environment. *World Development,* 29**,** 209-227.

RAMOHIA, P. 2006. Fisheries Resources: Commercially Important Macroinvertebrates. *In:* GREEN, A., LOKANI, P., ATU, W., RAMOHIA, P., THOMAS, P. & ALMANY, J. (eds.) *Solomon Islands Marine Assessment: Technical Report of the Survey Conducted May 13 - June 17, 2004.* Brisbane: The Nature Conservancy.

RASBAND, W. S. 1997-2012. ImageJ. Bethesda: U.S. National Institutes of Health.

RATNER, B. D., COHEN, P., BARMAN, B., MAM, K., NAGOLI, J. & ALLISON, E. H. in review. Governance of aquatic agricultural systems; analyzing representation, power and accountability. *Ecology and Society*.

REED, M. S., GRAVES, A., DANDY, N., POSTHUMUS, H., HUBACEK, K., MORRIS, J., PRELL, C., QUINN, C. H. & STRINGER, L. C. 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management,* 90**,** 1933-1949.

RIBOT, J. C. & PELUSO, N. L. 2003. A theory of access. *Rural Sociology,* 68**,** 153-181.

RICE, J. C. & GARCIA, S. M. 2011. Fisheries, food security, climate change, and biodiversity: characteristics of the sector and perspectives on emerging issues. *ICES Journal of Marine Science: Journal du Conseil,* 68**,** 1343-1353.

RICHARDS, A. H., BELL, L. J. & BELL, J. D. 1994. Inshore fisheries resources of Solomon Islands. *Marine Pollution Bulletin,* 29**,** 90-98.

ROBERTS, C. M., BOHNSACK, J. A., GELL, F., HAWKINS, J. P. & GOODRIDGE, R. 2001a. Effects of marine reserves on adjacent fisheries. *Science,* 294**,** 1920-1923.

ROBERTS, C. M., HALPERN, B., PALUMBI, S. R. & WARNER, R. R. 2001b. Designing networks of marine reserves: why small, isolated protected areas are not enough. *Conservation Biology in Practice,* 2**,** 10-17.

ROBERTS, C. M., MCCLEAN, C. J., VERON, J. E. N., HAWKINS, J. P., ALLEN, G. R., MCALLISTER, D. E., MITTERMEIER, C. G., SCHUELER, F. W., SPALDING, M., WELLS, F., VYNNE, C. & WERNER, T. B. 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science,* 295**,** 1280-1284.

ROBERTS, C. M. & POLUNIN, N. V. C. 1993. Marine Reserves - simple solutions to managing complex fisheries. *Ambio,* 22**,** 363-368.

ROUGHGARDEN, J., GAINES, S. & POSSINGHAM, H. 1988. Recruitment dynamics in complex life cycles. *Science,* 241**,** 1460-1466.

RUDDLE, K. 1994. External forces and change in traditional community-based fishery management systems in the Asia-Pacific Region. *Maritime Anthropological Studies,* 6**,** 1-37.

RUDDLE, K. 1998. The context of policy design for existing community-based fisheries management systems in the Pacific Islands. *Ocean & Coastal Management,* 40**,** 105-126.

RUDDLE, K. & AKIMICHI, T. 1984. *Maritime Institutions in the Western Pacific,* Osaka, National Museum of Ethnology.

RUSS, G. 1991. Coral Reef Fisheries: Effects and Yields. *In:* SALE, P. F. (ed.) *The Ecology of Fishes on Coral Reefs.* 1st ed. San Diego: Academic Press Inc.

RUSS, G. 2002. Yet Another Review of Marine Reserves as Reef Fishery Management Tools. *In:* SALE, P. F. (ed.) *Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem.* Amsterdam: Academic Press.

RUSS, G. R. & ALCALA, A. C. 1996. Marine reserves: Rates and patterns of recovery and decline of large predatory fish. *Ecological Applications,* 6**,** 947-961.

RUSS, G. R. & ALCALA, A. C. 1998a. Natural fishing experiments in marine reserves 1983-1993: community and trophic responses. *Coral Reefs,* 17**,** 383-397.

RUSS, G. R. & ALCALA, A. C. 1998b. Natural fishing experiments in marine reserves 1983-1993: roles of life history and fishing intensity in family responses. *Coral Reefs,* 17**,** 399-416.

RUSS, G. R. & ALCALA, A. C. 2003. Marine reserves: Rates and patterns of recovery and decline of predatory fish, 1983-2000. *Ecological Applications,* 13**,** 1553-1565.

RUSS, G. R. & ALCALA, A. C. 2004. Marine reserves: long-term protection is required for full recovery of predatory fish populations. *Oecologia,* 138**,** 622-627.

RUSS, G. R., STOCKWELL, B. & ALCALA, A. C. 2005. Inferring versus measuring rates of recovery in no-take marine reserves. *Marine Ecology - Progress Series,* 292**,** 1-12.

RUTTAN, L. M. 1998. Closing the commons: Cooperation for gain or restraint? *Human Ecology,* 26**,** 43-66.

SALE, P. F., COWEN, R. K., DANILOWICZ, B. S., JONES, G. P., KRITZER, J. P., LINDEMAN, K. C., PLANES, S., POLUNIN, N. V. C., RUSS, G. R., SADOVY, Y. J. & STENECK, R. S. 2005. Critical science gaps impede use of no-take fishery reserves. *Trends in Ecology & Evolution,* 20**,** 74-80.

SANDSTRÖM, A. & ROVA, C. 2010. Adaptive co-management networks: a comparative analysis of two fishery conservation areas in Sweden. *Ecology and Society,* 15.

SCHNEIDER, M., SCHOLZ, J., LUBELL, M., MINDRUTA, D. & EDWARDSEN, M. 2003. Building consensual institutions: Networks and the National Estuary Program. *American Journal of Political Science,* 47**,** 143-158.

SCHWARZ, A. M., BENE, C., BENNETT, G., BOSO, D., HILLY, Z., PAUL, C., POSALA, R., SIBITI, S. & ANDREW, N. 2011. Vulnerability and resilience of remote rural communities to shocks and global changes: Empirical analysis from Solomon Islands. *Global Environmental Change-Human and Policy Dimensions,* 21**,** 1128-1140.

SEN, A. 1983. *Poverty and Famines: An essay on entitlement and deprivation,* Oxford, Oxford University Press.

SILMMA 2009. Solomon Islands Locally Managed Marine Area Network Strategic Plan 2010-2014. Honiara.

SLUCZANOWSKI, P. R. 1984. A management-oriented model of an abalone fishery whose substocks are subject to pulse fishing. *Canadian Journal of Fisheries and Aquatic Sciences,* 41**,** 1008-1014.

SOLOMON ISLANDS NATIONAL STATISTICS OFFICE 1999. Census of population and housing. Honiara.

SOLOMON ISLANDS NATIONAL STATISTICS OFFICE, SECRETARIAT OF THE PACIFIC COMMUNITY & MACRO INTERNATIONAL INC 2009. Solomon Islands Demographic and Health Survey 2006-2007. *In:* COMMUNITY, S. O. T. P. (ed.). Noumea: Secretariat of the Pacific Community.

SOLOMON ISLANDS STATISTICS OFFICE 2006. Household income and Expenditure Survey 2005/6. National Report. *In:* SOLOMON ISLANDS STATISTICS OFFICE - DEPARTMENT OF FINANCE AND TREASURY (ed.). Honiara.

SPC 2012. Fish Aggregating Devices. *SPC Policy Brief* New Caledonia: Secretariat of the Pacific Community, Noumea.

STEPHENS, P. A., SUTHERLAND, W. J. & FRECKLETON, R. P. 1999. What is the Allee effect? *Oikos,* 87**,** 185-190.

STONER, A. W. & RAY-CULP, M. 2000. Evidence for Allee effects in an over-harvested marine gastropod: density-dependent mating and egg production. *Marine Ecology Progress Series,* 202**,** 297-302.

TAWAKE, A. & AALBERSBERG, W. G. L. 2002. Community-based refugia management in Fij. Suva: Institute of Applied Science, Faculty of Science and Technology, University of the South Pacific.

