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SOCIAL DETERMINANTS OF THE EXPLOITATION AND MANAGEMENT OF CORAL REEF RESOURCES IN SOLOMON ISLANDS

Thesis submitted by

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B.Sc. (Hons) University of Queensland

in 2013

for the degree of Doctor of Philosophy

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For Molly,

my future.

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I acknowledge openly, that from the outset of this thesis I have had an agenda beyond knowledge for knowledge sake. That agenda was, and remains, to better understand the interaction between people and natural resources for improved human welfare. I do not, however, believe that this agenda generated *a priori* bias within the thesis, but rather enhanced the accuracy of the content.

ABSTRACT

Globally, natural resources are declining due primarily to unsustainable human consumption. Resource scarcity and associated problems therefore arise fundamentally from social processes. This thesis compares and contrasts the relative merit of the three dominant environmental sociology perspectives for their respective ability to explain the effect of human societies on natural resources. First is the perspective of population pressure driving resource scarcity; a perspective commonly known, and referred to herein, as 'Malthusian overpopulation'. Second is the perspective of free market capitalism and associated market expansion driving resource scarcity; a perspective commonly cited as the 'treadmill of production' in environmental sociology (herein referred to as 'market expansion'). Third is the perspective of modernization driving resource scarcity at low levels of modernization and resource abundance at high levels of modernization; a perspective commonly known as 'ecological modernization' in environmental sociology and the 'environmental Kuznets curve' in ecological economics (herein referred to as 'modernization'). Each perspective is supported by many scholars, and has a significant literature to substantiate the respective claims of the key social processes that cause change in the state of natural resource. Critical comparison of the three perspectives will likely offer greater insight into interactions between societies and natural resources than examining one perspective alone, and may therefore offer more appropriate solutions to the challenges posed by resource scarcity.

There are gaps in our understanding of society's effects on natural resources that are apparent from a review of comparative studies on the three dominant perspectives. First, most studies that compare and contrast the relative merit of the three perspectives correlate proxy variables for each of the perspectives [e.g. human population density (for 'Malthusian overpopulation'), and Gross Domestic Product (for 'market expansion')] with environmental indicators (e.g. fishery biomass) without explicitly considering mechanisms such as resource exploitation intensity or resource management institution efficacy. Second, few of the comparative analyses that have been undertaken to date, explicitly compare and contrast the three perspectives at the local-level. Most studies have instead focused on the national-level. Yet interactions

between societies and resources vary significantly across social-political levels, and one could argue that most decisions to exploit and manage resources do occur at the local-level, particularly in less affluent societies where there is comparatively limited centralised management and vast reserves of natural resources. Third, there is inadequate attention paid to the developing country context. Most studies that compare the perspectives are either global or focused on affluent nations. Few studies have focused analyses on poorer, economically peripheral nations where much of the world's biodiversity and other natural resources exist. This is critical for two reasons; first, affluent and poor societies represent very different social contexts so conclusions drawn from global or affluent-nation analyses are unlikely to be transferrable to developing countries; second world systems theory suggests that affluent societies import resources and export pollutants to poorer societies and vice-versa, and therefore opportunities to modernize as per the modernization perspective might be difficult to realize. Fourth, no comparative analyses of the perspectives have included research on local perceptions of society's effects on natural resources. Understanding local perceptions, however, is useful to confirm (or refute) hypothesis-driven research and potentially useful to increase the likelihood of implementation of research recommendations in applied research.

The aim of this thesis is to fill these research gaps by 1) explaining society's effects on natural resources, at the local-level in an economically peripheral nation, using dominant environmental sociology perspectives (research gaps 1-3), and to 2) determine whether local perceptions, support or refute the scientific explanation (research gap 4). These broad aims are achieved by completing the following research objectives:

1. Determine which dominant environmental sociology perspectives, of societies effects on natural resources, best explains the effects of exploitation on;
    a) Coral reef fish that are vulnerable to extinction by overfishing;
    b) Function and diversity of coral reef fish;
2. Determine which of the perspectives explain the occurrence of coral reef resource management institutions; and

3. Determine whether local perceptions support, or refute, the findings, as identified in objectives 1 and 2, of society's effects on the exploitation and management of coral reef fish.

To achieve research objective 1, I collected secondary social (census) and ecological (survey) data from 25 local-level sites spanning Solomon Islands. I then analysed the data using structural equation models to explain how proxy variables, which represent each of the dominant perspectives, affect fishing pressure to, in turn, affect the distributions of a) biomass of coral reef fish that are vulnerable to overfishing and b) coral reef fish functional group biomass and diversity. The key aspects of fish distributions I examined were explained by fishing pressure. Specifically, there was lower biomass of coral reef fish that are vulnerable to overfishing, lower biomass of key functional groups of fishes, and lower fish species diversity where there was higher fishing pressure. The key finding, which addresses research objective 1 is that fishing pressure was, in turn, driven by high human population density and greater access to markets; proxy variables for the Malthusian overpopulation and market expansion perspectives, respectively. Modernization had no discernable effect on fishing pressure.

To achieve research objective 2, I collected data for proxy variables of each of the dominant perspectives and on coral reef resource management institutions (gear restrictions, species restrictions, and spatial closures) from ≥723 local-level sites spanning Solomon Islands (I developed some of the survey instrument on management institutions but the data were collected by the national government and other agencies). I then tested the effects of each set of proxy variables, which represent each of the perspectives, on the occurrence of management institutions using a range of statistical analyses. I found that the presence of management institutions was negatively correlated with human population density and positively correlated with modernization and the presence of fish markets, lending support to the Malthusian overpopulation perspective, and simultaneously detracting from the market expansion perspective. The results neither clearly supported nor refuted the modernization perspective.

To achieve research objective 3, I conducted interviews, using a survey instrument, with 119 fishers and fish traders in the major urban centres of Solomon Islands to identify which factors they perceive can increase and decrease coral reef fish stocks. The qualitative responses were coded, and analysed using Principal Components Analysis to derive the dominant perceptions. The interviewed fishers and middlemen perceived an extensive range of factors to be causing fish decline, and also stated a diverse range of management interventions that they perceived would increase fish stocks. Respondents identified fishing as a major cause of fish decline driven by income-related needs, among other factors, which is concordant with the findings of objectives 1 and 2.

In this thesis I compared the three dominant perspectives of society's effects on natural resources using a novel model in an economically peripheral nation at the local-level. In doing so, I found greatest support for both the Malthusian overpopulation and market expansion perspectives. This finding was concordant with local perceptions, adding further weight of evidence. Given these findings, it can be expected that, with predicted population growth and continued resource commoditization and aspirations of affluence, coral reef resources will likely continue to be depleted in Solomon Islands, and other locations with comparable context (economically peripheral). Policy prescriptions that aim to slow this depletion must consider local population pressure and markets as dominant driving forces.

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CHAPTER 1: INTRODUCTION

1.1 DECLINING NATURAL RESOURCES

The interaction between people, as individuals and societies, and the natural environment has attracted increasing attention from both the public and scientific community in recent years. Increased attention is likely attributable to our growing acknowledgement of the role of human agency in the depletion of finite natural resources (Frank 1925; Brueckheimer 1956; Machlis 1992; Grossman & Krueger 1995; Ehrlich & Ehrlich 2013), and the resulting decrease in biological diversity and collapse of ecological systems (e.g. Hughes 1994; Scheffer et al. 2001; Sanderson et al. 2002; Rockstrom et al. 2009; Barnosky et al. 2012; Nyström et al. 2012; Ehrlich & Ehrlich 2013). More importantly for humanity, however, is our increasing awareness that humans are dependent on functioning natural systems for our well-being (e.g. Catton Jr & Dunlap 1978; Fuller et al. 2007; Cardinale et al. 2012) and probably for our survival (for examples of localised collapse of societies see Diamond 2006).

Human understanding of both our dependency on the natural environment for our welfare, and the clear negative effect we are having on natural systems, has catalyzed a scientific effort to understand the causes of natural resource decline, particularly the social causes, and prescribe means of changing individual and social behaviour to enable a more sustainable environmental future (Schnaiberg 1980; York et al. 2003a; Mol et al. 2010). The applied aspect of this research assumes that the better we understand the social causes of resource decline, the more effectively we can prescribe policy to improve the condition of natural resources.

1.2 SOCIAL CAUSES OF NATURAL RESOURCE DECLINE

Identifying the social causes[1] of natural resource[2] decline is somewhat challenging due to the inherent dynamic complexity and contextual heterogeneity of social-ecological systems [3]. Both social and ecological systems are complex and dynamic, and processes within each system operate across multiple scales (Cash et al. 2006). This dynamic complexity is likely becoming more pronounced as societies become more globally connected with ever-increasing flows of information, resources, and people (e.g. Kramer et al. 2009). Both social and ecological systems also possess context-specific traits (Luck 2007), such as localized ecosystem processes and societal customs. Therefore, generalized theory cannot explain all ecological degradation or offer approaches for addressing all ecological degradation (Ostrom 2007).

Out of the complexity of understanding the social causes of natural resource decline, three dominant (i.e. pervasive in the literature) environmental sociology perspectives have emerged that relate to the social causes of natural resource decline. These form the theoretical foundation for this thesis. Each perspective arose at different periods in history, in different contexts, by observation of changing social processes that resulted in changing rates of resource exploitation. Such processes centre on for example, population growth, economic production, institutional adaptation, and technological innovation. Each perspective maintains a unique ideology of our relationship with natural resources, and offers substantively different solutions to halting natural resource decline. It is these differences between the perspectives, I think, that offer divergent insights into the key structural properties of society that cause natural resource decline. Therefore, they offer a fruitful set of perspectives to compare and contrast in this thesis. In short, the perspectives are:

1. “Malthusian overpopulation”: Human population growth drives natural resource scarcity.

[1] Herein the term ‘social cause’ refers to any human characteristic, be it economic, demographic, cultural etc., which explains the state of natural resources, correlative or causative.
[2] Herein the term ‘natural resources’ refers to any ecological quality that has recognized human utility.
[3] A social-ecological system is a system that acknowledges the interdependencies and feedbacks between social and ecological systems – a relatively new paradigm in environmental sociology (Catton Jr & Dunlap 1980).

2. “Market expansion”: Economic growth, by natural resource exploitation, drives natural resource scarcity.
3. “Modernization”: Development and associated affluence and institutional reform drive resource scarcity at low levels of modernization, and drive resource abundance at high levels of modernization.

I proceed with a brief summary of the three perspectives; including the thesis (theoretical foundation, narrative, and evidence) and the antithesis (limitations) of each.

1.2.1 DOMINANT PERSPECTIVES

Perspective 1: Malthusian overpopulation: Human population growth drives natural resource scarcity (broadly considered a demographic theory).

Theoretical foundation

The most publicly and academically prominent perspective on human-environment interactions is that human population growth and the associated pressure on natural resources is responsible for declining resource conditions (Ehrlich & Holdren 1971; Ehrlich et al. 1971; Pauly 1988; Cropper & Griffiths 1994; McKee et al. 2004). The rationale of this perspective is that resources are finite and so continued increase of human populations will inevitably lead to resource decline, potential species extinctions and ecological collapse. The foundation of this work dates to Rev. Thomas Malthus (1798), who proposed that increased productivity, enabled through linear increase of technological innovation, would temporarily buffer people from resource scarcity, but that human populations would eventually exceed innovation, due to geometric growth, leading to resource scarcity and human suffering. Consequently, proponents of this perspective argue that human population growth must be limited to avoid ‘Malthusian overpopulation’ and human suffering.

Narrative

Human societies, as with populations of other species', increase their total population to environmental carrying capacity[4]. Assuming there is environmental variability (e.g. droughts and floods), and inter-specific competition, there will be periods when the total population increases, and times when the population decreases. The ability of humans to increase their environmental carrying capacity through technological innovation (as has occurred in agricultural (and aquaculture/fisheries revolutions during the 20th Century) enables populations to grow. There are limits to innovation, however, and therefore limits to human-modified environmental carrying capacity, and so human populations are ultimately limited. Therefore, it is necessary to limit human populations to within environmental carrying capacity to avoid significant natural resource decline and consequent human suffering.

Evidence

There is no doubt that Malthusian overpopulation (frequently measured as population/potential resources) will explain some of the variance of the state of natural resources, including those resources that have direct utility such as fishes and forests, and broader measures of resources, such as biological diversity and the condition of functional groups (see Luck 2007 for a review). For example, there is substantial support in the coral reef literature of the negative effect of human population density on coral reef resources (Jennings & Polunin 1996, 1997; Dulvy et al. 2004a; Dulvy et al. 2004b; Newton et al. 2007; Mora 2008; Sandin et al. 2008; Williams et al. 2008; Cinner et al. 2009b; Mora et al. 2011; Williams et al. 2011; Bellwood et al. 2012). Indeed a popular term for overfishing caused by human population growth is 'Malthusian overfishing' (Pauly 1988).

Population density and size are also likely to affect the efficacy of natural resource management institutions[5]. When populations are adequately high that exploitation exceeds rates of ecological replenishment, it is possible that resource management

[4] 'Environmental carrying capacity' is defined here as the maximum number of people an environment can sustain indefinitely.

[5] Herein the term 'management institutions' refers to any set of rules relating to the exploitation of natural resources.

institutions, which are believed to mediate the effects of Malthusian overpopulation on natural resource exploitation (Agrawal & Yadama 1997), will fail, particularly in the context of common-pool resources (sensu Hardin 1968). There is also evidence that an optimum community population size (neither too small nor too large) might lead to the successful collective action such as natural resource management (Agrawal & Golyal 2001).

<u>Limitations</u>

There are five key limitations to the perspective that Malthusian overpopulation alone can explain declining resources. First is a debate on causality. Malthusian perspective proponents argue that increased means of production enables population growth, rather than population growth as the driver of increased production, as argued by Boserup (2005). The central tenet of Boserup's argument is that necessity (i.e. inadequate food supply) drives innovation as the means of production to prevent suffering and death, and therefore human populations will not outpace the means of production. Boserups thesis has given rise to the idea that rapid population growth, even in areas of marginal productivity, might generate economies of scale in production, and more sophisticated management institutions that ultimately reduce environmental footprints whilst improving quality of life (e.g. Malakoff 2011). Indeed, early research in the Pacific by Johannes (1978) suggests that resource management institutions emerge and evolve, as required, as human population pressure increases and decreased, assuming negative external influence, such as abolition of underlying access rights, is avoided. Second, proponents of Malthusian overpopulation tend to assume that all people interact with the natural environment in the same manner, and consume the same volume and types of natural resource (however Malthus himself acknowledged differences in consumption between individuals of different social class within societies) (see York & Gossard 2004 for an example of context variability in resource consumption). Therefore, human population size per potential available resources cannot accurately predict the state of natural resources. Third, the role of technology tends to be ignored (see Commoner 1972 for early debate on the relative importance of technology in explaining environmental impacts) in explaining natural resource exploitation rates. Yet technologies affect rates of exploitation and consumption, and different societies have access to different technologies. Fourth, local human population size/density does not account for trade of resources between social-ecological systems– relatively wealthier societies are able to import goods and services and export pollutants, such as those produced by heavy industry, and consequently maintain a population beyond local carrying capacity (Ehrlich & Holdren 1971; Wallerstein 1976). Therefore, it is not possible to conclude that any two societies, equal in population size and equal in net primary productivity (e.g. fisheries or forestry) will have resources of equal condition (e.g. number of trees, fishery biomass). Fifth, it has been observed that high population density (measured as number of fishers per length of coastline) can correlate positively with higher fish biomass (Pollnac et al. 2000). This result was explained by the mobility of fishers, enabling them to migrate to areas of higher resource density. Therefore, the relationship between density of people, and resource condition, should be considered critically, and particularly where human populations are mobile, including nomadic people. Further, a recent study by Pollnac et al. (2010) found stark differences in correlations between human population density and differencess in fish biomass inside and outside spatial closures among three regions; the Caribbean, the Philippines, and the Western Indian Ocean. Specifically, only the Caribbean exhibited a negative correlation between population density and differences in fish biomass, whilst the Western Indian Ocean exhibited a positive correlation among the same variables. The authors explained this as possible high exploitation outside spatial closures. Therefore, adherence to spatial closure rules had a possible over-riding effect on fish biomass in this instance. In essence, this perspective is crude and eco-centric, and does not take adequate account of the modern complex social matrix of human societies[6]. And so, to explain the human causes of resource decline it is necessary to explore beyond the simplistic narrative of human population size and/or density.

[6] While this perspective is ecologically centric, Malthus makes clear distinction between people and other species with respect to limits to growth and the response to resource scarcity. Subsequently, scholars have frequently ‘ecologised’ and consequently simplified Malthus’ work on the Principles of Population to suggest that individuals within a human society will respond similarly to individuals within a population of, for example, plant or other animal species. This simplification leads to a morally and ethically fraught position of the need to limit human population size to ensure sustainable natural resource use for human well-being.

Perspective 2: Market expansion: Economic growth, by natural resource exploitation, drives natural resource scarcity (based on the political-economic theory 'neo-Marxism', and more recently the environmental sociology theory of the 'treadmill of production').

Theoretical foundation

The underlying principle of this perspective, which is rooted in Marxist philosophy (Marx 1887)[7], is that of the social perception of the need for economic growth for improved personal and social welfare, enabled through 'free market' innovation and exploitation of natural resources. Proponents of this perspective argue that economic growth, rather than environmental sustainability, dominates social and political decision-making. Fundamentally, proponents of this perspective argue that problems related to natural resource scarcity cannot be solved as long as the ideology of dependence on economic growth persists, and that a radical restructuring of the political economy and the elimination of the growth-dependent ideology is required to ensure a sustainable future (Schnaiberg 1980). As stated by a proponent of this perspective '..economic growth remains the foundation of decision making with regards to the design, performance and evaluation of production and consumption, dwarfing any ecological concerns'(Schnaiberg et al. 2002, p1.).

The dominant thesis of this perspective is the treadmill of production (Schnaiberg 1980), which has been hailed 'the single most influential framework of analysis within environmental sociology in the United States' (Foster 2005). The treadmill of production thesis represents an addition to Marxist philosophy, by describing the process of natural resource degradation by capitalist production (Kovel 2011). However, as Foster states, the thesis is from the United States of America, and despite making reference to market expansion and capitalism, generally, the focus is on the

[7] The philosophy of Karl Marx; particularly in his work on the accumulation of Capital (Marx 1887), relates more to the social effects of resource privatisation, rather than the effect of economic production on natural resources discussed by Allan Schnaiberg as the treadmill of production. However, both theses suggest that the accumulation of capital from natural resources through the 'free market' ideology (sensu Smith 1843), is detrimental to human welfare (particularly equality of welfare distribution) and the natural environment. Fundamentally, therefore, this thesis loosely examines the effects of social adherence to the dominant western political philosophies of socialism and capitalism, on the state of natural resources.

post-WWII United States of America model of production expansion. That is, the purpose of Schnaiberg's work was to explain monopolistic production – the type of political-economic system promoted in the writings of Ayn Rand (2005), which was based on industrial nations extracting natural resources both domestically and from economically peripheral nations with cheap labour and limited environmental regulation (Gould et al. 2004). Therefore, the treadmill of production is fraught when it is applied to production systems owned and operated in economically peripheral nation contexts void of significant industry, a well-functioning civil service, and a stable society conducive to the development of a significant labour force. Yet, such nations, which are economically marginalised, and peripheral to the global economy (Wallerstein 1976), are prone to significant environmental degradation by natural resource extraction for local consumption, and for export to affluent nations (Singer 1975; Fischer-Kowalski & Amann 2001; Gould et al. 2004). Hence, there is a need to adapt the treadmill of production narrative to suit such contexts or to consider alternative perspectives (see Bunker 2005 for further rationale of the need to consider global position in treadmill of production analysis). Therefore, whilst acknowledging the treadmill of production, and the many subsequent publications reviewing and analysing it, the following narrative is generalised to suit broader contexts including less formal production systems that are common in peripheral nations such as Solomon Islands, which is context for this thesis.

Narrative[8]

Natural resources are exploited by producers (e.g. logging companies, fishers) to satisfy market demand. Production is supported by governments and other public administration entities because increases in production result in economic growth, employment and material affluence. Producers aim to increase net production and production efficiency to maximise profits (assuming the ideology of constant growth). Production efficiency is increased by the use of technology rather than by an expanded labour force. In the context of small-scale fisheries, fishers would be expected to maximise harvest to maximise income. The use of increasingly efficient gears would

[8] Note that this is a significantly simplified narrative to suit broader contexts than discussed by Schnaiberg (1980). The purpose of the simplification is to maintain relevance to the production system analysed in this thesis; a small-scale fishery in a peripheral nation. The next sections continue to refer to the treadmill of production because it has had significant influence in the literature.

make fishers more competitive by increasing catch, and reducing labour expenses (e.g. boat crew). Key to maximising profits is access to consumer markets (including proximity). Desire for maximised profits drives the use of technology which results in resource depletion. Thus, in the context of local-level social-ecological systems, this perspective differs from the Malthusian overpopulation perspective primarily in that resources are extracted for capital accumulation by exportation from the local social-ecological system, rather than for consumption and/or barter within the social-ecological system.

Evidence

There is a growing literature that supports the perspective that the economic growth ideology, manifest as capitalism and presented as the treadmill of production, is driving resource scarcity. Evidence exists in descriptive works and case studies such as a suite of papers by Gould on industry pollution on the Great Lakes of the United States of America (Gould 1991; Gould 1992, 1994), post-consumer recycling in the United States of America (Weinberg et al. 2000), rainforest eco-tourism in Belize (Gould 1999), and environmental injustice in electronic industries (Pellow & Park 2002; Pellow 2004), to name a few. More recently, scholars have conducted quantitative comparative analysis, using proxy, or manifest, variables [e.g. economic freedom, gross domestic product, urbanization (York et al. 2003a; Özler & Obach 2009)], to amass a significant body of evidence in support of treadmill of production perspective (e.g. Naidoo & Adamowicz 2001; York et al. 2003a; Hoffmann 2004; Clausen & York 2008b, a; Özler & Obach 2009; Bradshaw et al. 2010). In a coral reef context, distance to markets, which can be considered a manifestation of market expansion, explains the condition of harvested fish (Cinner & McClanahan 2006) and *in situ* fish stocks (Brewer et al. 2009; Cinner et al. 2012a; Cinner et al. 2012b). There is also substantial evidence to suggest that market access erodes fishery management institutions which exist, by and large, to constrain exploitation (e.g. Cinner 2005; McClanahan et al. 2006; Cinner et al. 2007).

Limitations

There are three clear limitations to the treadmill of production as a general theory for explaining socially driven resource scarcity. First, as stated above, Schnaiberg derived the treadmill of production from observations of the rapid rise of industry and corporate enterprise in post-WWII America. Second, the treadmill of production assumes that the producer privately owns natural resources, yet natural resources are often shared my means of common property institutions, with all community members acting as producers, the state (via institutions that set natural resource exploitation rules), and consumers (Weitzman 1974; Wade 1987; Ostrom et al. 1994). That is, in many societies, the members of society possess collective use-rights to resources, such as fisheries or forestry (Gordon 1954; McKean & Ostrom 1995). Third, the complexity of the treadmill of production narrative, which involves dynamic interaction of the state (governance), the production system and the labour force as consumers and workers(see Schnaiberg 1980) makes challenging, any attempts to comparatively and quantitatively test the relevance of the perspective. Consequently, research has focused on contextual descriptions or the use of proxy metrics such as gross domestic product (GDP), to test the occurrence of the treadmill of production, resulting in, what I perceive, to be a failure to produce substantive evidence to support this perspective. For example, quantitative studies often correlate production proxies (e.g. GDP, urbanization) with ecological indicators (e.g. fishery biomass), without considering how such proxies alter production (exploitation) and natural resource management institutions (e.g. Naidoo & Adamowicz 2001; York et al. 2003a; Hoffmann 2004; Clausen & York 2008b, a; Özler & Obach 2009; Bradshaw et al. 2010). A better understanding of how such proxies affect exploitation and management behaviours would improve understanding of the treadmill of production as a social process that causes resource decline. Therefore, while there is significant support for this perspective, there is a need to consider peripheral nation contexts, collective ownership of resources, and behavioural changes including resource exploitation and resource management.

Perspective 3: Modernization: Development and associated affluence and institutional reform drive resource scarcity at low levels of modernization, and drive resource abundance at high levels of modernization (referred to as 'ecological modernization' in environmental sociology and the 'environmental Kuznets curve' in ecological economics).

Theoretical foundation

The third and final perspective investigated in this thesis is that of ecological modernization and the related environmental Kuznets curve theory. Ecological modernization proponents believe there is a growing emancipation of politics and economy from the environment (Mol 1996), and therefore directly challenge the treadmill of production thesis - that deindustrialization and dramatic economic reform is required to ensure future environmental sustainability (Mol & Spaargaren 2000). Rather, ecological modernization proponents champion both increased efficiency by technological innovation and public and private institutional reform as mechanisms for ensuring a sustainable future (Fisher & Freudenburg 2001) without the need for dramatic economic restructuring of the global economy. They argue that the process of ecological modernization is an essential pre-condition to further development - a part of which is taking inspiration from ecological systems in the design of social and economic systems, to make them more compatible. In the words of a leading proponent of ecological modernization theory:

> "..the basic premise of the Ecological Modernization Theory is the centripetal movement of ecological interests, ideas and considerations involved in social practices and institution developments, which results in the constant ecological restructuring of modern societies. Ecological restructuring refers to the ecologically-inspired and environment induced processes of transformation and reform going on in the central institutions of modern society."

(Mol 2003, p59.)

The allied environmental Kuznets curve theory is an adaptation of the theory developed by Simon Kuznets of non-linear (inverse U-shaped curve) income inequality with increasing economic growth/production (Kuznets 1955; Grossman & Krueger 1991). The theory is rooted in economics, rather than sociology, and therefore, provides an economically rational explanation for the proposed improvement in natural resource state with increasing affluence (York et al. 2003a).

Narrative

At low levels of modernization, societies exploit natural resources for improved shared and personal welfare. Consequently, natural resources become scarce and pollution levels increase. Once a certain level of modernization, and associated affluence, is attained, societies have the luxury of being able to prioritize natural resource considerations in decision-making. Consequently, at the given level of modernization (which varies across different natural resources and pollutants), natural resources replenish and pollutants diminish as modernization progresses. Ecological modernization proponents suggest that this shift in the social-ecological trajectory is primarily a consequence of institutional reform and technological innovation that is driven by an awareness (largely in post-Industrial nations) of the limits to production and consumption combined with an environmental consciousness and consideration of the welfare of future generations (Mol 2003). Some environmental Kuznets curve scholars suggest that increased modernization and associated affluence allow for import of resources and export of pollutants (a 'scale effect'), transition from a primary industry to a service-based economy and, through research and development (a 'composition effect'), the application of technologies that have a reduced environmental impact (a 'technique effect') (see Grossman & Krueger 1991 for theory development; see Cinner et al. 2009b for testing of these effects).

Evidence

The modernization perspective is an attractive proposition: that institutions and technology are transforming to ensure sustainable social-ecological systems in the future. Consequently, there is a significant literature discussing the merits of, and providing evidence for, the theory. Evidence of ecological modernization is often based on case studies (e.g. Mol 1995; Mol & Sonnenfeld 2000). A classic example of ecological modernization is the chemical industry in Europe. The industry was the cause of severe environmental deterioration from prior to the Industrial Revolution until the 1980s, when widespread public concern triggered restructuring of the industry. The restructuring included environmental management systems in chemical companies, including environmental accounting, and the production of relatively environmentally products, driven by consumer demand. The industry is now far more aligned with environmental sustainability, and has a greatly diminished negative effect on ecological systems (Mol 1995). Further, proponents also provide more general regional and global evidence such as the proliferation of environmental non-government organizations (Mol 2000). The majority of quantitative research testing the merit of this perspective has been labelled as the environmental Kuznets curve. The environmental Kuznets curve has been observed in fish catch (Clausen & York 2008a), *in situ* fishery biomass (Cinner et al. 2009b), the number of threatened bird species (Naidoo & Adamowicz 2001), CO_2 emissions (Rosa et al. 2004), city air pollution and water quality (Grossman & Krueger 1995), and deforestation (Ehrhardt-Martinez et al. 2002), to name a few.

Limitations

Despite the accumulation of supporting comparative and case study evidence, the modernization perspective has received significant criticism from within the sociology (particularly York & Rosa 2003) and ecological economics (Arrow et al. 1995; Stern et al. 1996) fraternities. Criticisms of the perspective are numerous, so for brevity, I will elaborate on those that have relevance to this thesis only.

York & Rosa (2003) identified four key challenges to the claims of ecological modernization; 1) there is inadequate evidence that institutional modifications lead to ecological improvements; 2) there is inadequate evidence of changes in production and consumption patterns in the latter stages of modernity; 3) that ecological modernization does not adequately show that decreased ecological impact by some entities (e.g. firms, corporations, nations) does not result in increased negative ecological impact by other entities (i.e. ecological modernization does not adequately account for externalities); and 4) there is a need for ecological modernization to show, not only that economies are becoming more resource-efficient, but also that increased efficiency exceeds the pace of total production. Three of these apparent limitations are particularly relevant to this thesis, and therefore elaborated on here.

The second limitation identified by York and Rosa (2003), and elaborated by York et al. (2004), is one of evidence derived from variance (increased variability in context) rather than central tendency (mean trend). That is, in later stages of modernity there exists increased variability in environmental performance due to increased diversity in production forms (e.g. processes, products and institution types), and therefore, it is possible that outliers that support ecological modernization and the environmental Kuznets curve are being over-reported whilst the mean trend remains one of declining resources with increased affluence. Evidence of this limitation is that ecological modernization and the environmental Kuznets curve are infrequently identified in general cases, such as global analyses of the effects of modernization on environmental footprints (York et al. 2003a; Bradshaw et al. 2010) (Table 1.1), but are more common in context-specific cases in post-industrial nations (e.g. Mol 1995).

The third limitation identified by York and Rosa (2003) suggests that ecological modernization and the environmental Kuznets curve might only apply in affluent societies, such as post-industrial Europe (Fisher & Freudenburg 2001). Variability within nation states is still largely unknown(but see Grossman & Krueger 1995; M'henni et al. 2011), and whether this theory applies to any degree in economically peripheral nations is still unknown. Arthur Mol, a leading author of ecological modernization, acknowledges that a major shortcoming of the theory is that of its Europe-centric nature, and poorer nations and societies might not be undergoing ecological modernization (Mol 2003). This acknowledged limitation fits with world systems theory and dependency theory, whereby the wealthier (core) nations (e.g. United Kingdom, France, Germany, Japan, United States of America) maintain a healthy natural environment by importing goods from, and exporting pollutants to, poor (peripheral) nations (Wallerstein 1974; Singer 1975; Bruckner et al. 2012), and therefore ecological modernization/environmental Kuznets curve trends in core nations are spurious (Figure 1.1). If Wallerstein (1974) and Singer (1975) are correct, then natural resources in relatively poor social-political areas (nations, regions, communities) are being exploited, and consequently degraded, to support consumption by people in relatively affluent social-political areas. Ultimately, there is a distinct need for a better understanding of modernization theories as they apply to any potential development policies in peripheral nations (Frank 1966; but see Hoffmann 2004; Shandra et al. 2009 for evidence of the effect of world system position on natural resources; McKinney et al. 2010). Both of these limitations (2 & 3) suggest there is a need for comparative (as opposed to case-based) evidence in a peripheral nation context to determine whether the critique offered by York and Rosa (2003) has merit.

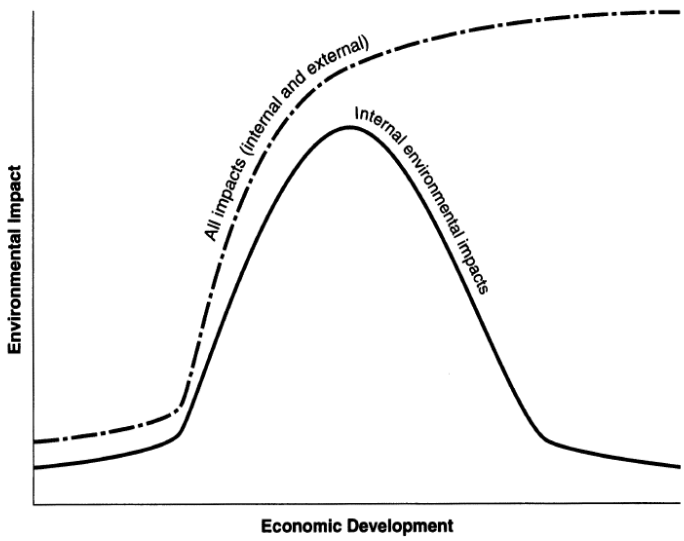

Figure 1.1 Theorized effect of modernization (expressed as economic development here) on environmental impact in affluent nations showing that, when externalities are considered, environmental impacts do not diminish at high levels of modernization. Source: York et al. (2003a).

A final important limitation, which exists across perspectives, is one of causality. The shared narrative of ecological modernization and the environmental Kuznets curve is one of changing social behaviour, including reduced resource exploitation, at a given level of modernization and associated affluence. Yet, there is scant evidence to suggest that modernization causes changing behaviour that, in turn, explains improvements in the state of natural resources. T hat is, the majority of studies correlate modernization (using proxy variables such as GDP and urbanization) with natural resource indicators (e.g. air pollution, species diversity, resource biomass), without explaining the mechanisms by which the non-linear relationship occurs (Grossman & Krueger 1995; York et al. 2003b). Such mechanisms include the scale, technique, and composition effects outlined by Grossman & Krueger (1991). One recent exception is a local-level multi-nation study by Cinner et al. (2009b) that explained increased coral reef fish biomass, with increased modernization, to be caused by differing levels of engagement in fishing (composition effect), differing fishing gears (technique effect), and better transportation (scale effect). Therefore there is a distinct need to understand causality, and in particular, how modernization drives improved resource management institutions and decreased exploitation (Mills & Waite 2009).

1.2.2 Synthesis of the dominant perspectives

Each of these three perspectives (Malthusian overpopulation, market expansion, and modernization) has a vast literature of supporting evidence in different forms, including qualitative and quantitative evidence from both case studies and comparative analyses. Attempts to compare and contrast the different perspectives have taken different forms, with the general trend of analysis type from descriptive case studies and basic modeling, through to more recent comparative analyses using a combination of social and ecological data.

Early attempts to understand human effects on natural resources began with models that incorporated aspects of each perspective, without explicitly making reference to all three perspectives. The most notable and enduring such model, developed by Barry Commoner, Paul Ehrlich and John Holdren is the I PAT model (Impact = Population * Affluence * Technology) that aimed to explain human impacts on the environment as the effect of population, affluence and technology, such that the effect of all three independent variables is greater than the sum of each in isolation (Ehrlich & Holdren 1971; Commoner 1972). The I PAT model was not an attempt to synthesise the three perspectives, but inadvertently incorporated some of the different variables contained within the three perspectives. Since this time, a number of refinements on this model have been developed (see Chertow 2000 for a review; see York et al. 2003c for a comparison of dominant models). This general model, and its refinements, is useful because it accounts for interaction between dominant independent variables. Conclusions from empirical investigations using I PAT based models vary, but generally, population (P) and technology (T) have frequently explained impact (I), whilst affluence (A) has mixed effects, depending on which indicator variables are used (e.g. gross domestic product), but each variable is context-dependent (York et al. 2002). This approach has generally lent weight to both the Malthusian overpopulation and market expansion perspectives (likely due to the dominant role that technology plays in market expansion) (e.g. York et al. 2003a; York et al. 2003c; Dietz et al. 2007).

Recently, with increased availability of large social and ecological data sets, and a more nuanced understanding of the aforementioned perspectives, research has focused on specifically comparing and contrasting the merit of the three perspectives, within single analyses, and in different contexts (e.g. natural resource type) (Table 1.1). The results vary, depending on response variables (measure of relative resource state) and predictor variables (that represent the respective perspectives). It is not clear, however, which resource types respond to which drivers (Table 1.1). For example, threatened species are negatively affected by proxy variables for all three perspectives, but not consistently across studies. However, natural resources would be expected to respond positively to, for example, improved management or the elimination of markets, with species-dependent variation in response (e.g. highly fecund species with a low age at maturity, such as some fish, would be expected to respond more rapidly). The disparate modes of analysis and data sources are also likely to affect the results. Generally, however, there is greatest support for the Malthusian overpopulation and market expansion perspectives.

As with the quantitative studies that address the merit of individual perspectives discussed above, there are limitations to the syntheses that have been conducted. First, the studies that have compared and contrasted all three perspectives (Table 1.1) were conducted at the nation-level. Because social-ecological dynamics vary across social-political levels, there is a distinct need to compare and contrast the three perspectives at levels other than nation/country, such as at the local-level (community or village). Second, quantitative comparisons rarely consider the perspectives as processes (but see Cinner et al. 2009b), and instead directly test (correlate) the effects of, for example, modernization on wild fish stocks (a limitation I earlier raised for each of the perspectives). T here is a clear need to understand how, in this example; modernization affects rates of exploitation and the efficacy of resource management institutions, to explain the condition of the fishery. Making this link between the variables that represent the different perspectives, and the human behaviour(s) associated with exploitation and management of natural resources will allow us to understand better the causal effects of abstract concepts like modernization on natural resources (Mills & Waite 2009).

Table 1.1 Studies that quantitatively test the relative merit of all three dominant perspectives.