THORBURN, C. C. 2000. Changing customary marine resource management practice and institutions: The case of Sasi Lola in the Kei Islands, Indonesia. *World Development,* 28**,** 1461-1479.

UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS 2010. The Millenium Development Goals Report 2010. New York: United Nations Department of Econimic and Social Affairs.

VALDERRAMA, D. & ANDERSON, J. L. 2007. Improving utilization of the Atlantic sea scallop resource: An analysis of rotational management of fishing grounds. *Land Economics,* 83**,** 86-103.

VANCE-BORLAND, K. & HOLLEY, J. 2011. Conservation stakeholder network mapping, analysis, and weaving. *Conservation Letters,* 4**,** 278-288.

VUNISEA, A. 2008. The "culture of silence" and fisheries management. *SPC Women in Fisheries Information Bulletin,* 18**,** 42-43.

WEEKS, R., RUSS, G. R., ALCALA, A. C. & WHITE, A. T. 2010. Effectiveness of Marine Protected Areas in the Philippines for Biodiversity Conservation. *Conservation Biology,* 24**,** 531-540.

WEERATUNGE, N., PEMSL, D., RODRIGUEZ, P., LI, C. O., BADJECK, M.-C., SCHWARZ, A.-M., PAUL, C., PRANGE, J. & KELLING, I. 2011. Planning the use of fish for food security in Solomon Islands. Honiara: WorldFish Center.

WEIANT, P. & ASWANI, S. 2006. Early effects of a community-based marine protected area on the food security of participating households. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin,* 19**,** 16-32.

WHITE, C. & COSTELLO, C. 2011. Matching spatial property rights fisheries with scales of fish dispersal. *Ecological Applications,* 21**,** 350-362.

WHITTINGHAM, E., CAMPBELL, J. & TOWNSLEY, P. 2003. *Poverty and Reefs,* Exeter, IMM Ltd.

WILD, C., HUETTEL, M., KLUETER, A., KREMB, S. G., RASHEED, M. Y. M. & JORGENSEN, B. B. 2004. Coral mucus functions as an energy carrier and particle trap in the reef ecosystem. *Nature (London),* 428**,** 66-70.

WILLIAMS, I. D., WALSH, W. J., MIYASAKA, A. & FRIEDLANDER, A. M. 2006. Effects of rotational closure on coral reef fishes in Waikiki-Diamond Head Fishery Management Area, Oahu, Hawaii. *Marine Ecology-Progress Series,* 310**,** 139-149.

WILSON, S. K., FISHER, R., PRATCHETT, M. S., GRAHAM, N. A. J., DULVY, N. K., TURNER, R. A., CAKACAKA, A. & POLUNIN, N. V. C. 2010. Habitat degradation and fishing effects on the size structure of coral reef fish communities. *Ecological Applications,* 20**,** 442-451.

WORLD BANK 2004. Saving fish and fishers: toward sustainable and equitable governance of the global fishing sector. Washington: The World Bank.

WORLD HEALTH ORGANISATION. 2010. *Food Security* [Online]. World Health Organisation. Available: http://www.who.int/trade/glossary/story028/en/ [Accessed 23 January 2010].

WORLD RESOURCES INSTITUTE. 2007. *Earth Trends Environmental Information* [Online]. Available: http://earthtrends.wri.org/ [Accessed].

YORK, R. & GOSSARD, M. H. 2004. Cross-national meat and fish consumption: exploring the effects of modernization and ecological context. *Ecological Economics,* 48**,** 293-302.

ZERNER, C. 1994. Through a green lens - the construction of customary environmental-law and community in Indonesia Maluku Islands. *Law & Society Review,* 28**,** 1079-1122.

Appendices

Appendix 1 – Local governance fisher and key informant interview

Interviewer name:
Date:

Name:
Age:
Tribe:
Gender:

Fisher:	☐ Yes	☐ No		
Type of main fishing:				
How regularly:	☐> 1/WEEK	☐ 1/ WEEK	☐ 1/ MONTH	☐ 1/ YEAR
For (circle):	☐ FOOD	☐ MONEY	☐ BOTH	

LMMA DESCRIPTION AND TENURE – *BOUNDARIES AND MEMBERSHIP*

1. Does this village have an area of reef or sea here that is managed? *Lo hia iu fela garem eni eria lo rif or sea wea iufela lukafterem?*
   ☐ Yes ☐ No

2. How were the locations and borders of area decided? *Hao nao gogo iufala kamap wetem oketa eria en dat boundary ya?*

3. Who has the strongest access and use rights to this place? *Hu nao barava garem rait long dat/olketa eria(s) ya?*

4. How do they have these rights/How were these rights decided? *Hao nao hem garem dat rait?*

5. Who has other rights to this place? *Olketa hu moa samfala man wea garem rait lo disfala olketa eria(s) ya?*

6. How do they have these rights/How were these rights decided? *Hau nao hem/olketa garem dat rait?*

LMMA ESTABLISHMENT/RULES

7. Why was the marine managed area established here? What issues was it suppose to address or what situations was it supposed to avoid? *Why nao iufala kamap wetem disfala idea for lukafterem sea eria blo iufala? Wat nao okleta issues iufala laik fo adressim or what nao samfala situations iufala sapos fo avoidim?*

8. What are the rules that you use inside your management area? *Wat nao samafala rules wea iufala putim fo disfala/olketa eria(s) (lo sea of solwater or rif) iufala lukafterem ya? ** create list***

9. Do the rules apply to; *Waswe, olketa rules ya apply lo*: (** use list**)

E	**E**verywhere/*Barava everywhere lo Solomon islands*
SR	**S**ome **R**eefs only/*Samfala rifs lo disfala village nomoa, olketa wat kain rif*
AR	**A**ll **R**eefs here only/*Barava every rif lo disfala village*
ARSI	**A**ll **R**eefs in **S**olomon **I**slands/*Barava every rif lo samfala ples*
ARD	**A**ll **R**eef and **D**eepsea here/*Barava every rifs en olketa deepsea lo disfala village*
D	**D**eepwater only/ *Deep sea nomoa*

10. Who decided these rules? *Hu nao makem disfala rules?*

11. Are any particular rules especially important? / *Eni kain rule hem barava important too mus?*

12. What are three important reasons for looking after marine resources? *Wat nao samfela important risons fo lukafterem marine risosis?*

TABU AREA DESCRIPTION AND TENURE – *BOUNDARIES*

13. Is there a tabu'd marine area near this village? *Waswe, eni rif or sea wea hemi tabu?*
    ☐ Yes ☐ No

14. Who is allowed to fish in this/these area(s) during an opening? *Olketa hu nao allow for go fishing lo disfala eria ya taim iufala save openim eria ya?*

15. Tell me about the different kinds of rights people claim to this/these area(s) (lineage, affinal, other)? *Iu save talem me, wat kain right nao pipol save usim/garem for claimim eni eria (said lo line, clan or samfala way moa?*

16. How do they have these rights/How were these rights decided? *Hau nao hem/olketa garem dat rait?*

17. Who has the strongest rights to this/these area(s)? *Hu nao barava garem big/strong right lo eria ya?*

18. How do they have these rights/How were these rights decided? *Hau nao hem/olketa garem dat rait?*

TABU CLOSURE – OPERATIONAL RULES & HISTORICAL

19. Is there any type of fishing that can be done in the tabu area during a tabu closure? *Waswe, iufala save duim eni taip of fishing insaed dis fela eria tu taim area ya hem stap close/tabu?*

    ☐ Don't know ☐ No ☐ Yes, what kind? *Ya, wat kain type fising?*................................

20. Are there any species than can be taken from the area during a closure? *Waswe, taim eria stap close iufala save tekem eni kaen type fish from tabu eria ya nomoa?*

    ☐ Don't know ☐ No ☐ Yes, what kind? *Ya, wat kain type fish?*................................

21. Is there anything else (aside from fishing) that people are not allowed to do inside the tabu area during closure? *Waswe, eni nara activities tu wea pipol no allow fo duim lo disfala tabu eria ya taim hem stap close?*

	Before the partner came/ *Bifoa partner no kam yeti*	30 or so years ago/*Taim 30 years ago or barava bifoa kam yet*
22. Did this village use a taboo over reef or sea? *Waswe iu save usim taboo lo rif or sea?*		
23. How is the taboo you are using now different from...*Hau nao disfala tabu iu usim distaim ya hem*		

differen..		