Study	Unit of analysis	Perspective	Explanatory variables	Response variable	Result
1	National	MO	Total Population	Ecological Footprint	+
			Population Density	‘’	+
			Nondependent population	‘’	+
		M	$[\text{GDP per capita}]^2$	‘’	NS
			$[\text{Urbanization}]^2$	‘’	+
		ME	GDP per capita	‘’	+
			Urbanization	‘’	+
2	National	MO	Population Density	Mammal and Bird endangerment rates	NS
			Annual population growth	‘’	NS
			Percent Urbanization	‘’	NS
			Annual Deforestation rates	‘’	NS
		M	$\log[\text{GDP per capita}]^2$	‘’	+
			$[\text{GDP per capita growth rate}]^2$	‘’	NS
		ME	log[GDP per capita]	‘’	+
			[GDP per capita growth rate]	‘’	+
3	National	MO	Average annual population	Threatened marine and freshwater fish	+
		M	$\log[\text{GDP per capita}]^2$	‘’	NS
		ME	log[GDP per capita]	‘’	+
4	National	MO	Total Population	Landed fish catch	+
			Total Population	Mean fish trophic level	+
		M	$[\text{GDP per capita}]^2$	Landed fish catch	-
			$[\text{GDP per capita}]^2$	Mean fish trophic level	-
			$[\text{Urbanization}]^2$	Landed fish catch	+
			$[\text{Urbanization}]^2$	Mean fish trophic level	-
		ME	GDP per capita	Landed fish catch	+
			GDP per capita	Mean fish trophic level	+
			Urbanization	Landed fish catch	-

			Urbanization	Mean fish trophic level	-
5	National	MO	log[Total Population]	Percent bird species threatened	+
			log[Population density]	‘’	NS
		M	Environmental treaties ratified	‘’	+
		ME	log[GDP per capita]	‘’	NS

N.B. In some instances authors have generated multiple models. Summary results presented here are either for an optimized model (optimised by e.g. lowest Akieke information criterion score) or a model specific to a particular perspective.
NS = Not significant. +/- = $p < 0.05$.
MO = Malthusian overpopulation; ME = market expansion; M = modernization.
Studies cited: 1. York et al. (2003a), 2. Hoffman (2004), 3. Clausen & York (2008b), 4. Clausen & York (2008a), 5. McKinney et al. (2009).

1.2.3 General conclusion about perspectives from the literature review

Each of the three perspectives has strengths and limitations. Differences in the conclusions drawn from the disparate studies are likely to result from differences in scale including differing social-political levels of analysis (e.g. local, provincial, national) and different contexts (e.g. resource type, levels of modernization, and connectivity to other social-ecological systems by trade). Consideration of all three perspectives, within any single context and scale, is likely to explain more of the variance in ecological distributions, than any one perspective alone. This point is illustrated by the following statement by Fisher & Freudberg with respect to ecological modernization:

> 'The mere accumulation of additional examples, accordingly, would seem highly unlikely to prove that one side is "right," while the other is "wrong." Instead, both the theory's proponents and its critics have met the philosophical condition of existence proof—anything that exists is possible—but it is equally clear that neither ecological modernization nor the obverse [market expansion] could be considered universal. The task that now faces the scientific community is thus to work toward greater rigor in identifying conditions under which "ecological modernization" outcomes are more or less likely.'

(Fisher & Freudenburg 2001, p704.)

This point is further illustrated by Arthur Mol, a leading author of the modernization perspective:

> 'At the same time we have to acknowledge that in the majority of situations the most fruitful explanations are to be found somewhere along the continuum between the two extremes [modernization and market expansion], albeit at different points for different social practices, localities, and times.'

(Mol 2003, p70.)

Ultimately, there are two potential social-ecological futures. If some combination of Malthusian overpopulation and market expansion dominate the future social-ecological landscape, then human and ecological welfare will diminish. If ecological modernization and the environmental Kuznets curve trends dominate the future social-ecological landscape, then human and ecological welfare will have a higher probability of flourishing.

> 'Come what may, the twenty-first century will be the century of the environment – either the century of ecological catastrophes or the century of ecological transformation.'
>
> (Sachs et al. 1998, p8)

So far I have presented a review of the dominant perspectives of society's effects on natural resources including their respective theory, narratives, evidence, and limitations. I have also reviewed studies that have synthesised the perspectives, and highlighted limitations to the syntheses. Based on this review, and the limitations to current perspectives, individually, and in synthesis, I now proceed by outlining the research gaps that are addressed in this thesis.

1.3 RESEARCH GAPS

Reviewing the literature highlights four clear research gaps in the dominant human-environment perspectives (described in detail below). The first research gap is one of causality. The second gap is one of scale. The third gap is one of context. The fourth gap is one of triangulation of findings. I have focused on research gaps that are ubiquitous across perspectives, and so contribute to general understanding of the effects of society on natural resources, rather than attempting to refine any one particular perspective. I have taken this approach because it is clear that each perspective has strengths and limitations, and is therefore, by itself, insufficient for explaining the effects of societies on natural systems.

Research gap 1: Limited understanding of causal links between social and ecological systems.

The majority of quantitative studies directly test the effect of proxy variables that are representative of the elements of the perspectives (e.g. population density, GDP, urbanization) against indicators of the state of natural resource (e.g. species diversity, fishery biomass), without considering the mechanisms by which these proxy variables act on natural resources. That is, there is distinct paucity of research on the effect of Malthusian overpopulation, market expansion or modernization, on resource exploitation or the success of resource management institutions[9] which more directly explain the state of natural resources (Mills & Waite 2009). That is, most studies that test the merit of the perspectives directly correlate, using regression techniques, the effect of ‘driver’ (D) variables (proxy variables for the respective perspectives) on ‘state’ (S) variables (the state of the natural resource in question), without considering the ‘pressure’ (P) variables that mediate the interaction between driver and state variables (but see Clausen & York 2008a; McKinney et al. 2010) (Figure 1.2).

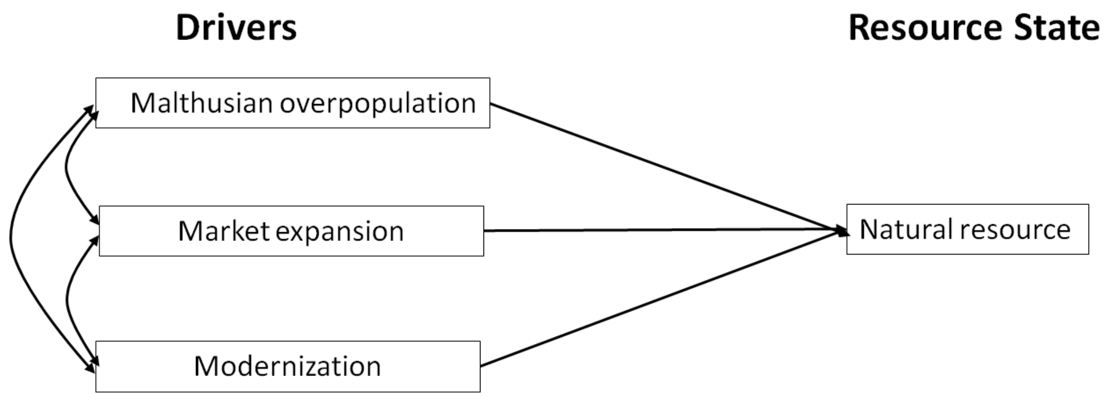

Figure 1.2 Model framework commonly used to test the merit of the three perspectives in explaining the effect of ‘drivers’ (D) on the ‘state’ (S) of natural resources.

To illustrate further- in the context of small-scale fisheries, modernization does not affect the biomass of targeted *in situ* fish stocks *per se*, but could result in increased access to, and subsequent use of, more efficient fishing gears (exploitation) that might, in turn, decrease fish stock biomass, or cause management institutions to fail (Cinner et al. 2009b). The argument is summarized by Alier:

> ‘The environment does not care at all about GNP [a proxy variable for, or manifestation of, modernization], it cares about absolute amounts of pollutants or extractions.’

(Alier 2003, p138)

[9] Other causes of resource decline exist including the indirect impacts of exploitation such as habitat degradation and runoff from logging, and atmospheric warming from burning fossil fuels. I argue here, however, that these are consequences of exploitation as I have defined it.

I address this research gap by developing and testing a more nuanced model than that presented in Figure 1.2. The model, based on a sound theoretical foundation that is outlined below, includes proxy variables for each of the perspectives, measures of both exploitation and management as mediating factors, and diverse measures of resource state.

A widely accepted sociological theory is that broad social phenomena (e.g. population growth, religious denomination, economic affluence), measured objectively, influence human behaviour (e.g. fishing effort) (Durkheim 1897). The general theory posits that individual actions (e.g. resource exploitation and management institution establishment and adherence) are determined by broader social function and phenomena, and therefore the behaviour of individuals and social sub-groups is constrained by the broader social context. Inherently, this infers causality between the social phenomena and human behaviour. The theory was first used to explain suicide rates in Europe (Durkheim 1897), but broadly applies to the behaviour of any sub-set of a human population.

This theory has facilitated the development of frameworks that link broad social phenomena to natural systems, through human behaviour. For example, it has been adapted as the driver, pressure, state (DPS) model wherein drivers are the broad social phenomena, pressures are those factors which directly affect ecological systems, and the state represents the measured condition of the ecological system (e.g. Pirrone et al. 2005; Mangi et al. 2007). The framework for analysing systems using this model is in the form D → P → S[10]. It was also used in the Millennium Ecosystems Assessment (2005). Similar frameworks have been adopted in contemporary research to explain sequential cause and effect in social-ecological systems (Forester & Machlis 1996; Agrawal & Yadama 1997; Geist & Lambin 2002; McKinney et al. 2010), whereby

[10] Additions to the three part model include, sequentially "I" (**impact** on society), and "R" (social **response** to the causes of changed environmental state which feeds back to "D" and "P") such that: D→P→S→I→R (e.g. Kristensen 2004).

broad social phenomena explain human activities which, in turn, explain environmental variability, following Durkhiem (1897). Yet, none of these studies has been used explicitly within the dominant perspectives. I argue, based on the work of Durkhiem and many since, that using this model structure within the three different perspectives will help inform our understanding of the cause and effect of societies on natural resources. I therefore use Durkheim's theory to generate a model structure that I use for testing the three dominant perspectives of the society's effects on natural resources.

In quantitative analysis, proxy variables are used to approximate each of the three perspectives. Such variables are, in effect, the measured manifestations of the underlying theory for each perspective. In the absence of reducing the complex narratives into measureable variables, it would not be possible to test quantitatively the perspectives, or any social-ecological phenomena for that matter. As reviewed above, such variables include distance to markets, urbanization, and population density. In this thesis, I maintain the use of proxy variables to represent each of the perspectives. Within the D → P → S framework such variables would be 'driver' (D) variables.

Further, I argue that the primary social causes (pressures in the DPS model) of resource decline are the utilization of natural resources (herein exploitation) by labour and technology, and failure of resource management institutions to constrain overexploitation. There is evidence of the negative effect of exploitation on natural resources in all ecosystems where resources with some utility exist (see Jennings et al. 1995; Jennings & Polunin 1996 for contextually relevant examples; Friedlander & Demartini 2002; DeMartini et al. 2008). There is also evidence that the presence of effective resource management institutions contributes to sustaining natural resources (see Russ & Alcala 1989 for contextually relevant examples; Cinner et al. 2012b). In this thesis, I therefore define the 'pressure' (P) variables as those social characteristics that represent natural resource exploitation, and suppression of exploitation, through resource management institutions. Within the model, driver variables, that are manifestations of each of the perspectives, act on the two key pressure variables, exploitation and management institutions, to effect a change in the state of natural resources. This approach provides a more nuanced understanding of each of the perspectives, and allows greater inference of causality, commensurate with the process-based narratives of each perspective. In figure 1.3 for example, population growth (a) causes increased exploitation of resources (b), and failure of management institutions to limit exploitation (c), resulting in decreased natural resources (d).

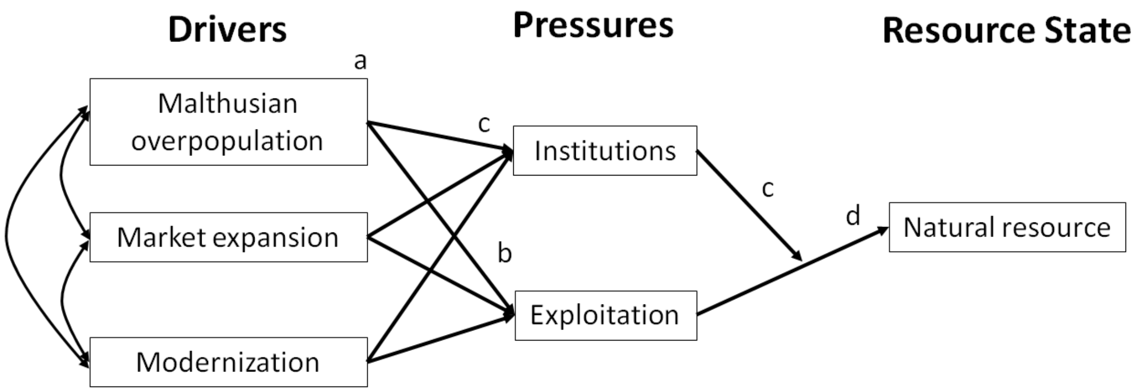

Figure 1.3 Model framework, derived from Driver, Pressure, State theory. DPS theory is to be applied in this thesis to explain the effects of society on natural resources. The purpose of this model is to synthesize the direct effects of human behaviour on natural resources, and does not claim to account for indirect effects such as variability related to climate change caused by the exploitation of tropical forests. Note that double-headed arrows represent interaction effects; single-headed arrows assume unidirectional flow of causality; institutions mediate the effects of exploitation on natural resources.

According to theory, each of the three perspectives would show different effects within the above model (Figure 1.3). Malthusian overpopulation would lead to failure in management institutions and increased exploitation intensity, including the use of more efficient and destructive gears, with clear negative flow-on effects to natural resources. Market expansion would lead to failure of institutions through factors such as rule transgression driven by potential economic gains, and increased exploitation intensity, including the use of more efficient gears, sourced through income generation. Modernization would, at some point in development, lead to more sophisticated management institutions able to cope with sustainable resource allocation issues, and the successful elimination of destructive exploitation practises, such as dynamite fishing and nylon nets with small mesh size. However, in early stages of development failure of relatively simple management institutions and use of unsustainable exploitation practises would be expected.

Research gap 2: Scale

There is bias toward national-level global analyses of the perspectives (York et al. 2003a, b; Hoffmann 2004; York & Gossard 2004; Clausen & York 2008b, a; McKinney et al. 2009) (Table 1.1). Preference for nation/state level analyses is probably driven by data availability and global relevance. Yet, it is clear that different factors drive resource decline at different social-political levels (Kronen et al. 2010), and there is a distinct paucity of comparative analyses at the local-level. Yet decisions to either exploit or conserve resources often occur at the individual and local-level, such as in coastal fishing communities, with limited influence from national-level policies. Also, it is likely that people and ecosystems are more tightly coupled at the local-level than at the nation/state level (Almany et al. 2013), and therefore feedbacks between society and ecology are more direct and consequently likely to be observable. This is particularly relevant to Solomon Islands coral reef social-ecological systems because, while there are certainly exceptions (Foale & MacIntyre 2000), coral reef resources are frequently exploited by the people living adjacent to the reef (Aswani 1999; Aswani 2002). Last, there is less social-ecological complexity and diversity at the local-level (particularly when comparing local-level sites within a nation/state), than at the nation/state level, and therefore less 'noise' in data, and greater likelihood of accounting for variability. The local-level, therefore, provides both a suitable and relatively novel level to compare the merit of the three perspectives. This thesis addresses research gap 2 by conducting the comparison of the perspectives using coastal communities in Solomon Islands as replicates within the analyses.

Variables that are used to approximate each of the perspectives (proxy variables) at the nation-level are not available at the local-level. For example, GDP, which is frequently used as a proxy for both modernization and market expansion, is not measured at the local-level. Therefore, in this thesis I use comparable proxy variables that are both available at the local-level and relevant to coral reef resources.

Research gap 3: Geo-political context

As stated by Fisher & Freudenberg (2001), acknowledged by a key proponent of ecological modernization (Mol 2003), and shown in table 1.1, the merit (explanatory power) of each perspective will vary among different social and ecological contexts. For the perspectives to develop therefore, it is essential to test them across a diverse set of contexts. Yet, there exists bias towards studies focused on modernized and affluent nations and societies (e.g. Schnaiberg 1980; Grossman & Krueger 1995; Mol 1995; Weinberg et al. 2000; Luck 2007). The perspectives have not been compared and contrasted within an economically disadvantaged, peripheral nation context. Yet, as discussed in the perspectives' limitations above, there is also strong evidence that the position of a nation in the world system (Wallerstein 1974), be it peripheral, semi-peripheral, or core, has a bearing on the state of its natural resources (Hoffmann 2004; Bunker 2005; Shandra et al. 2009; McKinney et al. 2010). Therefore, there is a distinct need to understand, better, the effects of societies on natural resources within a peripheral nation context, where a large portion of global biodiversity exists (Myers et al. 2000; Kramer et al. 2009). If, for example, there is no evidence of ecological modernization in peripheral nations then it is possible that ecological modernization observed in core nations and in global analyses is a result of core nations externalizing their ecological footprints through resource importation and pollution exportation.

To address research gap 3, the social-political context for this thesis, as stated above, is Solomon Islands, a peripheral nation that is highly dependent on marine resources situated in the western Pacific. Compared to other countries and territories in the Asia Pacific region, Solomon Islands is poor, has an average population density, and is highly dependent on coastal resources for livelihoods (Table 1.2).Solomon Islands is typical of a peripheral nation in that it has relied almost exclusively on resource extraction, including logging and tuna fishing, for income. Round-log exports, for example, accounted for between 50-68% of the country's GDP between the years 1990-2000 (Central Bank of Solomon Islands 2000). On a smaller scale, a number of other marine resources, including bêche-de-mer, trochus, and shark fin, have had a long history of both legal and illegal export (Bennett 1987). And so, in contrast to core nations, where the perspectives have been studied in greater detail, Solomon Islands is a nation of net resource export and net pollution import (largely by environmental degradation caused by logging and mining), and so is a contextually suitable location to conduct this research. It could be argued that using a single nation would not present an adequate range to test the merit of the modernization perspective (e.g. a large enough range of modernization, relating to domestic inequality), however, our understanding of what an adequate range might be is still limited, and non-linear effects of modernization have been observed previously within single nations (Grossman & Krueger 1995; M'henni et al. 2011).

Notably, several papers have begun addressing how these different perspectives explain key aspects of coral reef conditions at the local-level in a coral reef context, including study sites in peripheral nations. First, Cinner et al. (2009b) compared the Malthusian overpopulation and modernization perspectives at the local-level, and found modernization better explained much of the variance of the biomass of reef fish. The same study also proposed and tested the effects modernization on a number of mechanisms (akin to 'pressures', or proximate drivers, in this thesis) of fishery exploitation; the aforementioned composition, technique and scale effects, and found strong correlations between many of the indicator variables and modernization. Second, Cinner et al. (2012a) compared the Malthusian overpopulation and market expansion perspectives by meta-analysis on a global dataset. The results show that distance to market, as a proxy for market expansion, better explained fish biomass than did Malthusian overpopulation measured as human population density. Therefore, at the local-level, within the ecological context of this thesis, there is strong support for both the modernization and market expansion perspectives, which challenges the dogma of Malthusian overpopulation. While very informative, neither of these studies tested all three perspectives. Yet this is important in accounting for colinearity between the perspectives and considering which perspective is dominant. Further, the first of these studies was conducted in the western Indian Ocean, and the second was a global analysis. Yet, there is evidence of regional variation in coupled coral reef social-ecological systems (Pollnac et al. 2010). Therefore, Solomon Islands, situated in Melanesia in the western Pacific Ocean, represents a spatially novel context in which to test the merit of the perspectives.

Table 1.2 Dominant perspective attributes of Countries and Territories in the Asia Pacific region, including coral triangle initiative member countries. Included here are key variables relating to each of the three perspectives similar to those variables used in studies presented in Figure 1.1. GDP is a variable commonly used at the nation-level to represent both the market expansion and ecological modernization perspectives, and population density is commonly used to represent the Malthusian perspective. Further, data on population employed in coastal fishing has been included to reveal both dependence on, and level of market integration of, coastal fishing. Note that, for the region, Solomon Islands has a low GDP, average population density, and high dependence on coastal fisheries.- = no data, * = Coral Triangle member countries. Data on population size was derived from the World Bank (The World Bank Group 2004) and the United Nations Common Database (United Nations 2008) and the CIA World Fact book, (CIA 2012). Coral reef area data was derived from the World Atlas of Coral Reefs (Spalding et al. 2001). GDP data was sourced from the CIA World Fact Book (CIA 2008, 2013) and the United Nations (United Nations 2008).

Countries and Territories in the Asia Pacific region	GDP per capita (PPP) (avg. 1990-2000)	Population / km^2 coral reef	% Population employed in coastal fisheries
Malaysia*	$17,200	8230.11	-
New Caledonia	$16,606	39.16	-
French Polynesia	$15,551	42.61	-
CNMI	$10,950	1605.16	-
Timor-Leste*	$10,000	-	-
Palau	$5,657	17.5	14
Indonesia*	$5,100	4922.78	-
Philippines*	$4,500	4218.70	-
Cook Islands	$4,477	12.49	25
Fiji	$2,259	82.64	30
Marshall Islands	$1,849	9.28	32
Fed. States of Micronesia	$1,807	25.36	14
Tonga	$1,670	66.24	10
Vanuatu	$1,286	52.4	45
Tuvalu	$1,183	14.71	79
Samoa	$1,078	375.19	34
Tokelau	$1,000	28.02	-
Papua New Guinea*	$932	438.56	33
Solomon Islands*	**$881**	**82.16**	**60**
Kiribati	$499	31.29	69

Research gap 4: Triangulation using local perceptions.

None of the quantitative comparative studies relating to the dominant perspectives has used local perceptions to triangulate conclusions. Understanding of local perceptions is likely to contribute to both theory development and maturation. Local people within a study system (e.g. fishers in a fishery) are likely to have knowledge that is not apparent to system observers (e.g. scientists), and can therefore contribute additional knowledge to understanding the social processes that lead to resource decline (e.g. Berkes et al. 2000; Johannes et al. 2000). Local perceptions are also likely to either support or refute quantitative models, and therefore add weight to evidence, or force review of conclusions drawn from quantitative models alone. Understanding of local perceptions is also likely to aid in developing a realistic resource management agenda because, if local perceptions are not aligned with scientific conclusions then the application of scientific conclusions, for improved resource management will likely be untenable (see Foale 2006 for a discussion on scientific and local knowledge relevant to the context of this thesis).

I address research gap 4 by conducting interviews, using a survey, with fishers and middlemen (fish traders) in Solomon Islands. The surveys were conducted in major fish markets, where a large portion of the national reef fish catch is sold. A component of the survey included a series of questions relating to the respondents' perceptions of the causes of coral reef fish abundance decline, and what they perceived would cause an increase in coral reef fish abundance. The interviewer asked probing questions to obtain the respondents' perceptions beyond a single answer response. For example, if a respondent perceived that fishing causes coral reef fish to decline, then the interviewer would probe by asking what the respondent believed to be causing fishing to increase. By doing so, qualitative responses were obtained that are comparable to the scientific model presented in figure 1.3.

So far I have critically reviewed the dominant perspectives of the effects of society on natural resources, individually, and in synthesis. I have also outlined four clear research gaps and summarised how they are addressed in this thesis. I now proceed by outlining the aim of this thesis including stated research objectives and an outline of the thesis chapters.

1.4 RESEARCH OBJECTIVES

The aim of this thesis is to fill the aforementioned research gaps by 1) explaining society's effects on natural resources, at the local-level in an economically peripheral nation, using dominant environmental sociology perspectives (research gaps 1-3), and to 2) determine whether local perceptions, support or refute the scientific explanation (research gap 4). These broad aims are achieved by completing the following research objectives:

4. Determine which dominant environmental sociology perspectives, of societies effects on natural resources, best explains the effects of exploitation on;
    a) Coral reef fish that are vulnerable to extinction by overfishing;
    b) Function and diversity of coral reef fish;
5. Determine which of the perspectives explain the occurrence of coral reef resource management institutions; and
6. Determine whether local perceptions support, or refute, the findings, as identified in objectives 1 and 2, of society's effects on the exploitation and management of coral reef fish.

1.5 THESIS OUTLINE

The analytical component of this thesis is presented as three chapters, which comprise four stand-alone manuscripts (two manuscripts in chapter 2, and one in each chapter's 3 and 4; Figure 1.4). This section indicates the contribution of each chapter to the thesis to filling the identified research gaps, by completing the thesis objectives.

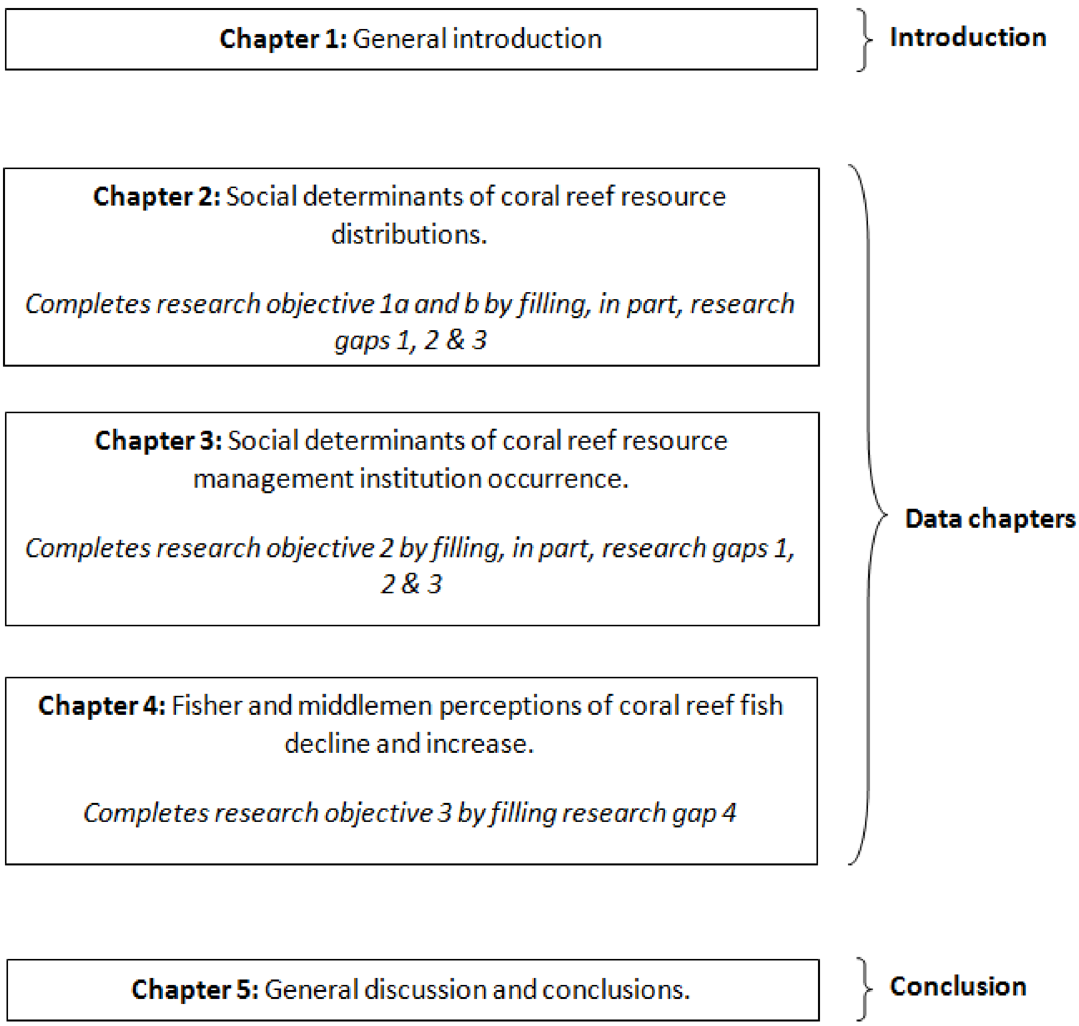

Figure 1.4 Thesis chapter outline

1.6 SUMMARY OF THESIS CHAPTERS:

Chapter 1: General Introduction

This (i.e. current) chapter provided a review of the dominant perspectives on the social causes of natural resource decline, and highlights limitations of each of the perspectives. Research gaps were identified, including a brief overview of how the research gaps will be filled in the thesis.

Chapter 2: Social determinants of coral reef resource distributions

In this chapter, I quantitatively test the relative merit of each of the three perspectives in explaining the coral reef fish distributions using comparative methods (grey dashed line in Figure 1.5). This chapter focuses on the relationships between proxy variables for each of the perspectives and exploitation (fishing) pressure on coral reef ecology (the next chapter focuses on the relationship between proxy variables for each of the perspectives and resource management institutions). The analysis includes 25 sites across Solomon Islands. The chapter is divided into two papers, with one focused on how the dominant human-environment perspectives explain the distribution of coral reef finfish that are vulnerable to exploitation by fishing, and the other paper focused on how these perspectives explain the ecological function and diversity of finfish. The rationale for writing two papers was that the ecological measures in each paper represent different dimensions of the ecology of coral reef fish. The paper on fish that are vulnerable to overfishing is more relevant to fisheries livelihoods, whilst the paper on function and diversity is more relevant to ecosystem resilience. Both papers partly fill research gap 1 by including fishing and coral reef habitat as a mediating variables within the models. The studies are conducted at the local-level, in a peripheral nation, Solomon Islands, and therefore both papers also address research gaps 2 and 3. The results of both papers show that, within the study context, both local human population pressure and access to markets explains the use of sophisticated fishing gear, which, in turn, best explains lower biomass of fish that are vulnerable to overfishing, and decreased fish species diversity, and biomass of key functional groups. Thus local population growth and market access are likely driving ecological decline, which supports the Malthusian overpopulation and market expansion perspectives respectively, and refutes the modernization perspective.

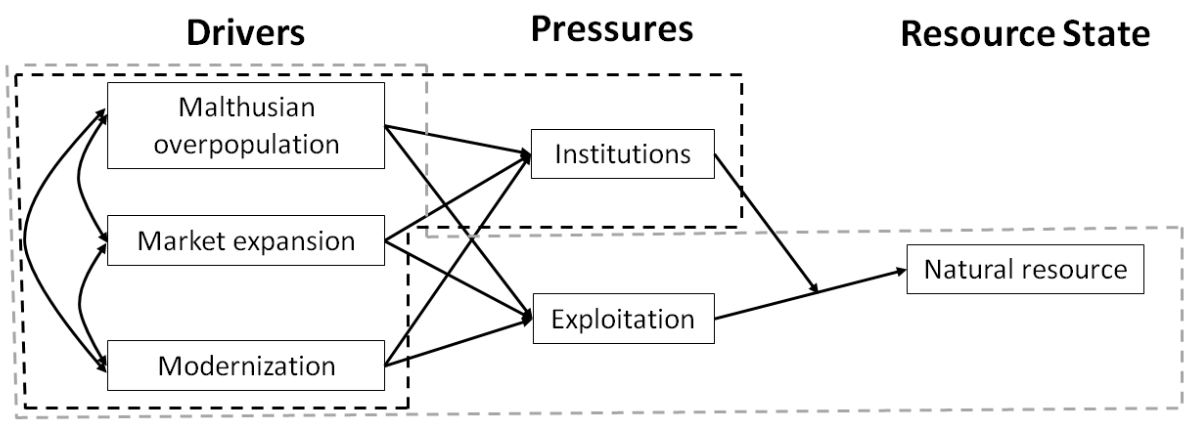

Figure 1.5 Generalised model used in this thesis to test the relative merit of each of the three dominant perspectives for explaining natural resource state. Grey dashed line is the component of the model addressed in chapter 2. Black dashed line is the model component addressed in chapter 3. Thus, the

application of this novel model addresses research gap 1, and applying it at the local-level in a peripheral nation addresses research gaps 2 and 3. Chapter 4, which addresses research gap 4 is derived from perceptions based research so does not fit the model a priori.

Publications derived from chapter 2:

Brewer, T.D., Cinner, J.E., Green, A., Pressey, R.L. Local human population density and proximity to external markets explain patterns of exploitation of vulnerable coral reef fishes. Conservation Biology. DOI: 10.1111/j.1523-1739.2012.01963.x

Brewer, T.D., Cinner, J.E., Fisher, R., Green, A., Wilson, S.K. 2012. Market access, population density, and socioeconomic development explain diversity and functional group biomass of coral reef fish assemblages. Global Environmental Change. 22; 399-406

Chapter 3: Social determinants of coral reef resource management institution occurrence

In this chapter I empirically examine the relative merit of each of the three perspectives in explaining the occurrence of coral reef resource management institutions using comparative methods (black dashed line in Figure 1.5), and thus fill, in part, research gap 1. I also fill, in part, research gaps 2 and 3 because, as with chapter 2, it is conducted in Solomon Islands at the local-level. I conclude that human population density has a dramatic negative effect on the likelihood of any given community having fishery management institutions, which lends weight to the Malthusian overpopulation perspective. Yet, relatively modernized (modernization was measured as summed infrastructure and amenities in communities) communities and communities with fish markets are more likely to have a fishery management institution that could help mediate a given population's environmental impact. These findings lend weight to the modernization perspective, but detract from the market expansion perspective.

Therefore, based on the results of chapters two and three, I conclude that local population pressure (Malthusian overpopulation) intensifies exploitation and has a negative effect on management; access to markets (market expansion) also intensifies exploitation, but has a positive effect on management; and infrastructure and amenities (modernization) has minimal effect on exploitation, and a positive effect on management.

Publication derived from chapter 3:

Brewer, T.D., Kool, J.K., Foale, S., Cinner, J.E. *Social and economic drivers of natural resource management institution occurrence.* In preparation

Chapter 4: Fisher and middlemen perceptions of coral reef fish decline and increase

This chapter, based on field surveys with fishers and fish middlemen in Solomon Islands, assesses local perceptions of the causes of reef fish decline and increase. Comparison of local perceptions with the findings of chapters two and three fills research gap 4. Perceived causes of fishery decline and recovery were numerous, based on results of surveys with 119 respondents. However, dominant themes emerged including the role of fish markets in causing fish decline, and the role of access to consumables, by modernization, increasing fishing effort to result in fishery decline. I conclude that local perceptions are similar to the findings presented in chapters two and three, and to previous published literature. Therefore, management intervention, based on scientific evidence, might be well received.

Publication derived from chapter 4:

Brewer, T.D. 2013. Dominant discourses, among fishers and middlemen, of the factors affecting coral reef fish distributions in Solomon Islands. Marine Policy. 37; 245-253

Chapter 5: General discussion and conclusions

This, the final chapter, summarises the findings of the thesis and discusses them in the context of the dominant perspectives of society's effects on natural resources. Discussion and theoretical contributions relating to each of the three data chapters (four papers) is contained within each respective chapter. Therefore those chapter-specific points of discussion and theoretical contribution will not be repeated here. Instead I 1) review the research gaps, show how they have been addressed in this thesis, and highlight how addressing the research gaps contributes to theory, 2) present a unified narrative of society's effects on coral reef fishery resources in Solomon Islands as the broad theoretical contribution of this thesis, 3) discuss limitations to the thesis, and associated future research, and 4) draw general conclusions.

Note regarding chapter terminology and consistency

Because this is a thesis by publication, each of the four papers had to be tailored to the journal audience and editorial requirements of specific journals. To provide consistency throughout the thesis, I have amended the contents of the publications to make terminology consistent, minimise redundancy, and maintain a consistent voice.

CHAPTER 2: SOCIAL DETERMINANTS OF CORAL REEF RESOURCE DISTRIBUTIONS

CHAPTER 2A: SOCIAL DETERMINANTS OF THE EXPLOITATION OF CORAL REEF FISHES THAT ARE VULNERABLE TO FISHING[11]

ABSTRACT

Coral reef fisheries are crucial to the livelihoods of tens of millions of people, yet widespread habitat degradation and unsustainable fishing are causing severe depletion of reef fish stocks. Understanding how social and economic factors such as human population density, access to external markets, and modernization interact with fishing and habitat to affect fish stocks is vital to sustainably managing coral reef fisheries. This chapter assessed whether these factors explain variation in biomass of coral reef fish among 25 sites in Solomon Islands, with *in situ* fish data and national social and economic data, using structural equation models. I categorized fishes into three groups based on life history characteristics that make certain fishes more, or less, vulnerable to extinction. The results show that the biomass of fish with low extinction vulnerability was positively related to habitat. The biomass of fish with high extinction vulnerability was negatively related to fishing using efficient gear that, in turn, was strongly positively related to both population density and market proximity, suggesting additive effects. Biomass of the fish species of medium extinction vulnerability was not explained by fishing intensity or habitat, which suggests these species might be resilient to both habitat degradation and fishing.

[11] **Brewer, T.D.**, Cinner, J.E., Green, A., Pressey, R.L. 2013. Local human population density and proximity to external markets explain patterns of exploitation of vulnerable coral reef fishes. Conservation Biology. 27; 443–452

2A.1 Introduction

Conservation actions frequently aim to reduce the proximate drivers of natural resource decline, such as unsustainable fishing or land clearing. However, a sole focus on managing proximate drivers can limit the efficacy of local conservation action by overlooking the underlying drivers of resource exploitation (Geist & Lambin 2002; Kramer et al. 2009). Alternatively, underlying drivers (hereafter distal drivers) such as human population growth, economic inequality, and per capita wealth have been used to directly explain variability in the condition of natural resources (York et al. 2003a; Bradshaw et al. 2010). However, these distal drivers are conceptually remote from the natural resource in question, making inference of causality tenuous (Mills & Waite 2009). For example, in the context of small-scale fisheries, modernization (which reflects not only affluence as in economic development, but also variables such as access to infrastructure and institutions) does not affect the biomass of targeted *in situ* fish stocks *per se*, but could affect proximate drivers such as increased access to, and subsequent use of, more efficient fishing gears that might, in turn, decrease fish stock biomass (Cinner et al. 2009b).

Here, I explore how elucidating relationships among distal drivers, proximate drivers, habitat and natural resources can inform conservation and management actions. I investigate whether potential distal and proximate drivers explain coral reef fish biomass across a gradient of social and economic conditions in Solomon Islands. Theoretical and empirical work on social-ecological interactions suggest three dominant perspectives of how societies affect the state of natural resources and so provide a foundation for this investigation.