24. Have people ever disagreed with the proposed closure? *Waswe olketa or samfela pipol no agree lo plan fo closem rif?*

☐ Don't know ☐ No ☐ Yes
↓
25. What has happened when they disagree? *Wat nao happen taem olketa no agree?*

TABU OPENING – OPERATIONAL RULES

26. Are there any types of fish or invertebrates that can NOT be taken when the tabu area is open? *Waswe, eni nara type fish or invertebrates (olsem sela, beche demer, crayfish etc) tu iufala NO ALLOW for tekem out from tabu eria ya taim hem open?*

27. Which fishing and fishing gears are used when the tabu area is open? *Wat kain fishing gear nao iufala save usim taim tabu eria ya open for iufala fishing lo hem?*

☐ Spear	☐ drop line fishing line	☐ gleaning/pick	☐ trap	☐ dynamite
☐ Net	☐ strike line	☐ kastom poison	☐ OBM	
☐ Diving glasses	☐ trolling	☐ Canoe	☐ new poison	

28. Are there any types of fishing and fishing gears that can NOT be used when the tabu area is open? If yes, why? *Waswe, eni nara type fishing technique and gears tu wea iufala MUST NO usim taim disfala tabu eria ya open? Wae nao iu no allow fo usim?*

☐ Spear	☐ drop line fishing line	☐ gleaning/pick	☐ trap	☐ dynamite
☐ Net	☐ strike line	☐ kastom poison	☐ OBM	
☐ Diving glasses	☐ trolling	☐ canoe	☐ new poison	

29. Are there any other limits placed on fishing when the tabu area is open (e.g. certain people cannot go, only men can go, only take 5 fish etc)? What are they? (as precisely as possible) *Waswe samfala samfela rules hem stap tu taim disfala eria hem open? (olsem samfela pipol hem no allow fo go, or only men nomoa save go, or takem 5 fish nomoa olsem) Wat nao samting ya?*

30. Why are there limits? *Wae nao iufela garem disfala rules?*

TABU CYCLE – OPERATIONAL RULES

31. What are the reasons that this area is tabu'd? *Wat nao samfala rIsons why iufala putim eni eria fo tabu?*

32. Who makes the decisions to open and close the area? *Hu nao save mekem decisions or garem right for openim or closim eni tabu eria?*

33. Who is responsible for declaring (telling the people) that the area has been opened or closed? *Waka or responsibility blo hu nao fo talem olketa pipol osem tabu eria ya hem open or close nao?*

34. What kind of power do they appeal to (use) when declaring the closure or opening (kastom, church, other)? *Wat kain power nao disfala man ya save usim fo talem out lo public osem eria ya hem close or open?*

35. What times and for what reason is the area closed to fishing? *Wat taims nao disfala eria save stap close and wat olketa reasons for closim eria ya from fishing lo hem?*

36. What times and for what reasons is the area open to fishing? *Wat taims nao disfala eria save open back moa fo fishing and wat nao reasons fo iufala openim eria back moa?*

COST OF MANAGEMENT

37. Did you have to move to a different fishing area during a closure?

Waswe, iu save move go lo nara different fishing eria tu taim tabu hem stat for close

☐ No ☐ Yes

↓

38. Compared to that closed fishing area is the new fishing area... *Sapos iu comparem disfala niu eria witem old eria hem;*

☐ closer ☐ further away ☐ the same distance
Kolsap farawe same distance nomoa

39. How did you feel about moving to a different fishing area?
Hau nao iu feel sapos iu have to move go lo nara differen fishing eria?

COMPLIANCE – *MONITORING RESOURCE USE and SANCTIONS and ACCOUNTABILITY*

---

40. Does anyone check if people are following the fishing rules in the management area? Who and how? *Waswe, eni wan save stap fo check tu if olketa pipol followem/obeym olketa fishing rules insaed disfala eria iu lukafterem ya? Hu nao save mekem olketa kain checks osem en hao hem duim disfala waka blo hem ya?*

41. Have you ever seen anyone fishing inside the tabu areas when it is closed? *Ui save lukim eniwan go fishing nomoa lo olketa erias wea hem tabu/close ya.*

☐ Yes ☐ No

42. Have you ever seen anyone fishing using gears or taking fish they were not supposed to when the area is opn? *En waswe, iu save lukim olketa pipol gohed nomoa fo usim samfala fishing gears or tekem samfala fish wea rules stopem/no allowem taem eria hem open?*

☐ Yes ☐ No

43. If yes, which rules and how are they breaking them? *Sapos hem true, wat kain fules nao olketa pipol ya brekem en hao nao olketa gohed fo brekem olketa rules ya?*

44. How many times in the past year? *Sapos iu save tinking back lo bifoa, hao many taims insaed one year nao olketa pipol been gohed fo brekem olketa kain rules olsem ya?*

45. What did you do after you saw them? *So wat nao iu duim taim iu lukim olketa brekem rules ya?*

____ confront them/*go lukim olketa stret*
____report them to village management committee member/*reportem lo village management komiti memba*
____report them to village chief or leader/*reportem olketa lo village sif*
____report them to the ones affected by the rule breaking (owner)/*reportem lo olketa owner blo resos or eria*
____tell friends/family/*talem olketa nara fren or family*
____report them to fisheries officer/*reportem olketa lo fisheries officer*
____report them to police/*reportem olketa lo polis*
____Other/*eni nara samting*
____nothing /*no entiting*

↓

45. If you did not report them, why not? *Sapos iu natin reportem olketa nomoa, why nao iu duim olsem?*

46. What happens to a person if they break the rules? (If punishment, by who?) *Wat nao save happen lo eni one wea hem brekem olketa rules ya? Sapos bae hem punis, who nao bae panisim hem?*

47. What sort of power do they appeal to when imposing sanctions for breaking rules the closure (kastom, church, other)? *Wat kain power (olsem lo saed lo kastam, or church or law or nara kaen type power) nao olketa man save usim lo hem sapos olketa putim punisim taim olketa man brekem kain rules olsem ya?*

48. What happens if a person breaks the rules a second time, or more than twice? *Wat nao bae save happen lo eniwan wea hem brekem olketa rules ya fo second taim moa or barava staka taim?*

49. Why do you think some people break the rules? Why do you think others don't? *Wat nao thinktink blo iu, why nao samfala pipol olketa brekem rules ya en why nao samfala no laik brekem nomoa?*

50. What types of people break rules? *Wat kaen type pipol noa save brekem rules?*

FUTURE - *PRESSURE, FLEXIBILITY, ROBUSTNESS, NON-COMPLIANCE*

---

51. Have the planned times of opening the tabu been changed because someone or the village needed cash or food for a feast, school fees or another reason? *Waswe, olketa taim iufala save planim fo openim disfala tabu eria ya save change tu taim iufala lukim olsem samfala man or olketa pipol lo village nidim seleni or kakai fo feast, school fees and/or samfala moa reasons?*
    ☐ Don't know ☐ Yes ☐ No

GOVERNANCE- *COLLECTIVE CHOICE*

---

52. Is there a committee, group or person ultimately responsible for the marine managed area? Who? *Waswe eni komiti fo lukafterem marine eria blo iufala?*

53. What are their responsibilities? *Wat nao waka blo olketa komiti or disfala man?*

54. How was membership decided? (e.g. village leaders, educated people, any interested person). *Hau nao bae olketa become members? (Olsem hem big man, or educated man, or eniwan save sapos hem garem interest)*

55. How are members of the community made aware of the marine managed area (fishing rules, tabus, updates)? *Hau nao komuniti olta awares olketa rules long fishing en tabu ples?*

56. How are the community involved in meetings, consultations - # of community? *Hao nao komuniti involved long olketa meeting olta marine erias iufela lukafterem? Hao meni pipol save involve?*

58. In addition to committee, who else can contribute to making decisions about marine resource management? *Hu moa samfela pipol wea save contribute long mekem decision about marine risos blong iufela apart from komiti?*

Appendix 2 – Local governance focus group

Group (men, women, male youth, female youth):
Number in Group:
Facilitator:
Notes on group dynamic:

LMMA ESTABLISHMENT

1. Why was the marine managed area established here? What issues was it suppose to address or what situations was it supposed to avoid? *Why nao iufala kamap wetem disfala idea for lukafterem sea area blo iufala? Wat nao okleta issues iufala laik fo adressim or what nao samfala situations iufala sapos fo avoidim?*

2. Did your village seek assistance outside the village to address these problems? *Waswe iufala been lukoutim samfala help/assistance from outside lo village blo iufala tu fo lukafterem rif en solwater?*

☐Don't know ☐ No ☐ Yes, who from? *Hu nao helpem iufala?*...............
↓
3. Why from them? *Why nao iu choosem olketa____?*

....

4. Why did your village seek help? *Why nao iufala askem help lo outside komuniti blo iufala? JOIN WITH BELOW*

5. Do you think the community could have dealt with these problems themselves? If not, why not? *Waswe iu fala save fixem sileva? Sapos nomoa, why?*

LMMA RULES

6. What are the rules that you use inside your management area? *Wat nao samfala rules wea iufala putim fo disfala/olketa eria(s) (lo sea or solwater or rif) iufala lukafterem? **create list***

7. Do the rules apply to; *Waswe, olketa rules ya apply lo*: (** use list**)
   E **E**verywhere/*Barava everywhere lo Solomon islands*
   SR **S**ome **R**eefs only*/Samfala rifs lo disfala village nomoa, olketa wat kain rif*
   AR **A**ll **R**eefs here only/*Barava every rif lo disfala village*
   ARSI **A**ll **R**eefs in **S**olomon **I**slands*/Barava every rif lo samfala ples*
   ARD **A**ll **R**eef and **D**eepsea here/*Barava every rifs en olketa deepsea lo disfala village*
   D **D**eepwater only/ *Deep sea nomoa*

8. Who decided these rules? *Hu nao makem disfala rules?*

9. Are any particular rules especially important? / *Eni kain rule hem barava important too mus?*

10. What rules work and don't work? And why (i.e. not enforced, political, cultural) **use list** *Wat nao olketa rules wea waka en olketa wea hem no waka?*

11. What are the differences in what the village is doing when fishing or looking after marine resources compared with what you did before? ** *use the list to see what rules were in place at these times***Wat nao samfala olketa differences lo hao iu lukafterem risosis taim iu comparem wat iu duim today en wat iu save duim kam lo bifoa?*

    a) Before the partner came/ *taim bifoa wanfala partner kam*
    b) 30 or so years ago / *taim 30 years ago or barava bifoa kam yet*

12. What are three important reasons for looking after marine resources? *Wat nao 3 fela important risons fo lukafterem marine risosis?*

**** If Q. 1 is extensive then use that info and don't repeat. If they only ave one reason then remind them of that and ask if there are other reasons.*

GOVERNANCE- *COLLECTIVE CHOICE*

There is a committee here for managing the marine area.....*

13. How are members of the community made aware of the marine managed area (fishing rules, tabus, updates)? *Hau nao komuniti olta awares olketa rules long fishing en tabu ples?*

14. How are the community involved in meetings, consultations - # of community? *Hao nao komuniti involved long olketa meeting an decisions olta marine erias iufela lukafterem?*

15. Is there any conflict among committee members of between committee members and other members of the community? *Waswe eni conflict bitwin komuniti en olketa members lo komiti or bitwin olketa komitis?*

↓

16. If yes, does it affect the work of the committee or the management of the marine area? *Sapos ya, hao, affectem nao waka blo komiti or waka blo komuniti lo said lo marine risosis?*

17. Who else can contribute to making decisions about marine resource management? *Hu moa samfela wea save contribute long said long decision long marine risosis?*

TABU - HISTORICAL CYCLE

	Before the partner came/ *Bifoa partner kam*	30 or so years ago/*Taim 30 years ago or barava bifoa kam yet*
18. Did this village use a taboo over reef or sea? *Waswe iu save usim taboo lo rif or sea?*		
19. Have the reasons for closing and opening changed compared with now? Why and how? *Waswe, olketa risons fo close and open lo erias ya change tu taim iu comparem taim lo bifoa and taim today? Why (en hao) nao hem change?*		
20. How is the taboo you are using now different from... *Hau nao disfala tabu iu usim distaim ya hem differen..*		
21. What were the reasons for opening and closing in the past? *Lo taim bifoa wat nao samfala risons why pipol closim en openim olketa tabu erias?*		

22. Compare the duration of closure – rank 1=closed for the longest period to 3=closed for the shortest period. *Iu save comparem taim eria ya stap close insaed melewan rank 1=taim eria ya stap close fo barava long taim en givem/rank 3= taim eria ya stap close fo short taim nomoa*
    __ Now/*Lo distaim*
    __ Prior to partner engagement or 5 years ago/*Bifoa iufala waka todega wetem partner*

__ 30 or so years ago/*Taim 30 years ago nao or barava bifoa kam yet*

*** Don't use this format, just compare the lengths of duration they tell you

23. Compare the frequency of closure – rank 1=closed most often to 3=closed least often. *Iu save comparem/talem kam hau meni taims nao disfala eria ya save stap close melewan rank 1+ staka taim hem save stap closeolowe en rank 3= hem save stap close for samtaims nomoa*

    __ Now/*Lo distaim*

    __ Prior to partner engagement or 5 years ago/*Bifoa iufala waka todega wetem partner*

    __ 30 or so years ago/*Taim 30 years ago nao or barava bifoa kam yet*

***These will probably be the same, just use an eg like so not it is 1/year, how about before 1/year or 1/10 years…

FUTURE - *PRESSURE, FLEXIBILITY, ROBUSTNESS, NON-COMPLIANCE*

24. Have the planned times of opening the tabu been changed because someone or the village needed cash or food for a feast, school fees or another reason? *Waswe, olketa taim iufala save planim fo openim disfala tabu eria ya save change tu taim iufala lukim olsem samfala man or olketa pipol lo village nidim seleni or kakai fo feast, school fees and/or samfala moa reasons?*

    ☐ Don't know ☐ No ☐ Yes, what kind of situation/*why nao hem happen?*

    **** push for benefits communal or personal, what kind of occasions, in 2010 # times this happened, durations, who can fish, how many fishers…*

25. If there were more people in the village in the future do you think tabu areas might [FREQUENCY]....*Sapos lo taim bae kam/future wea pipol lo village barava staka tumas, waswe iu think bae olketa tabu erias ya bai still;*

    ☐ open more often/*open staka taim*

    ☐ open the same/*open semsem nomoa*

    ☐ open less often/*open lelebet taim no nomoa*

    ☐ permanently closed/*barava close olowe*

26. If there were more people in the village in the future do you think tabu areas might [DURATION]........*Sapos lo taim bae kam/future wea pipol lo village bae barava staka tumas waswe, iu think bae olketa tabu erias ya bae still;*

    ☐ open for a longer period of time/*Open fo staka/lelebet long taim*

    ☐ open the same period of time/*open semsem taim nomoa*

    ☐ open for a shorter period of time/*bae open for short taim nomoa*

    ☐ permanently open/*barava open olowe*

27. If school fees increased in the future do you think tabu areas might [FREQUENCY]....*Sapos skul fee blo olketa pikinini blo iufela go high moa lo future waswe iu think bae olketa tabu eria ya bae still;*

    ☐ open more often/*open staka taim*

    ☐ open the same/*open semsem nomoa*

    ☐ open less often/*open lelebet taim no nomoa*

    ☐ permanently closed/*barava close olowe*

28. If school fees increased in the future do you think tabu areas might [DURATION]....Sapos skul fee blo olketa pikinini ya go high moa lo future waswe iu think bae olketa tabue erias ya bae still;

    ☐ open for a longer period of time/ *Open fo staka/lelebet long taim*

    ☐ open the same period of time/*open semsem taim nomoa*

    ☐ open for a shorter period of time/*bae open for short taim nomoa*

    ☐ permanently open/*barava open olowe*

29. Do you think in the future; *Waswe iu tink ota samting bae hem happen lo future? ** use list prepared***

	XX	X	√	√√
	Very unlikely	Won't happen	Could happen	Very likely
	Barava no save happen	Bae hem no save happen	Bae save happen	Barava happen
School fees increased/Skul fee go high	☐	☐	☐	☐
Other demands for cash increase/Nara kaen need for bae seleni hem go high	☐	☐	☐	☐
More people in the village/staka pipol lo village	☐	☐	☐	☐
There could be conflict in the village/conflict or difference lo village	☐	☐	☐	☐
External fishers/staka pipol lo outside kam fishing	☐	☐	☐	☐
Partner leaves/Partner hem lusim iu	☐	☐	☐	☐
New village leader/Niu big man lo village bae hem kam	☐	☐	☐	☐
Climate change damage to reefs/ Climate change bae spoilem reef	☐	☐	☐	☐

Any other reasons........