2A.1.1 Dominant perspectives

Malthusian overpopulation

First, local human demography influences the status of natural resources; increasing human population density is generally thought to cause resource decline (see Malthus 1798 for foundational theory). Population size of people has been shown to negatively correlate with small ecological footprints (York et al. 2003a; Dietz et al. 2007), low absolute environmental impact (Bradshaw et al. 2010), species richness of threatened mammals and birds (McKinney et al. 2010), high mean trophic level of marine fish (Clausen & York 2008a), and the extent of distributions of threatened marine and freshwater fish (Clausen & York 2008b). I hypothesize three ways in which increased local human population pressure can deplete coral reef fish stocks: increase in fishing intensity using basic fishing gear for local consumption; increased use of efficient fishing gear as human population size increases concordant with 'Malthusian overfishing' (Pauly 1988); and reduction in habitat quality via direct damage and runoff of land-based pollutants.

Market expansion

Second, declines in local resources can also result from net resource export through increased production driven by access to markets (see Schnaiberg 1980 for foundational theory). The state of coral reef fisheries has been shown to correlate negatively with proximity to domestic markets (Cinner & McClanahan 2006; Brewer et al. 2009; Aswani & Sabetian 2010) and international trade in coral reef fish (Warren-Rhodes et al. 2003). I hypothesize that market proximity, as a proxy for market expansion, can deplete fish stocks via two key proximate drivers: increasing fishing intensity using efficient gears to supply external markets; and degradation of habitat caused by efficient gears which damage habitat structures.

Modernization

Third, considerable research has shown that modernization and associated affluence can influence the ways in which societies use natural resources. Modernization is related to, for example, the tools that societies use to produce goods and services, the types of goods and services traded, the ability of societies to extract resources from distant locations, and the ability of societies to fund scientific and resource management institutions (Arrow et al. 1995). Relations between modernization and resource conditions can be complicated, with some empirical observations of a nonlinear U-shaped relation inferring improved environmental condition at high levels of modernization (see Grossman & Krueger 1991 and; Mol et al. 2010 for foundational theory). This type of relation has been observed in, for example, fish catch (Clausen & York 2008a), *in situ* fish biomass (Cinner et al. 2009b), the number of threatened bird species (Naidoo & Adamowicz 2001), CO_2 emissions (Rosa et al. 2004), city air pollution and water quality (Grossman & Krueger 1995), and deforestation (Ehrhardt-Martinez et al. 2002). Thus, one hypothesis is that modernization could have a nonlinear effect on fish stocks by increased fishing pressure and habitat degradation at low levels of modernization followed by a decline in fishing pressure, and reduced habitat degradation at higher levels of modernization. An alternative hypothesis is that modernization is achieved through exploitation of natural resources and its relationship with the condition of natural resources is consistently negative.

To date, no studies have simultaneously looked at the relative importance of these three perspectives in explaining fish biomass distributions across a gradient of vulnerability to human activities. To address this, we collected social, economic, and ecological data from 25 sites across Solomon Islands (Figure 2A.1) and examined relationships between three distal drivers (population density, access to fish markets, and modernization), two proximate drivers (fishing with basic gears requiring small capital investment and fishing with efficient gears requiring large capital investment), habitat (coral cover), and *in situ* reef fish biomass.

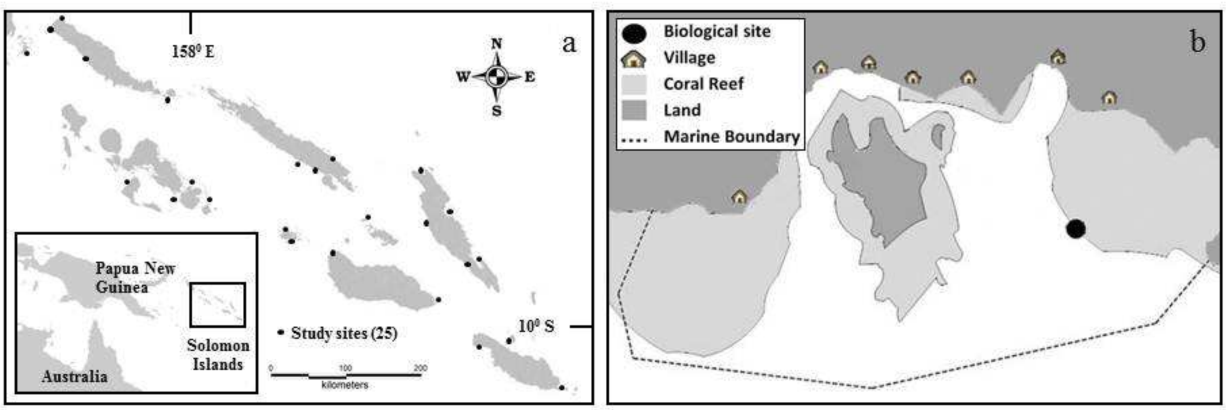

Figure 2A.1 a) The main islands of Solomon Islands showing study site locations, and b) a generalized image of a study site including marine site boundary, ecological sampling location, coral reef area, and villages.

2A.2 METHODS

2A.2.1 FISH BIOMASS AND VULNERABILITY

Fish biomass data were collected at 66 sites across the Solomon Islands between May to June 2004 using underwater visual census along five 50m belt transects at each site, at a depth of 10 m (Green et al. 2006) (see Appendix 2 for detailed sampling method). From these survey data, we used a measure of vulnerability to extinction (hereafter 'vulnerability') based on the index developed by Cheung et al. (2005), and available from FishBase (Froese & Pauly 2011). This index scores each species' vulnerability (0 to 100) based on ecological characteristics and life history traits. I grouped an approximately equal number of species into the three categories of vulnerability: low (*n*=111), medium (*n*=90), and high (*n*=85) (Table 2A.1). It was not possible to assign an equal number of species to each category because many species had the same vulnerability score (Appendix 3). In cases where fish were not identified to species they were assigned the mean vulnerability of recorded species within the respective genera from within the sample. Species from families *Kyphosidae*, *Diodontidae* and *Synodontidae* were omitted because no vulnerability values were available within the sample at the genus level. I omitted families *Carangidae* and *Caesionidae* because their species are highly mobile (Thresher & Gunn 1986) and can form large schools (Graham et al. 2003), and both characteristics could have affected the accuracy of the belt transect sampling technique. We included all other demersal reef fish. Biomass was then summed for each vulnerability category at each site (Appendix 3).

Table 2A.1 Potential distal and proximate drivers, habitat, and resource state variables used in models, including raw data, data sources, and pre-model transformations.

Model Components	Variables within model components[a]	Pre-model transformations	Data source	Supporting literature[h]
Distal Drivers				
Human population density	Human population density	Ln (human population/km^2 coral reef)	SIC[d]	1, 2, 3, 4, 5, 6, 7, 8, 9, 10.
Market proximity	Shortest distance from ecological survey location to the nearest local fish market (*lfm*), provincial capital (*pc*), and national capital (*nc*), by road and sea	Sum (*lfm* + *pc* + *nc*)	SIVRS; SIDLHS[e]	12, 13, 14, 15.
Modernization	Presence of pre-school, kindergarten, primary school, community high school, clinic, wharf, trade store, supermarket, postal service, fuel depot, credit facility, bank, airport	Ln (sum (all modernization variables/number of villages))	SIVRS[f]	11.
Proximate Drivers				
Small-investment, basic gear fishing	Population consuming fish (*cf*) No. fishing lines (*fl*) No. wooden canoes (wc)	PCA[c] (ln(*cf*/km^2 coral reef) + ln(*fl*/km^2 coral reef) + ln(*wc*/ km^2 coral reef))	SIC; SIVRS	
Large-investment, efficient gear fishing	Population selling fish (*sf*) No. eskies (*e*) No. fibreglass boats (*fb*) No. spear guns (*sg*) No. fishing nets (*fn*)	PCA (ln(*sf*/km^2 coral reef) + ln(*e*/km^2 coral reef) + ln(*fb*/km^2 coral reef) + ln(*sg*/km^2 coral reef) + ln(*fn*/km^2 coral reef))	SIC; SIVRS	
Habitat				
Live coral cover	% live coral cover	N/A	REA[g]	16, 17, 18.
Fish Biomass				
All demersal fish	All demersal fish	Biomass/ha.	REA	
Low vulnerability fish	Vulnerability score[b] = 10 to 23	Biomass/ha.	REA	

Medium vulnerability fish	Vulnerability score = 24 to 35	Biomass/ha.	REA
High vulnerability fish	Vulnerability score = 36 to 76	Biomass/ha.	REA

[a] Description of acronyms of variables within model components: *lfm* - a small local market where reef fish are likely to be frequently sold. *pc* - a capital exists in each of the provinces, and each capital has frequently operating fish markets, likely to be larger than local fish markets, and selling fish at a higher price. *nc* - national capital, having the largest fish market in the nation, where fish prices are likely to be higher than elsewhere, attracting fish sellers from further afield. *cf* - the number of people consuming fish at each study site. *fl* - fishing lines, likely comprising mainly handlines. *wc* - wooden canoes are typically dugouts powered by paddle. *sf* - the number of people selling fish at each site. *e* - insulated ice boxes frequently used for preserving perishable food including fish. *fb* - fibreglass boats are typically 5m to 8m in length and powered by outboard motors. *sg* - spearguns are likely to include both Hawaiian sling-like spears which do not have a trigger mechanism, but are exceptionally efficient when used at night, and some more advanced models with trigger mechanisms, either locally made or imported. *fn* – fishing nets are likely to include both traditional bush material nets and nylon gill nets.

[b] See Cheung et al. (2005)

[c] Principal Components Analysis

[d] Solomon Islands 1999 National Census

[e] Solomon Islands Departments of Lands, Housing, and Survey

[f] Solomon Islands 2008 Village Resource Survey

[g] Rapid Ecological Assessment (Green et al. 2006)

[h] Supporting literature: 1. Jennings & Polunin (1996), 2. Jennings & Polunin (1997), 3. Dulvy et al. (2004a), 4. Dulvy et al. (2004b), 5. Newton et al. (2007), 6. Williams et al. (2008), 7. Mora (2008), 8. Sandin et al. (2008), 9. Stallings (2009), 10. Mora et al. (2011), 11. Cinner et al. (2009b), 12. Cinner & McClanahan (2006), 13. Brewer et al. (2009), 14. Aswani & Sabetian (2010), 15. Schmitt & Kramer (2010), 16. Friedlander & Parrish (1998), 17. Graham et al. (2008), 18. Beger & Possingham (2008). Citations are only to literature that provides quantitative evidence of effects on resource state, in a coral reef context.

2A.2.2 Social and Economic Data

Social and economic data were derived from national surveys including national census data (Solomon Islands Government 1999), and a national village resource survey (Solomon Islands Government 2008) (Table 2A.1). All social and economic data were measured at the village scale. I defined the spatial extent of each site to determine which villages (and the related social and economic data) were associated with the fish data from the rapid marine assessment. The spatial extent of each site was elicited from individuals possessing local knowledge of marine resource use by people residing in villages adjacent to the fish survey location. The interviews were conducted in Honiara, the national capital. One constraint of this method is that, particularly for finfish, site boundaries are not necessarily strictly adhered to; probably due to their relatively low economic value compared to other fisheries such as trochus and bêche-de-mer (Ruddle 1996). Therefore fishers with adequate transport are able to fish over vast distances, rather than being constrained to their territories. Alternative methods exist for estimating resource use boundaries, including friction mapping using thiessen polygons (Mulller & Zeller 2002), ethnographic studies (Aswani 1999), and participatory GIS mapping (Aswani 2011). However, the large-scale nature of this study inhibited the use of these more localized resource use mapping techniques. The marine boundary, as elicited from experts, was defined as the area within the vicinity of fish survey sites likely to be exploited by people living in villages within 1 km of the adjacent coastline (Fig. 2A.1b). Boundaries were drawn on 1:150,000 digital maps.

Distal Drivers

Three variables were used to represent potential distal drivers associated with each of the perspectives of how societies affect natural resources: human population density, market proximity, and modernization (Table 2A.1; Figure 2A.2). Human population density was measured as the total number of inhabitants within the boundary of each site per coral reef area (km^2). Fisher mobility across boundaries is likely to constrain the accuracy of this method of measuring human population density as mentioned above. However, this method is used based on the assumption that there is not bias fishing effort outside marine boundaries across the study sites. Coral reef area was measured at each site by tracing all visible coral reef within site boundaries, using Google Earth

Pro, defined as the total visible coral reef area within site boundaries, as derived from the expert elicited site boundary maps (Fig. 2A.1b) (Brewer et al. 2009). Market proximity was measured as the shortest distance from the centre of each ecological sample location to the centre of the nearest local fish market, provincial capital, and national capital (all of which have fish markets) using roads and sea as possible routes within the same distance measure, using ArcGIS (Table 2A.1). A single measure of market proximity was developed, for each site, by summing the unweighted distances from the ecological sampling location to the nearest local fish market, provincial capital, and the national capital (Table 2A.1). Modernization was measured as the sum of a set of unweighted infrastructures and amenities within site boundaries (Table 2A.1), using indicators of modernization similar to previous studies (Cinner et al. 2009b; Pollnac et al. 2010). The aggregate score for each site was then divided by the number of villages at each respective site, to control for infrastructure and amenity accessibility (Cinner & McClanahan 2006).

Proximate Drivers

Two potential proximate drivers (Table 2A.1) likely to mediate the effect of distal drivers on fish biomass were measured: small-investment fishing using basic gear (hereafter "basic gear fishing"), and larger-investment fishing using efficient modern gear (hereafter "efficient gear fishing") (Figure 2A.2). Basic gear fishing was measured as the total human population consuming fish, the numbers of wooden canoes (Photo 2A.1), and the number of fishing lines, all expressed per km^2 of reef area at each site, the data for which were derived from the census and village resource survey (Table 2A.1). Efficient gear fishing was measured as the total human population selling fish and numbers of fiberglass boats (Photo 2A.2), insulated ice boxes (referred to as "eskies") (Photo2A.3), spearguns, and fishing nets, all expressed per km^2 of coral reef at each site, the data for which were also derived from the census and village resource survey (Table 2A.1). Within basic and efficient gear categories, we combined the variables using Principal Components Analysis (PCA) for each fishery separately. The two fishing types were distinguished by the investment required to acquire and maintain the respective gears, and the relative increase in catch-per-unit-effort that can be expected with efficient gear (Hallwass et al. 2011). Basic gears and efficient gears also reflect fishing for local use and fishing for markets respectively.

Photo 2A.1 Fishers in traditional wooden paddle canoes in Roviana lagoon, heading out to the reef edge for fishing at dusk.

Photo 2A.2 A typical fibreglass boat used for fishing and transport throughout Solomon Islands. Most are roughly 5 -7 metres in length, equipped with a 6-15 horsepower engine. They require significant financial outlay and are costly to run due to local fuel and fibreglass costs, as well as outboard maintenance, but far more efficient and stable than dug-out canoes. This particular boat belonged to Michael Giningele, the father of Joe, who assisted with the field work for this thesis.

Photo 2A.3 A very kind fish seller, 'Buss', who introduced me to fish sellers at the Honiara market. Seen here replenishing ice in his esky on a hot day at the Fishing Village market situated on the outskirts of Honiara.

Habitat

Habitat occurrence and condition is an important determinant for explaining ecological communities. Habitat was defined as percent living coral cover (Table 2A.1) which has previously been shown to explain reef fish distributions (e.g. Friedlander & Parrish 1998; Beger & Possingham 2008; Graham et al. 2008; Pinca et al. 2012) (Figure 2A.2). To do this substrate type was measured, including coral cover, at three points every 2m along five 50m belt transect (totalling 375 points at each survey location), using the same transects used in the fish survey (Hughes 2006).

2A.2.3 Linking Fish Data to Social and Economic Data

A number of the initial 66 ecological survey sites could not be included in the final analysis. Reasons included incomplete fish data, absence of social and economic data, unclear association between villages and ecological data (due largely to complex resource-use rights determined by genealogies), and the need to reduce ecological variability by omitting fish survey locations classified as sheltered from prevailing weather (Karlson et al. 2004). Consequently, prior to analysis, the data set included three potential distal drivers, two potential proximate drivers, habitat, total fish biomass, and fish biomass in three vulnerability categories: low, medium and high (Table 2A.1) for 25 sites.

2A.2.4 ANALYSIS

Partial least squares regression, in the program Warp PLS, was used to build structural equation models (SEMs) (Figure 2A.2). Partial least squares was chosen over covariance-based approaches primarily because it suited the small sample size (Chin & Newstead 1999; Reinartz et al. 2009). Distal drivers, proximate drivers and habitat variables remained consistent across models with only the fish biomass response changing between models. This resulted in unique models for each of the four fish biomass categories - total fish biomass, biomass of fish of low vulnerability, biomass of fish with medium vulnerability, and biomass of fish of high vulnerability - each of which had the structure presented in figure 2A.2. The partial least squares method partials out each analysis (e.g. the effect of population density and modernization on coral cover) from the overall model and therefore, in this study, is equivalent to sets of non-linear regressions, except that overall model fit statistics are also generated. The models were bootstrapped, set at 999 iterations. All models were constrained to second-order polynomial relationships, thereby allowing simple, non-linear relationships between variables. Warp PLS software has an inbuilt function whereby the relationship between two variables will default to a smaller order polynomial if it is deemed linear (Kock 2010). The output generated included individual standardized path coefficients (β), partial model fit scores (r^2) and overall model p values calculated through resampling estimations coupled with Bonferroni-like corrections (Kock 2010). The total effect of each distal driver (market proximity, modernization and population density) was calculated by multiplying the standardized coefficients (β) within each pathway then summing these values for pathways associated with each distal driver.

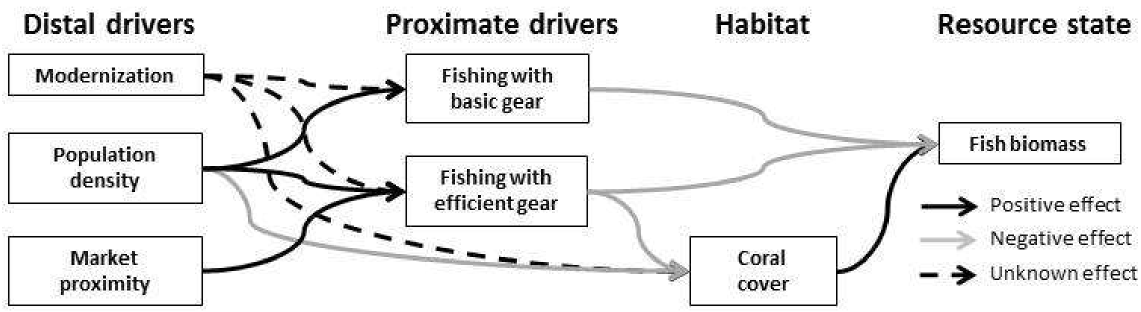

Figure 2A.2 Schematic structural equation model of the social and economic determinants of coral reef fish biomass distributions. Arrows show hypothesized correlations between variables within the model. Unknown effect of modernization due to divergent perspectives. Note “Population density” is the dominant surrogate variable for the “Malthusian overpopulation” perspective, and “Market proximity” is the dominant surrogate variable for the “market expansion” perspective.

2A.3 RESULTS

2A.3.1 DATA REDUCTION

One principal component was adequate to describe each fishing intensity variable: basic gear fishing (λ = 2.4; variance explained = 79.3%) and efficient gear fishing (λ= 3.3; variance explained = 65.4%). The variables that comprised both basic gear and efficient gear fishing had positive factor loadings of ≥ 0.65 on each principal component, and therefore all variables contributed positively and strongly to each respective fishing intensity variable. The mean density, per reef area, of basic gear fishing variables was markedly higher than those representing efficient fishing (Figure 2A.3).

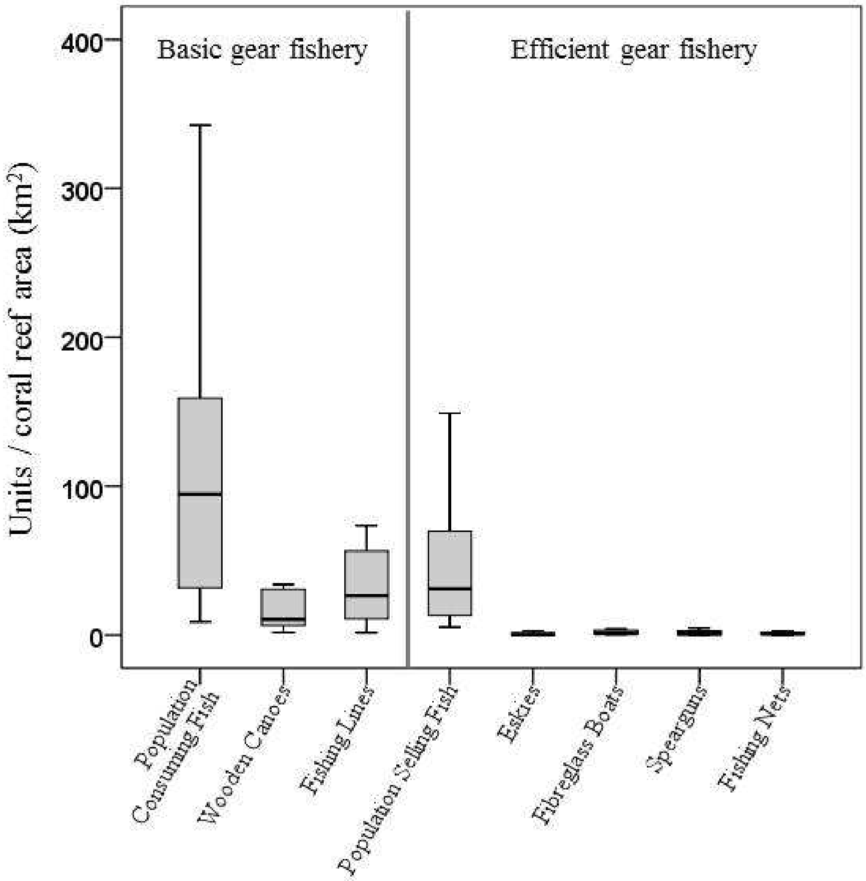

Figure 2A.3 Density of variables comprising basic gear fishing and efficient gear fishing, across sites. The central bar within the box represents the median value. The range within the closed box represents the middle 50% of data points (25% below and 25% above the median). The range between the ends of the box and the 'whisker' lines represents the upper and lower 25% of data, excluding outliers.

2A.3.2 EFFECTS OF DISTAL DRIVERS ON PROXIMATE DRIVERS AND HABITAT

Distal drivers explained much of the variance of the proximate drivers and some of the variance of coral cover. Together, the three distal drivers - modernization, population density and market proximity - explained 76% of the variance of efficient gear fishing. Modernization and population density explained 82% of the variance of basic fishing gear. Modernization, population density and efficient gear fishing explained 33% of the variance of coral cover. Therefore, the distal drivers proved to be good predictors of fishing, but poor predictors of our measure of habitat condition.

2A.3.3 DISTAL AND PROXIMATE DRIVERS OF TOTAL FISH BIOMASS

Total fish biomass was best explained proximately by the negative effect of efficient gear fishing (β = -0.62; p <0.01) (Figure 2A.4A). Coral cover had a non-significant ($p \geq$ 0.05) negative effect on total fish biomass, and basic gear fishing had a negligible effect. The two proximate drivers and coral cover explained 40% of the variance of total fish biomass. The effect of efficient gear fishing on total fish biomass was explained by both population density (β = 0.39; p <0.01) and market proximity (β = 0.55; p <0.05). Modernization had a weak negative effect (β = -0.1; $p \geq$ 0.05) on efficient gear fishing. Therefore, population density and market proximity together, through increased efficient gear fishing, best explained the distribution of total coral reef fish biomass in Solomon Islands.

2A.3.4 DISTAL AND PROXIMATE DRIVERS OF FISH BIOMASS IN VULNERABILITY CATEGORIES

The biomass of fish with low vulnerability to fishing was best explained proximately by coral cover (β = 0.39; p <0.01) (Figure 2A.4B). Basic gear fishing also had some weak negative effect (β = -0.21; $p \geq$ 0.05). These two proximate drivers combined and coral cover explained only 26% of the variance of low vulnerability biomass. Coral cover, in turn, was partly, but not significantly, explained by efficient gear fishing (β = -0.38; p =0.06). Therefore, coral cover had a clear positive effect, but no distal drivers had a discernable effect, on the biomass of fish with low vulnerability. The biomass of fish with medium vulnerability to fishing was not significantly (p >0.05) explained by any of the proximate drivers or coral cover (Figure 2A.4C). The biomass of fish with high vulnerability was best explained by fishing with efficient gears, which, as with total biomass, was explained by both population density and market proximity (Figure 2A.4D). Coral cover had a negative, but not significant, effect on the biomass of fish of high vulnerability. This unexpected effect might be explained by one site that had low coral cover but exceptionally high biomass of highly vulnerable fish. Combined, the two proximate drivers and coral cover explained 36% of the variance of high vulnerability biomass.

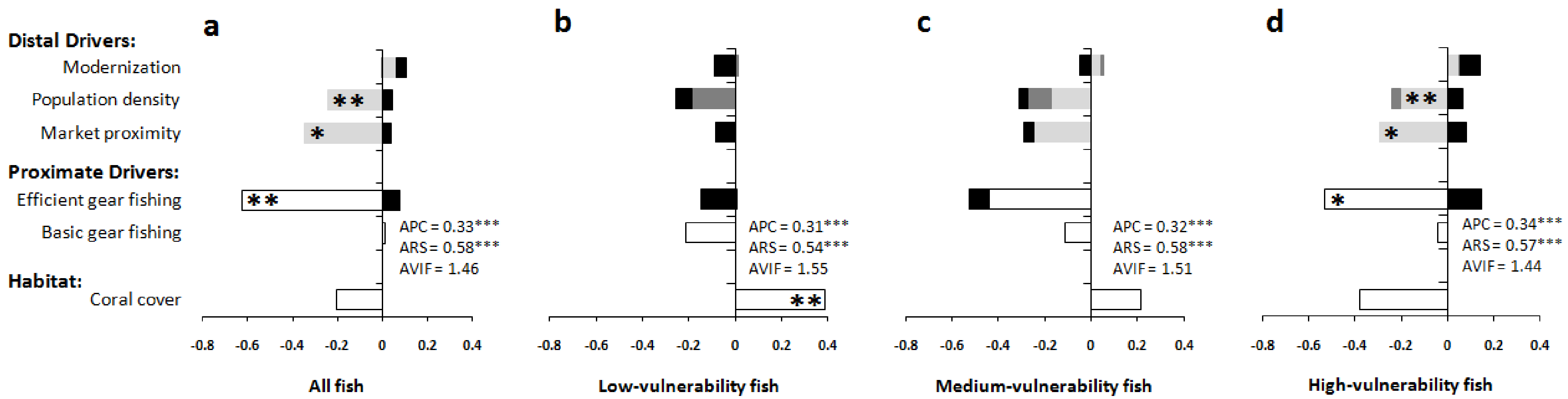

Figure 2A.4 Structural equation modeling results (SEM) of the total effect size (determined by multiplication of path coefficients (β) along each distinct path, prior to summing of distinct paths) for the different distal and proximate drivers for each of the resource state variables based on the general model (Fig. 2A.2). Unshaded bars show direct effects of coral cover, basic gear fishing, and efficient gear fishing on fish biomass. Black bars show the effect of distal drivers and efficient gear fishing on each category of vulnerability through coral cover. Dark grey bars show the effect of distal drivers on fish biomass through basic gear fishing. Light grey bars show the effect of distal drivers on fish biomass through efficient gear fishing. APC = average path coefficient (β) value within the model. ARS = average variance explained (r^2) within the model from each of four response variables. AVIF = average variance inflation factor. (*p ≤0.05, *p ≤0.01, *p ≤0.001).

2A.4 DISCUSSION

This study determined whether potential distal and proximate drivers explained spatial variation in the biomass of reef fish in Solomon Islands. Total fish biomass was explained proximately by fishing with efficient gears, which was, in turn, explained by market proximity and population density. However, the findings differed when total fish biomass was disaggregated into low, medium, and high vulnerability categories. Variation in biomass of low vulnerability reef fish was explained proximately by living coral cover. This suggests that fish that are less vulnerable to fishing are likely vulnerable to factors that degrade habitat (Graham et al. 2011). As with total biomass, the biomass of high vulnerability fish species was explained proximately by fishing with efficient gear, which in turn was significantly explained best by market proximity but also by population density. This suggests that fish in this highly vulnerable category are sensitive to multiple human activities, requiring a multifaceted management approach to ensure their persistence. Variation in biomass of fish species of medium vulnerability was not explained significantly by any of the proximate drivers. In a study using creel survey (fish landings) data from the neighbouring country of Papua New Guinea (where fishing techniques could be considered broadly comparable), only 34% (31/90) of species in the medium vulnerability category were recorded in catch records (Cinner et al. 2009c) , suggesting that the majority of medium vulnerability species are not targeted by fishers. Furthermore, the medium vulnerability fishes only comprised 13% of 223 species targeted by Papua New Guinea fishers. Understanding the functional roles of fish (i.e. the roles of different fish assemblages in maintaining broader ecosystem function) in this medium vulnerability category could lend insight into the potential resilience of coral reefs to both habitat degradation and fishing pressure.

Broadly, the findings suggest that, in Solomon Islands, market proximity and local human population density explain the effects of fishing on fish biomass distributions. The strong relationship observed between human population density and fish biomass supports previous studies (e.g. Jennings & Polunin 1997; Mora 2008; Williams et al. 2008) and the

Malthusian overpopulation perspective. This simultaneous exploration of distal and proximate drivers showed that the effect of population density on fish biomass was greatest through the use of efficient fishing gear. This finding provides some support for the 'Malthusian overfishing' concept, whereby growing local human populations overexploit resources, and use more efficient technologies to maintain exploitation levels, which can ultimately lead to resource collapse (Pauly 1988). However, consistent with other detailed studies in the region (e.g. Cinner & McClanahan 2006), this study also shows that market proximity can have an equal or greater effect, which supports the market expansion perspective.

Market proximity best explained the biomass of coral reef fish in Solomon Islands. Market-driven investment in technology to improve profitability has previously been observed in the Solomon Islands reef fishery (Sabetian & Foale 2006; Brewer et al. 2009). Increased market access, through road construction, has been shown elsewhere to increase fish sales to non-local buyers, and increase the diversity of marine products sold at markets (Schmitt & Kramer 2010). More broadly, the importance of market proximity in explaining resource state highlights a key future challenge for conservation initiatives in the face of increased trade in diminishing natural resources, particularly with increasing globalization that could make social-ecological systems more open to trade and migration (Wallerstein 1976; Berkes et al. 2006; Kramer et al. 2009).

Photo 2A.4 The fish section in the Honiara fish market. On busy days, when many of the provincial ships are in port there can be in excess of 30 esky's containing roughly 150kilograms of fish. The high prices at the central market mean fishers and traders are drawn from across much of Solomon Islands to sell their catch. Previous research (Brewer et al. 2009) has shown the significant negative relationship between the distance to this particular market and reef fish biomass.

Modernization was not significantly correlated with fishing using basic or efficient gear, or coral cover. Therefore, the level of modernization was not related to the state of coral reef fisheries in Solomon Islands through any of the pathways hypothesized in this study. One plausible explanation is that our study was conducted over a limited modernization gradient within a single country that is at the lower end of the development spectrum (United Nations Development Programme 2009).

The application of structural equation modeling in this study allowed exploration of how distal drivers explain relationships between proximate drivers and resources. Distal drivers, and particularly population density and market proximity, explained the effect of fishing on resources. However, responses varied greatly depending on the path between distal driver and fish biomass. Broadly, these results suggest that distal drivers do affect local patterns of resource exploitation, so need to be considered in the development of resource management strategies, but the results also indicate that the responses of resource state can be both complex and variable. The results suggest that successful reef fishery management initiatives will require multiple strategies that include local-level conservation efforts such as locally managed protected areas (Aswani & Lauer 2006), gear restrictions (McClanahan & Cinner 2008; McClanahan 2010), and improved governance of markets across all levels of institutions involved in the trade of reef fish.

CHAPTER 2B: SOCIAL DETERMINANTS OF THE DIVERSITY AND FUNCTION OF CORAL REEF FISH ASSEMBLAGES[12]

ABSTRACT

There is overwhelming evidence that many local-level human activities (e.g. fishing) have a deleterious effect on coral reef fish assemblages. Our understanding of how broad social phenomena (e.g. modernization) affect the diversity and function of coral reef fish assemblages however, is still poor. Here, structural equation models are used to reveal how human population density, modernization, and market proximity affect fishing pressure and coral cover to, in turn, explain the diversity and biomass of key functional groups of reef fish assemblages within Solomon Islands. Fishing pressure is predominantly driven by both market proximity and local population density, and has a clear negative effect on the diversity and function of coral reef fishes. The strong positive effect of market proximity on fishing pressure makes clear the importance of understanding social-ecological linkages in the context of increasingly connected societies. This study highlights the need to address broad social phenomena rather than focusing on proximate threats such as fishing pressure, to ensure the continued flow of coral reef goods and services in this time of rapid global social and environmental change.

[12] **Brewer, T.D.,** Cinner, J.E., Green, A., Fisher, R., Wilson, S. 2012. Market access, population density, and socioeconomic development explain diversity and functional group biomass of coral reef fish assemblages. Global Environmental Change 22: 399-406

2B.1 INTRODUCTION

There is overwhelming evidence that human activities are profoundly altering marine ecosystems on a global scale (e.g. Hughes 1994; Pandolfi et al. 2003). Of particular concern are the poorly understood, yet potentially disastrous environmental changes that human activity is causing to the functioning of coral reef ecosystems upon which millions of people depend (Mora et al. 2011). Ecosystem function is conceptually and analytically complex, requiring a diverse array of metrics to understand ecosystem response to human activity. High biological diversity is thought to contribute to maintaining ecosystem resilience (e.g. McCann 2000; Cardinale et al. 2006; Tilman et al. 2006) through increased response diversity to perturbations and functional redundancy (Naeem 1998; Chapin III et al. 2000; Hooper et al. 2005; but see Ives & Carpenter 2007; Maestre et al. 2012), assuming that species respond to threats uniquely. The use of diversity metrics as surrogates for ecosystem function however, does not come without criticism. There is, for example, some evidence that particular species (Bellwood et al. 2003; Bellwood et al. 2006; Hoey & Bellwood 2009), and functional groups (e.g. Hughes et al. 2007) perform disproportionately important functional roles, acting as energy conduits through trophic levels and maintaining broader ecosystem processes. Therefore, it is important to consider measures of both diversity and functional groups to understand how ecosystems may respond to human activities.

Coral reef fishes are vital to ecosystem function, and provide significant goods and services to people. A range of factors has been identified as important drivers of the diversity, biomass, and abundance of reef fish functional groups. At large biogeographic scales, distributions of diversity and function can be explained by environmental factors, including available habitat, latitude-longitude gradients, the mid-domain effect, gyre influence, history of environmental stress, and larval subsidy from species-rich regions (Bellwood & Hughes 2001; Connolly et al. 2003; Mora et al. 2003; Bellwood et al. 2005; Mora & Robertson 2005; McClanahan et al. 2011b). At local and national social-political scales, various environmental and social factors have been used to explain fish diversity and biomass of functional groups. Environmental factors include depth, exposure to prevailing weather, season, reef zone, coral cover, substrate rugosity, habitat complexity, and larval dispersal (Luckhurst & Luckhurst 1978; Molles Jr. 1978; Bell & Galzin 1984; Roberts & Ormond 1987; Friedlander & Parrish 1998; Friedlander et al. 2003; Gratwicke & Speight 2005; Jones et al. 2005; Graham et al. 2006) (Table 2B.1). In contrast to the depth of work assessing environmental drivers of fish diversity and function, assessments of the potentially important role that human activity might have in shaping ecological assemblages have focused largely on human population density (Jennings et al. 1995; Jennings & Polunin 1996, 1997; Bellwood et al. 2003; Dulvy et al. 2004a; Dulvy et al. 2004b; Mora 2008; Williams et al. 2008; Stallings 2009; Williams et al. 2011) and fishing pressure (DeMartini et al. 2008; Wilson et al. 2008). However, recent research has highlighted the potentially important role of factors such as market proximity and modernization (including for example, affluence and urbanization) in explaining functional group distributions (Brewer et al. 2009; Cinner et al. 2009b; Stallings 2009; Aswani & Sabetian 2010). What is not clear, however, is how market proximity and modernization affect fish species diversity, and whether market proximity and modernization have an effect on fish diversity and function beyond what is explained by human population density. This paper aims to contribute to this research gap by examining relationships between social drivers and the diversity and function of reef fish communities.

Table 2B.1 Key environmental and human factors that explain in situ coral reef fish diversity and functional group distributions at biogeographic scales relevant to this study.