30. What do you think would happen to compliance with fishing and marine resource use rules if..../ *Waswe pipol bae hem save follwem rules saed lo fishing en marine risosis lo disfala situation....*

	Stronger Followem gud	Same Semsem	Weaker No followem
School fees increased/Skul fee go high	☐	☐	☐
Other cash demand increase/Nara kaen need for seleni hem go high	☐	☐	☐
More people in the village/staka pipol lo village	☐	☐	☐
There could be conflict in the village/conflict en different lo village	☐	☐	☐
External fishers/staka pipol lo outside kam fo fishing insaed eria blo iu	☐	☐	☐
Partner leaves/Partner hem lusim iu	☐	☐	☐
Niu village leader/Niu big man lo village bae hem kam	☐	☐	☐

A new partner came/Niu partner bae hem kam	☐	☐	☐
Climate change damage to reefs/climage change bae spoilem reef	☐	☐	☐

31. Why do you think compliance would change (as indicated above)? *Wat nao tinktink blo iufela, wae nao disfala changes bae hem happen? *** This should come during questions 30 for each one*

Appendix 3 – Catch record sheet

Your initials	Date	Fishers Name & village	M/F	# Fishers	Start- Finish time 24:00	Vessel (no boat, canoe, OBM__hp)	Fuel L	Fishing location	Area=lagoon/reef flat/reef edge/deep/FAD	Always or tabu open?	Landing location	Fishing Method/Gear (depth)	Fish/Invert Name	#	Total weight	F	S	G	T	Photo ID

Initials	Date	Fishers Name & Village	M/F	# Fishers	Start - Finish time (24:00)	Vessel (no boat, canoe, OBM__hp)	Fuel L	Fishing location	Area=lagoon/reef flat/reef edge/deep/FAD	Always or tabu open?	Landing location	Fishing Method	Fish/Invert Name	#	Total weight	F	S	G	T	Photo ID
PJC	31/10/2010	Jon Smith/Kolo		1	1300 - 1700	canoe	0	Tibitibi reef	reef edge	tabu open	Paramata	Spear	Bubuku	4		√				
													Sindau	7		√				
									reef flat			Snorkelling	Trochus	3			√			
														14	5.5kg					001 and 002
PJC	1/11/2010	Steve Moana/Sia		1	1700- 2100	OBM 15HP	12	Kilezaru reef	reef edge	Always open	Tiberius	Drop line	Samboka	4		√				
								Out from Kilezaru	deep			troll	Silver Trevally	2		1	1			
														6	8kg					003
PJC	2/11/2010	Simon Smith		1	1-									0						

1. Record the name of the person collecting the data using initials
2. Name, village and gender
3. The number of fishers that helped to catch the fish you are recording - if they have not mixed their catch then record them separately
4. Use 24 hour time!
5. Record the boat type or 'none' of they did not use a boat. If they used an OBM record its' horse power.
6. Make sure the name of the fishing location is on the map - if not, add it to the map so we know wherre it is later
7. If they were fishing in deep water, away from reefs then you must record this data on a new line - not mixed with reef fishing!
8. Is the reef one that is always open, or is it a tambu reef that has been open for fishing this time
9. If they used many methods, record the appropriate method next to the catch
10. Record all the types and numbers of catch by extending this list. If you don't know its name write unknown and a short description
11. Number of fish or invetebrates of that type
12. For each trip you record, rule off and summarise the trip with the total number of animals and total weight of catch
13. Tick if the catch is for food (F), sale (S), Gift (G) or trade or barter (T). If it is a mixture write the number of each fish in each category
14. You must take one or many a photos to record all the catch - record the number of the photo as recorded by the camera
15. If a fisher catches nothing it is important to record that too!
16. NAMES - use the local name, common name or scientific name recorded on the fish name sheet. If that type of fish is not on the list yet then add it to the bottom of this list. and make sure that Pip knows to update the main list later
17. PHOTO - spread the catch out on the piece of plastic & stand directly over the mat to take your photo - make sure the label is in the photo. Repeat this if there are too many fish to fit on the mat once.
18. If you have any important notes or comments from the fisher put them underneath once you have recorded all the details and then rule off under that.

Appendix 4 – National social networking qualitative interview

Knowledge Sharing and Social Learning Survey – National SILMMA partners

	BACKGROUND					
1	Name					
2	Organisation					
3	Position in Organisation					
4	Description of your role					
5	Highest level of education					
5	Gender					
6	Describe your association with Solomon Islands...	Locally based Solomon Islander	Expat based in Solomon Islands	Expat based abroad	Solomon Islander based abroad	other
7	Type of organisation you work for? (circle one)	University	Gov't	International NGO	Local NGO	NGO Regional
8	What broadest geography does your organisation serve? (circle one)	International	Pacific region	Solomon Islands	Province	Village
9	How many people work for your organisation in marine resource management in Solomon Islands					
10	How many years have you worked in Solomon Islands in marine resource management?					
11	How many years have you worked in Solomon Islands in marine resource management for the current organisation?					
12	How many years has your organisation been involved in Solomon Islands in marine resource management?					
13	What are the priorities of organisation (**ranked** from 1 highest priority down to 5 for lowest priority, place a zero for not at all):	Research	Social Development	Economic Development	Habitat & Biodiversity Conservation	Fisheries Management
	If other (please describe)					
14	Your preferred source of formal organisation description:					
15	Do you (personally) engage directly with Solomon Island communities/villages for Marine Resource Management? (yes or no)					

16	Do you think the engagement of your organisation improves coastal fisheries resources in these communities and villages?					
	MEASURES AT SITES					
17	Which villages, regions (LMMA) etc? Think about up to four sites that you are most familiar with. List them here and then answer the following questions for each site.					
18	How did you or your organisation select these villages/regions to work with?					
19	What are your priorities of engagement at each village/region - ranked 1 (most) to 5 (least), place a zero for not at all	Research				
		Social Development				
		Economic Development				
		Habitat and Biodiversity Conservation				
		Fisheries Management				
	Other (please specify)					
20	What marine resource management measures are employed at sites you engage with? Tick for employed - leave blank if not employed.	permanent area closure				
		non-permanent area closures				
		harvesting limits				
		size limits				
		gear restrictions				
		Species restrictions				

		access controls				
		alternative livelihoods				
		other approaches (please specify)				
21	What best describes the origin of resource use rules applied at sites	Traditional - reinforced				
		Traditional - Contemporary Hybrid				
		National regulations enforced locally				
		Contemporary locally derived rules				
		Contemporary rules				
		Other				
22	Respond to this statement - Contemporary marine resource and fisheries management science forms the basis of design of resource use rules at sites you work in	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
23	Respond to this statement - Local (site specific) traditiions and knowledge form the basis of design of marine/fisheries resource use rules at sites you work in.	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
	Thoughts…					

	NETWORKING					
24	Where do you predominantly receive information about successful (best/better practice) or unsuccessful/less successful approaches to marine resource management - ranked 1 (most) up to 5 (least) and 0 (not at all)	Within Organisation Internationally	Within your organisation in Solomons	Other Organisations/individuals in Solomons	Other organisations internationally	Learning by doing at sites in Solomons?
	Other or Notes					
25	What is the frequency of your organisations collaboration with others organisations to implement marine resource management in Solomon Islands? (excluding donors) Circle the most appropriate response.	All projects/ work collaborative	3/4 of work/projects are collaborative	Around half of projects/work are collaborative	Around 1/4 projects/work are collaborative	No projects/work are collaborative
26	If you work in a collaborative way, is there one key organisation that you work with most often or most intensely? Yes or no (which one)					
27	**(If one main partner then..)** If you excluded your one main partner what is the frequency of collaboration with others organisations to implement marine resource management in Solomon Islands? (excluding donors) Circle the most appropriate response.	All projects/ work collaborative	3/4 of work/ projects are collaborative	around half of projects/ work are collaborative	around 1/4 projects/ work are collaborative	No projects/ work collaborative
28	Refer to table below, column 1 - to identify the organisation you work with.	See TABLE sheet, column 1				
	RECEIVE INFORMATION					
29	From which organisations have you **received** new ideas or information that has helped increase the success of your efforts in marine resource and fisheries management	See TABLE sheet, column 2				

30	From column 2, referring to the organisations you ranked with a 1 or a 2, can you provide an example of where information from another organisation or person working in Solomon Islands nearshore marine resource management has influenced **your approach** to nearshore marine resource management - including how your engagement or management (rules) were altered, and the geographic areas that were involved, the type of information and the reason the information was influential.					
31	How do you receive information that has been useful or influential for your apporach to nearshore marine resource management - ranked 1 (most) to 5 (least), 0 for not at all	Informal Commun ication	Formal meetin gs and worksh ops	Written Public Report	Scientific Journal Publicatio n	Websites (not downloaded reports)
	PROVIDE INFORMATION					
32	To which organisation working in Solomon Islands have you **provided or** given new ideas or information that has influenced the approach and helped increase the success of that agencies efforts in marine resource or fisheries management	See TABLE sheet, column 3				
33	From column 3, referring to the organisations you ranked with a 1 or a 2, can you provide an example where information from you or your organisation has influenced the approach to nearshore marine resource management of another organisation - including how their engagement or management (rules) were altered, and the villages that were involved the type of information and the reason the information was influential.					
34	How have you predominantly provided information on about marine resource management - successes and failures - ranked 1 (most) to 5 (least), 0 for not at all	Informal Commun ication	Formal meetings and worksho ps	Written Public Report	Scientific Journal Publicatio n	Websites (not downloaded reports)
	INFORMATION IMPACT					

35	Have rules employed at sites you are involved in changed since first LMMA implementation?					
36	When thinking of situations where rules have changed since first implementation what has been the reasons for those changes?					
37	If new information or knowledge has played a role where has this information predominantly come from? ranked 1 (most) to 5 (least), 0 for not at all	Within Organisation Internationally	Within organisation locally	Other Organisations/individuals locally	Other organisations internationally	Learning by doing at sites?
38	Has information you have received relating to marine resource management, influenced the approach you now support or rules you promote at sites?					
	NATIONAL SCALING					
39	Do you think information sharing between marine resource management organisations working in Solomon Islands promotes improvements in marine resource management in Solomon Islands?					
40	Do you think information developed and provided by the Solomon Islands network of marine resource management organisations can influence national or regional policies?					
41	Has information you have provided influenced national or regional policies? If yes which policies?					
42	If yes to above, what types of information have been influential?					
43	Do you intend to expand and extend your nearshore marine resource management engagement into new geographic areas?					

44	How will your organisation select which new areas/villages to work with?					
45	Why have communities sought your organisations advice and support to implement marine resource management?					
	FORMAL NETWORKING					
46	Are you a member of SILMMA?					
47	If yes, what are the main goals of your membership to SILMMA? Please be as specific as possible.					
48	What information sharing forums, venues or mechanisms do you most value for sharing lessons learned?					
49	Who are the individuals in these organisation, that you consider to be the key facilitators of exchange of information relating to nearshore marine resource management?	See below Table, column 6				
50	Describe your usage of the following information sharing forums to gain information. If you are not aware of one, please select this and I will give you its location or details after the interview is finished. Tick the most appropriate selection for each list below.	Regularly rely on to get information	Sometime use to get information	Unaware of	Aware of but don't use	
	ReefBase Pacific					
	Solomon Islands Information Network					
	SILMMA meetings					
	SPC digital library					
	PROCFish information portal					
	PIMRIS Ocean Portal					
	Meetings (non-SILMMA)					
	Western Solomons Research database					
	Pacific Environment Information Network (PEIN-SPREP)					
	Pacific Islands Marine Resource Information Network (PIMRIS - USP) MOANA DATABASE					
	Other (please specify)					
	FUTURE NETWORKING					

51	Do you feel marine resource organisations in Solomon Islands respond and adapt to new marine resource management infomation from practitioners in other organisations ? Why or why not?	
52	Do you feel there are sufficient structures and systems to share lessons learned in marine resource management? Why or why not?	
53	Do you feel there are sufficient opportunities to share lessons learned in marine resource management? Why or why not?	
54	How should opportunities be created or supported to optimize information exchange (relating to nearshore marine resource management)?	
55	Do you feel people working in Solomon Islands in marine resource management put adequate effort into sharing (giving and obtaining) lessons learned? Why or why not?	

Appendix 5 – National social networking quantitative interview

TABLE	COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4
	collaboration	information exchange	Give Information	Key contacts
Consider your own personal experience working for your current organisation. **1 strongly agree, 2 agree, 0 disagree**	My agency has well developed collaborative working relationship with …	My organisation has gotten new ideas or information that has influenced approach of my **organisations** marine resource and fisheries management efforts from …..	I (or my organisation) have given new ideas or information that has influenced the approach and helped increase the success of **other agencies** marine resource and fisheries management efforts to…	Who are the **key individuals,** in or out of Solomons, that you value most highly for receiving marine resource information from?
Foundation of Peoples of the South Pacific International (FSPI)				
WorldFish Center				
The Nature Conservancy (TNC)				
WWF				
Conservation International (CI)				
Secretariat Pacific Regional Environment Programme (SPREP)				
University of the South Pacific (USP)				
Secretariat of the Pacific Community (SPC)				
Solomon Islands Development Trust				
Roviana Conservation Foundation				
Environmental Concerns Action Network of the Solomon Islands (ECANSI)				
Tetepare Descendants Association				
Live and Learn				
NZAid Fisheries Project				
Ministry of Fisheries and Marine Resourses				

Ministry of Environment and Conservation				
University of Queensland				
James Cook University				
University of Bergen, Bergen Pacific Studies Research Group				
University of Waikato				
Australian National University				
South Pacific Applied Geoscience Commission (SOPAC)				
Forum Fisheries Agency (FFA)				
Pacific Horizons				
Malaita Provincial Government				
Central Province Government				
Western Province Government				
XX Province Government				
other…..				
other…..				
other…..				

Appendix 6 – Social networking local partner interview

	Name:	
	Gender:	
	Approx age:	
	Village:	
	Home village:	
1	Are you a fisher? (prompt detail of activities, level of reliance, and frequency of fishing)	Iu save go fishing tu?
	UPTAKE	
2	Does this village have an marine managed area? What is the name of that area?	Iu garem eni eria lo solwater or rif wea iu fela save or community blo iu save luk aotem or managem, lo dis fela ples? Wat nao nem blo dis fela eria?
3	How did this area come about?	Iu save stori lele bit, hau nau dis fela management eria hem stet? Samfala lo iufala lo vilij, o samfala long olketa NGO or gavman helpem iu fela fo statem?
4	For what reasons did you/this village establish a marine managed area?	Wat nao olketa reasons for garem management area? Wae nao iu fela decide fo havem management eria overem sol water en rif blo iu?
5	Were there any problems or issues with your reef or sea water area that made you decide to establish marine managed area?	Bifoa iu fela statem dis fela management eria iu fela lukim eni problem or rubbish someting, das de wae iu putem management eria?
6	Did you think that there would be any positive outcomes from establishing a marine managed area?	Waswe bifoa management eriu iu tink enu gud someting bae save kam out from putem management area?
7	Did any one from outside the village help you establish the marine managed area?	Hau, eni wan from nara ples hem helpem iu witem dis fela management eria ya?
8	Who helped you established the marine managed area	Hu nau helpem iu fo statem up management area?
9	Did you think that there would be any positive outcomes from working with the people assisting you in establishing the managed area?	Wanem kaen benfit iufala tingim bae hemi kam long disfala waka item NGO or gavemen hu helpem iu? Iufala tingim fis an troka nomoa or samfala nara kaen benefit tu?
10	What is difference about management used now compared with the way you did things before?	Iu talem kam hao disfala tambu en rules blo fising iufala iusim distaem long projek hemi difren long olketa tambu iufala iusum bifoa.
11	Why are you not just using the way you did before?	Wae nau dis taem iu fela usem niu kaen tabu and rules blo fishing? Wae nau iu fela no iusim kaen tamby and rules blo fishing long befoa?
	INFORMATION FLOW	
12	Have you heard about marine managed areas in other regions in Solomon Islands or other countries?	Iu save eniting aboutem managed eria lo solwata or rif story tu? or management area lo solwata or rif lo nara ples insaed lo Solomon Islands or eni nara ples?
13	What have you heard?	Wat kaen samting iu hearem?
14	How did you hear about these things?	Hau nau iu hearem dat fela someting?