Factor	Explains diversity measures[a]	Explains functional group biomass[b]	Controlled for in this study?
Environmental			
Depth	1, 2, 3.[c]	1, 3.	S[d]
Exposure	4.	11, 12.	S
Time	5.	-	S
Reef zone	1.	1, 13.	S
% Coral cover	6, 7.	1, 3, 7.	M[e]
Habitat complexity	4, 8, 9.	9, 14.	*[f]
Habitat rugosity[g]	1, 4, 10.	1, 15.	*
Human			
Proximate drivers			
Fish consumption	-	14.	M
Fishing pressure	16.	16, 19, 20.	M
Distal drivers			
Population density	17, 18.	15, 17, 18, 21-26.	M
Affluence	-	15, 18[h].	M
Urban development	-	24, 27.	M
Market proximity	-	28.	M

[a] references relate to any measure of diversity (e.g. richness, evenness)
[b] references relate to any functional group abundance or biomass measure (e.g. herbivore biomass)
[c] Supporting references:
1. Friedlander and Parrish (1998), 2. Roberts and Ormond (1987), 3. Öhman and Rajasuriya (1998), 4. Friedlander et al. (2003), 5. Molles Jr. (1978), 6. Bell and Galzin (1984), 7. Wilson et al. (2006), 8. Gratwicke and Speight (2005), 9. Graham et al. (2006), 10. Luckhurst and Luckhurst (1978), 11. Fulton and Bellwood (2005), 12. Floeter et al. (2007), 13. Russ (2003), 14. Wilson et al. (2008), 15. Cinner et al. (2009b), 16. Jennings et al. (1995), 17. Jennings and Polunin (1997), 18. Stallings (2009), 19. DeMartini et al. (2008), 20. Jennings and Polunin (1996), 21. Bellwood et al. (2003), 22. Dulvy et al. (2004a), 23. Dulvy et al. (Dulvy et al. 2004b), 24. Mora (2008), 25. Williams et al. (2011), 26. Williams et al. (2008), 27. Aswani and Sabetian (2010), 28. Brewer et al. (2009).
References include only those that show, statistically, the effect of the factors listed, on measures of coral reef fish diversity or function.
[d] controlled during sampling
[e] controlled in model
[f] * correlated with coral cover (Graham et al. 2008)
[g] also measured as number of 'holes' and hole volume of reef substrate (Friedlander & Parrish 1998).
[h] not significantly correlated

Social scientists working on social-ecological interactions often differentiate between proximate (e.g. fishing pressure) and distal (e.g. market proximity, modernization, and human population density) drivers of environmental degradation (Forester & Machlis 1996; Agrawal & Yadama 1997; Geist & Lambin 2002; Kramer et al. 2009; McKinney et al. 2010). In a coral reef context, there is clear evidence that, at the local-level, people directly affect coral reef fish diversity and function through proximate drivers such as fishing pressure and habitat degradation (Wilson et al. 2008). What is less clear, however, is the role of distal drivers, in shaping these proximate drivers and ultimately coral reef fish diversity and function. For example, increased socioeconomic development (akin to modernization) does not directly affect fish diversity and function, but might intensify local fishing pressure through greater access to more efficient fishing gear, which might, in turn, decrease diversity and function of coral reef fish. Alternatively, increased socioeconomic development might reduce dependence on local resources, or enable improved resource management practices, resulting in increased fish diversity and function (Cinner et al. 2009b).

Here, I explore the linkages between three recognised distal drivers (population density, modernization and market proximity), two proximate drivers (fishing pressure and coral cover), and a range of metrics of fish diversity and function. Similarly to chapter 2A, structural equation models are used to understand the sequential effects of distal drivers on proximate drivers, and proximate drivers on diversity and function metrics across 25 sites in Solomon Islands.

2B.2 METHODS

2B.2.1 SITE SELECTION AND DELINEATION

The 25 sites used in this chapter are the same as used in chapter 2A (Figure 2A.1). The only variation in the social and economic data is that 'basic gear fishing' was not included here because it was found to have limited effect in the models in chapter 2A.

2B.2.2 ECOLOGICAL RESPONSE VARIABLES

Fish species used in this study included all fishes surveyed across the same 25 sites used in chapter 2A (Appendix 4). Four metrics of species diversity were used to test the effect of proximate and distal drivers on fish diversity; 1) species richness, 2) Pielou's species evenness, 3) average taxonomic distinctness (AvTD), and 4) variation in taxonomic distinctness (VarTD). Species evenness warrants investigation as it considers the relative abundance of species and can have important ecosystem ramifications well before species become locally extinct (Chapin III et al. 2000). AvTD is a measure of the average distance between all pairs of species in a taxonomic tree, which captures phenotypic differences and functional richness (Clarke & Warwick 1999; Rogers et al. 1999). VarTD is the variance of the path lengths between every pair of species in a taxonomic tree, and represents the unevenness of the taxonomic tree (Clarke & Warwick 2001). Taxonomic hierarchy levels used to measure AvTD and VarTD were Class, Order, Family, Genus and Species. Path lengths between taxonomic levels were equally weighted.

Total biomass estimates were derived for two key functional groups: piscivores and herbivores. Piscivores were classified as fishes that, based on gut content analyses (Froese & Pauly 2011) predominantly consume fishes. Piscivores can inhibit increase in abundance of lower trophic level species through predator prey interaction (Jennings et al. 1995; Graham et al. 2003), and are particularly sensitive to fishing pressure (e.g. Jennings & Polunin 1997; DeMartini et al. 2008; Sandin et al. 2008). Herbivores were classified as those species that predominately feed on large fleshy algae or the epilithic algal matrix (censuWilson & Bellwood 1997). This includes fish that remove part of the reef by scraping or excavating the substratum, and grazers that mainly ingest filamentous algae (censu Choat et al. 2002). Herbivores are thought to play a critical role in the resilience of coral reef ecosystems by preventing algal overgrowth that can smother corals (Mumby 2006; Hughes et al. 2007; Green & Bellwood 2009). Piscivore and herbivore species were divided into target and non-target species to further explore the effect of fishing on these functional groups. The list of target and non-target species was constructed using expert opinion of Solomon Islands target species (Green et al. 2006), and creel survey data from adjacent Papua New Guinea (Cinner et al. 2009c) (Appendix 4).

2B.2.3 PROXIMATE DRIVERS

We measured two proximate drivers previously shown to be related to fish diversity and function: 1) coral cover, and 2) fishing pressure. Coral cover here is the same variable used in chapter 2A. Fishing pressure here is the same variable as 'efficient gear fishing' used in chapter 2A. As stated above, 'basic gear fishing', as a proximate driver, has been omitted because it had limited effect on the ecological response variables (biomass in vulnerability categories) used in chapter 2A.

2B.2.4 DISTAL DRIVERS

This chapter used the same distal driver variables that were used in chapter 2A; human population density (Malthusian overpopulation), modernization (modernization), and market proximity (market expansion). The distal drivers were measured by the same method among the same 25 sites, and are therefore identical.

2B.2.5 MODEL CONSTRUCTION

As with chapter 2A, this chapter used partial least squares regression, in the program Warp PLS, to build structural equation models (SEMs) of the general form: distal drivers → proximate drivers → ecological response to analyse the data. Distal and proximate drivers remained consistent across models with only the ecological response changing between models (Figure 2B.1a). All distal drivers (market proximity, modernization and population density) were linked to the two proximate drivers (fishing pressure and coral cover), except market access to coral cover as there was no theoretical justification for this link. Both proximate drivers were linked to the ecological response variable in all models. This resulted in unique models for each ecological response; species richness, Pielou's evenness, AvTD, VarTD, total herbivore biomass, non-target herbivore biomass, total piscivore biomass, and non-target piscivore biomass. As in chapter 2A, the output generated included individual standardized path coefficients (β), partial model fit scores (r^2), overall model p values calculated through resampling estimations coupled with Bonferroni-like corrections (Kock 2010), and individual explanatory and response x, y plots (Appendix 5). The total effect of distal drivers (market proximity, modernization and population density) were calculated by multiplying the standardized coefficients (β) within each pathway then summing these values for pathways associated with each driver.

2B.3 RESULTS

2B.3.1 EFFECTS OF PROXIMATE DRIVERS ON FISH FUNCTION AND DIVERSITY

Fishing pressure had a clear negative effect on both fish diversity and the biomass of key functional groups of fish. Specifically, fishing pressure correlated negatively with species richness, and AvTD, and positively with species evenness (Figure 2B.1b-d). Fishing pressure however, did not noticeably affect VarTD, with only a small decrease in VarTD associated with increased fishing pressure (Figure 2B.1e). Also, fishing pressure had a clear negative effect on both all piscivore and all herbivore biomass, yet non-target biomass of the two functional groups was negligibly affected by fishing pressure (Figure 2B.f-i). Coral cover generally had a smaller effect on diversity and functional group metrics than fishing pressure (Figure 2B.1b-i); Coral cover was positively related to richness, AvTD, VarTD and non-target piscivores. Coral cover was strongly negatively correlated with species evenness and all herbivore biomass (Figure 2B.1c, g).

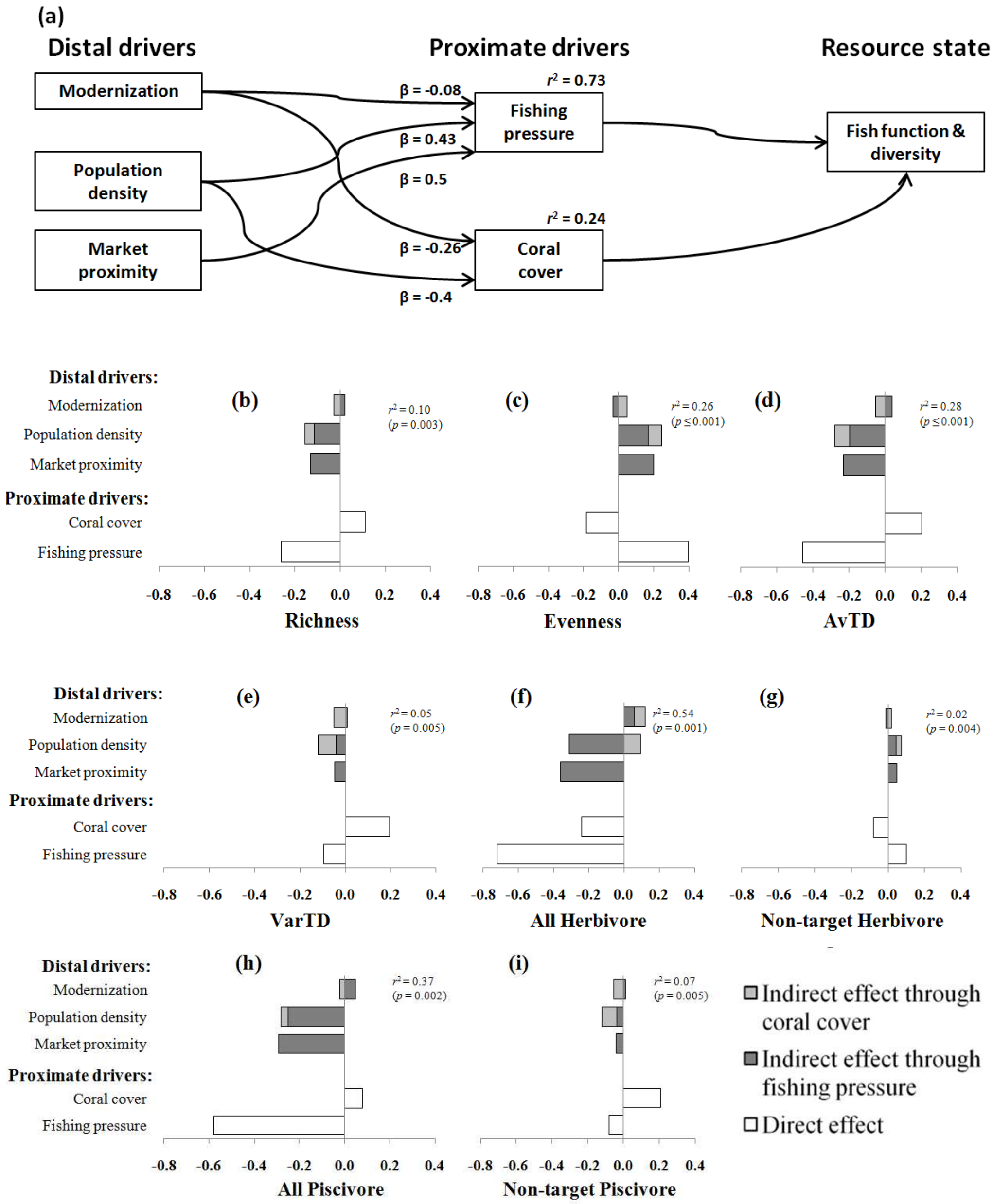

Fig. 2B.1 Structural equation modeling results (SEM) showing (a) general model used including distal and proximate drivers and (b-i) the total effect size (determined by multiplication of β coefficients along each distinct path, prior to summing of distinct paths) of the different distal and proximate drivers for each of the ecological response variables. The effect of each distal driver, on each ecological response variable, is categorized by proximate drivers to show the positive and negative effect of each path. In (a) values adjacent to arrows are beta (β) coefficients for relationship between respective distal and proximate driver, and values above proximate driver boxes are r^2 values. In (b-i) r^2 values are variance explained by fishing pressure and coral cover, and *p* is the likelihood of the model fit occurring by chance based on resampling estimates coupled with Bonferroni-like corrections (Kock 2010).

2B.3.2 Effects of Distal Drivers on Fish Function and Diversity

Distal drivers explained much of the variance of fishing pressure (r^2 = 0.73), particularly market proximity and population density (Figure 2B.1a). Population density and modernization were, however, comparatively poor descriptors of coral cover (r^2 = 0.24). Modernization had a weak negative effect on fishing pressure and on coral cover, thus had both positive and negative effects on fish diversity and function, except for all herbivore biomass which was positively affected by modernization through both decreased fishing pressure and decreased coral cover. Population density had a negative effect on all herbivore biomass through increased fishing pressure, and a positive, but weaker, effect on all herbivore biomass through decreased coral cover. Market proximity and population density, more than modernization, explained decreased diversity and function of coral reef fish (Figure 2B.1b-i). The strong indirect effect of market proximity on diversity and function was particularly noteworthy because the model specified that market proximity indirectly affected function and diversity only through fishing pressure, rather than through both fishing pressure and coral cover (Figure 2B.1a).

2B.4 Discussion

In this sub-chapter I explored how habitat and social factors explain spatial variability in the diversity and functional group biomass of coral reef fishes at 25 sites across Solomon Islands. Results indicate that population density and market access increase fishing pressure, which is a major driver of fish diversity and functional group biomass. These distal social drivers have a negative effect on the biomass of piscivores and herbivores targeted by fishers. Moreover the relative abundance of species becomes more even, whilst species richness and AvTD decline as population density increases and markets become more accessible.

2B.4.1 Explaining the effects of Proximate Drivers on Fish Function and Diversity

A decline in taxonomic distinctness is often associated with a decline in functional diversity (Rogers et al. 1999; Chapin III et al. 2000; Nyström et al. 2000). This is supported here by the finding that fishing pressure had a negative effect on average taxonomic distinctness and the biomass of two important functional groups, herbivores and piscivores. Conversely, there was negligible effect of fishing on non-target species from these functional groups. Thus, the direct effect of fishing is likely to be confined largely to those species and functional groups that are targeted by fishers. A decrease in diversity, and increased evenness with increased fishing pressure, might relate to removal of relatively rare large bodied predators, which are often targeted by fishers (Pauly et al. 1998).

Target species on coral reefs tend to be large bodied (Dulvy et al. 2004b; Graham et al. 2005), while many of the non-target species tend to be small and have close affiliation with the reef benthos (Munday & Jones 1998). In this study, coral cover and fishing pressure had a similar effect on non-target herbivore and piscivore biomass, compared to all herbivore and all piscivore biomass which was largely explained by fishing pressure alone. Interestingly, the relationship between non-target herbivore biomass and coral cover was negative, possibly because many of these fish are damselfishes that maintain territories covered with algae (Ceccarelli 2007) (Appendix 4). Conversely, biomass of piscivores, particularly non-targeted species, tended to increase with coral cover. This may be because many smaller bodied non-target predators and their prey take refuge among corals. Indeed a loss of coral and associated structural complexity can lead to declines in small bodied prey fish and their medium sized predators (Graham et al. 2007). Functionally, non-target species are likely to perform a very different role to the larger bodied species targeted by fishers. Fishing and habitat degradation might therefore have different consequences for both herbivore and piscivore assemblages and the functional services associated with these groups.

2B.4.2 EXPLAINING THE EFFECTS OF DISTAL DRIVERS ON FISH FUNCTION AND DIVERSITY

By disaggregating distal and proximate drivers and modeling fish assemblage response to different causal paths of human activity, this study has shown that social drivers can have both positive and negative effects on fish communities and their functional role in ecosystems. Population density had both positive and negative effects on all herbivore biomass through coral cover and fishing pressure, respectively. The positive effect, through decreased coral cover, might be explained by increased nutrient levels indirectly caused by high coastal population densities without access to sewage treatment facilities. Resultant excess nutrients have been shown to increase algal growth (e.g. Pastorok & Bilyard 1985), and consequently increase food availability to herbivores.

Modernization had a negative effect on coral cover, resulting in marginally reduced species richness and taxonomic distinctness, and increased species evenness and total herbivore biomass. Modernization however, had a weak negative effect on fishing pressure, leading to marginally increased species richness, average taxonomic distinctness, and functional group biomass. These results are broadly consistent with studies conducted across five Indian Ocean countries that found a decrease in fishing with higher levels of modernization (Cinner et al. 2009b; Cinner & Bodin 2010). In comparison to the large modernization spectrum in these multi-nation studies, the relatively small effect size of modernization on fishing pressure presented in this study might reflect, as suggested in chapter 2A, a small development gradient in Solomon Islands.

The majority of studies that have explored the effect of human activity on coral reef fish diversity and function have shown that these assemblage characteristics are explained by either fishing pressure (Jennings et al. 1995; Jennings & Polunin 1996; DeMartini et al. 2008) or human population density (Jennings & Polunin 1997; Bellwood et al. 2003; Dulvy et al. 2004a; Dulvy et al. 2004b; Mora 2008; Williams et al. 2008; Stallings 2009; Williams et al. 2011) (Table 2B.1). While it is clear that local human population density and direct fishing effects are important in explaining ecological gradients, this study has shown that trade, measured as market proximity, is also important (Figure 2B.1). In Solomon Islands trade likely affects fish diversity and function through small-scale commercial fishing to supply urban markets, whereas population density likely affects diversity and function through semi-subsistence based fishing to supply local needs. Trade allows societies to acquire resources from further afield, externalizing environmental footprints beyond local human-environment systems (Arrow et al. 1995; Berkes et al. 2006; Shandra et al. 2009). Resource management and biodiversity conservation initiatives must recognize that trade and local population pressure represent different drivers of ecological degradation, and consequently apply different strategies to address their effects on ecosystems. For example, strong governance of markets through sustainable harvesting certification, and market-specific gear and species restrictions, will become increasingly important if coral reef fish continue to be a readily traded commodity (Berkes et al. 2006).

2B.4.3 FUTURE MODEL EXTENSIONS

Expansion of the models developed in this paper to other social-ecological contexts would help to provide a better understanding of how marine ecosystems will respond to key social dynamics. However, three key advancements are necessary to improve the predictive capacity of such models. First, analysis of the indirect effects of distal drivers on the proportionate representation of multiple functional groups (including higher resolution herbivore functional groups such as grazers, scrapers, and excavators) (Wilson & Bellwood 1997) and species might lend further insight into the role of distal drivers in shaping ecosystem function (Wilson et al. 2008). Second, coral cover is only one measure of coral reef habitat and more detailed models including other environmental and habitat variables (e.g. Wilson et al. 2008), could shed additional light on the relative contribution of distal drivers on diversity and function, particularly for species richness and non-target assemblages of coral reef fish. Third, temporal assessments would be vital to understand the feedbacks that might exist in this system.

2B.5 Conclusion

Management measures which address proximate drivers, such as fishing pressure, typically have localized effects on diversity and ecosystem function. Yet, they are limited in their ability to alleviate the effects of distal social drivers such as market proximity and modernization (Birkeland 2004). Therefore, whilst managing proximate threats represents an important (if not limited) management approach, and means of increasing local resilience, governing reefs in a changing world will require becoming better acquainted with the threats, and potential solutions posed by broader social drivers such as markets and population growth.

CHAPTER 3: SOCIAL DETERMINANTS OF CORAL REEF RESOURCE MANAGEMENT INSTITUTION OCCURRENCE[13]

ABSTRACT

Resource management institutions are vital for constraining natural resource exploitation. There is evidence that a society's characteristics explain whether or not the society is able to collectively manage their resources. This study assessed the effects of key social and economic characteristics (herein drivers) of resource management institution occurrence and efficacy; local population size and density, modernization and market access) on a set of common resource management strategies. The study is conducted in a Solomon Islands across ≥ 723 coastal villages adjacent to coral reefs. In accordance with current theory, a medium village population size of ≈ 350 presented the highest probability of management institution occurrence. However, population density had an overwhelming negative effect on the probability of institution occurrence. Both modernization and the presence of markets had week positive effects on some management types. Broadly, the findings suggest that, contrary to popular belief, not all dominant drivers of institution occurrence erode local resource management institutions, but human population density negates the positive effect of medium population size, market access and modernization.

[13] **Brewer, T.D.,** Cinner, J.E., Kool, J., Foale, S. Social and economic drivers of natural resource management institution occurrence. In preparation.

3.1 Introduction

There is growing concern that humanity does not possess institutions able to buffer the negative effects of social and economic change (such as human population growth and commoditization of resources) on the earth's finite natural resources (Walker et al. 2009). In developing countries, where much of the world's biodiversity lies, natural resources are often collectively managed by local communities (Ostrom 1990; Donner & Potere 2007). These local institutions play a significant role globally in maintaining biodiversity, but are highly vulnerable to the negative effects of some social and economic drivers of change (Agrawal & Yadama 1997).

An enduring debate exists, on whether institutions can adapt to social and economic drivers of change. This debate is particularly prominent in relation to communities of the Asia-Pacific region that depend on marine resources for their livelihoods. There is extensive evidence of decreased prevalence, or efficacy, of traditional community-based management institutions with increased social and economic change (Baines 1989; Ruddle 1993; Cinner 2005; Cinner et al. 2007). In his seminal work, Johannes (1978) argues that westernization; the introduction of money economies, the breakdown of traditional authority, and the imposition of colonial laws and practice are responsible for the demise of traditional community-based marine resource management in the Pacific. However, there is also support for the notion that local management institutions are adaptive and flexible, which might enable them to endure social and economic change (Hviding & Baines 1994; Hviding 1998). For example, in retraction of his earlier stance, or perhaps through personal observation of contextual change, Johannes (2002) champions the 'renaissance' of community marine resource management institutions in Oceania in response to 'westernization'.

Broadly, the aim of this chapter was to determine the likelihood of institution occurrence across a gradient of social and economic drivers of change. More specifically, this study tested a suite of hypotheses relating to the effect of population pressure (Malthusian overpopulation), access to resource markets (market expansion), and development and affluence (modernization) on local-level fishery management institutions in Solomon Islands. First, it has long been asserted that human population size (number of people with access to a commons) is likely to affect collective action designed to manage common-pool resources (Olson 1965). Recent theoretical and empirical evidence suggests that there is likely to be an optimal population size to effectively manage resources through an institution; effective institutions are unnecessary for small populations and cost inhibitive for larger populations (Agrawal & Golyal 2001). Further, dissolution of resource management institutions in communities with large populations might also be a function of increased social and cultural heterogeneity caused by, for example, migration and rapid population growth (Aswani 2002; Poteete & Ostrom 2004). Population size is considered in this chapter and not in earlier chapters of the thesis because it has substantial theoretical relevance to institutions. Second, population density (human population per units of resource), affects the occurrence and efficacy of institutions. One hypothesis is that, as with population size, there is an optimum population density for collective action (Pender & Scherr 1999). The logic follows that at low population density the demand for collective action is low because there is an abundance of resource. As population density increases the resulting resource scarcity induces collective action. However, at high population density the benefits of collective action may be outweighed by incentives for individuals to 'free-ride' or transgress institutional rules due to increased resource scarcity (Gebremedhin et al. 2003). Therefore, based on current evidence, one would expect to see a non-linear institutional response to both population size and population density. Third, commoditization of natural resources will lead to a failure of resource management institutions. Some empirical evidence exists of the negative effect of market access on exclusivity of marine tenure in the Indo-Pacific (Cinner 2005), yet there is a need to better understand how access to trade effects particular local resource management institutions (Agrawal 2001) that are often embedded within the marine tenure system (Ruddle 1998). Fourth, with increased modernization, resource management institutions will fail (Cinner et al. 2007), to a point, after which they will re-emerge as societies can afford and demand environmental quality, in accordance with environmental Kuznets curve theory (Arrow et al. 1995; Cinner et al. 2009b). This theory implies that an increase in modernization (from an undefined point) will result in decline of environmental quality, and yet further modernization will result in improved environmental quality.

3.2 METHODS

To test these hypotheses this study measured the effect of the four key social and economic drivers ; human population size, human population density, market access, and modernization, on a suite of management institutions common in artisanal coral reef fisheries, across a nation. A range of data sources were used on a minimum of 723 (range = 723-1123) communities for any single analysis. Population size was measured as the number of people living within each community. Population density was measured as the number of people living in each community per resource area (coral reef). Market access was measured as the presence, or absence, of a fish market within each community. Modernization was measured as the summed occurrence of a set of 16 infrastructure and amenity items in each community (Pollnac et al. 2010). Components of modernization were also measured using Principal Component's Analysis, on the infrastructure and amenity items that comprised modernization. The management institutions assessed were temporary spatial closures, species restrictions and fishing gear restrictions (Johannes 1978; Cinner & Aswani 2007); all measured as present or absent.

3.2.1 DATA SOURCES AND REDUCTION

All communities recorded in the 2007/08 Solomon Islands Village Resource Survey (VRS) (Solomon Islands Government 2008) were spatially referenced using the 1999 Population and Housing Census (PHC) (Solomon Islands Government 1999) locations, which was deemed to be more accurate of the two sources. Those villages that could not be spatially identified using the PHC or were not spatially located within the ward (local political constituency) they were assigned in the VRS, were considered potential errors, and were subsequently omitted from the data set. As with chapter 2, villages greater than 1 km from the coastline were also omitted from the data set. Subsequently, spatial boundaries between communities were measured using thiessen polygons. Thiessen polygons are generated such that each community boundary is equidistant from the location of each adjacent point (community) location. This method has been previously applied to estimating community resource use boundaries (Mulller & Zeller 2002). W hilst this method of associating resource user groups with resource does not account for intra- or inter-community resource use-rights, it was deemed appropriate because the management institution questions in this study relate explicitly to community-level institutions. Coral reef area was then overlaid with population data and thiessen polygons to derive a measure of coral reef area available to each community. Communities that did not have coral reef area within their thiessen polygon boundary were omitted from the data set.

3.2.2 SOCIAL AND ECONOMIC DRIVERS

Following the data reduction process, human population size was measured as the total number of people living in communities within 1 km of the coast, in each thiessen polygon that contained coral reef. Data on human population size was not available from the VRS so population data and locations were derived from the PHC. Human population density was measured as the derived human population size divided by coral reef area in each thiessen polygon. Change in population size between the time of the PHC, and the time of the VRS was corrected for all communities assuming an annual growth rate of 2.8% (World World Bank 2012). Modernization was measured as the equally weighted summed set of infrastructure and amenity items derived from the VRS (Table 3.1). Principal Components Analysis (PCA), using a varimax rotation, was used to derive sub-components of modernization from the entire set of infrastructure and amenity items. Data on market access was derived from the VRS, and defined as the presence, or absence, of a fish market within each community.

Table 3.1 Principal components analysis of modernization variables. (Kaiser-Meyer-Olkin measure of sampling adequacy = 0.73; Bartlett's test of sphericity = 2764***). All communities included in PCA (n = 975) had responses for all modernization variables. Variables with loading of ≥ 0.4 are shown in bold, and represent those variables which contribute most to each respective component.

		Modernization Components				
	% occurrence	Health and education	Public infrastructure	Economic	Social	Tourism
Primary school	23.4	0.79	0.06	0.07	0.23	-0.04
Pre-school	30.2	0.72	0.03	0.13	0.33	-0.07
High school	5.9	0.67	0.07	0.04	-0.04	0.10
Clinic	14.1	0.57	0.15	0.33	-0.05	0.04
Government offices	1.2	0.05	0.85	0.07	-0.03	0.06
Postal service	1.0	0.08	0.81	0.10	-0.04	-0.02
Airport	2.2	0.09	0.68	-0.05	0.03	0.03
Fuel depot	21.2	0.11	-0.02	0.78	0.15	0.03
Market	11.4	0.18	0.07	0.69	0.02	-0.02
Trade store	36.5	0.12	0.01	0.63	0.31	0.06
Church	63.5	0.23	-0.02	0.07	0.75	-0.07
Village hall	26.0	0.18	-0.04	0.08	0.67	0.04
Water source	50.4	-0.15	0.02	0.26	0.44	0.04
Tourism	1.1	-0.12	0.08	-0.10	0.18	0.77
Social club	0.6	0.29	-0.15	0.07	-0.16	0.62
Banking	1.3	-0.05	0.25	0.33	-0.06	0.43
Eigenvalue		3.22	1.95	1.37	1.19	1.04
% variance explained		20.15	12.16	8.56	7.43	6.50

3.2.3 Resource management institutions

Community leaders were surveyed, as part of the VRS, to identify the presence of management institutions. Community leaders were defined as a recognized elder or chief, but might have included other community members such as school teachers, or local pastors. Community leaders are generally responsible for enforcing marine harvest restrictions, particularly in the traditional context (Hviding 1998). Enumerators were chosen to survey particular communities because of their affiliation with the communities. Enumerator training was conducted over a three week period prior to enumeration. During the enumeration field period, villages were defined as a large settlement, encompassing smaller satellite villages within 15 minutes walking distance. The satellite villages were likely to include many of the additional communities recorded in the PHC that were not recorded in the VRS. The enumerators grouped settlements within a single polity (e.g. under the jurisdiction of a single chief) where possible. Thiessen polygons, as used to define human populations and coral reef area, compared to alternate methods of remotely defining of defining spatial boundaries, such as radial distance, was deemed more compatible with the definition used during the VRS enumeration. The three questions, used in this study, that pertain to current management were intentionally general to capture the diversity of institutions that exist in Solomon Islands and broader Melanesia (Cinner & Aswani 2007). Explicitly the questions asked of the community leaders were:

Does your village have any of the following community fishing regulations?

7. Reef area closed on and off (Yes/No)
8. Particular species restrictions (Yes/No)
9. Fishing gear restrictions (Yes/No)

Data on permanent spatial closures was also elicited, but omitted because of possible misinterpretation. Specifically, it was possible that many of the recorded permanent closures represented sacred sites with no explicit resource management purpose.

3.2.4 ANALYSIS

Multicolinearity between the social and economic drivers was tested using Spearman's rank correlation. The effect of the presence of a market on each management institution was tested using Fisher's exact test. In addition, the relationship between the continuous predictor variables (population size, population density, modernization) and response (management institutions) variables was modeled using a combination of locally weighted scatter plot smoothing (lowess) and logistic regression. Logistic regression evaluates the probability of occurrence for a binary outcome (e.g. yes/no) in relation to a given independent variable (Hilbe 2009). Lowess is used to perform locally weighted regression by passing a sliding window (convolution) over the data and evaluating the predicted relationship within its range (Cleveland & Devlin 1988). A neighboring-point approach was used to define the scope of the window. Neighboring values within 100 points to either side of the reference value were used to calculate the regression relationship. If the dependent variable value was 'No Data', then it was not used in determining the predicted value. The window size was not adjusted to make up for values having 'No Data'. A Gaussian scheme was used to weight the points (implemented using MATLAB's gausswin function), so that points near the center of the sliding window would have a proportionally greater degree of influence than those near the edges. For reference points near the edge of the data set (i.e. less than 100 points), the maximum number of data points available were used, and the Gaussian weighting was truncated according to the data points that were not used. The data was bootstrapped 4999 times, merged with the observed data (yielding a total of 5000 curves) and then 5% and 95% confidence limits were calculated using percentiles, as well as the average trend.

3.3 RESULTS AND DISCUSSION

Average community population size was 170, median population density was 302 people/km^2 coral reef, 4% (43) of communities had recognized fish markets, and communities had an average of 2.75 modernization items. Of the communities that responded to the management institution questions; 35% (389) had temporary spatial closures, 24% (258) had species restrictions, and 20% (215) had gear restrictions. There was some colinearity between independent variables ($p < 0.05$) however, correlations were all less that 0.5 (*rho* value) which was deemed adequately low to retain all variables; particularly given their individual theoretical merit.

The occurrence of resource management institutions is, in part, dependent on human population size in Solomon Islands. Population size had a positive effect on occurrence of management institutions(Table 3.2), however, at high population size (≈350) the probability of each; temporary spatial closures, species restrictions, and fishing gear restrictions occurring, is diminished (Figure 3.1A). The observed curvilinear trend fits current theory that medium sized populations are more likely to have resource management institutions. Indeed, the highest probability of management institution occurrence was observed in communities with population size comparable to previously published optimum population size estimates for forest management in India, measured as frequency of resource management meetings (Agrawal & Golyal 2001); a vastly different social-ecological context. However, the confidence intervals increase notably at population size beyond the optimum (Figure 3.1A), and therefore should be considered with caution.

Table 3.2 Effects of social and economic drivers, including components of modernization, on community-level management institutions. Numbers in parentheses indicate the number of communities in each analysis. * $p \leq 0.05$, ** $p \leq 0.01$, ***$p \leq 0.001$.

	Temporary closures	**Species restrictions**	**Fishing gear restrictions**
Population size[a]	15.2*** (1123)	6.76** (1069)	4.5* (1059)
Population density[a]	-21.6*** (1123)	-30.35*** (1069)	-21.23*** (1059)
Market access[b]	5.25* (802)	1.01 (785)	3.01 (778)
Modernization[a]	1.08 (745)	5.07* (729)	11.52*** (723)
Health and education[a]	1.71 (745)	6.02* (729)	4.178* (723)
Public infrastructure[a]	-2.47 (745)	0.152 (729)	2.02 (723)
Economic[a]	-1.52 (745)	3.47 (729)	2.29 (723)
Social[a]	0.56 (745)	0.112 (729)	6.01* (723)
Tourism[a]	-1.61 (745)	-2.82 (729)	-1.01 (723)

[a] Absolute values were log10(x+1) transformed prior to performing binary logistic regression.
[b] Fisher's exact test.

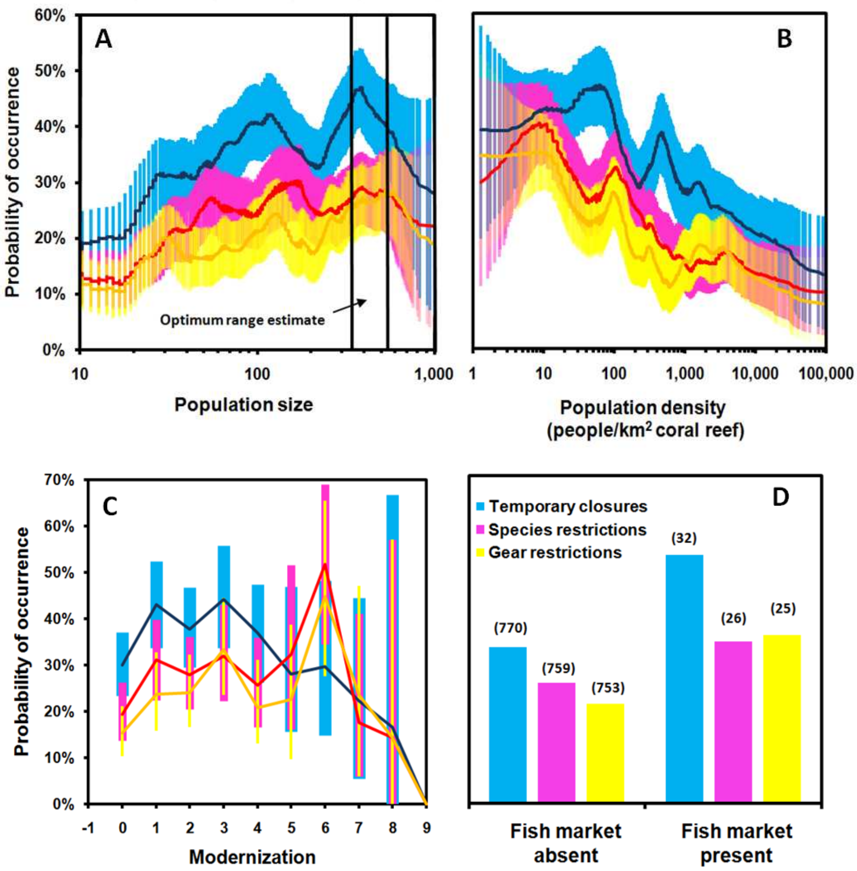

Figure 3.1 Effect of (A) human population size, (B) human population density, (C) modernization, and (D) market access, on the probability of management institution occurrence (± 95% C.I. for A, B, C). *X* axis has been clipped where C.I. large and site (village) occurrence infrequent (i.e. a large gap in the *x* axis between data points). Optimum population size range estimate (A) is based on the optimum number of households (61-100) (for highest incidence of resource management meetings as a proxy for collective action) presented in Agrawal & Golyal (2001) multiplied by the mean number of occupants per household (5.3) in Solomon Islands in 2007 (Solomon Islands Statistics Solomon Islands Government 2007).

Population density had a dramatic negative effect on the occurrence of all management institutions (Table 3.2; Figure 3.1B). Indeed, there is no evidence that institutional response to increased population density is non-linear, as shown elsewhere (Gebremedhin et al. 2003). Melanesian society, of which Solomon Islands is a part, is renowned for being egalitarian (Baines 1989). Consequently, communities are generally likely to ensure relatively equal internal distribution of resources, particularly for subsistence needs, rather than commercial gain (Hviding and Baines 1994). It is therefore plausible that management institutions are doomed to failure in high population density areas because of cultural norms that demand equality of resource allocation by precluding restrictions on harvesting; a finding that resonates with the long standing tragedy of the commons perspective (Malthus 1798; Hardin 1968; Pauly 1988).

Management institutions, particularly temporary closures, were more likely to occur in communities with recognized fish markets (Table 3.2; Figure 3.1D). This finding challenges the theory that commoditization of resources adversely effects management institutions (Cinner et al. 2007). However, markets are likely to provide benefits to a select few (Carrier 1987; Ruddle 1993). Thus, in contrast to the institutional response observed with increasing population density, it is possible that restricting exploitation in close proximity to markets would ensure that those who do exploit for market sale do not gain excessive advantage through exploitation (Hviding & Baines 1994), which would otherwise result in inequality and social hierarchy. Alternatively, institutions might have been established by those exploiting the fishery to maximise commercial gain (Ruttan 1998). Identifying which proposition is true would require the identification of who is imposing and benefiting from the restrictions.