15	Have you visited any of these management areas?	Iu go lukim olketa management eria?
16	Did you or your community learn anything or borrow anything from these other places when designing an implementing your marine managed area?	Iu save learnem enisomting from olketa nara ples dat iu fela putem insaed lo managemen eria lo solwata en rif blo iu?
	INCLUSION	
17	Do you have a management committee for that marine managed area?	Iu garem komiti lo managemen eria blo dis fela ples tu?
18	Are you a member of the manage management committee? If yes what is your position?	Iu memba blo dat fela committee tu? Wat nao waka blo iu lo komiti?
19	Are you a resource owner, outside your committee responsibilities? Is this a traditional/customary role? What is your role?	Hau, iu nau ownem ples blo solwata Lo saed lo kastom ya? Hau nau iu luk aftaem?
	RULES IN USE	
19	Who is in charge of the marine managed area?	Hu nau luk afterm dis fela managemen eria lo hia?
20	What rules do you have in place in the marine managed area?	Wat nao sam fela rules blo iu fela lo dis fela managemen eria ya? (see table)
21	Is there anything a fisher should or shouldn't do?	Hao, anything moa olketa fisherman or fisherwoman save duim or no duim?
	INFLUENTIAL INFORMATION & LEARNING	
22	What information did you use to design rules? (SEE LIST - each rule)	Lo keta rules ya, iu save doem bicos lo kastom no moa or hau? Wat nau rison lo olketa rules iya? SEE LIST
23	(What info and where from? Are they kastom rules or new? Or a mixture? (SEE LIST - Each rule)	Wea nau iu takem tingting blo olketa rules? Hem kastam one or hem jes stat no moa? Or Hem mix witem kastom en niu wan? SEE LIST
24	Did anyone assist you in making these rules?	Eniwan helpem iu fela for straightem olketa rules ya?
25	Who did you receive advice and assistance from for rule formation?	Hu nao givem advice en hu noa helpem iu for straightem olketa rules ya?
26	Have you communicated with anyone for assistance with making or changing these rules? SEE ORGANISATION LIST	Eni wan telem iu fela or iu askem help lo olketa nara pipol fo helpem iu lo saed lo makem or straigtenem olketa rules ya? Eni wan lo dis fela list wea bae me readem kam iya? SEE ORGANISATION LIST
27	Were your ideas/experiences and the ideas/experiences of the rest of the village considered in the rules that were decided upon?	Everi tingting blo iu fela everiwan nau go insaed olketa rules iya? Ui timkem olketa rules dis taem hem showem tingting blo iu fela everiwan?
28	Did your knowledge of the environment and your resources influence the formation of rules?	Hau, no gogo olta rules hem kam about, iu fela usem sae blo iu fela marine environment lo olta risosis fo mekem ota rules?
29	Are you aware of any national fishing regulations?	Iufala save eni rul long fiseri long gavman long Solomon? Iu save telem kam? [Maybe prompt about easy things like banned species - clams, turtles…]
30	Are these national fishing regulations known and respected here?	Hao olketa lo dis ples save national fishing regulations tu? Hao olketa save followem too?

31	Did you include some national fishing regulations in your rules? Which ones?	Iu fela putem eni rules blo national fishery law insaed witem olketa rules blo aria ya? Which wan nau lo olketa rules ya?
	MONITORING	
32	Do you conduct monitoring related to your marine managed area	Iu fela garem monitoring programme lo management area lo solwata en rif tu?
33	What forms of monitoring do you conduct?	Wat nau olketa moniutoring activity blo iu fela?
34	When and why do you conduct monitoring?	Wat taem nau iu save go fo doem monitoring? Wae nau iu laek fo monitoring?
35	Do you report changes in the resource status to anyone? i.e. physical condition of the fish and waters in your LMMA?	Suppose iu lukim ani changes or any niu someting, iu save telem eni wan tu? Hu nao bae iu reportem any changes lo something insaed lo solwata or out from monitoring?
36	How often have you communicated with these organisations about the state of your resources?	Eni taem iu toktok witem olketa pipol or organisation aboutem olketa risosis blo iu fela. Hau (OPTIONS)
37	How did you or will you report changes?	Hau nau iu reportem changes or someting out from monitoring?
	ADAPTATION	
38	Have rules changes since they were first put in place? Did you add any new rules or change any old ones? SEE LIST	Hau, since taem iu fela statem management plan lo disfela ples, eni taem after iu fela senisem eni rule? Which fela rules iu senisem and why?. SEE LIST
39	Why did they change?	Wae nao hemi change?
40	What rules work and don't work? SEE LIST	Waswe lo olketa rules blo iu fela ya? Which rule nau hemi waka en which wan hemi no waka? SEE LIST
41	Why do they work or not work? SEE LIST	Wae nau hem waka en wae nau hem no waka? SEE LIST
42	What situations do you foresee might make you change rules? And why?	Waswe lo tinktink blo iu, iu lumkim lo future bae garem need fo changem samfela lo olketa rules or Or bae iu stae witem saem wan no moa? Wae nao bae hem change or wae nao bae hem olsem?
43	What is the process for changing these rules? e.g. would you need to hold a meeting?	Hau nao iu fela go aboutem suppose iu fela changem sam fela lo olketa rules ya? Wat nau iu fela duim? Olsem iu fela garem need for meeting?
44	When rules changed did you use that process or another way (what forms of adaptation happen anyway)?	Hau, taem rules changem iu fela usem dat fela process or different waes iu fela usem?

Appendix 7 - Chapter 5 supplementary methods

1.1 Respondent selection

Selection of interview respondents was based on the criteria that individuals were an employee or affiliate of the identified SILMMA member agencies. I tended to identify more senior staff but to verify that they were knowledgeable about "ground-level" partnerships I asked respondents "Do you personally engage directly with Solomon Island communities/villages for marine resource management?" All respondents answered yes to this questions apart from the national government fisheries agency which noted that they do this via partnerships with NGOS and that their direct engagement with one site has ceased in recent years. In addition, I also asked "For how many years have you worked for this organisation?" These responses were used to confirm that these individuals were deemed knowledgeable of their agencies' engagement in marine resource management and conservation and their agencies' relationships with other marine resource practitioners and agencies.

Interview respondents were asked "How many people in your agency work in marine resource management in Solomon Islands?" (i.e., to allow us to discount staff from less relevant or outside of the country offices, in the case in international NGOs). Depending on the size of agency and my confidence in responses from interviews completed, between 1 and 4 people were interviewed from each agency (Table S2).

Table S2 The size of SILMMA member agencies and the number and proportion of people interviewed. The sum of years the respondents had worked in coastal ecosystem management.