Modernization had a significant positive effect on both species restrictions and fishing gear restrictions, but no clear effect on temporary closures (Table 3.2). However, mean probability of the occurrence of all institutions declined markedly at high levels of modernization ($\geq$ 7 infrastructure and amenity items) (Fig 3.1C). This result counters theory that suggests higher incidence of management institutions at higher levels of development. However, if one considers the potential range of community level modernization globally, Solomon Islands communities lie at the lower end of the continuum(but see Grossman & Krueger 1995 for an example of modernization observed within a single nation). Thus the range of modernization tested here might represent the left side of the environmental Kuznets curve. However, because the measure of modernization used in this study is not directly comparable to any previous studies in more modernized communities dependent on coral reefs (e.g. Cinner et al. 2009b) (i.e. does not use the same variables), it is not possible to conclude that this is the case. In the absence of a repeatable measure of modernization, (that is more holistic than, for example, gross domestic product or the human development index) it will not be possible to discern the level of modernization of any one community to that of any other community outside the study sample.

The principal components analysis on the 16 modernization items resulted in 5 components that were classed; health and education, public infrastructure, economic, social, and tourism (Table 3.1). Each component affected the occurrence of management strategies differently. Health and education had a statistically significant positive effect on both species restrictions and gear restrictions, and social modernization had a statistically significant positive effect on gear restrictions (Table 3.2). The variables associated with social modernization; church, village hall and water source, might engender social capital, which is likely to promote collective action (Pretty 2003). The reason for health and education positively affecting institutions is less clear. However, natural resource awareness programs in schools, if they exist, could conceivably instigate exploitation restrictions. Importantly, with the exception of the effect of tourism modernization on all three institutions, and public infrastructure modernization and economic modernization on temporary closures, all effects were positive. Yet economic modernization which is often considered a key factor in environmental Kuznets curve trends did not have a significant effect on institution occurrence.

With the exception of human population density, the social and economic drivers tested in this study have either a positive effect, or non-linear effect, on the probability of institution occurrence which suggests that institutions are adapting to social and economic change (Hviding & Baines 1994; Hviding 1998) in Solomon Islands. Yet, evidence suggests that, by way of increasing fishing pressure, population density and markets negatively effect, and modernization has no effect on reef fish stocks in Solomon Islands (Brewer et al. 2009; Aswani & Sabetian 2010; Brewer et al. 2012a). Therefore it is possible that despite higher probability of occurrence in more modernized communities with medium population size and fish markets, management institutions exist, but are not succeeding in stemming resource decline due to efficacy limitations such as transgression of institutional rules.

3.4 LIMITATIONS

This study has tested theory on the effects of social and economic drivers on common-pool resource management institutions. The findings both confirm and challenge commonly held notions of these relations. However, I suggest three areas of research that would refine the general trends identified in this study. First, the findings are based on occurrence data, rather than efficacy of management institutions. There is significant evidence that efficacy of management institutions for coral reef resources varies from a set of rules that are tightly adhered to with limited transgression, to what are commonly referred to as ‘paper parks’, in the case of spatial closures, which exist on paper but not in practice (Alcorn 1993; Campbell et al. 2012). Second, historical analysis would complement the spatial comparison used in this study by, for example, determining whether long enduring institutions are adapting to, or failing because of change, or contemporary institutions are emerging because of change (Ruddle 1998). Third, management institutions governing the exploitation of marine resources occur across multiple levels on the social-political scale in Solomon Islands ranging from national legislation such as species bans to unwritten user-rights based on historical genealogies. Communities, as used in this study, are only one level at which marine resources are used and governed in Solomon Islands.

3.5 CONCLUSIONS

This study tested a suite of recognised social and economic drivers of collective action for managing common-pool resources. The findings support the hypothesis that, locally, community-level resource management institutions are surviving and adapting to social and economic change including modernization and commoditization of resources by way of access to markets (Hviding & Baines 1994; Hviding 1998). The findings also support the theory of optimum population size (Agrawal & Golyal 2001), and challenges the theory that resource commoditization, by way of market access, can inhibit collective action to manage common-property resources. Importantly, however, the over-riding negative effect of population density cannot be over-emphasized and must be better understood to prevent failure of common-property institutions, particularly in places of high and rapidly increasing population density.

CHAPTER 4: FISHER AND MIDDLEMEN PERCEPTIONS OF CORAL REEF FISH DECLINE AND INCREASE[14]

ABSTRACT

Understanding resource stakeholders' perceptions of resource condition and management is vital to the formulation of efficacious management policy to sustain natural systems because agreement among stakeholders is likely to result in more effective outcomes. Understanding perceptions is particularly important in the context of coral reefs because threats are often diverse and management options are numerous, and therefore perceptions are likely to be diverse. This chapter identified the dominant discourses of reef fish decline, and increase, among 119 fishers and fish traders (herein middlemen) in Solomon Islands, and compared these discourses to current scientific knowledge (earlier work and chapters' 2 and 3 of this thesis). Discourses were then explored for dominant themes that might improve understanding of resource user perceptions. The findings suggest that certain fisher and middlemen discourses align with scientific understanding of the causal links between human activity and fish stock declines, and that many of the elicited management strategies are aligned with current scientific recommendations. A theme that emerged across the fisher and middlemen discourses of fish decline was a dichotomy in perception between fishing for economic affluence and fishing for subsistence and economic survival. A theme that emerged across discourses of fish increase was a dichotomy between support for command-and-control approaches and support for community-based approaches to management. Differences between some fisher and middlemen discourses were explained by the location in which interviews were conducted suggesting consensual perceptions achieved through local knowledge networks. Similarity between scientific understanding and local perceptions suggests that local resource users are aware of, and might support fishery management strategies based on scientific evidence. Such strategies must consider factors such as location because resource user

[14] **Brewer, T.D.** 2013. Dominant discourses, among fishers and middlemen, of the factors affecting coral reef fish distributions in Solomon Islands. Marine Policy. 37; 245-253.

perceptions differ between locations and because many threats to the fishery and preferred management strategies are likely to be context specific.

4.1 INTRODUCTION

Coral reef fish stocks, as with so many natural resources, are declining globally (Hughes 1994; Pandolfi et al. 2003). The causes of reef fish decline are diverse, including, but not limited to, fishing pressure, destructive fishing, habitat degradation due to destructive fishing and pollution, and coral bleaching (Russ & Alcala 1989; Grigg 1994; Graham et al. 2006; Graham et al. 2007). As with the causes of decline, there are also a diverse range of approaches prescribed for sustaining and increasing coral reef resources, ranging from designation of areas that exclude extractive activities, species restrictions, fishing gear restrictions to reef restoration and reduction of carbon dioxide emissions (Hoegh-Guldberg 1999; McClanahan & Mangi 2004; McClanahan et al. 2006).

Faced with diverse threats and management prescriptions it is likely that different stakeholders (e.g., resource users, governments, scientists, and third parties including non-government organizations (NGOs)), with different agendas and mental models, will have different perceptions on appropriate courses of action for increasing fish stocks. For example, ecologists might support measures that maintain key species to ensure ecosystem function, environmental NGOs might aim for maximizing biodiversity by, for example, establishing no take areas, whilst resource users are more likely to focus on measures that ensure livelihoods to meet immediate food security needs and aspirations of economic affluence. Strategies to limit and reverse current trajectories of decline might be more likely to succeed when stakeholders are in agreement of both the causes of decline, and the means of slowing and ultimately reversing the decline (Grimble & Wellard 1997; Brown et al. 2001; Pomeroy & Douvere 2008). In the absence of agreement it is likely that management measures desired by different stakeholders will attract resistance from other stakeholders, potentially resulting in inefficiencies, conflict, and failure to improve the state of resources (human-induced climate change is a poster-child example of this phenomenon).

It has been argued that there are significant differences in understanding, between scientists and local people, on factors that affect coral reef fish populations in Melanesia and the broader Pacific (Bulmer 1982; Polunin 1984; Carrier 1987; Foale 1998) . This difference is particularly relevant to natural resource exploitation wherein traditional knowledge asserts that, for example, the spiritual realm affects resource abundance (Bulmer 1982; Carrier 1987; Foale 2005). A more specific example observed at West Ngella in Solomon Islands is that locals perceive that trochus (a species of turban snail with market value) reside in deep water, and migrate to shallow water to replenish harvested stocks (Foale 1998). There is no scientific evidence to support this perception. Such traditional dogma, according to scientific 'western' understanding, could lead to a fatalistic relationship between people and resources as exploitation pressure intensifies (Foale 2006) because there is a belief that no matter how much exploitation occurs, the resource will always recover. This apparent difference in understanding of both natural systems, and the effect of human agency on natural systems, has long been acknowledged by resource management and conservation scientists and practitioners throughout the region, as evidenced by Bob Johannes' (1978, p349.) observation 33 years ago in relation to Oceania societies:

> "Understanding a conservation system means understanding not only the nature of what is being conserved, but also the viewpoint of the conserver. Knowledge of this second element is essential if we are to comprehend a system of resource management employed by a people whose perception of their environment differs from our own."

Traditional knowledge and scientific knowledge, however, are not necessarily incommensurable (Foale 2006). In fact, traditional ecological knowledge is frequently used to complement scientific knowledge in inshore fisheries management in the region (e.g. Foale 1998; Aswani & Hamilton 2004; Aswani & Lauer 2006; Cinner & Aswani 2007; Hamilton et al. 2012), and has been advocated as a primary means of fisheries management (Johannes 1998; Johannes et al. 2000). Such knowledge relates to, but is not limited to, fish spawning aggregation locations and timing, seasonal variability in fish abundance and spatial distributions of fish and habitat. It is also generally accepted that Melanesian fishers recognize that increased fishing pressure can deplete fish stocks (Foale et al. 2010). Therefore, there is a wealth of local knowledge on the distribution of fished species in space and time, yet there has been relatively little research into local causal explanations for these patterns (but see Carrier 1987; Lieber 1994; Foale 1998; Foale et al. 2010). If, therefore, the perceived causes of declining fish stocks and of management intervention differ between scientists and local resource users then there is limited scope for efficacious fishery management derived from scientific evidence (Sabetian & Foale 2006; Brewer et al. 2009; Aswani & Sabetian 2010; Brewer et al. 2012a).

Solomon Islands, a nation situated within Melanesia, is an appropriate location to explore this question of differing perceptions for a number of reasons. First, there is an extensive literature discussing traditional ecological knowledge (e.g. Hviding & Baines 1994; Hviding 1996; Foale 1998; Lauer & Aswani 2008). Second, there exists scientific knowledge on the historic (Richards et al. 1994) and contemporary causes of coral reef resource decline. For example, there is evidence to suggest that fishing to supply domestic markets is significantly reducing coral reef fish stocks, and in particular, that larger market centres are having a pronounced effect on *in situ* biomass (Sabetian & Foale 2006; Brewer et al. 2009; Aswani & Sabetian 2010). There is contemporary evidence for particular distal drivers; markets, population density, and modernization affecting both proximate causes of fish decline (largely market-based fishing), and management institutions. In particular, access to fish markets and local human population density both increase market-based fishing which, in turn, decreases in-situ fish stock function and diversity (Brewer et al. 2012a)(chapter 2B of this thesis). Fish that are vulnerable to extinction, by fishing, measured as *in situ* biomass, are also particularly susceptible to market-based fishing (Brewer et al. 2012b)(chapter 2A of this thesis). Moreover, the occurrence of management strategies, including species restrictions, gear restrictions, and temporary spatial closures has been explained by presence of fish markets, local human population density, and modernization (chapter 3 of this thesis). This study represents an opportunity to test whether the perceptions of the agents (fishers and fish traders (herein middlemen) in the artisanal fishery), who are in-part responsible for fish decline as evidenced by previous studies (Sabetian & Foale 2006; Brewer et al. 2009; Aswani & Sabetian 2010), are aligned with scientific perceptions.

As with a number of the scientific assessments, perceptions of both the proximate and distal factors associated with fishery decline, and the proximate and distal factors associated with increasing fish stocks were elicited. Obtaining the distal factors, such as human population pressure, that might be perceived to be driving activities such as over-fishing, or stronger governance that might be perceived to enable establishment of spatial closures, facilitates a better understanding of the discourses and a broader discussion on numerous factors, and their interaction, that potentially affect fish stock distributions. This approach also enables a comparison between the current scientific discourse described above, and dominant discourses of fishers and middlemen involved in the artisanal fishery in Solomon Islands.

4.2 METHODS

4.2.1 FIELD INTERVIEWS

From September to November 2010, 119 people, including fishers and middlemen, were interviewed at six sites across Solomon Islands (Figure 4.1; Table 4.1). Dunde is classed as a provincial sub-station. Auki, Buala, Gizo, and Tulaghi are provincial capitals. Honiara is the national capital. All sites are major urban centres and have significant infrastructure, including port facilities, medical facilities, and all sites except Buala and Tulaghi had functional airstrips during the survey period. Given that current evidence suggests that the artisanal fishery, comprising fishers and middlemen, has a significant negative effect on coral reef fish stocks, interviews focused on this sector of society.

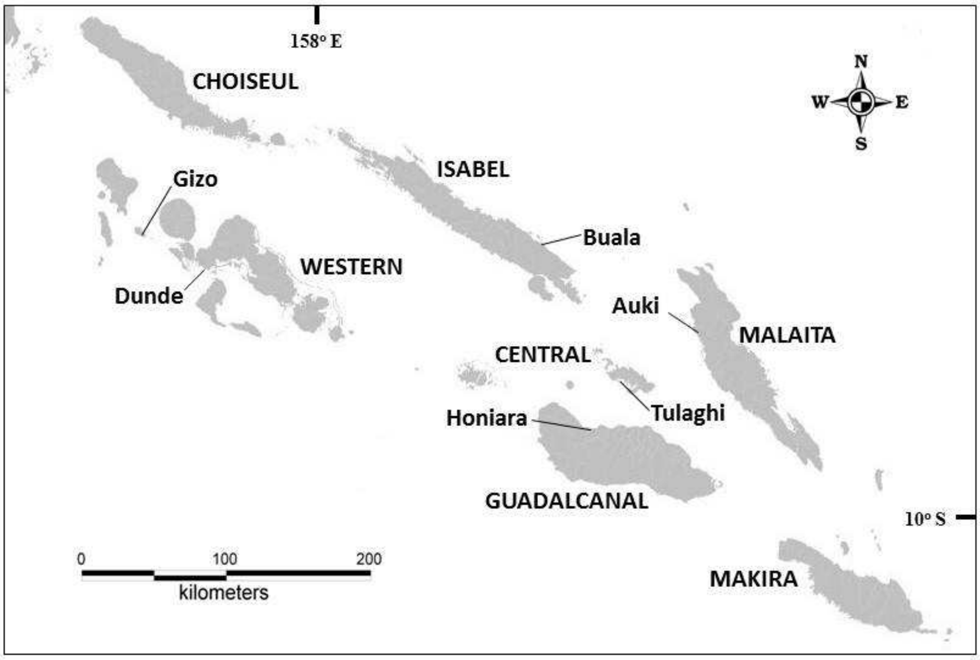

Figure 4.1 Main island chain of Solomon Islands with provinces denoted in uppercase, and survey sites denoted in lower case.

Due to the informal, complex, and frequently dispersed nature of reef fish marketing in Solomon Islands, it was necessary to employ multiple sampling strategies. Systematic sampling, whereby all willing respondents were interviewed within a given time period, was used at Honiara and Gizo which have geographically nuclear fish markets. Snowball sampling was used at Dunde and Buala (Photo 4.1) due to the geographically and socially dispersed nature of the fish marketing networks (Goodman 1961). It was also necessary to use snowball sampling at Tulaghi and Auki because few fishers or middlemen were selling fish at the respective markets during the sampling period.

Interviews were conducted in, and adjacent to, major open-air fish markets in each of the locations, except Dunde and Buala, which do not have open air fish markets, but instead have a number of private middlemen who on-sell to the general public. All interviews were conducted in Solomon Islands Pijin.

Specifically, respondents were asked to explain what they thought reduced the number of fish inhabiting coral reefs, and what they thought could increase the number of fish inhabiting coral reefs. Respondents were asked, explicitly, to divulge their own opinions. To do so, the phrase 'ting ting blo iu' (what do **you** think) was verbalized proceeding the initial question.

Photo 4.1 Fera island with Buala township in the background. Captain 'Jack Sparrow' (second from left) and Sonny (far right) fed and housed me, and taught me a lot about local customs and fishing, including the sedating effect of eating too much crab. Joe Giningele (second from right) travelled with me and helped with the research.

Respondents were asked to divulge both proximate and distal factors associated with each decline and increase of fish stocks. For example, if a respondent said that 'overfishing' reduced the number of fish on the reef, then the interviewer probed to identify what the respondent thought caused overfishing. A response to this might have been 'the need for money to help the family buy food', thus both proximate and distal causes of fish decline were identified. Respondents were not constrained to single answers for either proximate or distal factors. Thus, the model developed in this chapter is relatively comparable with the model presented in chapters 2 and 3 of this thesis.

Socio-demographic attributes were obtained from the respondents using a survey, during the interviews, to determine whether these attributes could explain discourses of perceived fish decline or increase. Socio-demographic variables collected were: site; age; years of formal education; gender; whether the respondent was a migrant; primarily a middleman or fisher; head of their household; and whether income from the sale of fish was their primary household income (Table 4.1). Some perceived causes of resource decline are likely to be site specific which might be reflected in the discourses. Likewise, management options for increasing fish stocks might have greater support at some sites than others, particularly if the respondents within sites have been exposed to particular management approaches that they have seen succeed or fail. Older people might identify with longer-term, or chronic, factors that shape the fish resource, while young people might identify with short-term, or pulse, variability in accordance with the shifting baseline syndrome (Pauly 1995). Years of formal education, including primary school, high school and tertiary education, is likely to introduce western worldviews including scientific models that emphasize the role of human agency in resource variability. Gender is a significant social division in Melanesia (Knauft 1997). Therefore it is possible that men and women are likely to have different life experience, and consequently hold differing views on issues such as fisheries degradation and management. Migrants, defined as respondents who migrated to where they currently reside at some time after their early childhood, are more likely to be socially and culturally marginalized (Cinner 2009). Therefore they might have less site-specific knowledge, and therefore perceive ecological variation differently to non-migrants. Middlemen and fishers perform different functions within the fishery, and are therefore likely to hold different perceptions. Fishers might have a more intimate relationship with the fish *in situ*, whilst middlemen are likely to have a better understanding of the effect of, for example, supply and demand on fish stocks. Heads of households, who are generally men in Solomon Islands, are responsible for the welfare of the household, and might therefore have a greater awareness of, for example, threats to the viability of the fishery. Those whose primary source of income is from fish are likely to have different perceptions of resource decline and, potentially, negative attitudes towards conservation (Marshall et al. 2010) due to fear of regulations, and therefore propose factors other than fishing to primarily reduce fish stocks.

Table 4.1 Distribution of respondent socio-demographic attributes across study sites.

	All Sites (119)	**Auki (20)**	**Buala (17)**	**Dunde (35)**	**Gizo (16)**	**Honiara (18)**	**Tulaghi (13)**
Age (mean)	39.39	38.45	40.65	44.69	34.44	36.83	34.62
Education (mean)	8.39	8.45	8.82	8.34	7.50	9.72	7.08
Fish primary income source (yes)	88	16	12	25	13	13	9
Gender (male)	112	20	17	29	16	17	13
Migrant (yes)	38	6	4	11	6	6	5
Head of household (yes)	102	20	14	28	13	15	12
Middleman / fisherman (middleman)	17	1	2	5	1	8	0

4.2.2 DATA ANALYSIS

Three sequential analyses were performed on the data. First, qualitative responses relating to perceived causes fish decline and increase were coded to generate quantitative variables. All perceived proximate and distal factors of fish stock decline and increase were identified for each respondent (n=119) in the form of notes taken during interviews. Notes were subsequently categorized to themes that emerged by coding the notes (Glaser & Strauss 1965). Categorizing the qualitative responses provided a set of variables for distal and proximate factors of both decline and increase. Second, the dominant discourses of each decline and increase of fish stocks were identified by coupling perceived proximate factors with their associated perceived distal factors. Principal Components Analysis (PCA), with varimax rotation, was used on the variable set to generate latent variables (variables that are inferred from a set of observed variables) that represented different discourses of fish stock decline and increase, such that all factors affect each latent variable, but some factors have a stronger effect than others and consequently contribute more to defining the latent variable. A PCA comprising all proximate and distal factors violated the test requirements of a Kaiser-Meyer-Olkin (KMO) value of ≥ 0.5 (Kaiser 1974) for both decrease and increase of fish stocks. Therefore, to generate the dominant discourses, the PCA included, using fish decline as an example, the most frequently stated proximate cause of fish decline and its associated distal causes, followed by the second most stated proximate cause of fish decline and its associated distal causes, and so on in a forward step-wise manner, until KMO measure of sampling adequacy was <0.5. The data set from the PCA immediately preceding the PCA of KMO <0.5 was retained. By utilizing this step-wise procedure, it was possible to ensure that the more dominant discourses were retained, that the results conform to the analysis requirements, and to retain a high number of respondents in the analysis. Third, each of the latent variables generated by the two PCAs (one each for decline of fish stocks and increase of fish stocks), which here reflect a dominant discourse, was then tested against key socio-demographic attributes to determine whether dominant discourses could be explained by respondent attributes.

4.3 RESULTS

4.3.1 FISH DECLINE

A total of 17 unique perceived proximate factors associated with fish decline were derived from the 119 respondents (Table 4.2). Fishing effects, including general overharvesting (39/119) and harvesting with modern fishing gear, comprised the majority of responses. In particular, dynamite fishing (28/119), net fishing (34/119), and spear fishing (23/119) (Photo 4.2) were perceived to decrease fish stocks. Dynamite fishing, in particular, was highly site specific. Other proximate factors associated with fish decline included particular forms of habitat degradation. A limited number of respondents stated that fish behaviour, such as migration, also reduced fish stocks.

Photo 4.2 A typical catch from a night spearfishing trip in Roviana lagoon, Western Province that I was fortunate to participate in. The catch includes bumphead parrotfish ('Topa') that were later sold to a local tourist resort.

Table 4.2 Proximate causes of fish decline as perceived by respondents across sites. Values are the percentage of the sample population that mentioned particular proximate factors. Columns do not sum to 100% because respondents were not constrained to a single answer. Grey shaded causes are those retained as dominant proximate causes in the PCA.

	Total (119)	Auki (20)	Buala (17)	Dunde (35)	Gizo (16)	Honiara (18)	Tulaghi (13)
Fishing effects							
General overfishing	39	25	53	43	38	39	38
Net fishing[a]	34	15	18	43	56	50	15
Dynamite fishing	28	50	0	0	0	72	77
Spear fishing[b]	23	20	6	43	31	11	0
Poison fishing[c]	17	10	0	29	31	6	15
Custom vine fishing[d]	9	0	18	20	0	6	0
Efficient gear (general)	5	10	6	9	0	0	0
Line fishing	4	5	6	9	0	0	0
Target spawning aggregations	4	0	0	14	0	0	0
Lamp fishing[e]	2	5	0	0	0	6	0
Habitat degradation							
Pollution[f]	12	10	6	17	0	11	23
Mangrove harvest	12	30	41	0	0	6	0
Coral harvest[g]	11	25	18	6	6	11	0
Stones[h]	1	0	0	0	0	0	8
Fish behaviour							
Fish mobility	10	5	29	6	13	6	8
Natural variability	7	0	0	3	31	6	8
Not sure	1	0	6	0	0	0	0

[a] Net fishing included more precise factors such as nets with fine mesh, and mosquito nets used to harvest juvenile fish.
[b] Spear fishing includes both trigger mechanism spear fishing and hand spear fishing, a technique which is frequently used at night to harvest sleeping fish such as parrotfish.
[c] Includes a number of locally acquired poisons such as bush leaves and vines, and bêche-de-mer poison.
[d] A traditional method of cooperative fishing, frequently used to harvest fish for ceremonies and community fundraising.
[e] Lamp fishing is relatively common in Malaita province. Fishers use lamps to attract fish.
[f] Pollution includes sediment and urban waste run-off from land, and discharge from WWII wrecks and vessels currently operating.
[g] Coral is primarily harvested for the aquarium trade, to produce lime for consumption with betel nut, and for coastal construction.
[h] Line fishermen commonly use stones as weights to get their baited hook to the substrate.

Forward step-wise inclusion of proximate factors, and associated distal factors resulted in a PCA that included four proximate factors and eight distal factors (KMO = 0.501; Bartlett's Test of Sphericity = 235; $p \leq 0.05$) (Table 4.3). Eighty seven percent (104/119) respondents stated at least one of the four proximate factors as causing decline in fish stocks. Here, each of the five Principal Components (PCs) is a latent variable which represents a different discourse, with the five discourses explaining a total of 66% of the variance of responses from the 104 respondents. Three of five PCs include both proximate and distal factors associated with fish decline at a factor loading score of ≥ 0.3. PC1 represents a discourse of ‘net fishing’ and ‘spear fishing’ caused by ‘fishing for immediate economic gain’ and ‘laziness’, and ‘general overharvest’ not caused by ‘fishing for immediate economic gain’. The second PC, which does not include any proximate factors, represents a dichotomy in discourses between ‘fishing for economic affluence’, and ‘fishing for economic survival’ and ‘no alternatives to fishing’. PC3 represents a dichotomy in discourse between ‘dynamite fishing’ caused by ‘poor knowledge of sustainable fishing techniques’, and ‘spear fishing’ caused by a ‘lack of alternatives’. PC4 represents a discourse of ‘dynamite fishing’ caused by ‘fishing for immediate economic gain’, ‘laziness’ and ‘lack of alternatives’, and not with ‘consumption related survival’. PC5 represents a less clear discourse; however, a weak ‘general overharvesting’ effect (-0.27 loading) is caused by ‘population growth’ and not by ‘poor knowledge of sustainable fishing techniques’.

Table 4.3 Principal Components Analysis of key proximate factors (P) and associated distal factors (D), for fish stock decline. Bold values are loadings of ≥ 0.3. Components 1, 3 and 4 contain both proximate and distal factors.

	PC1	PC2	PC3	PC4	PC5
General overfishing (P)	**-0.79**	-0.08	0.10	0.03	-0.27
Fishing for immediate economic gain[a] (D)	**0.72**	0.01	-0.19	**0.35**	0.10
Net fishing (P)	**0.71**	-0.15	0.16	-0.14	-0.13
Fishing for economic affluence[b] (D)	0.03	**-0.84**	0.11	0.12	0.22
Fishing for economic survival[c] (D)	-0.04	**0.82**	0.09	-0.03	0.09
Dynamite fishing (P)	0.21	0.26	**-0.69**	**0.42**	0.18
No alternatives to fishing[d] (D)	-0.11	0.32	**0.67**	**0.35**	0.12
Spear fishing (P)	**0.51**	-0.07	**0.58**	-0.13	0.01
Fishing for consumption survival[e] (D)	0.22	0.04	0.08	**-0.75**	0.09
Laziness[f] (D)	**0.30**	-0.14	0.08	**0.51**	0.01
Population growth[g] (D)	-0.21	0.11	-0.16	0.00	**-0.84**
Poor knowledge of sustainable fishing techniques[h] (D)	-0.08	0.02	**-0.40**	-0.07	**0.55**
Eigenvalue	2.35	1.76	1.53	1.18	1.03
% variance explained	19.6	14.65	12.74	9.87	8.59

[a] Responses relate to ‘quick’or ‘easy’ money obtained from selling fish. For example, some respondents referred to fishing locations as their ‘bank’ or ‘atm’ (automatic teller machine). Assuming a fishing trip is successful, and that fish are sold, fishing provides a means of rapidly obtaining income compared to, for example, gardening which requires planning and significant work before a return is realized.
[b] Responses relate to fishing and selling fish to accrue financial wealth.
[c] Responses relate to using income to meet economic needs such as school fees and basic household expenses such as kerosene and clothing.
[d] Responses relate to a lack of opportunities to pursue other sources of income which is an ongoing challenge in Solomon Islands for reasons too complex to extrapolate here.
[e] Responses relate to, for example, the purchase of rice, common in areas where people do not have land for gardening, such as around Auki.
[f] Responses relate to respondents perception that work ethic is absent among artisanal fishers.
[g] Responses relate to the perception that increasing human populations is causing increased fishing.
[h] Responses relate to the perceived reason why people use particular fishing gears.

4.3.2 FISH INCREASE

Proximate factors perceived to increase fish stocks did not correspond with proximate factors perceived to decrease fish stocks. For example, whilst specific fishing gears were commonly perceived to be the proximate cause of stock decrease (Table 4.2), the banning of particular gears was infrequently perceived as a means of increasing fish stocks (Table 4.4). Instead spatial closures were the most common solution proposed for increasing fish stocks. In particular, strong support was observed for spatial closures from respondents in Dunde and Buala, both of which have protected area programs which restrict human activities.

Photo 4.3 The provincial market in Gizo, Western Province, with local fishers selling their catch, primarily caught by night spearfishing using torches and sling spears.

Table 4.4 Proximate causes of fish stock increase as perceived by respondents across sites. Values are the percentage of the sample population that mentioned particular proximate factors. Columns do not sum to 100% because respondents were not constrained to a single answer. Grey shaded causes are those retained as dominant proximate causes in the PCA.

	Total (119)	Auki (20)	Buala (17)	Dunde (35)	Gizo (16)	Honiara (18)	Tulaghi (13)
Fishing restrictions							
Spatial restrictions	63	55	76	80	50	50	46
General spatial restriction[a]	46	30	71	54	38	39	38
Spatial restriction for spawning[b]	20	25	12	31	13	17	8
Gear restrictions	19	25	0	17	13	28	38
Ban net fishing[c]	8	5	0	9	13	11	15
Stop dynamite[d]	8	15	0	0	0	17	31
Ban poison fishing[e]	2	0	0	3	6	0	0
Reduce / ban spear fishing[f]	6	0	0	11	6	0	15
Line fishing only	6	10	0	6	0	6	15
Effort restrictions	15	10	12	14	19	28	8
Size restrictions	13	15	24	14	6	6	8
Species Restrictions	1	0	0	3	0	0	0
Habitat management							
Ban habitat harvest[g]	6	20	6	0	6	6	0
Stop land-based pollution[h]	2	5	0	0	0	6	0
Ban sea cucumber harvest[i]	1	5	0	0	0	0	0
Build artificial structure	2	5	0	0	0	0	8
Fish behaviour							
Good habitat and food	4	0	6	3	19	0	0
Oceanographic variability	1	0	0	0	0	0	8
Not sure	3	5	6	0	13	0	0

[a] Includes both permanent and periodic closures. Responses were often unspecified.
[b] Relates primarily to the closure of areas when and where target species aggregate to spawn
[c] Includes the use of nets with small mesh size including, in some instances, the use of mosquito nets.
[d] Dynamite is largely sourced from WWII ordinances. It is an illegal and destructive, but potentially highly profitable method of fishing.
[e] Includes toxins from terrestrial plants and sea cucumbers.
[f] Spear fishing, particularly at night using torches to target parrotfish, and other fish that sleep at night, has become a very popular and efficient means of obtaining a substantial catch.
[g] Habitat harvest includes mangroves for firewood and construction, and coral for construction, lime production, and the aquarium trade.
[h] Includes sediment from logging and urban waste run-off from land.
[i] Primarily at Auki and Buala some respondents perceived an ecological relationship between sea cucumbers and reef fish, such that overharvesting sea cucumbers caused fish to leave the overharvested location.

Forward step-wise inclusion of proximate factors, and associated distal factors resulted in a PCA that included four proximate factors and eight distal factors (KMO = 0.507; Bartlett's Test of Sphericity = 156; $p \leq 0.05$) (Table 4.5). Eighty five percent (101/119) of respondents stated at least one of the four proximate factors as causing increase in fish stocks. Here, as with dominant discourses of fish decline, each of the six PCs is a latent variable which represents a different discourse, with the six PCs explaining a total of 66% of the variance of responses from the 101 respondents. All PCs explain a relatively equal portion of the variance, suggesting no definitive pattern or single dominant discourse. Five of six PCs include both proximate and distal causes of fish decline at a factor loading score of ≥ 0.3. PC1 represents a dichotomous discourse, with one reflecting ‘spatial restrictions’ enabled through community cooperation, and the other representing ‘effort restrictions’ and ‘size restrictions’ enabled through ‘market regulation’. PC2 represents a dichotomy between ‘spatial restrictions’ and ‘gear restrictions’ enabled through ‘bylaws with penalties’. PC3 represents a dichotomy between ‘size restrictions’ enabled through ‘community law and leadership’ and ‘government law and enforcement with penalties’, and ‘community cooperation’ and ‘alternatives to fishing’. PC4, absent of proximate factors, is a discourse of compatibility between ‘paid security’ and ‘bylaw with penalties’ at one end of the range, and ‘community cooperation’ at the other end. PC5 is a dichotomy between ‘size restrictions’ enabled through ‘co-management’ and ‘bylaws with penalties’, and ‘effort restrictions’. PC6 is a dichotomy between ‘size restrictions’ enabled through ‘education and awareness’, and ‘strong community law and leadership’.

Table 4.5 Principal Components Analysis of key proximate factors (P) and associated distal factors (D), for increasing fish stocks. Bold values are loadings of ≥ 0.3. Components 1, 2, 3, 5, 6 contain both proximate and distal factors.

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Market regulation[a] (D)	**-0.72**	0.17	-0.04	0.08	0.24	-0.07
Effort restrictions (P)	**-0.70**	-0.03	-0.26	0.03	-0.41	0.06
Gear restrictions (P)	0.14	**-0.84**	0.18	0.08	0.04	-0.07
Spatial restrictions (P)	**0.62**	**0.62**	-0.13	-0.07	0.09	-0.03
Government law and enforcement with penalties[b] (D)	0.04	-0.10	**0.77**	0.17	0.03	-0.04
Alternatives including aquaculture[c] (D)	-0.08	0.17	**-0.57**	0.29	0.09	0.00
Paid security[d] (D)	0.20	0.22	-0.10	**-0.78**	-0.12	-0.05
Community cooperation ('one mind')[e] (D)	**0.39**	0.04	**-0.35**	**0.54**	-0.01	0.01
Co-management[f] (D)	0.00	0.00	-0.06	0.11	**0.77**	-0.07
Bylaw with penalties[g] (D)	0.08	**-0.39**	-0.04	**-0.50**	**0.50**	0.14
Size restrictions (P)	**-0.33**	0.26	**0.39**	-0.10	**0.44**	**0.38**
Education and Awareness by government and NGOs[h] (D)	0.18	0.14	0.11	0.11	-0.02	**0.83**
Strong community law and leadership[i] (D)	0.24	0.21	**0.33**	0.13	0.05	**-0.59**
Eigenvalue	1.91	1.76	1.49	1.24	1.13	1.08
% variance explained	14.72	13.51	11.46	9.57	8.70	8.28

[a] Includes numerous strategies focused on controlling the sale of fish.
[b] Relates to the perceived need for Ministry of Fisheries and Marine Resources to legislate, disseminate and enforce restrictions.
[c] Relates to the provision of economically viable alternatives to reduce fishing pressure.
[d] Anecdotal evidence suggests that poaching, particularly from protected areas, is prolific in some places. Previously, there was security for protected areas around Dunde however the security failed to prevent poaching.
[e] A number of respondents referred to the need for 'one mind' which, I believe, relates to the need for communities, and society more broadly, to agree on management strategies, and act accordingly.
[f] Relates to cooperation between different levels of management including collaboration between government and communities.
[g] Provincial bylaws provide a legally binding foundation for communities to be able to establish resource use rules and have them enforced through the respective provincial government.
[h] Natural resource education and awareness is primarily conducted by NGOs in Solomon Islands in collaboration with various government ministries. The perceived need for further education and awareness suggests that some respondents perceived that lack of knowledge is an indirect cause of fish decline.
[i] Social and cultural change is eroding traditional power systems in Solomon Islands communities leading to a disregard for local resource management rules.

4.3.3 Socio-demographic attributes

Some socio-demographic attributes exhibited co-linearity (Table 4.6). Therefore, to retain the maximum number of explanatory socio-demographic attributes, whilst removing those that were significantly correlated ($p \leq 0.05$), education and head of household were omitted from further analysis. Only 7 women were interviewed, so gender was also omitted from further analysis.

Table 4.6 Spearman's Rank correlations between candidate socio-demographic explanatory variables. Socio-demographic variables retained for further analysis denoted in bold. *p ≤0.05, **p ≤0.01, ***p ≤0.001.

	Age (ln)	Education (ln+1)	**Dependence (Y=1)**	Gender (Male=1)	**Migrant (Y=1)**	Head of household (Y=1)
Education (ln+1)	-0.05					
Dependence (Y=1)	-0.14	-0.18*				
Gender (Male=1)	-0.08	0.00	0.02			
Migrant (Y=1)	-0.04	-0.03	-0.01	-0.13		
Head of household (Y=1)	0.26**	-0.06	-0.13	0.31***	-0.15	
Middleman / fisherman (M=1)	0.11	0.221*	-0.17	-0.10	0.13	-0.11

A number of the remaining socio-demographic attributes explain, significantly, some of the dominant discourses of each fish decline and increase (Table 4.7). Site explained, significantly, PC2, PC3, and PC5 of fish decline which represent the dichotomies between; (a) 'economic affluence' and 'economic survival' caused by a 'lack of alternatives'; (b) use of 'dynamite' caused by 'poor knowledge of sustainable fishing techniques', and 'spear fishing' caused by a 'lack of alternatives'; and (c) 'poor knowledge of sustainable fishing techniques' and 'general overharvest' caused by 'population growth', respectively. No other socio-demographic attributes explained discourses of fish decline.

Table 4.7 Effect of socio-demographic attributes on the dominant discourses (PC's) of both fish stock decline and fish stock increase.*p ≤0.05, **p ≤0.01, ***p ≤0.001.

	Site[a]	**Age**[b]	**Dependence**[c, d]	**Middleman**[c, e]	**Migrant**[c, f]
Fish stock decrease					
PC 1	1.69	3^{-3}	-0.66	0.08	0.14
PC 2	5.04***	-0.13	0.24	-0.57	1.26
PC 3	8.23***	0.09	-1.18	-1.54	0.64
PC 4	1.83	-0.09	0.77	-1.24	-0.24
PC 5	2.38*	0.05	0.59	-1.31[g]	0.83
Fish stock increase					
PC 1	0.44	0.05	-0.35	-2.16*[g]	0.29
PC 2	3.78**	0.06	-0.78	-0.27	-2.09*
PC 3	2.2	-0.1	0.65	0.65	1.4
PC 4	4.42**	-0.01	-0.3	0.78[g]	-2.0*
PC 5	3.9**	0.09	-0.26	-0.74	0.29
PC 6	1.05	0.15	-0.59	0.33	0.59

[a] Analysis of variance (F statistic)
[b] Pearson's correlation coefficient
[c] Independent sample t-test (t statistic)
[d] Fishing as primary occupation = 1
[e] Fisher = 0; Middleman = 1
[f] Non-migrant = 0; Migrant = 1
[g] Equal variance not assumed

Site also explained PC2, PC4, and PC5 of fish increase which represented the dichotomies between; (a) 'spatial restrictions' and 'gear restrictions' enabled through 'bylaws'; (b) 'community cooperation' and 'paid security' in conjunction with 'bylaws with penalties'; and (c) 'effort restrictions' and 'size restrictions' enabled through 'co-management' in conjunction with 'bylaws with penalties', respectively. Middlemen were significantly more likely to be supportive of effort and size restrictions enabled through market regulation, and less likely to support spatial restrictions through increased community cooperation, than were fishers. Migrants were more likely to be supportive of gear restrictions enabled through bylaws, and less supportive of spatial closures, than non-migrants. Migrants were also more likely to be supportive of bylaws in conjunction with paid security, and less supportive of community cooperation, as a means of increasing fish stocks, than non-migrants. Respondent age and dependence on fishing as a primary source of income did not explain, significantly ($p \leq 0.05$), any of the discourses of fish stock decline or increase.

4.4 DISCUSSION

4.4.1 SCIENTIFIC AND LOCAL EXPLANATIONS OF CORAL REEF FISH DISTRIBUTIONS

The perceived causes of fish decline identified in this study, among artisanal fishers and middlemen in Solomon Islands, are concordant with scientific evidence. I n particular, respondents most frequently identified fishing, and its derivatives including specific gear types, as the proximate cause of fish decline. The perceived distal factors of overfishing also have some compatibility with earlier studies that identified population growth, access to markets, modernization and associated urbanization as driving increased market-based fishing pressure (Sabetian & Foale 2006; Brewer et al. 2009; Aswani & Sabetian 2010). For example, the perceived distal factors associated with efficient gears used for market-based fishing included fishing for cash income and associated economic survival, gain and affluence. This perception aligns with links, identified in this thesis, between market-based fishing and access to markets (Brewer et al. 2012a).

The perceived means of increasing fish stocks are aligned with current scientific and government views on fishery management. Spatial closures, which are readily advocated in the literature as a primary fishery management tool, were perceived by the majority of respondents to be an efficacious approach to managing the reef fishery. Importantly, permanent spatial closures are very rare in Solomon Islands so respondents were likely to instead be advocating temporary spatial closures. Secondary to spatial closures, respondents perceived that gear, effort, and size restrictions would increase fish stocks, which is also aligned with current scientific recommendations for Melanesia (Cinner & Aswani 2007; McClanahan & Cinner 2008; Cinner et al. 2009c). Particular gears, however, were readily perceived to cause fish decline, yet far fewer respondents perceived that banning specific gears would be an appropriate management action. Fishers are likely to own and possess greater skill with particular fishing gear, and would therefore consider the banning of gear that they own or are skilled at using to be an unfair regulation compared to spatial restrictions which would, depending on their location, restrict all gear types and be a fairer solution.

Local knowledge can provide important insights, not apparent in broader scientific assessments, of our effects on resources (Johannes 1981; Johannes et al. 2000), and therefore contribute to broader resource management knowledge (e.g. Aswani & Hamilton 2004). A number of the distal causes of fish decline in this study relate to fisher motivations to fish, which are not directly reflected in the previous studies that identified human population pressure, market access and socio-economic development as distal drivers of fish decline (Brewer et al. 2012a). These factors include laziness, fishing for immediate economic gain and poor knowledge of sustainable fishing techniques. Improved understanding of motivations to exploit, at the scale of the individual person, might provide opportunities for targeting management in a manner that individuals can empathize with and potentially respond to.

4.4.2 DOMINANT DISCOURSES

There is no single dominant discourse within the population sampled. Proximate factors are numerous, PCA was not possible for the complete sample, and the derived discourses including both proximate and distal factors are multiple and complex. This result reflects the diversity of challenges to the management of inshore fisheries in Solomon Islands.

The most pronounced theme across the discourses of fish decline is that of the divide between what I will term ‘self-interest and affluence’ on one side, and what I will term ‘poverty and lack of alternatives’ on the other, which reflects a gradient of perceived inequality. For example, the first discourse (PC1) is polarized into respondents who perceive fish decline due to the use of modern gears motivated by economic gain and laziness, and those who perceive general overharvest to be a major cause of fish decline. The second discourse (PC2) is polarized into fishing for affluence and fishing for survival motivated by a lack of alternatives. The fourth discourse (PC4) is polarized into those who perceive that laziness induced destructive fishing practices (dynamite) causes fish decline, and those who perceive fish decline is due to basic consumption survival. This polarity of perception across multiple discourses might reflect the social-political transformation underway in Solomon Islands whereby the increasing availability of consumer commodities, facilitated through trade under a common domestic currency, is driving fishers to over-exploit resources for income to attain increased social status (Ruddle 1993) and force inequality. However, the perception of affluence as a driver of overfishing is likely to be only perceived rather than real because there was, based on field observations, little evidence of fishers or middlemen attaining significant economic affluence from the fishery. Rather, affluence likely reflects resentment toward fishers and middlemen who, for example, have access to more efficient fishing gear or have exclusive rights to particular markets, and therefore aspire to, rather than realize, significant affluence.

A dominant theme across discourses for fish increase is that of a gradient from top-down command-and-control government management to decentralized community management based on an environmental ethic of resource users. Distal factors associated with command-and-control are market regulation, government law and enforcement with penalties, and bylaws with penalties. Distal factors associated with decentralized management are community cooperation, education and awareness, and strong community law and leadership (Table 4.5). There has been significant adverse reaction, in recent years, to command-and-control fisheries management and concurrent advocacy for the devolution of inshore fisheries management to the level of resource user groups, and for co-management whereby government and resource users work in dynamic partnership (e.g. Cinner et al. 2012b). Supporting arguments for the shift away from command-and-control management include the potential for empowerment of resource users, and increased social-ecological resilience achieved through a shift from panacea management toward context dependent management (Holling & Meffe 1996; Knight & Meffe 1997) that relies more heavily on local knowledge. Indeed, while the people of Solomon Islands have always had control over the exploitation and management of their resources, there is growing support of resource management by people with user rights from national and provincial government. For example, the national and provincial governments are taking action to ensure there is legislative support for community regulations in co-management-like arrangements, including fisheries management plans that explicitly include community-based management (Govan et al. 2011), provincial bylaws and forthcoming amendments to the National Fisheries Act.

It is possible that the support for command-and-control by some fishers and middlemen is because respondents perceive that small social-political groups such as clans, which theoretically control resource use, are impotent in enforcing regulations. This potential impotence might stem from the weakening of traditional management authorities such as village chiefs (Ruddle 1993; Dinnen 2002) and more recently the church. Therefore, while command-and-control fisheries management clearly has limitations, fisheries managers should not 'throw the baby out with the bathwater'. That is, some dimensions of command-and-control management, such as banning the importation of destructive fishing gears, might be well received by the fishers and middlemen. Further research, is needed, that identifies which social-political levels, from nation to resource user groups, are best suited to formulating and enforcing different management approaches (but see Govan et al. 2011).

4.4.3 Socio-demographic attributes

Respondents within sites have similar perceptions relative to respondents between sites across a number of discourses. It is possible that fishers and middlemen, through frequent within-site dialogue relating to fish stocks, have developed some consensual perceptions (Evans et al. 2011). Cultural consensus has been shown to relate to marine ecological knowledge and customary sea tenure in Solomon Islands (Grant & Miller 2004; Aswani 2005). Therefore it is possible that artisanal fishers and middlemen have developed a site-specific market culture relating to the fishery, including a shared understanding of causality of fish stock variability.

Middlemen were more likely than fishers to be supportive of size and effort restrictions enabled through market regulation, whilst fishers were more supportive of spatial restrictions enabled through community cooperation. This finding suggests an element of altruism because such measures would (at least temporarily) restrict middlemen, requiring them to adapt their business practices, and fishers because it would reduce the area from which they are able to fish. One possible explanation for this result is that both middlemen and fishers believe that fish stocks are adequately depleted to justify a reduction in potential income to ensure the long-term viability of the fishery (Cinner et al. 2009a). However, there are a diverse set of both forms of altruism, and motivations for altruistic behaviour (Fehr & Flschbacher 2003), which would have to be further explored to more confidently explain this finding. Alternatively, the responses might reflect a dichotomy in knowledge between fishers and middlemen, whereby fishers are better acquainted with community fishing regulations and middlemen are better acquainted with markets.

4.4.4 LIMITATIONS

The interviews were conducted in major urban centres where markets exist because there is strong evidence that market-based fishing is having a negative effect on reef fish distributions across Solomon Islands (Brewer et al. 2009; Aswani & Sabetian 2010; Brewer et al. 2012a). Therefore the population sampled in this study does not explicitly consider remote populations where market-based fishing is less pervasive. Remote populations might have different perceptions and a different discourse. However, at the time of the interviews, a number of the respondents were living in remote rural areas and travelling to urban centres to sell their catch.

It is not possible to infer whether the results of this study represent true fisher and middlemen perceptions or rhetoric obtained through information networks divulged to please the interviewers. Conservatively assuming that responses largely represent rhetoric, it is possible to conclude that fisher's and middlemen are informed of the scientific explanation for fishery decline and management strategies. The most likely answer, however, is that the responses represent a combination of both true perception and rhetoric.

4.5 CONCLUSIONS

This chapter has generated two insights that are directly relevant to the establishment of marine policy. First, fishers and middlemen involved in market-based fishing in Solomon Islands generally are aware that fishing pressure affects fish stocks and that broad social and economic factors affect fishing pressure. Therefore the perceptions of fishers and middlemen are compatible with the current perceptions of scientists, and support the findings of this thesis. Second, there is a dichotomy in perceptions for the causes of fish stock decline and increase. Respondents tended to perceive that fish decline was caused by either fishing for survival-related reasons or fishing for reasons of affluence and aspiration which highlights perceived inequality. Respondents also tended to perceive that either command-and-control or community-based management would increase fish stocks. Further research interrogating these dichotomies of both decline and increase might contribute to improved management approaches for identified causes of resource decline.

CHAPTER 5: GENERAL DISCUSSION AND CONCLUSIONS

In this thesis I have compared the relative merit of the three dominant environmental sociology perspectives; Malthusian overpopulation, market expansion, and modernization, using a novel comparative model that accounts for resource exploitation and management, in a novel social-political context at the local-level (chapters 2 and 3). I have also identified the dominant discourses of local resource users regarding the social factors that affect natural resource conditions (chapter 4), thus triangulating the comparative modeling (chapters 2 and 3). In doing so, this thesis has contributed to theory of human-environment interactions and has consequently broadened our understanding of the social processes that explain variability in the state of natural resources.

Discussion and theoretical contributions relating to each of the three data chapters (four papers) is contained within each respective chapter. Therefore those chapter-specific points of discussion and theoretical contribution will not be repeated here. Instead I: 1) review the research gaps, show how they have been addressed in this thesis, and highlight how addressing the research gaps contributes to theory, 2) present a unified narrative of society's effects on coral reef fishery resources in Solomon Islands as the broad theoretical contribution of this thesis, 3) discuss limitations to the thesis, and avenues of potential future research, and 4) draw general conclusions.

5.1 REVIEW OF THE RESEARCH GAPS ADDRESSED IN THIS THESIS INCLUDING THEORETICAL CONTRIBUTIONS

The broad aim of this thesis was to determine which environmental sociology perspective about society's effects on natural resources best explains natural resource distributions in the Solomon Islands. Many scholars have addressed this aim using particular models (i.e. testable frameworks such as Figure 1.5 in this thesis), at particular scales (e.g. York et al. 2003a; Hoffmann 2004), and in particular ecological contexts. However, there is clear evidence that the merit of each of the dominant perspectives varies across models, scales, and contexts (Fisher & Freudenburg 2001). In this thesis, I used a novel model that incorporates elements of human behaviour (exploitation and management institutions), to test the merit of the perspectives in a novel context at the local-level. In doing so, this thesis 1) incorporated elements of behaviour into the model, advancing our understanding of the social processes that explain the state of natural resources; 2) contributed to the growing quantitative literature for and against each of the dominant perspectives by quantitatively analyzing results in a novel context and an important, but understudied social-political scale; 3) triangulated the findings derived from the quantitative model with local perceptions of the drivers of natural resource state. In doing so, the model was internally verified. That is, the people within the context of this study confirmed the conclusions drawn from the general model. I proceed by reiterating the identified research gaps and how they were addressed in this thesis, and outline the theoretical contributions derived from doing so.

The first identified research gap was one of ‘limited understanding of causal links between social and ecological systems’. The majority of studies that compare the relative merit of each perspective (Malthusian overpopulation, market expansion, modernization) examine the effect of distal drivers on resource state (Figure 1.2) by direct correlation (e.g. York et al. 2003a; Hoffmann 2004). This thesis advanced this general model by including both exploitation and management institution variables within the model as proximate drivers that mediate the relations between the distal drivers and resource state variables (Figure 1.5). Inclusion of these proximate drivers added to our understanding of each of the perspectives by presents the perspectives as a sequential process, rather than a direct correlation. For example, in the context of coral reefs there is evidence that increased fishing pressure (proximate driver), unsurprisingly, is negatively correlated with in situ fish assemblages (e.g. biomass) (e.g. Jennings et al. 1995; Jennings & Polunin 1996). There is also evidence that the distal drivers including market access and population pressure, explain in situ fish assemblages (Brewer et al. 2009; Cinner et al. 2009b; Cinner et al. 2012b). Yet there is little evidence of the sequential effects of distal drivers on proximate drivers, and proximate drivers on fish assemblages (a paucity of evidence that extends to all ecological systems). One exception is an aforementioned study by Cinner (2009b) that found that, across a number of countries in the Western Indian Ocean, 77% of the variance of fish biomass was explained by local-level socioeconomic development concordant with the environmental Kuznets curve, and population density was a poorer descriptor of fish biomass. Further, the study explained the effect of socioeconomic development on fish biomass by a number of mechanisms (equivalent to proximate drivers) including more benign fishing gears such as handlines and higher salaried employment at higher levels of socioeconomic development. The study by Cinner and colleagues showed that some of the proposed modernization mechanisms did explain why environmental conditions are better at high levels of modernization. This thesis has arguably advanced on the study by Cinner et al. by analysing the three identified dominant perspectives within a single system model (Figure 1.5), showing how distal drivers (as manifestations of the three dominant perspectives) relate key proximate drivers, and how exploitation, as a proximate driver, explains the state of the natural resource. In doing so, this thesis has built a more complete social-ecological system model, than earlier studies, based on a firm foundation of environmental sociology theory.

Inclusion of these proximate drivers, and testing their relation with distal drivers and natural resources, has contributed to theory of how human societies affect natural resources. Specifically, chapter 2 of this thesis shows that, in Solomon Islands, both distance to market (as a manifestation of the market expansion perspective) and local population density (as a manifestation of the Malthusian overpopulation perspective) explained 76% of the variance of fishing pressure (using efficient fishing gear) which, in turn, explains, to varying degrees, a number of *in situ* fish assemblage parameters including biomass, biomass of fish that are vulnerable to fishing, species diversity, and functional group biomass. Importantly, their effects represent different variance explained (i.e. population density and distance to markets have additive effects) and so both the Malthusian overpopulation and market expansion perspectives have merit, and therefore attachment to any single perspective is likely inappropriate when formulating policy to address issues of resource scarcity.

Chapter 3 of this thesis showed the effects of distal drivers on the occurrence of resource management institutions [institutions could not be linked to resource state for reasons outlined in the limitations (section 5.3)]. There is a significant literature on social and economic factors that affect the success of resource management institutions, particularly relating to common-property resources (Ostrom 1990; Agrawal 2001; Cinner 2005; Agrawal & Chhatre 2006; Cinner et al. 2007; Ostrom 2007; Cinner et al. 2012b). However, no studies, that I am aware of, have explicitly considered how the dominant perspectives (measured as manifest variables such as human population density as done in this thesis) explain institutional efficacy or occurrence. Chapter 3 shows that, within the scope of the thesis, population size (as a manifestation of Malthusian overpopulation) has an overall positive effect on the probability of institution occurrence, suggesting management response to declining resources driven by high populations, which supports optimum population size theory (Agrawal & Golyal 2001). However, human population density had a strong negative effect on institution occurrence, suggesting possible failure of institutions with increased population per available resources, which is also supported in fisheries literature (Pauly 1988). That population size had a positive effect on probability of institution occurrence and population density had a negative effect on institution occurrence will require further investigation. While the merit of the Malthusian overpopulation perspective, for explaining institutional occurrence, is not clear, it is probable that management is more likely to occur in instances of relatively large populations (for the Solomon Islands) with a large resource base. The positive effect of market presence on institution occurrence counters market expansion claims, that economic growth and expansion over-ride environmental concerns (Schnaiberg et al. 2002). However, it is possible that the positive effect of market presence, on institution occurrence might be a result of resource owners using management institutions to exclude non-owners, thus maximising economic gain (Ruttan 1998). This proposition is likely because the effect of markets on management institution occurrence was only significant for temporary closures – which might represent a more discrete approach for excluding non-owners.

The second identified research gap was one of 'social-political scale'. There is a distinct paucity of studies that compare the three perspectives at the local-level on the social-political scale, yet social-ecological patterns vary across the social-political hierarchy (individual person to global) (Warren 2005), and it has been acknowledged that there is a need to understand how the different perspectives explain resources at different social-political levels (Clausen & York 2008a). All quantitative analyses of the three perspectives have been conducted at the national-level (York et al. 2003a; Hoffmann 2004; Clausen & York 2008b, a; McKinney et al. 2009). National-level data is useful because it shows general global trends across a broad spectrum of modernization, Malthusian overpopulation and market expansion. However, it does not allow the use of detailed ecological data that is more relevant to, for example, ecosystem function. Neither does it allow the inclusion of detailed exploitation and management institutions, for specific resource types, as used in this thesis. Further, in a peripheral nation context, resources are often only managed at the local-level. Analysis at the local-level in this thesis has overcome these limitations showing variation in ecological responses to different social factors (chapter 2). As a result this thesis has shown strongest support, at the local-level, for both the Malthusian overpopulation and market expansion perspectives; a result that is broadly aligned with the national-level analyses. However, given the different model used in this thesis (research gap 1) and the geo-political context (research gap 2) it is not possible to draw direct comparison between this thesis and the nation-level studies.

The third identified research gap was one of 'geo-political context'. Studies that compare and contrast all three perspectives tend to focus on modernized and affluent nations and societies (e.g. Schnaiberg 1980; Grossman & Krueger 1995; Mol 1995; Weinberg et al. 2000; Luck 2007), and no comparative studies have focused on the global economic periphery. Yet, there is strong evidence that the position of a nation in the world system

(Wallerstein 1974), be it peripheral, semi-peripheral, or core, has a bearing on the state of its natural resources (Hoffmann 2004; Bunker 2005; Shandra et al. 2009; McKinney et al. 2010). World system position has particular relevance to the modernization perspective, because the theory implies that more affluent, or modernized, societies are able to externalise their ecological footprints. Thus, quantitative evidence of the modernization perspective within core nations (Grossman & Krueger 1995; M'henni et al. 2011) might be due to import of resources and export of pollutants (Figure 1.1). Therefore, there was a distinct need to understand, better, the effects of societies on natural resources within a peripheral nation context, where a large portion of global biodiversity exists (Myers et al. 2000; Kramer et al. 2009). I addressed this research gap by focusing analyses on Solomon Islands, a peripheral nation (Babones 2005). In doing so, I found only limited substantive evidence for the modernization perspective in Solomon Islands. In fact, modernization had no discernable effect on fishing pressure, suggesting that in the within-peripheral nation context, modernization has little bearing on natural resources and that markets and local population pressure are the dominant forces. However, there was some evidence of higher incidence of species and gear restrictions in more modernized communities, suggesting that, overall, and modernization might have a net positive effect on coral reef fisheries in Solomon Islands. Yet, the communities in this study would certainly lie at the lower end of the global modernization spectrum; therefore the positive effect of modernization of species and gear restrictions is not explained as the environmental Kuznets curve.

The fourth research gap was one of 'triangulation of findings'. None of the quantitative comparative studies of the three perspectives have used local perceptions data to triangulate comparative findings. Yet, two significant benefits to theory development are likely to be derived from analysis of local perceptions. First, local perceptions will either support or refute the comparative model, adding to weight of evidence, or force a review of the comparative model and its assumptions, respectively. Generally, the analysis of local perceptions in this thesis (chapter 4) (Brewer 2012) supported the findings of the comparative analyses. In particular, fishers and middlemen perceived that efficient and destructive fishing gears (e.g. fishing nets and spears) were the dominant proximate drivers

– a finding that supports the results of chapter 2. Further, distal drivers of resource decline perceived by fishers and middlemen were concordant with both Malthusian overpopulation and market expansion, including population growth, fishing for consumption survival and fishing for economic gain. Modernization was not a perceived driver of fish decline [partly because the terminology is not common in the local vernacular, however, 'development' as a comparable concept which is common in the vernacular (Foale 2001), was not mentioned explicitly], but does relate to fishing for affluence and immediate economic gain for aspirations associated with modernization. Fisher and middleman perceptions of means of increasing fish stocks were also broadly concordant with the findings of chapter 3. Frequently elicited proximate drivers of fish stock increase included spatial restrictions and fishing gear restrictions that were both analysed in chapter 3. Distal drivers associated with spatial restrictions included market regulations and bylaws with penalties which supports, in part, the market expansion perspective. The only distal drivers perceived to assist gear restrictions was bylaws with penalties. The perceived importance of bylaws shows the perceived need for assistance with local regulation from the provincial and national-levels of governance (which is raised further as an issue of social-political scale in the limitations section). Also interesting was that, despite the Malthusian overpopulation perspective dominating the comparative analysis in chapter 3, managing population effects was not perceived by any respondents as a means of increasing fish stocks. The reason for this difference is not clear, especially given that population growth was frequently perceived as a cause of fishery decline. All evidence considered, local perceptions were broadly supportive of the results of the comparative analyses in chapters 2 and 3, except for the effects of population size and density on the occurrence of fishing restrictions that I believe contributes robustness to the conclusions of the comparative analysis. Second, local perceptions are likely to include factors that operate at the level of the individual rather than the local- or national-level (following research gap three above). Indeed, there were a number of perceived factors identified by resource users, which likely drive individuals to over-exploit coral reef fisheries in Solomon Islands that were not considered in the local-level analysis in this thesis. These factors included, for example, 'laziness' and 'poor knowledge of sustainable fishing techniques'. As mentioned in chapter 4, consideration of these factors might provide opportunities for targeting management in a manner that individuals can empathize with and potentially respond to.

5.2 The broad theoretical contribution of this thesis: A unified narrative of society's effects on coral reef fishery resources in Solomon Islands.

It is clear from the results presented in each of the data chapters, that no single perspective explains society's effects on coral reef resources at the local-level in Solomon Islands. In fact, there is evidence that elements of all three perspectives operate within the fishery.

There is support for both the Malthusian overpopulation and market expansion perspectives with regards to fishery exploitation and the state of the fishery (chapters 2 and 4). Relatively efficient fishing gears explain the state of the fishery, with greater density of more efficient fishing gear correlated with reduced biomass of vulnerable species, species diversity, and biomass of functional groups (Figure 5.1 (a)). Efficient fishing gear is synonymous with both Malthusian overpopulation and market expansion perspectives. Within the Malthusian overpopulation narrative, local human population growth leads to declining resources, forcing resource exploiters to increase gear efficiency to maintain catch-per-unit effort (Pauly 1988). Within the market expansion narrative, labour is exchanged for technology (efficient gears) to maximise profit (Schnaiberg 1980). That both human population density and access to markets explain efficient fishing gear (Figure 5.1 (b, c)) lends further support to the Malthusian overpopulation and market expansion perspectives, respectively. These findings are broadly consistent to previous studies, conducted at the nation-level that showed Malthusian overpopulation and the market expansion perspectives best explained resource distributions (York et al. 2003a; Hoffmann 2004; Clausen & York 2008b, a; McKinney et al. 2009) (Table 1.1). Further, fisher and middlemen perceptions of the cause of fishery decline supported both the Malthusian overpopulation and market expansion perspectives. In particular, respondents perceived that fishing for affluence and fishing to meet immediate family needs were primary drivers of fishery decline, which support the market expansion and Malthusian overpopulation perspectives, respectively.

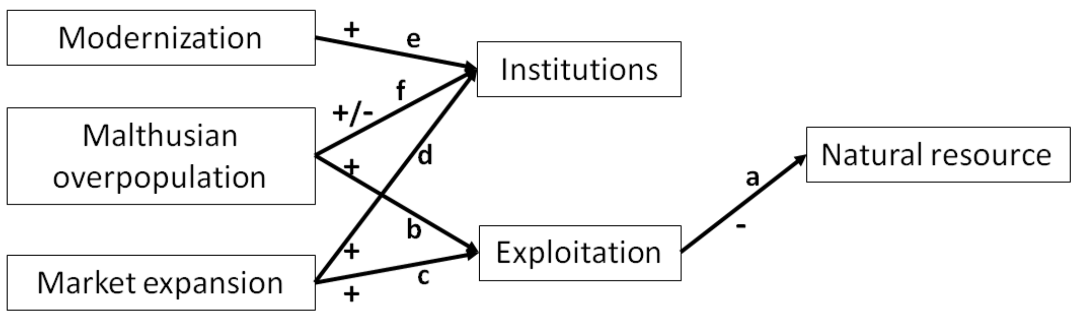

Figure 5.1 Local-level process-based model (which could also be considered a narrative) of society's effects on coral reef resources in Solomon Islands derived from chapters 2 and 3 of this thesis.+/- = direction (slope) of effects; a-f = see text above and below.

The support for both Malthusian overpopulation and market expansion perspectives highlights a spectrum of drivers of resource decline. Malthusian overpopulation, at one extreme likely relates to exploitation to meet local needs. In times past, when there was not cash-based trade of resources, but only barter or the use of local currency, population was likely the dominant driver of the state of natural resources. Indeed, Malthus' calculations considered local and national population growth, without any explicit mention of the potential for trade to buffer future environmental catastrophe (Malthus 1798). Then, the insurgence of other ways of thinking and doing, by increased globalisation, opened communities to trade, through a common currency, and novel material goods that presented incentive to exploit resources beyond immediate needs (Ruddle 1993; Sabetian & Foale 2006). This change represents a transition from population to markets and trade as drivers of over-exploitation, from fishing motivated by needs to fishing motivated by material wants, and, socio-politically, from relatively egalitarian communities (Marx 1887; Baines 1989) to communities containing entrepreneurial capitalist enterprise aimed at maximising personal gain (Smith 1843; Brewer 2011). The result of this transition, from one end of the spectrum to the other (which is likely continuing), is increased inequality in the allocation in benefits from the fishery.

To contextualise this spectrum I turn to field observations of the two extremes. In one community visited, there was a women's fishing group that used basic fishing gear including wooden canoes and handlines. They would frequently fish through the night, and return with a small catch. Some of the members of the group reported that most of the fish were for personal consumption or for local sale to meet basic household needs including family support. This group epitomises the egalitarian fishery, elsewhere viewed as the welfare fishery (Béné et al. 2010), where fishery resources are seen as insurance against poverty and unemployment. In the same community there were young men who fished using comparatively sophisticated gear including fibreglass boats with outboard motors, spears, and torches for night-spearing. Catches could be significant, particularly if fish spawning aggregations were targeted, or particular parrotfish were found in abundance. The catch of this group was invariably sold. Indeed, in this community and others, particular reefs were given names, relating to immediacy of the economic utility of the resource, such as "A.T.M." (automatic teller machine) – rapid access to cash. While I cannot confirm how income from the catch was spent, it is likely a portion was spent on luxury items including imported non-essentials, purchased at local stores. This group represented the capitalist production, or rent-maximisation fishery (Béné et al. 2010) – the more recent of the two. These two groups, though targeting the same resource, represent markedly different sectors of the small-scale fishery, and of the community. The support of either of these fishery types must be carefully considered in policy relating to maximising societal benefits (rent or welfare) from small-scale fisheries.

However, the narrative of society's effects on coral reef resources is not fully explained by this spectrum. With the exception of human population density, the distal drivers have a positive effect on the probability of institution occurrence. These positive effects suggest that institutions might be adapting to social and economic change (Hviding & Baines 1994;

Hviding 1998) in Solomon Islands (Chapter 3). In particular, institutions are more likely to occur in communities with fish markets (Figure 5.1 (d)), in more modernized communities (Figure 5.1 (e)), and in communities with medium- to large-sized populations (Figure 5.1 (f)). This finding lends some weight to the modernization perspective. Yet, evidence suggests that, by way of increasing fishing pressure using sophisticated gears, population density and markets negatively effect, and modernization has no effect on, reef fish stocks in Solomon Islands (Chapters 2 and 4) (Brewer et al. 2009; Aswani & Sabetian 2010; Brewer et al. 2012a). It is possible, therefore, that despite higher probability of occurrence in more modernized communities with medium to large population size and fish markets, management institutions exist, but are not succeeding in stemming resource decline. This begs the question of why institutions are not sustaining or improving resource condition with high population pressure and access to fish markets.

According to the modernization perspective, the primary reason why institutions are not stemming resource decline is because a high enough level of modernization has not been attained for consideration of the environment, to the point of increased resource abundance. Instead, focus remains on meeting basic needs including food security and housing (Maslow 1943), which is certainly evident in Solomon Islands. Secondarily, and associated with increased modernization, the mechanisms for improved resource conditions are not present, including adequate investment in scientific and management institutions that prevent overexploitation (see Cinner & Aswani 2007 for a review of institutions relevant to the context), alternative livelihoods outside of resource exploitation, and importation of resources instead of local exploitation. Logically, therefore, if the modernization perspective is relevant to Solomon Islands communities, there is a need for increased modernization to enable decreased exploitation pressure on local resources.

However, it is likely that factors operating at larger social-political levels (national and global) are driving local-level over-exploitation and constraining local-level modernization. It is possible that because of poor governance (Kaufmann et al. 2009) including corruption in extractive industries (Larmour 1997), social and political instability, and poor terms of trade internationally, Solomon Islands [as is likely in other peripheral nations (Wallerstein 1976)] might not reach a level of modernization that enables discernable consideration of environmental welfare, as predicted by the environmental Kuznets curve (Figure 5.2). For example, timber has historically been the major source of federal revenue – largely shipped offshore, to more affluent nations, as unprocessed logs to the economic benefit of multinational companies (Foale 2001). Anecdotally, little income from logging is received at the local-level, and when it is, it is not equitably distributed, and often squandered. Few significant timber resources remain in Solomon Islands due to overexploitation. Further, Solomon Islands does not possess significant secondary (e.g. manufacturing) or tertiary (e.g. information technology and services) industries, and is consequently heavily reliant on imports. The primary means of accessing these imports is through resource rents from fisheries, forestry and mining. Therefore, I think that the poor return on investment from extractive activities subject communities in Solomon Islands to chronic poverty that might not change with continued resource exploitation. Instead poverty traps - a self-reinforcing mechanism which causes poverty to persist (Azariadis & Stachurski 2005; Barrett & Swallow 2006; Cinner 2011) - might become more prevalent if local-level resources continue to diminish without significant improvements in terms of trade and improved national-level governance. The relevance of social-political scale in explaining local-level resource conditions is further discussed in the limitations (section 5.3).

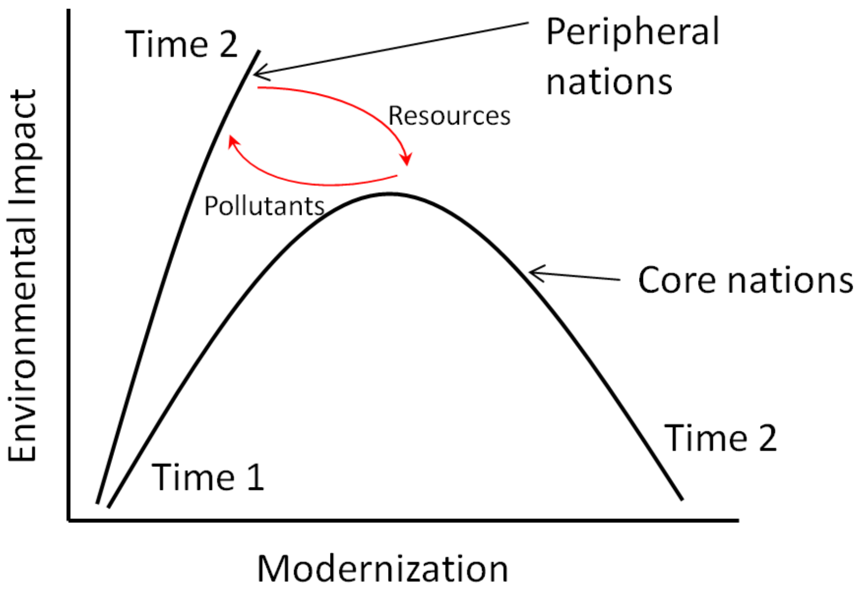

Figure 5.2 A heuristic model of the effect of world systems trade on modernization trajectories for core and peripheral nations. Here, I hypothesise that core nations achieve environmental Kuznets curve trajectories by way of importation of resources from, and export of pollutants to, peripheral nations. Based on this hypothesis, there is a need for national- and global- level shifts in terms of trade if local-level communities in peripheral nations are to modernize in the form of the environmental Kuznets curve.

In summary, local population growth and commoditization of resources, and a transitioning economy, from one of egalitarian distribution of resources to one of personal gain, is driving increased exploitation using efficient fishing gear. However, there is a local-level response, in increased likelihood of occurrence of management institutions in more modernized communities with fish markets, and in communities with medium to large populations. Yet, ensuring future sustainable use of resources locally will likely require addressing issues such as trade inequalities in national and global social-political systems.

5.3 Limitations to the Thesis and Consequent Future Research

The narrative presented in section 5.2 is the process-based model that has resulted from this thesis, including the comparative analyses in chapters 2 and 3, and the information elicited from surveys associated with chapter 4. In this section I describe limitations to the thesis narrative outlined above. In doing so, I build on the narrative to incorporate the broader system properties that represent limitations to the thesis. This results in an extended model including tested (this thesis) and hypothesised factors that are likely to explain resource distributions in peripheral nations at the local-level. Thus, this section culminates in a broader model for future testing.

5.3.1 THE WRONG METHOD OR MISSING VARIABLES IN THE GENERAL MODEL?

This thesis has used mixed methods (Tashakkori & Teddlie 2002) to reach its conclusions; quantitative analysis was used for chapters 2 and 3, and a combination of quantitative and qualitative analyses were used for chapter 4. The conclusions of the thesis are derived from the quantitative analyses in chapters 2 and 3, and qualitative responses from fishers and middlemen to triangulate the quantitative findings.

Detailed fishers' and middlemen's perceptions, combined with the complex narratives of each of the perspectives (summaries of which are presented in the Introduction) highlights the incompleteness of the overarching thesis model (Figure 1.5). That is, there is contextual complexity that cannot be captured only by such statistically testable, quantitative, reductionist models (Johnson & Onwuegbuzie 2004). For example, there are a number of environmental non-government organisations now based in Solomon Islands, including The Nature Conservancy, WorldFish, World Wildlife Fund, and the Coral Triangle Initiative that focus on natural resource management and rural livelihoods. The actions of these organizations, in theory, are supportive of the modernization perspective because they represent a dampening response to environmental degradation, and the evolution of traditional management systems towards hybrid systems more adept at managing modern resource management challenges (Cinner and Aswani 2007). In addition, review of national fisheries policy might show a shift from a focus on resource exploitation to one of conservation that would also lend weight to the modernization perspective. Consequently, the thesis might have benefited from the inclusion of a qualitative description of evidence for each of the perspectives. The main benefits of doing so would be further triangulation of the quantitative findings and further embedding of each of the perspectives within the context. However, it is possible that focus on a particular strand of qualitative evidence (such as the effect of an environmental non-government organization on a few villages) would produce bias towards a certain perspective where the quantitative analysis was less likely to have done so.

One alternative to a qualitative description would be to incorporate contextual factors such as the presence of environmental non-government organizations, or alternate sources of income such as coral reef tourism that may have accounted for additional variance in the quantitative model (Figure 1.5). The diagnostic framework for analyzing social-ecological systems developed by Elinor Ostrom (2007) provides a comprehensive example of the numerous indicators that may contribute to different types of social-ecological outcomes. However, as noted by Ostrom, simultaneously examining all potential variables would require an enormous sample size. Compared to other social-ecological studies with comparably detailed ecological data (Cinner et al. 2009b), this thesis used a moderately large sample size (for Chapter 2), but adding more explanatory variables would have overfitted the models. Further, the model I developed (Figure 1.5) did explain much of the variance in fishing pressure, institution occurrence, and ecological distributions (i.e. it had reasonable power of prediction), and represents the study system distilled to an arguably minimum adequate model. Therefore, despite omitting some potentially important contextually relevant variables, the model was successful in addressing my research aims.