	Number of marine resource management staff	Number of staff interviews	% interviewed	Sum of years worked in coastal ecosystem management
Community based organisation 1	3	2	67	27
Community based organisation 2	7	1	14	8
Community based organisation 3	2	1	50	2
International NGO 1	3	2	67	9
International NGO 2	5	2	40	16
International NGO 3	7	2	29	6.5
International NGO 4	18	3	17	10
International university	4	1	25	6
National government agency 1	12	2	17	7
National government agency 2	26	4	15	37

1.2 Interview technique

Each respondent acted as a representative for his or her organization (Schneider 2003). In May – November 2010 semi-structured interviews were conducted in the respondents own work settings, with the exception of 1 interview which was conducted via Skype. Interviews lasted between fifty minutes and 2 hours. I conducted interviews were in English. Responses were hand written *in situ* and digitally recorded (Sony ICD-SX700) for later transcription. Between one and four people were interviewed from each agency and where there were multiple interviewees from the one agency, I used the highest strength of relationship reported for the network analysis.

1.3 Identification of organizations

Recognition as a network member is dependent on meeting membership criteria, however at the time or writing formal membership processes were not in place. Agencies who meet membership criteria were documented in the SILMMA strategic plan (SILMMA, 2009) and these ten agencies are referred to from here as ‘members’.

A pilot study using informal interviews of key informants, identified 20 non-member agencies that were involved in coastal ecosystem governance in Solomon Islands. Due to concerns with interview fatigue, I included only three of nine provincial agencies and prompted for ‘any other provincial agencies?’ Respondents added a further 11 agencies throughout the course of interviews. Donor agencies were not included for this analysis unless they also provided technical support to co-management initiatives.

1.4 Focus group methodology

Focus group discussion points were identified subsequent to analysis of SILMMA member interview data. In November 2010 at a SILMMA annual general meeting, discussions were conducted with the meeting attendees. Over half of the individual respondents to interviews were present at this meeting and 100% of agencies interviewed were represented within the group. Three questions were posed to the group: (1) What prevents the exchange of information and knowledge between SILMMA members?; (2) What constrains learning (i.e., applying knowledge when it is received) when implementing management?; (3) How can SILMMA address these problems? The groups were given about 40 minutes to discuss the questions and transcribe their responses.

1.5 Key informant interview technique

Sites were selected as they were the focus of engagement of two different SILMMA members. All ‘sites’ represent regions that contain multiple villages that have a history of direct engagement with a SILMMA member the support agency. The investigation used semi-structured interviews conducted in at least three villages in each region. I conducted interviews in Solomon Islands’ Pijin. In each village interviews were conducted with at least three key informants; both men and women who are members and/or leaders of a reef owning clan or are members of a formal marine resource management committee, and all were fishers. Interviews prompted discussion of perceptions of the origins of information that influenced their uptake and design of co-management of coastal ecosystems and key informants were specifically asked to identify agencies or people (who were later assigned to the agency that employs them) that had provided information or technical support for their co-management initiatives.

Appendix 8 - Household survey

HOUSEHOLD DETAILS				
	1	Name (names are for record-keeping and will not be published or revealed):	Nem blo iu?	
	2	Relationship to household head:		
	3	Village:	Village blo iu?	
	4	Respondant;s Age:	Hau old nay iu?	
	5	Respondent's gender:	Women or Man?	
	6	How many people in this household at present?	Hau meni fala pipol nau step lo disfala haus ya distaim?	
	a.	Adults (>18 years old):	Hau meni nao olketa big man?	
	b.	Children:	Hau meni nao olketa pikinini?	
DIET				
	7	What did you eat for the last two main meals? (list everything you ate and drank) ***If fresh fish is named in either of these meals, ask for the local names[s]***	Wat nau iu kaikam lo last 2 meals blo iu? Listim kam	
	a.	Meal 1:	Meal 1:	
	b.	Meal 2:	Meal 2:	
	8	**If fresh fish was consumed in either of the last two meals** was it **caught** by a member of this household or **given** to you by someone from another household or did you **buy** it?	**Sapos fresh fish nao iu been kaikam lo last 2 meals ya** Waswe eniwan from disfala haus nao catchim fish ya or man from nara haus or iu seleva nomoa baim?	
	9	How many times do you normally eat fresh fish in a week?	Hau meni taims nao iu save kaikam fresh fish insait lo 1 week?	
	10	What are the main types of fish you typically eat? (use local names):	Wat nau main type of fish iu save kaikam olowe? Telem kam lo langus nem:	
	11	How many times do you normally eat tinned fish in a week?	Hau meni taims nao iu save kaikam tinned fish insait lo 1 week?	

	12	How many times do you normally eat any other type of meat in a week? E.g. Chicken, corned beef. What type and how often?	Hau meni taims nao iu save kaikam eni nara type meat insait lo 1 week? Olsem kokuraku or corned bif. Wat kain type en hau meni taims insait one week iu kaikam?	
	13 & 14	12. What are the main non-fish sea foods you eat e.g. shells, crabs, crayfish, squid, turtles, seaweed (use local names):	13. How often do you eat non-fish seafood per week?	
		12. Wat nau samfala main seafood wea hem no fish iu felasave kaikam? Olsem sela, crab, cary fish, squid, totel, siwid. Talem kam lo langus name:	13. Hau meni taims nau iu save kaikam olketa nara samtin insait lo sea lo 1 week?	
FISHING PARTICPATIONS				
	15	How many people in the household go fishing?	Hau meni fala pipol insait lo disfala haus nao save go out fishing?	
	16	What is the combined total number of fishing trips made by members of this household in one week? E.g. So if i lived with my husband and we both fish. I went twice a week and he went 3 times a week then the total is 5 times a week. So how about you, how many times?	Hau meni taims, supos iu countem nao taim wea olketa member lo disfala haus go fishing lo 1 week. Olsem Sapos me stop insaed haus witem husband blo mi en mi tu fela save go fishing. Insaed 1 week me go 2 fela taems en husband blo mi hem go 3 fela taems. So total taiem me tufela go out fishing hem 5 taems. So iu fela bae hau? Hau meni taems?	
	17	Where do members of this household normally go to catch fish? Name the places on the shore or the islands which are closest to the fishing grounds and also whether it is: **fill in table below**	Wea nao olketa member lo disfala haus ya save go fishing? Givem kam name blo ples lo shore or lo island which one nau kolsap? ** fill in table below**	
Person Name	Location names	Location type (e.g. **L**agoon, **R**eef **T**op, **S**ide of **R**eef, **D**eep, **M**angrove, **FAD**, **O**ther)	What is the fishing methods and/or gears mainly used by members of this household used?	What are the species of fish (and non-fish seafood) most commonly targeted by fishers in this family?

Nem blo man hem save fishing & relationsh ip to HHH	Nem blo ples fo fishing	Wea lo (** say nem blo ples hem telem iu**). Olsem Lagoon, Lo top lo reef (**RT**), saed lo rif (**SR**), lo deep (**D**), Magrove (**M**), rafta (FAD), eni nara ples (**O**)	Wat nao barava main fishing method gear (olsem spear, droplining) wea iufala lo disfala hous save useim? Talem kaim samfala iufala save usim olowe and ani save usim sam taims nomoa?	Wat nao sam fala sa,fala samtin lo sea wea hem fish and hem no fish and member blo disfala haus try for pulim alowe?
HOUSEHOLD ECONOMICS				
	18	What is the most important source of money in this household?	Wat nao barava main waka or main source iufala save tekem seleni lo hem lo disfala haus?	
	19	Please list any other sources of money for this household in order of importance	Iu talem kam moa eni nara way iufala save tekem selni; telem kam start lo barava important source go kasem hem no important tu mus.	
	20	Does your family have access to land for gardening? If yes, where is it?	Waswe family blo iu hem stop lo haus garem land for mekem garden? If ya wea nao area ya?	
		How long does it take to get there? By canoe or walking or other?	Hau lon nao iu save tekem fo go lo there? Iu go usim canoe or walkabout or hao?	
	21	**If yes to the above** Does this garden on its own provide enough food for the household?	**Sapos hem garem garden** Waswe disfala garden blo iu ya providin kaikam wea fitim everiwan lo disfala haus tu?	
	22	Do you ever have an excess of garden food or fish? If yes, what do you do with the excess?	Waswe iu save garem extra kaikai olsem fish or eni nara samtin long gardin tu? Sapos hem true wat nao iu duim witem olketa extra kaikai?	
	a)	Sell	Selem	
	b)	Store	Storim	
	c)	Give away	Givem away	
	d)	Other	Eni nara somting	