5.3.2 A MISSING LINK IN THE MODEL

The general model used in this thesis (Figure 1.5) to test the effects of proxy variables for each of the perspectives, on exploitation and management institutions, to explain natural resource distributions, was missing one key link. The missing link was the effect of resource management institutions on the relationship between resource exploitation and in situ resources (red arrow in Figure 5.3). Inclusion of this link would have shown, directly, whether institutions were actually constraining exploitation. The reason why I was unable to include this link in my study of Solomon Islands is because I integrated two datasets that were collected for different objectives, which meant there was little geographic overlap between the surveys. Specifically, data on management institutions (from the village resource survey) were sparse across the sites where ecological data were collected, and consequently there were not enough sites to test the complete model. Consequently, the model was split into two components, focusing on exploitation and management institutions separately (see Figure 1.5). While I would expect that institutions would have some dampening effect on the effect of fishing pressure on the fishery (Agrawal & Yadama 1997; McClanahan et al. 2011a), thus a positive effect on fish stocks (natural resource in Figure 5.3), it is not possible to definitively draw such a conclusion with the data used in this thesis. To address this limitation it would be necessary to identify the occurrence, and efficacy, of the relevant coral reef resource management institutions across the 25 sites used in chapter 2. This was not possible due to a range of reasons including difficulties in obtaining field permits for all sites, and the extremely remote locations of some sites.

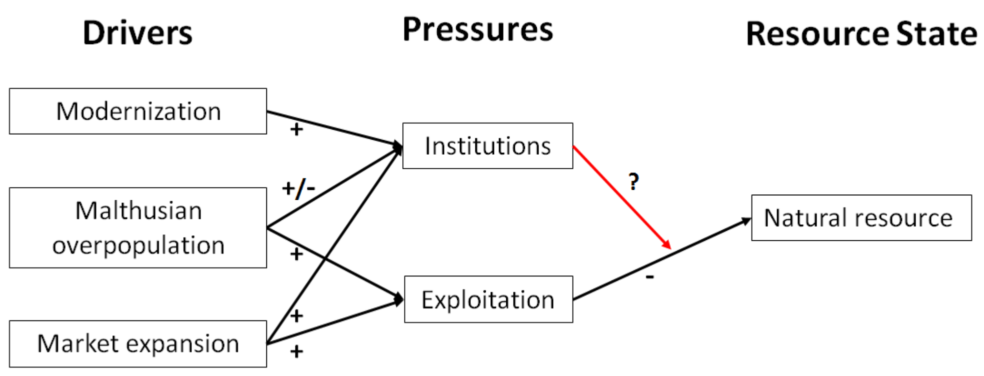

Figure 5.3 Generalised model used in this thesis. Black arrows denoting links that were tested and showed significant correlation, and the red arrow denoting a link that was not tested. +/- = direction of significant effect. ? = unknown strength and direction of effect.

5.3.3 A MODELED SYSTEM OF FLOWS AND FEEDBACKS

Analyses within this thesis have assumed that social manifestations cause change to ecological manifestations. This assumption is concordant with the human exceptionalism paradigm (HEP); that social change is independent of the environment the society exists in. That is, cause and effect is unidirectional from society to ecology. However, the New Ecological Paradigm (Catton Jr & Dunlap 1978), which is now widely accepted in environmental sociology, challenged the HEP by arguing that the interactions between society and ecology are bi-directional. Indeed, there is a growing body of social-ecological systems literature that explicitly acknowledges, and models, bi-directional effects (flows and feedbacks) (e.g. Cinner 2011; Nyström et al. 2012). For example declining fish catch, due to overfishing, might cause increased fishing pressure, or force fishers to exit the fishery (Cinner et al. 2011).

Feedbacks can be explored using time series data (Granger 1969). Crucial feedbacks in the system would include effects of changing resource state on distal and proximate drivers (Figure 5.4). Time series data would also be beneficial in identifying lag effects, which aid in inference of causality (Granger 1969). For example, as shown in figure 5.5, there is a lag effect between the hypothesised sequential effects of increased population density on fishing pressure, increased fishing pressure on declining resource state, and declining resource state on institutional efficacy. Time series data would be particularly useful for management because it would enable the identification of system dynamics including effects of interventions such as government policy, changing economic structure, or the influence of external agency such as the Coral Triangle Initiative.

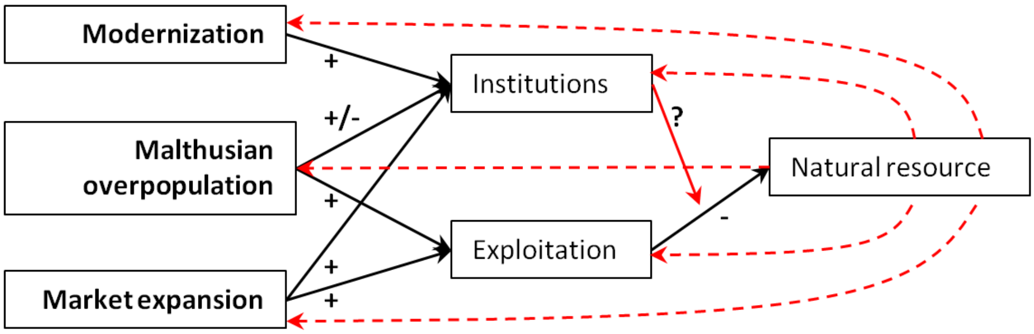

Figure 5.4 Proposed generalised model of the dominant sociological perspectives of society's effects on natural resources at the local-level embedded within a social-ecological framework. Links tested in this thesis denoted as black arrows. Link identified as missing from the unidirectional model (Figure 5.1) denoted as red solid arrows. Links to be tested for social-ecological feedbacks denoted as red dashed arrows.

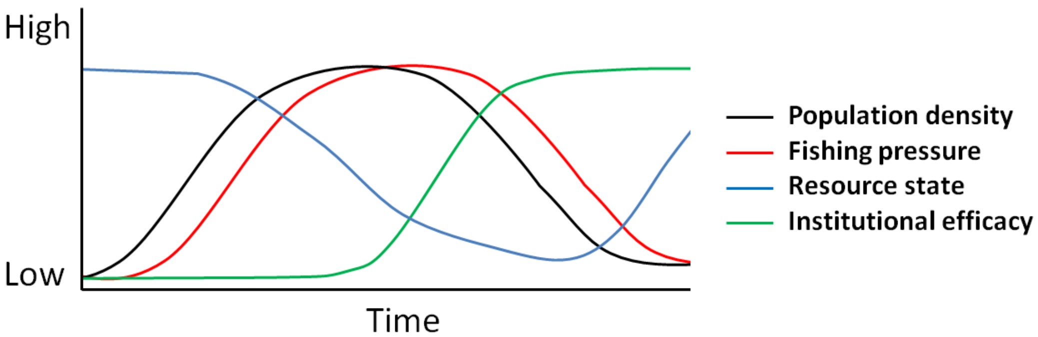

Figure 5.5 Heuristic model showing hypothetical lag effects between model variables, driven by increasing population density.

To develop a time series for the general model including feedbacks (Figure 5.4) would require a long-term data collection program. The program would require frequent measurement of variables to ensure that cause and effects were observed, dependent on the rate of social-ecological change occurring within the system and how tightly coupled various variables are. For example, increase in population density might have a very immediate effect on increase in fishing pressure, improvements in institutional efficacy might occur when resources are still abundant, or when severely depleted, and ecological systems can be prone to rapid shift to alternate states (Hughes 1994; Lester & Fairweather 2011).

5.3.4 Linkages among and between levels in the social-political scale

This thesis focused on the local-level (chapters 2 and 3) (supported by the individual-level analysis) to draw its conclusions, for sound reasons. First, coral reef social-ecological systems are relatively tightly coupled at the local-level (Almany et al. 2013). For example, in Solomon Islands natural resources are largely exploited and managed by local communities of people (Hviding & Baines 1994; Hviding 1998; Foale & MacIntyre 2000; Govan 2009) (exceptions being examples such as large logging companies that are socially exogenous to the local social-ecological system). Further, more detailed data, particularly ecological, is available at the local-level compared to, for example the nation-level (e.g. York et al. 2003a; Hoffmann 2004; Bradshaw et al. 2010), allowing the observation of social effects on key aspects of ecology such as species diversity and functional group biomass.

However, as 'no man is an island' neither is any local-level community or individual fisher or middleman, isolated from other social-political levels (Wallerstein 1976), particularly in our increasingly interconnected world (Cash et al. 2006; Young et al. 2006). According to theory of human geography, there are levels of organisation on the social-political scale that takes the form of a vertical hierarchy (Warren 2005), with lower levels nested in those above (see Agnew 1995; Marston 2000 for early work on socio-political levels, and critique of scale in human geography; Marston et al. 2005). Levels include, but are not necessarily limited to, the; individual, family/household, community/village/town, province, nation, and global. Each of the levels within the hierarchical scale is affected by all other levels, indirectly or directly (red bi-directional arrows with associated numbers in Figure 5.6).

In the context of small-scale reef fisheries in Solomon Islands, the resource ownership group, which operates at the local-level and was the focus of chapters 2 and 3 of this thesis, is the primary social-political level of coral reef resource exploitation and management. However, the within the local-level there exists families/households, and within families/households there are individuals (chapter 4 of this study). Individuals within communities are likely to affect exploitation and management by, for example, showing strong leadership qualities (Ostrom 2007). Differences among households might also affect local-level exploitation and management of resources. For example, cultural heterogeneity among households is not conducive to collective action at the local-level (Aswani 2002; Thompson et al. 2003). Local-level communities also interact with one another, primarily through trade and migration, including resource dispersal (Figure 5.6, number 1). Further, local-level communities are nested within provinces in Solomon Islands[15]. Factors operating at the provincial-level will affect local exploitation and management patterns (Figure 5.6, number 2). For example bylaws, which were a commonly elicited management response in chapter 4, operate at the provincial level, and offer support for local-level resource management. The national social-political level also affects local-level resource exploitation and management, either directly (Figure 5.6, number 3), or indirectly through provincial governance (Figure 5.6, number 7). Direct effects include bans on the exploitation of particular species (e.g. bêche-de-mer) and the use of particular fishing gears (e.g. dynamite). Indirect effects include the national-level support of provincial fisheries officers who are responsible for fisheries law enforcement, and in aiding marketing of fisheries products. The global-level also affects, directly and indirectly, the exploitation and management of local-level coral reef resources. For example, from time to time particular species are exploited locally to supply markets in Asia through the live reef food fish trade (Warren-Rhodes et al. 2003), which represents a direct link between global and local social-political levels (Figure 5.6, number 4).

[15] The social-political scale used here is the scale implemented during British colonisation. It is used for simplicity and so that it is comparable with other contexts. I am not using it because I think it should be the dominant scale, or necessarily the scale most suited to natural resource management. The other social-political scale - the traditional system of social-political power, still maintains influence in enforcement of traditional laws, is essential to local custom and cultural survival, and plays a significant role in the management of coral reef resources in Solomon Islands. In fact, both social-political systems play integral roles in both the exploitation and management of natural resources.

Accounting for these multi-level effects on local-level exploitation and management of coral reef resources will improve the predictive capacity of social-ecological systems models. Further, it might enhance coral reef resource management approaches by improving our understanding of the interactions among levels and the possible positive and negative effects of factors operating at multiple levels, on local-level resources.

The set of limitations described above represents a suite of extensions on the model developed in this thesis. I have shown, where addressing the limitation would contribute to broader system linkages and feedbacks. The above model (Figure 5.6) represents the next step, in my opinion, in modeling linked social-ecological systems, at the local-level in economically peripheral contexts[16].

[16] Over a significant career Elinor Ostrom developed a well-recognised framework for testing the sustainability of local-level social-ecological systems (discussed in section 5.2.1). The purpose of the model presented in this thesis (Figure 5.4) is not to suggest the framework of Ostrom (Ostrom 2007) is in any way inadequate or obsolete. Rather, the model in this thesis does not have global application to social-ecological systems because of the specific peripheral nation context. Further, the model in this thesis is based on environmental sociology theory, whilst the framework of Ostrom is based on a rich career in studying common-property.

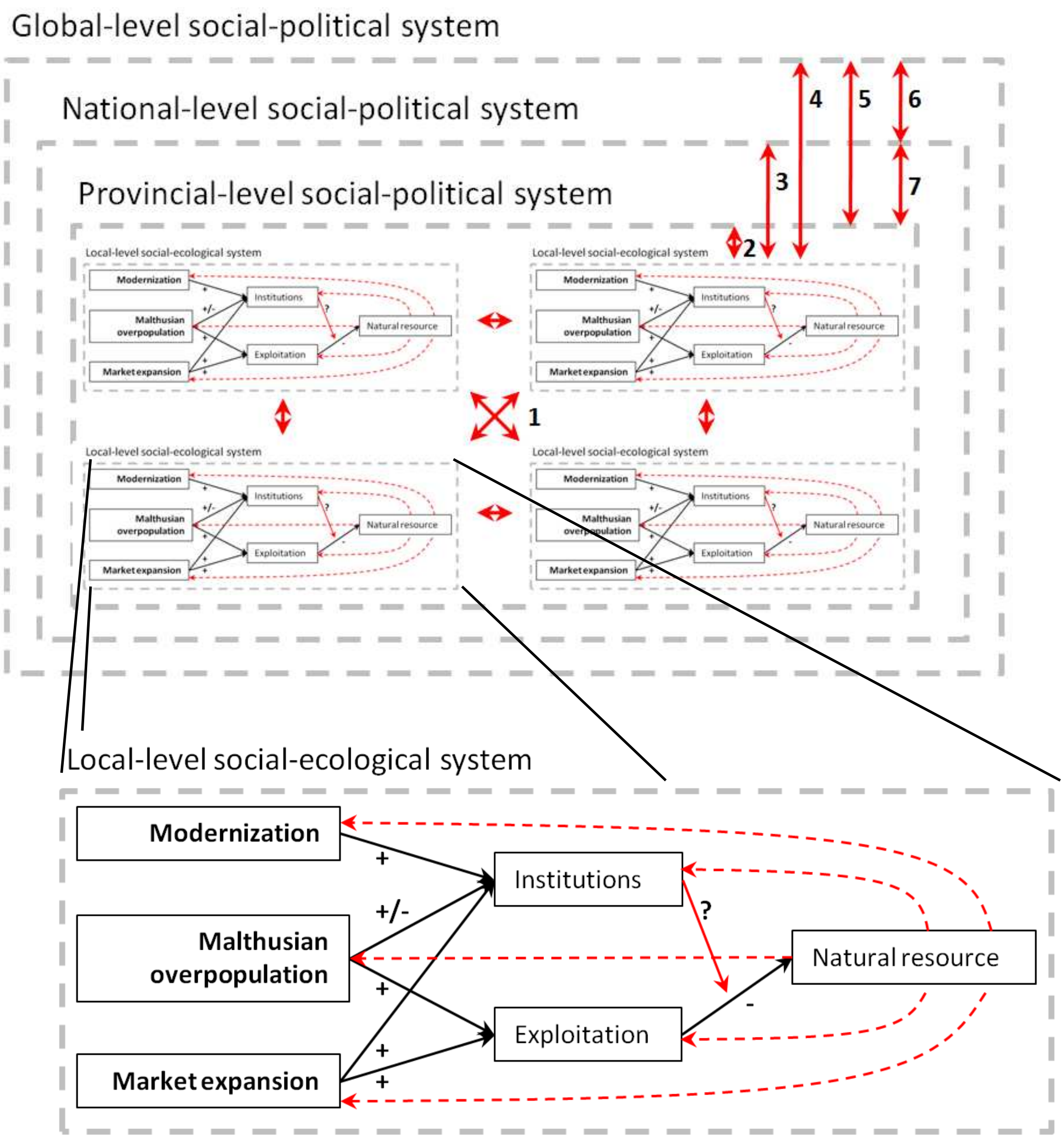

Figure 5.6 Nested social-political levels that interact to effect the local-level exploitation and management (institutions) of coral reef resources in Solomon Islands. In interpreting this figure consider that there are multiple local social-ecological systems within the provincial-level social-political system, multiple provincial-level social-political systems within the national-level social-political system, and multiple national-level social-political systems (countries) within the global-level social-political system. Black arrows show tested and significant effects. Red arrows show untested effects. Note that the individual and family/household level is not depicted in this figure because their effects on local-level social-ecological systems used in this thesis, is not clear.

5.4 GENERAL CONCLUSIONS

The broad aim of this thesis was to explain the state of coral reef resources using dominant environmental sociology perspectives of human-environment interaction; Malthusian overpopulation, market expansion, and modernization. To do so I used a novel comparative model at the-local level in a geo-politically peripheral nation (chapters 2 and 3). I have also identified the dominant discourses of locals within the context of the thesis, of the social factors that affect natural resource conditions (chapter 4), thus triangulating the comparative modeling (chapters 2 and 3). In doing so, this thesis has contributed to theory of human-environment interactions and has consequently broadened our understanding of the social processes that explain variability in the state of natural resources. Key conclusions are that no one perspective best fits the scale and context used for this thesis, which is a finding that resonates with nation-level analyses. Further, whilst the Malthusian overpopulation and market expansion perspectives best explained exploitation effects on the fishery, there is also evidence of a possible management response to population growth and markets. Therefore, there is some evidence of modernization-like characteristics; however, these characteristics have not translated into real improvements in resource conditions in more modernized communities.

These findings are directly relevant to policy for natural resource management. Broadly, focus should be on shifting from a Malthusian overpopulation and market expansion fishery to a modernization fishery. To instigate this shift will require two areas of focused effort. First, fishing overcapacity should be addressed. To do so, the model suggests a need to dampen the current drivers of overexploitation, including population pressure and market access. Obvious, but not necessary feasible (due to limited capacity) solutions include limiting entry into the fishery and managing fishing gears (McClanahan et al. 2008) to constrain Malthusian overpopulation effects, and market restrictions including species and size restrictions (Brewer 2011) to constrain market expansion effects. Importantly, the national government should avoid subsidising the fishery through provision of boats and fishing gears, forcing the industry to find a point of economic viability and avoid subsidy-driven over-exploitation. The second area of focus should be supporting the conditions that are likely to result in a modernized fishery. That is, the focus should be on factors that are theorized to cause the change in trajectory in the environmental Kuznets curve. These factors include improved management, a decrease in direct exploitation pressure, and limiting the use of destructive gears (Cinner et al. 2009b) through stronger, integrated institutions.

A critical challenge pervasive across many countries is balancing economic development and environmental concerns. Constraining resource exploitation (including market-based artisanal fishing) will also constrain development because exploiting and selling natural resources, including fisheries, contribute to economic growth. For example, Jaunky (2011) found that fisheries export contributes significantly to sustained economic growth in Small Island Developing States. Yet, rather than maximising economic rent as rapidly as possible, it is essential to take a longer, and more strategic, view on development, with the aim to achieve a higher level of affluence and wellbeing whilst avoiding significant, if not irreparable, damage to the environment.

Part of the longer view strategy lies in developing management institutions that enable strategic, evidence based decisions to be made relating to the intensity and extent of resource exploitation, and some control over how the derived capital should be invested to enable more efficient development. That is, Solomon Islands needs systems that provide the greatest development return for the given level of environmental degradation. A part of this return-on-investment approach includes implementing numerous strategies such as banning destructive exploitation approaches and developing networks of protected areas that would, collectively, increase returns-on-investment. However to achieve resilient improvements in resource stewardship at the local-level, there must also be changes at the national-level. Such changes include increased social stability, absence of corruption, fair and sustainable international trade in natural resources, and some collective vision of desired development; all of which are limited in Solomon Islands. Solomon Islands is a young nation with an under-resourced national government forced with the daunting task of caring for a very diverse set of ancient customs and contemporary vested interests.

Navigating sustainable development in a way that suits Solomon Islands traditions and current context, and the evolving collective vision of desired development will require significant trial-and error and tenacity. However, other nations in the region, with a loosely similar context have been experimenting with different management strategies for some time, and therefore present Solmon Islands with a wealth of knowledge that might limit failures and strengthen successes. For example, Philippines which is relatively more modernized and has more depleted coral reef resources, but where institutions are evolving to counter continued degradation (i.e. Philippines is likely at the inflection point of the environmental Kuznets curve). Coastal communities in Philippines have, for over three decades, been experimenting with different approaches to coastal artisanal fisheries management in response to awareness of resource degradation (White et al. 2006). Indeed, since the late 1970s there has been a rapid proliferation of community-based marine protected areas across the Philippines (Weeks et al. 2010). Contributing to the success of the growth and evolution of the institutions are a set of key factors. First, awareness of resource decline, through fishing pressure, was apparent in the 1970s (Green et al. 2003). Second is evidence of increased resource stocks following implementation of management restrictions (Lowrie et al. 2009). Third, community involvement and ownership of management responsibility has been heavily prioritized (White et al. 2006; Alcala & Russ 2006). Fourth, government support for community-based management has been in place since 1998 (White et al. 2006). Finally, across-scale integration of management planning and implementation has been made possible through positive collaboration between government, non-government organizations and local communities (Courtney & White 2000; Christie et al. 2002; White et al. 2006; Lowrie et al. 2009).

Solomon Islands is actively learning lessons from Philippines, and other similar nations, through programs such as the Coral Triangle Initiative, and it is hoped that management measures can be fast-tracked through lessons learnt. Certainly, Solomon Islands Fisheries Department, a number of non-government organizations and numerous other organisations and individuals are already taking action in these areas, including, for example, the application of social network analysis to identify strengths and weaknesses in collaboration networks among stakeholders (Cohen et al. 2012). Yet, coral reef resources in Solomon Islands are still in much better condition than Philippines, so it might take significant further education and awareness before there is a proliferation of protected areas, and other management measures, across Solomon Islands. Still, building networks of protected areas, and other such measures does not address population and market pressures discussed in this thesis, and so, does not represent a long term solution as long as there is continued resource dependency, growing populations and access to markets. To address issues such as population growth and market expansion will require truly integrated efforts including government departments and non-government organizations involved in issues such as family planning, economics, and alternative livelihoods.

Both social systems and ecological systems are complex. Predicting the timing, intensity, direction, and type of change in either system is fraught with challenges. Understanding interaction between the two systems adds further complexity. Certainly, the effect of basic human behaviours on simple ecological systems (e.g. fishing on a single species fishery) can be predicted with some certainty. However, when we acknowledge, and try to account for the effect of broader social drivers such as modernization on behaviours such as exploitation on diverse ecological systems, the challenge of predicting timing, intensity, direction, and type of change becomes significantly harder. However, complex social process and ecological responses are our reality, and therefore represent true challenges to sustainability. In this thesis I have been able to show, with some certainty, society's effects on a complex ecological system. This has only been possible because of previous research on the three perspectives that have been refined over time through debate in environmental sociology and allied fields. Thus, it is this body of work that provided a strong theoretical foundation for this thesis. Further advancements in our understanding of social-ecological systems will probably come more readily if analysis is based on this rich theoretical foundation. Research that fails to use this foundation (e.g. research that collects, and analyses, a large suit of social and ecological data without a clear suite of a priori questions or understanding of social-ecological processes, theoretically and in application) will likely be peripheral to the debate on society's effects on natural systems, and therefore have less impact than desired.

Current trends of anthropogenically-driven natural resource decline are concerning for anyone abreast of the literature. What the future holds remains unclear except that, in the near to medium future, there will be further depletion of the natural resource base globally. Shifting the narrative of our relationship with nature, from Malthusian overpopulation and market expansion to modernization will require social-ecological systems to internalise their environmental footprints, thus existing within the limits of their production potential (Dasgupta & Ehrlich 2013). To achieve this will require significant enhancement in our understanding of ecological systems, and of society's effects on ecological systems, to improve the accuracy of environmental accounting. Sophisticated institutions will be required to administer and enforce the environmental accounting mechanisms. This is likely at some point in the future simply because there is no alternative if humanity is to prosper.

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CHAPTER 6: APPENDICES

APPENDIX 1: RESEARCH CONDUCTED, AND SYMPOSIA/CONFERENCES ATTENDED DURING DISSERTATION PERIOD NOT INCLUDED WITHIN THE THESIS

Peer-reviewed Publications:

Brewer, T.D., Cinner, J., Green, A., Pandolfi, J. 2009. Thresholds and multiple scale interaction of environment, resource use, and market access on reef fishery resources in the Solomon Islands. **Biological Conservation** 142: 1797-1807.

Skinner, M. P., **Brewer, T.D**., Johnstone, R., Fleming, L. E., Lewis, R.J. 2011. Ciguatera fish poisoning in the Pacific Islands (1998 to 2008). **PLoS Neglected Tropical Diseases** 5: e1416.

Bohensky, E., Smajgl, A., **Brewer, T.D.** 2012. Patterns in household engagement with climate change in Indonesia. **Nature Climate Change.** DOI:10.1038/nclimate1762.

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Pandolfi, J. M., Kaplan, D., **Brewer, T.D.**, Schultz, J.K., Kittinger, J.N., Prescott, R., Lewis, N, Friedlander, A.M., Berzunza-Sanchez, M, Bird, C.E., Cinner, J.E., Toonen, R.J., Fa'anunu, A.I., Pikitch, E.K., Wilcox, B.A.. The de-coupling of human and ecological heath in Pacific Island nations. **PNAS.** In preparation

Wamukota, A., **Brewer, T.D.** Market access and income inequality among small-scale Kenyan coral reef fishery: Implications for management. In preparation

Other Publications (reports, book chapters, other):

Brewer, T.D. 2011. *Coral reef fish value chains in Solomon Islands: Market opportunities and market effects on fish stocks*. ARC Centre of Excellence for Coral Reef Studies report to Solomon Islands Ministry of Fisheries and Marine Resources and Secretariat of the Pacific Community. 46 pages.

Pratchett, M.S., Munday, P.L., Graham, N.A.J., Kronen, M., Pinica, S., Friedman, K., **Brewer, T.D.**, Bell, J.D., Wilson, S.K., Cinner, J.E., Kinch, J.P., Lawton, R.J., Williams, A.J., Chapman, L., Magron, F., Webb, A. (20011) Vulnerability of coastal fisheries in the tropical Pacific to climate change Chapter 9 In: Bell, J.D., Johnson, J.E. and Hobday, A.J. (eds) (2011) *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Secretariat of the Pacific Community, Noumea, New Caledonia.

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APPENDIX 2: FISH SURVEY METHODS AND BIOMASS ESTIMATION

Fish survey methods and biomass estimation used for chapter 2 (adapted from Green et al. 2006).

Fish survey methods

Coral reef fish communities were surveyed using underwater visual census methods including a) transects and b) timed swims. A restricted list of 37 families was used comprising only those families that are amenable to visual census techniques, because they are relatively large, diurnally active and conspicuous in coloration and behaviour. This method excludes species that are not amenable to the technique because they are very small, nocturnal or cryptic in behaviour (e.g. gobies, blennies, cardinalfish).

Transects

Fish were surveyed along five replicate transects on the reef slope at a depth of 10 metres at each site. Fishes were surveyed by three passes along the transect counting different species in each pass, using different transect dimensions for each group (based on their behaviour, size and abundance):

1. Large, highly mobile species that are most likely to be disturbed by the passage of a diver (such as parrotfishes, snappers and emperors) were surveyed on the first pass using transect dimensions of 50m x 5m.
2. Medium sized mobile species (including most surgeonfishes, butterflyfishes and wrasses) that are less disturbed by the presence of a diver, were counted on the second pass using transect dimensions of 50m x 3m.

3. Small, site attached species (mostly damselfishes) that are least disturbed by the presence of a diver, were counted on the third pass using transect dimensions of 30m x 1m.

During each pass of the transect, the number of individuals of each species was counted and recorded. The size of each individual (length in cm) was also estimated and recorded. Fish identifications were based on Allen (2003). Transect lengths were measured using 50m tapes, and transect widths were estimated using known body proportions. Transect tapes were laid during the first pass by an assistant following the observer (to minimize disturbance to the fish communities being counted). The tapes then remained *in situ* until all the surveys were completed at that site. Fish counts (i.e. each pass of the transect) were separated by a waiting period of ~5 minutes between counts.

Timed swims

Key fisheries species of food fish that are large and particularly vulnerable to overfishing were counted (and their size estimated) using long swim methods specifically developed for this purpose (Choat and Spears 2003). Species included in this study that were sampled using timed swims included:

4. Maori wrasse (Cheilinus undulatus);
5. Humphead parrotfish (Bolbometopon muricatum) and steephead parrotfish (Chlorurus microrhinos);
6. Large groupers (Cromileptes altivelis and Variola louti);
7. Large and uncommon emperors (Lethrinus olivaceus, Lethrinus erythropterus, Lethrinus rubrioperculatus and Lethrinus xanthochilus).

This method was developed to improve estimates of the abundance of these species, since they tend to be uncommon and clumped in distribution, so smaller transects dimensions (e.g. 50m x 5m) are not suitable for obtaining reasonable estimates of their abundance. In this method, the observer surveys a wide area during a single pass of the reef slope over a set time period (15 mins) scanning the reef slope for these species. This method was repeated at each site.

Biomass Calculation

Fish biomass was calculated by converting estimated fish lengths to weights using the allometric length-weight conversion formulae [weight (kg) = (total length in cm x constant a)b] where a and b are constants for each species. Constants were not available for most species in the Solomon Islands, so they were obtained from New Caledonia (Kulbicki, unpublished data), which was the closest geographic area where this information was available. Where constants were not available for a species, the constants for a similar species (usually a congeneric species) were used.

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APPENDIX 3: LIST OF FISH INCLUDING VULNERABILITY CATEGORY AND SCORE USED FOR CHAPTER 2A

Fish species of low vulnerability

Family	**Species**	**Vulnerability**	**Biomass (kg/ha./site)**
Acanthuridae	Acanthurus lineatus	23	5.0040
Acanthuridae	Ctenochaetus cyanocheilus	22	0.3979
Acanthuridae	Ctenochaetus striatus	17	61.0205
Acanthuridae	Ctenochaetus tominiensis	22	0.0976
Chaetodontidae	Chaetodon auriga	12	0.2934
Chaetodontidae	Chaetodon baronessa	14	3.1991
Chaetodontidae	Chaetodon bennetti	15	0.2257
Chaetodontidae	Chaetodon citrinellus	10	0.0308
Chaetodontidae	Chaetodon ephippium	23	2.0336
Chaetodontidae	Chaetodon kleinii	12	0.2837
Chaetodontidae	Chaetodon lunula	15	0.1197
Chaetodontidae	Chaetodon meyeri	15	0.2932
Chaetodontidae	Chaetodon ocellicaudus	12	0.0295
Chaetodontidae	Chaetodon ornatissimus	15	2.5697
Chaetodontidae	Chaetodon oxycephalus	20	0.5551
Chaetodontidae	Chaetodon pelewensis	10	0.0918
Chaetodontidae	Chaetodon rafflesi	14	1.2611
Chaetodontidae	Chaetodon reticulatus	14	0.0971
Chaetodontidae	Chaetodon semeion	20	0.6706
Chaetodontidae	Chaetodon speculum	14	0.1777
Chaetodontidae	Chaetodon trifasciatus	10	2.0621
Chaetodontidae	Chaetodon ulietensis	12	0.5169
Chaetodontidae	Chaetodon unimaculatus	15	0.1769
Chaetodontidae	Chaetodon vagabundus	17	2.8173
Chaetodontidae	Coradion chrysozonus	12	0.0666
Chaetodontidae	Forcipiger flavissimus	17	0.5530
Chaetodontidae	Heniochus chrysostomus	14	2.9402
Chaetodontidae	Heniochus monoceros	18	1.0319
Chaetodontidae	Heniochus singularius	23	2.7884
Chaetodontidae	Heniochus varius	14	7.0017
Cirrhitidae	Cirrhitichthys falco	10	0.0097

Cirrhitidae	Paracirrhites arcatus	10	0.0817
Cirrhitidae	Paracirrhites forsteri	11	0.0843
Labridae	Diproctacanthus xanthurus	20	0.0027
Labridae	Halichoeres biocellatus	23	0.1501
Labridae	Halichoeres chrysus	23	0.0206
Labridae	Halichoeres hortulanus	21	2.6858
Labridae	Halichoeres marginatus	20	0.0345
Labridae	Halichoeres melanurus	23	0.0834
Labridae	Halichoeres scapularis	23	0.0206
Labridae	Labroides pectoralis	21	0.0431
Labridae	Labropsis alleni	20	0.0060
Labridae	Labropsis australis	20	0.0170
Labridae	Macropharyngodon negrosensis	23	0.0084
Labridae	Pseudocheilinus evanidus	15	0.0218
Labridae	Pseudocheilinus hexataenia	20	0.0251
Labridae	Stethojulis trilineata	13	0.0877
Labridae	Thalassoma hardwicke	14	0.2007
Lutjanidae	Lutjanus fulvus	23	0.2616
Lutjanidae	Lutjanus semicinctus	19	0.5875
Monocanthidae	Oxymonacanthus longirostris	23	0.0222
Mullidae	Mulloides vanicolensis	23	0.9772
Nemipteridae	Scolopsis affinis	23	0.0461
Nemipteridae	Scolopsis bilineatus	22	1.3443
Ostraciidae	Ostracion cubicus	23	0.1362
Ostraciidae	Ostracion meleagris	13	0.1590
Pinguipedidae	Parapercis millipunctata	21	0.1292
Pomacanthidae	Centropyge bicolor	23	1.1761
Pomacanthidae	Centropyge bispinosus	15	0.0105
Pomacanthidae	Centropyge vroliki	19	0.2576
Pomacentridae	Abudefduf vaigiensis	16	0.1715
Pomacentridae	Amblyglyphidodon curacao	23	1.0077
Pomacentridae	Amphiprion chrysopterus	16	0.7299
Pomacentridae	Amphiprion leucokranos	19	0.0387
Pomacentridae	Chromis acares	11	0.0203
Pomacentridae	Chromis alpha	22	0.0286
Pomacentridae	Chromis amboinensis	19	3.1789
Pomacentridae	Chromis atripes	19	2.5232
Pomacentridae	Chromis delta	14	0.1107
Pomacentridae	Chromis lepidolepis	19	0.3917
Pomacentridae	Chromis lineata	14	0.0901
Pomacentridae	Chromis margaritifer	19	2.3466
Pomacentridae	Chromis retrofasciata	11	0.0770
Pomacentridae	Chromis spp.	18.85*	0.1848

Pomacentridae	Chromis ternatensis	21	8.5608
Pomacentridae	Chrysiptera flavipinnis	16	0.0039
Pomacentridae	Chrysiptera parasema	14	0.0358
Pomacentridae	Chrysiptera rex	14	0.0108
Pomacentridae	Chrysiptera rollandi	15	0.0695
Pomacentridae	Chrysiptera talboti	12	0.6596
Pomacentridae	Plectroglyphidodon dickii	23	0.5536
Pomacentridae	Plectroglyphidodon lacrymatus	21	11.4002
Pomacentridae	Pomacentrus adelus	17	0.6167
Pomacentridae	Pomacentrus amboinensis	19	3.4391
Pomacentridae	Pomacentrus bankanensis	19	5.9765
Pomacentridae	Pomacentrus brachialis	21	5.9182
Pomacentridae	Pomacentrus coelestis	19	0.9157
Pomacentridae	Pomacentrus grammorhynchus	23	0.2176
Pomacentridae	Pomacentrus lepidogenys	23	3.0712
Pomacentridae	Pomacentrus nagasakiensis	21	0.0001
Pomacentridae	Pomacentrus nigromanus	19	0.7355
Pomacentridae	Pomacentrus philippinus	23	7.4159
Pomacentridae	Pomacentrus reidi	19	3.3443
Pomacentridae	Pomacentrus vaiuli	23	1.0856
Scaridae	Chlorurus sordidus	20	9.5128
Scaridae	Scarus chameleon	22	0.3435
Scaridae	Scarus niger	23	14.3341
Scaridae	Scarus psittacus	22	0.8923
Serranidae	Cephalopholis urodeta	14	1.8228
Serranidae	Epinephelus merra	23	0.0444
Serranidae	Luzonichthys waitei	11	0.0067
Serranidae	Pseudanthias dispar	14	0.4483
Serranidae	Pseudanthias huchti	16	0.7194
Serranidae	Pseudanthias spp.	15.33*	0.1495
Serranidae	Pseudanthias tuka	16	2.6516
Siganidae	Siganus argenteus	22	0.1288
Siganidae	Siganus doliatus	23	0.6248
Siganidae	Siganus fuscescens	21	0.0876
Siganidae	Siganus vulpinus	23	1.2620
Tetradontidae	Canthigaster papua	15	0.2037
Zanclidae	Zanclus cornutus	12	1.7779
		Total	**207.0384**

* Average vulnerabililty score within Genus used because fish not identified to species

Fish species of medium vulnerability

Family	Species	Vulnerability	Biomass (kg/ha./site)
Acanthuridae	Acanthurus nigricans	34	2.0568
Acanthuridae	Acanthurus nigricauda	25	1.7686
Acanthuridae	Acanthurus nigrofuscus	27	2.6951
Acanthuridae	Acanthurus nubilus	26	0.1128
Acanthuridae	Acanthurus olivaceus	31	1.3853
Acanthuridae	Acanthurus pyroferus	29	20.2638
Acanthuridae	Acanthurus spp.	31.83*	89.5172
Acanthuridae	Acanthurus thompsoni	26	0.1372
Acanthuridae	Ctenochaetus binotatus	24	8.0510
Acanthuridae	Naso brevirostris	33	8.8320
Acanthuridae	Naso lituratus	34	11.8811
Aulostomidae	Aulostomus chinensis	34	0.5457
Balistidae	Balistapus undulatus	30	5.5174
Balistidae	Melichthys vidua	34	1.3268
Balistidae	Pseudobalistes flavimarginatus	29	3.6983
Balistidae	Sufflamen bursa	27	0.1135
Balistidae	Sufflamen chrysopterus	30	0.2887
Balistidae	Xanthichthys auromarginatus	30	0.0299
Chaetodontidae	Chaetodon trifascialis	24	0.3119
Labridae	Anampses meleagrides	31	0.0411
Labridae	Anampses twistii	28	0.0718
Labridae	Bodianus mesothorax	33	0.9806
Labridae	Cheilinus oxycephalus	27	0.0673
Labridae	Cirrhilabrus punctatus	24	1.9820
Labridae	Coris batuensis	27	0.0602
Labridae	Halichoeres spp.	23.75*	0.0212
Labridae	Halichoeres prosopeion	28	0.4557
Labridae	Halichoeres richmondi	29	0.0254
Labridae	Halichoeres spp.	23.75*	0.0196
Labridae	Labrichthys unilineatus	27	0.2772
Labridae	Labroides bicolor	25	0.0963
Labridae	Labroides dimidiatus	24	0.1807
Labridae	Labropsis xanthonota	24	0.0107
Labridae	Macropharyngodon meleagris	30	0.3474
Labridae	Novaculichthys taeniourus	35	0.1478
Labridae	Oxycheilinus celebicus	32	0.0044
Labridae	Pseudocoris yamashiroi	26	0.0493
Labridae	Pseudodax moluccanus	35	0.3822
Labridae	Stethojulis bandanensis	25	0.0594

Labridae	Stethojulis strigiventer	25	0.0061
Labridae	Thalassoma amblycephalum	32	0.1217
Labridae	Thalassoma lunare	35	0.4007
Labridae	Thalassoma quinquevittatum	27	0.0239
Lethrinidae	Gnathodentex aurolineatus	29	15.5337
Lutjanidae	Lutjanus biguttatus	24	0.3031
Lutjanidae	Lutjanus gibbus	32	258.0318
Monacanthidae	Amanses scopas	30	0.0713
Monacanthidae	Cantherhines pardalis	33	0.0149
Mullidae	Parupeneus bifasciatus	30	5.0068
Mullidae	Parupeneus spp.	33*	8.0798
Mullidae	Parupeneus multifasciatus	30	2.9440
Mullidae	Parupeneus pleurostigma	29	0.0224
Nemipteridae	Scolopsis margaritifer	25	0.2562
Pomacanthidae	Apolemichthys trimaculatus	31	0.1297
Pomacanthidae	Pomacanthus navarchus	32	0.4162
Pomacentridae	Acanthochromis polyacanthus	25	9.4741
Pomacentridae	Amblyglyphidodon aureus	24	0.2860
Pomacentridae	Amblyglyphidodon leucogaster	24	10.8926
Pomacentridae	Amphiprion clarkii	32	1.1349
Pomacentridae	Chromis weberi	25	0.7488
Pomacentridae	Chromis xanthochira	25	0.2859
Pomacentridae	Chromis xanthura	26	6.3538
Pomacentridae	Dascyllus reticulatus	25	0.9045
Pomacentridae	Dascyllus trimaculatus	26	0.3593
Pomacentridae	Neoglyphidodon melas	29	0.4599
Pomacentridae	Neoglyphidodon nigroris	24	16.2043
Pomacentridae	Pomacentrus moluccensis	25	2.8391
Pomacentridae	Stegastes gascoynei	26	0.4542
Pomacentridae	Stegastes spp.	26*	0.0399
Scaridae	Calotomus carolinus	35	0.1971
Scaridae	Chlorurus bleekeri	33	7.3324
Scaridae	Chlorurus pyrrhurus	25	9.2043
Scaridae	Hipposcarus longiceps	29	132.3466
Scaridae	Scarus dimidiatus	29	2.4359
Scaridae	Scarus flavipectoralis	29	0.3729
Scaridae	Scarus forsteni	35	11.4253
Scaridae	Scarus frenatus	24	6.4976
Scaridae	Scarus oviceps	27	1.4516
Scaridae	Scarus quoyi	29	1.0246
Scaridae	Scarus spinus	25	0.7426
Serranidae	Cephalopholis leopardus	28	0.0447
Serranidae	Diploprion bifasciatum	29	0.1157

Serranidae	Epinephelus melanostigma	34	0.0387
Serranidae	Epinephelus spilotoceps	34	0.1451
Serranidae	Variola albimarginata	29	0.2209
Siganidae	Siganus corallinus	30	0.0613
Siganidae	Siganus lineatus	25	47.3128
Siganidae	Siganus puellus	26	2.7992
Siganidae	Siganus punctatissimus	30	0.3153
Tetraodontidae	Arothron nigropunctatus	31	0.2507
		Total	**729.95**

* Average vulnerabililty score within Genus used because fish not identified to species

Fish species of high vulnerability

Family	Species	Vulnerability	Biomass (kg/ha./site)
Acanthuridae	Acanthurus blochii	38	0.1633
Acanthuridae	Acanthurus fowleri	47	0.5765
Acanthuridae	Acanthurus mata	39	15.3112
Acanthuridae	Acanthurus xanthopterus	37	2.6495
Acanthuridae	Naso hexacanthus	41	42.4215
Acanthuridae	Naso spp.	41.25*	11.8413
Acanthuridae	Naso unicornis	57	14.5074
Acanthuridae	Zebrasoma scopas	66	5.4352
Acanthuridae	Zebrasoma veliferum	37	0.8837
Balistidae	Balistoides conspicillum	38	0.7218
Balistidae	Balistoides viridescens	53	36.0977
Balistidae	Odonus niger	38	13.5517
Chaetodontidae	Chaetodon melannotus	47	0.0554
Chanidae	Chanos chanos	76	10.0704
Haemulidae	Plectorhinchus albovittatus	67	7.3199
Haemulidae	Plectorhinchus chaetodonoides	54	2.5569
Haemulidae	Plectorhinchus chrysotaenia	49	0.3832
Haemulidae	Plectorhinchus lineatus	37	24.1888
Haemulidae	Plectorhinchus spp.	53.6*	0.2245
Haemulidae	Plectorhinchus vittatus	61	17.0489
Holocentridae	Sargocentron spiniferum	41	0.5042
Labridae	Anampses caeruleopunctatus	43	0.0563
Labridae	Anampses neoguinaicus	36	0.0308
Labridae	Bodianus diana	40	0.1349
Labridae	Cheilinus chlorourus	46	0.1233
Labridae	Cheilinus fasciatus	54	4.8089
Labridae	Cheilinus undulatus	74	22.7236
Labridae	Cheilio inermis	60	0.0043
Labridae	Coris gaimard	41	0.5248
Labridae	Epibulus insidiator	61	1.0505
Labridae	Gomphosus varius	45	0.4504
Labridae	Hemigymnus fasciatus	62	0.3629
Labridae	Hemigymnus melapterus	64	0.7457
Labridae	Hologymnosus annulatus	41	0.0087
Labridae	Hologymnosus spp.	41*	0.0205
Labridae	Oxycheilinus diagrammus	54	0.8135
Lethirinidae	Monotaxis grandoculis	42	192.6851
Lethrinidae	Lethrinus erythropterus	37	0.7211
Lethrinidae	Lethrinus olivaceus	40	0.7672

Lethrinidae	Lethrinus rubrioperculatus	40	1.5256
Lethrinidae	Lethrinus spp.	43.5*	13.6711
Lethrinidae	Lethrinus xanthochilus	57	0.6482
Lutjanidae	Aphareus furca	36	0.6353
Lutjanidae	Aprion virescens	61	6.8274
Lutjanidae	Lutjanus argentimaculatus	60	0.2661
Lutjanidae	Lutjanus bohar	69	204.2151
Lutjanidae	Lutjanus monostigma	40	0.2762
Lutjanidae	Macolor macularis	39	120.9320
Lutjanidae	Macolor niger	46	78.8201
Lutjanidae	Macolor spp.	42.5*	24.3949
Lutjanidae	Symphorichthys spilurus	39	0.2488
Monocanthidae	Aluterus scriptus	70	1.2908
Monocanthidae	Cantherhines dumerilii	39	0.0657
Mullidae	Mulloides flavolineatus	39	0.3218
Mullidae	Parupeneus barberinus	40	2.4638
Mullidae	Parupeneus cyclostomus	36	1.1200
Pomacanthidae	Pomacanthus imperator	50	2.1887
Pomacanthidae	Pomacanthus semicirculatus	50	0.5212
Pomacanthidae	Pomacanthus sexstriatus	41	3.4934
Pomacanthidae	Pomacanthus xanthometopon	36	0.5212
Pomacanthidae	Pygoplites diacanthus	38	3.0100
Scaridae	Bolbometopon muricatum	67	233.3674
Scaridae	Cetoscarus bicolor	58	3.0512
Scaridae	Chlorurus microrhinos	41	21.1597
Scaridae	Scarus ghobban	37	0.8547
Scaridae	Scarus prasiognathos	39	4.6046
Scaridae	Scarus rivulatus	39	1.0140
Scaridae	Scarus rubroviolaceus	52	5.4201
Scaridae	Scarus schlegeli	38	1.1600
Serranidae	Aethaloperca rogaa	49	0.3538
Serranidae	Anyperodon leucogrammicus	52	0.2756
Serranidae	Cephalopholis argus	49	0.6027
Serranidae	Cephalopholis cyanostigma	36	0.3995
Serranidae	Cephalopholis miniata	61	0.0676
Serranidae	Cephalopholis spp.	43.5*	0.0138
Serranidae	Cromileptes altivelis	54	0.0309
Serranidae	Epinephelus corallicola	41	0.1190
Serranidae	Epinephelus fasciatus	46	0.0716
Serranidae	Epinephelus spp.	35.6*	0.1943
Serranidae	Plectropomus areolatus	56	3.7583
Serranidae	Plectropomus laevis	72	1.2491
Serranidae	Plectropomus leopardus	51	1.2954

Serranidae	Plectropomus oligacanthus	56	0.3693
Serranidae	Plectropomus spp.	58.75*	0.5982
Serranidae	Variola louti	49	9.2550
		Total	**1189.29**

* Average vulnerabililty score within Genus used because fish not identified to species

APPENDIX 4: LIST OF FISH INCLUDING FUNCTIONAL GROUPING, AND WHETHER THEY ARE FISHERIES SPECIES, USED IN CHAPTER 2B

Family	Species	Piscivore	Herbivore	Fisheries Species
Acanthuridae	Acanthurus blochii	0	1	1
Acanthuridae	Acanthurus fowleri	0	1	1
Acanthuridae	Acanthurus lineatus	0	1	1
Acanthuridae	Acanthurus mata	0	0	1
Acanthuridae	Acanthurus nigricans	0	1	0
Acanthuridae	Acanthurus nigricauda	0	1	1
Acanthuridae	Acanthurus nigrofuscus	0	1	0
Acanthuridae	Acanthurus nubilis	0	0	0
Acanthuridae	Acanthurus olivaceus	0	1	0
Acanthuridae	Acanthurus pyroferus	0	1	0
Acanthuridae	Acanthurus spp.	0	1	1
Acanthuridae	Acanthurus thompsoni	0	0	0
Acanthuridae	Acanthurus xanthopterus	0	1	1
Acanthuridae	Ctenochaetus binotatus	0	0	1
Acanthuridae	Ctenochaetus cyanocheilus	0	0	1
Acanthuridae	Ctenochaetus striatus	0	0	1
Acanthuridae	Ctenochaetus tominiensis	0	0	1
Acanthuridae	Naso brevirostris	0	0	1
Acanthuridae	Naso hexacanthus	0	0	1
Acanthuridae	Naso lituratus	0	1	1
Acanthuridae	Naso spp.	0	0	1
Acanthuridae	Naso unicornis	0	1	1
Acanthuridae	Zebrasoma scopas	0	1	0
Acanthuridae	Zebrasoma veliferum	0	1	0
Acanthuridae	Aulostomus chinensis	1	0	0
Balistidae	Balistapus undulatus	0	0	1
Balistidae	Balistoides conspicillum	0	0	0
Balistidae	Balistoides viridescens	0	0	1
Balistidae	Melichthys vidua	0	0	0
Balistidae	Odonus niger	0	0	0
Balistidae	Pseudobalistes flavimarginatus	0	0	1
Balistidae	Sufflamen bursa	0	0	0
Balistidae	Sufflamen chrysopterus	0	0	0
Balistidae	Xanthichthys auromarginatus	0	0	0
Chaetodontidae	Chaetodon auriga	0	0	0
Chaetodontidae	Chaetodon baronessa	0	0	0

Chaetodontidae	Chaetodon bennetti	0	0	0
Chaetodontidae	Chaetodon citrinellus	0	0	0
Chaetodontidae	Chaetodon ephippium	0	0	0
Chaetodontidae	Chaetodon kleinii	0	0	0
Chaetodontidae	Chaetodon lunula	0	0	0
Chaetodontidae	Chaetodon melannotus	0	0	0
Chaetodontidae	Chaetodon meyeri	0	0	0
Chaetodontidae	Chaetodon ocellicaudus	0	0	0
Chaetodontidae	Chaetodon ornatissimus	0	0	0
Chaetodontidae	Chaetodon oxycephalus	0	0	0
Chaetodontidae	Chaetodon pelewensis	0	0	0
Chaetodontidae	Chaetodon rafflesi	0	0	0
Chaetodontidae	Chaetodon reticulatus	0	0	0
Chaetodontidae	Chaetodon semeion	0	0	0
Chaetodontidae	Chaetodon speculum	0	0	0
Chaetodontidae	Chaetodon trifascialis	0	0	0
Chaetodontidae	Chaetodon trifasciatus	0	0	0
Chaetodontidae	Chaetodon ulietensis	0	0	0
Chaetodontidae	Chaetodon unimaculatus	0	0	0
Chaetodontidae	Chaetodon vagabundus	0	0	0
Chaetodontidae	Coradion chrysozonus	0	0	0
Chaetodontidae	Forcipiger flavissimus	0	0	0
Chaetodontidae	Heniochus chrysostomus	0	0	0
Chaetodontidae	Heniochus monoceros	0	0	0
Chaetodontidae	Heniochus singularius	0	0	0
Chaetodontidae	Heniochus varius	0	0	0
Cirrhitidae	Cirrhitichthys falco	1	0	0
Cirrhitidae	Paracirrhites arcatus	1	0	0
Cirrhitidae	Paracirrhites forsteri	1	0	0
Haemulidae	Plectorhinchus albovittatus	0	0	1
Haemulidae	Plectorhinchus chaetodonoides	0	0	1
Haemulidae	Plectorhinchus chrysotaenia	0	0	0
Haemulidae	Plectorhinchus lineatus	0	0	1
Haemulidae	Plectorhinchus spp.	0	0	0
Haemulidae	Plectorhinchus vittatus	0	0	1
Holocentridae	Sargocentron spiniferum	1	0	1
Kyphosidae	Kyphosus spp.	0	1	1
Labridae	Anampses caeruleopunctatus	0	0	0
Labridae	Anampses meleagrides	0	0	0
Labridae	Anampses neoguinaicus	0	0	0
Labridae	Anampses twistii	0	0	0
Labridae	Bodianus diana	0	0	0
Labridae	Bodianus mesothorax	0	0	0
Labridae	Cheilinus chlorourus	0	0	0
Labridae	Cheilinus fasciatus	0	0	1

Labridae	Cheilinus oxycephalus	0	0	0
Labridae	Cheilinus undulatus	0	0	1
Labridae	Cheilio inermis	1	0	0
Labridae	Cirrhilabrus punctatus	0	0	0
Labridae	Coris batuensis	0	0	0
Labridae	Coris gaimard	0	0	0
Labridae	Diproctacanthus xanthurus	0	0	0
Labridae	Epibulus insidiator	1	0	0
Labridae	Gomphosus varius	0	0	0
Labridae	Halichoeres biocellatus	0	0	0
Labridae	Halichoeres chrysus	0	0	0
Labridae	Halichoeres hortulanus	0	0	0
Labridae	Halichoeres marginatus	0	0	0
Labridae	Halichoeres melanurus	0	0	0
Labridae	Halichoeres nebulosus/margaritaceus/miniatus	0	0	0
Labridae	Halichoeres prosopeion	0	0	0
Labridae	Halichoeres richmondi	0	0	0
Labridae	Halichoeres scapularis	0	0	0
Labridae	Halichoeres spp.	0	0	0
Labridae	Hemigymnus fasciatus	0	0	0
Labridae	Hemigymnus melapterus	0	0	0
Labridae	Hologymnosus annulatus	1	0	0
Labridae	Hologymnosus sp	1	0	0
Labridae	Labrichthys unilineatus	0	0	0
Labridae	Labroides bicolor	0	0	0
Labridae	Labroides dimidiatus	0	0	0
Labridae	Labroides pectoralis	0	0	0
Labridae	Labropsis alleni	0	0	0
Labridae	Labropsis australis	0	0	0
Labridae	Labropsis xanthonota	0	0	0
Labridae	Macropharyngodon meleagris	0	0	0
Labridae	Macropharyngodon negrosensis	0	0	0
Labridae	Novaculichthys taeniourus	0	0	0
Labridae	Oxycheilinus celebicus	0	0	0
Labridae	Oxycheilinus diagrammus	0	0	0
Labridae	Pseudocheilinus evanidus	0	0	0
Labridae	Pseudocheilinus hexataenia	0	0	0
Labridae	Pseudocoris yamashiroi	0	0	0
Labridae	Pseudodax moluccanus	0	0	0
Labridae	Stethojulis bandanensis	0	0	0
Labridae	Stethojulis strigiventer	0	0	0
Labridae	Stethojulis trilineata	0	0	0
Labridae	Thalassoma amblycephalum	0	0	0
Labridae	Thalassoma hardwicke	0	0	0

Labridae	Thalassoma lunare	0	0	0
Labridae	Thalassoma quinquevittatum	0	0	0
Lethrinidae	Gnathodentex aurolineatus	0	0	0
Lethrinidae	Lethrinus erythropterus	0	0	1
Lethrinidae	Lethrinus olivaceous	0	0	1
Lethrinidae	Lethrinus rubriopeculatus	0	0	1
Lethrinidae	Lethrinus spp.	0	0	1
Lethrinidae	Lethrinus xanthochilus	0	0	1
Lethrinidae	Monotaxis grandoculis	0	0	1
Lutjanidae	Aphareus furca	1	0	0
Lutjanidae	Aprion virescens	1	0	1
Lutjanidae	Lutjanus argentmaculatus	1	0	1
Lutjanidae	Lutjanus biguttatus	1	0	0
Lutjanidae	Lutjanus bohar	1	0	1
Lutjanidae	Lutjanus fulvus	1	0	0
Lutjanidae	Lutjanus gibbus	1	0	1
Lutjanidae	Lutjanus monostigma	1	0	1
Lutjanidae	Lutjanus semicinctus	1	0	0
Lutjanidae	Macolor macularis	1	0	1
Lutjanidae	Macolor niger	1	0	1
Lutjanidae	Macolor spp.	1	0	1
Lutjanidae	Symphorichthys spilurus	1	0	1
Malacanthidae	Aluterus scriptus	0	0	0
Malacanthidae	Amanses scopas	0	0	0
Malacanthidae	Cantherhines dumerilii	0	0	0
Malacanthidae	Cantherhines pardalis	0	0	0
Malacanthidae	Oxymonacanthus longirostris	0	0	0
Mullidae	Mulloides flavolineatus	0	0	0
Mullidae	Mulloides vanicolensis	0	0	1
Mullidae	Parupeneus barberinus	0	0	1
Mullidae	Parupeneus bifasciatus	0	0	1
Mullidae	Parupeneus bifasciatus/trifasciatus	0	0	1
Mullidae	Parupeneus cyclostomus	1	0	1
Mullidae	Parupeneus multifasciatus	0	0	0
Mullidae	Parupeneus pleurostigma	0	0	0
Nemipteridae	Scolopsis affinis	0	0	0
Nemipteridae	Scolopsis bilineatus	0	0	0
Nemipteridae	Scolopsis margaritifer	0	0	0
Ostracidae	Ostracion cubicus	0	0	1
Ostracidae	Ostracion meleagris	0	0	0
Pinguipedidae	Parapercis miillipunctata	0	0	0
Pomacanthidae	Apolemichthys trimaculatus	0	0	0
Pomacanthidae	Centropyge bicolor	0	1	0
Pomacanthidae	Centropyge bispinosus	0	1	0
Pomacanthidae	Centropyge vroliki	0	1	0

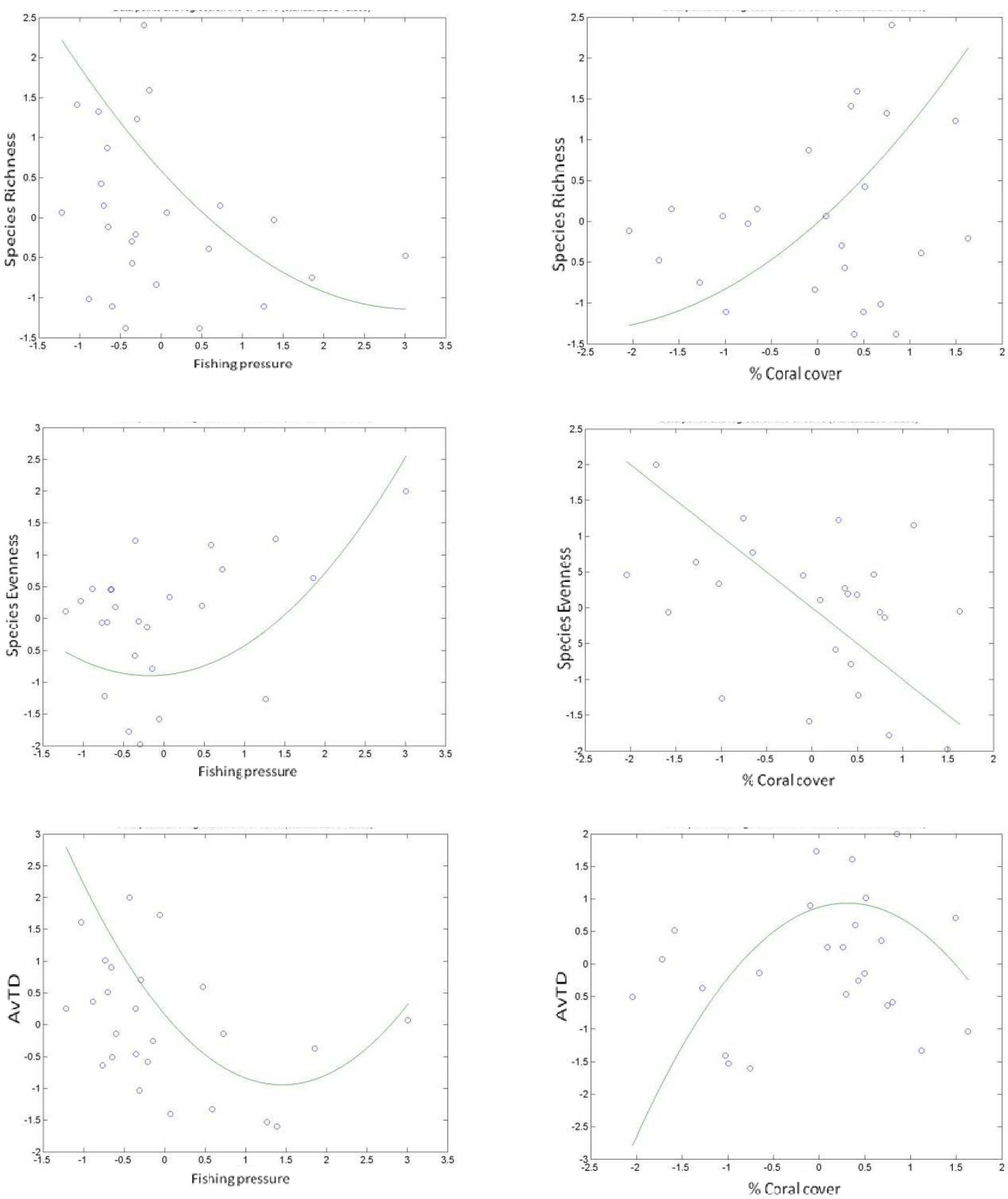
Pomacanthidae	Pomacanthus imperator	0	0	0
Pomacanthidae	Pomacanthus navarchus	0	0	0
Pomacanthidae	Pomacanthus semicirculatus	0	0	0
Pomacanthidae	Pomacanthus sexstriatus	0	0	0
Pomacanthidae	Pomacanthus xanthometopon	0	0	0
Pomacanthidae	Pygoplites diacanthus	0	0	0
Pomacentridae	Abudefduf vaigiensis	0	0	0
Pomacentridae	Acanthochromis polyacanthus	0	0	0
Pomacentridae	Amblyglyphidodon aureus	0	0	0
Pomacentridae	Amblyglyphidodon curacao	0	0	0
Pomacentridae	Amblyglyphidodon leucogaster	0	0	0
Pomacentridae	Amphiprion chrysopterus	0	0	0
Pomacentridae	Amphiprion clarkii	0	0	0
Pomacentridae	Amphiprion leucokranos	0	0	0
Pomacentridae	Chromis acares	0	0	0
Pomacentridae	Chromis alpha	0	0	0
Pomacentridae	Chromis amboinensis	0	0	0
Pomacentridae	Chromis atripes	0	0	0
Pomacentridae	Chromis delta	0	0	0
Pomacentridae	Chromis lepidolepis	0	0	0
Pomacentridae	Chromis lineata	0	0	0
Pomacentridae	Chromis margaritifer	0	0	0
Pomacentridae	Chromis retrofasciata	0	0	0
Pomacentridae	Chromis spp.	0	0	0
Pomacentridae	Chromis ternatensis	0	0	0
Pomacentridae	Chromis weberi	0	0	0
Pomacentridae	Chromis xanthochira	0	0	0
Pomacentridae	Chromis xanthura	0	0	0
Pomacentridae	Chrysiptera flavipinnis	0	0	0
Pomacentridae	Chrysiptera parasema	0	0	0
Pomacentridae	Chrysiptera rex	0	0	0
Pomacentridae	Chrysiptera rollandi	0	0	0
Pomacentridae	Chrysiptera talboti	0	0	0
Pomacentridae	Dascyllus reticulatus	0	0	0
Pomacentridae	Dascyllus trimaculatus	0	0	0
Pomacentridae	Neoglyphidodon melas	0	0	0
Pomacentridae	Neoglyphidodon nigroris	0	0	0
Pomacentridae	Plectroglyphidodon dickii	0	0	0
Pomacentridae	Plectroglyphidodon lacrymatus	0	1	0
Pomacentridae	Pomacentrus adelus	0	0	0
Pomacentridae	Pomacentrus amboinensis	0	0	0
Pomacentridae	Pomacentrus bankanensis	0	0	0
Pomacentridae	Pomacentrus brachialis	0	0	0
Pomacentridae	Pomacentrus coelestis	0	0	0
Pomacentridae	Pomacentrus grammorhynchus	0	0	0

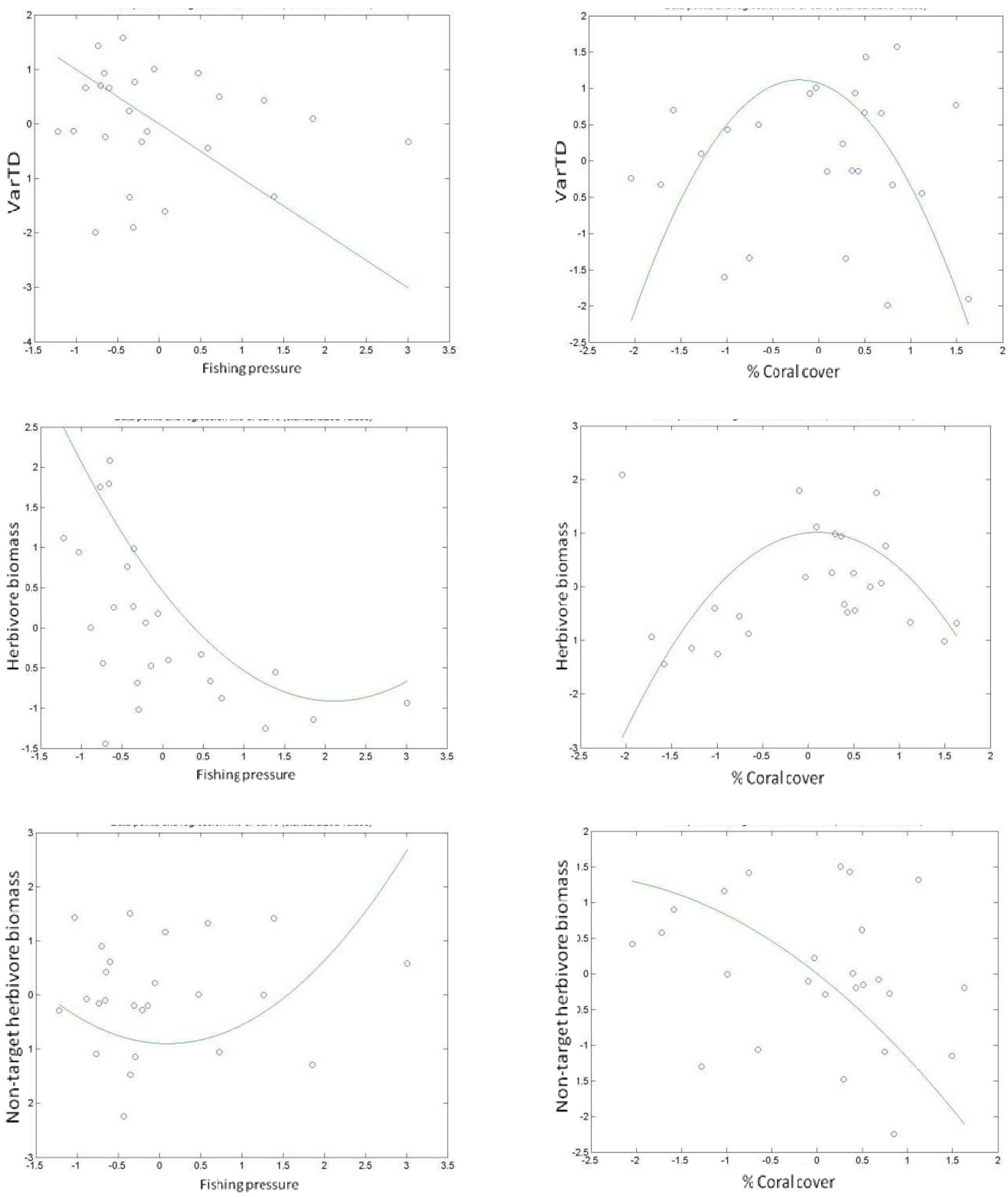
Pomacentridae	Pomacentrus lepidogenys	0	0	0
Pomacentridae	Pomacentrus moluccensis	0	0	0
Pomacentridae	Pomacentrus nagasakiensis	0	0	0
Pomacentridae	Pomacentrus nigromanus	0	0	0
Pomacentridae	Pomacentrus philippinus	0	0	0
Pomacentridae	Pomacentrus reidi	0	0	0
Pomacentridae	Pomacentrus vaiuli	0	0	0
Pomacentridae	Stegastes gascoynei	0	1	0
Pomacentridae	Stegastes spp.	0	1	0
Scaridae	Bolbometopon muricatum	0	1	1
Scaridae	Calotomus carolinus	0	1	0
Scaridae	Cetoscarus bicolor	0	1	0
Scaridae	Chlorurus bleekeri	0	1	0
Scaridae	Chlorurus microrhinos	0	1	1
Scaridae	Chlorurus pyrrhurus	0	1	0
Scaridae	Chlorurus sordidus	0	1	0
Scaridae	Hipposcarus longiceps	0	1	1
Scaridae	Scarus chameleon	0	1	0
Scaridae	Scarus dimidiatus	0	1	0
Scaridae	Scarus flavipectoralis	0	1	0
Scaridae	Scarus forsteni	0	1	0
Scaridae	Scarus frenatus	0	1	0
Scaridae	Scarus ghobban	0	1	0
Scaridae	Scarus niger	0	1	0
Scaridae	Scarus oviceps	0	1	0
Scaridae	Scarus prasiognathos	0	1	0
Scaridae	Scarus psittacus	0	1	0
Scaridae	Scarus quoyi	0	1	0
Scaridae	Scarus rivulatus	0	1	0
Scaridae	Scarus rubroviolaceus	0	1	0
Scaridae	Scarus schlegeli	0	1	0
Scaridae	Scarus spinus	0	1	0
Scaridae	Scarus spp.	0	1	0
Serranidae	Anyperodon leucogrammicus	1	0	0
Serranidae	Cephalopholis argus	1	0	1
Serranidae	Cephalopholis cyanostigma	1	0	1
Serranidae	Cephalopholis leopardus	1	0	0
Serranidae	Cephalopholis miniata	1	0	1
Serranidae	Cephalopholis spp.	1	0	0
Serranidae	Cephalopholis urodeta	1	0	0
Serranidae	Cromileptes altivelis	1	0	1
Serranidae	Diploprion bifasciatum	1	0	0
Serranidae	Epinephelus corallicola	1	0	0
Serranidae	Epinephelus fasciatus	1	0	0
Serranidae	Epinephelus melanostigma	1	0	0

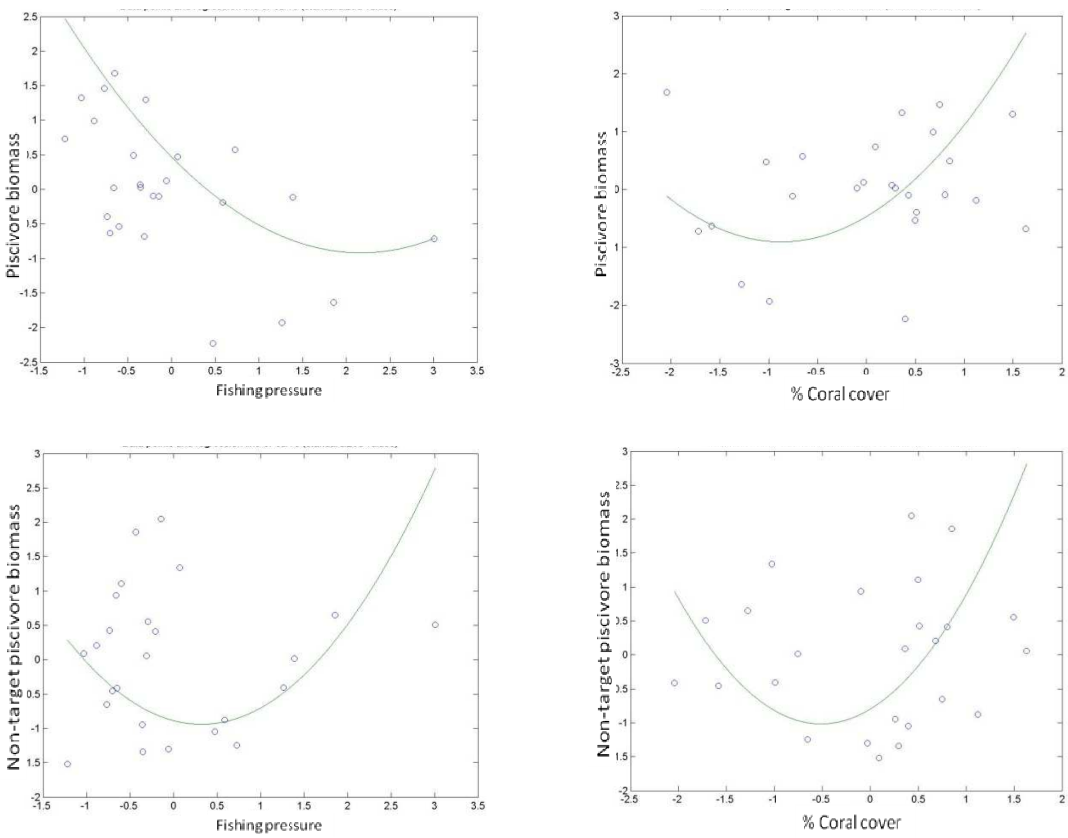
Serranidae	Epinephelus merra	1	0	1
Serranidae	Epinephelus spilotoceps	1	0	0
Serranidae	Epinephelus spp.	1	0	0
Serranidae	Luzonichthys waitei	0	0	0
Serranidae	Plectropomus areolatus	1	0	1
Serranidae	Plectropomus laevis	1	0	1
Serranidae	Plectropomus leopardus	1	0	1
Serranidae	Plectropomus oligacanthus	1	0	1
Serranidae	Plectropomus spp.	1	0	1
Serranidae	Pseudanthias dispar	0	0	0
Serranidae	Pseudanthias huchti	0	0	0
Serranidae	Pseudanthias spp.	0	0	0
Serranidae	Pseudanthias tuka	0	0	0
Serranidae	Variola albimarginata	1	0	1
Serranidae	Variola louti	1	0	1
Siganidae	Siganus argenteus	0	1	0
Siganidae	Siganus corallinus	0	1	0
Siganidae	Siganus doliatus	0	1	0
Siganidae	Siganus fuscescens	0	1	1
Siganidae	Siganus lineatus	0	1	1
Siganidae	Siganus puellus	0	1	1
Siganidae	Siganus punctatissimus	0	1	0
Siganidae	Siganus vulpinus	0	1	0
Synodontidae	Synodus spp.	1	0	0
Tetraodontidae	Arothron nigropunctatus	0	0	0
Tetraodontidae	Canthigaster papua	0	0	0
Tetraodontidae	Diodon sp	0	0	0
Zanclidae	Zanclus cornutus	0	0	0

APPENDIX 5: X, Y PLOTS OF STANDARDISED A) PROXIMATE DRIVERS AND DIVERSITY AND FUNCTION, AND B) DISTAL AND PROXIMATE DRIVERS

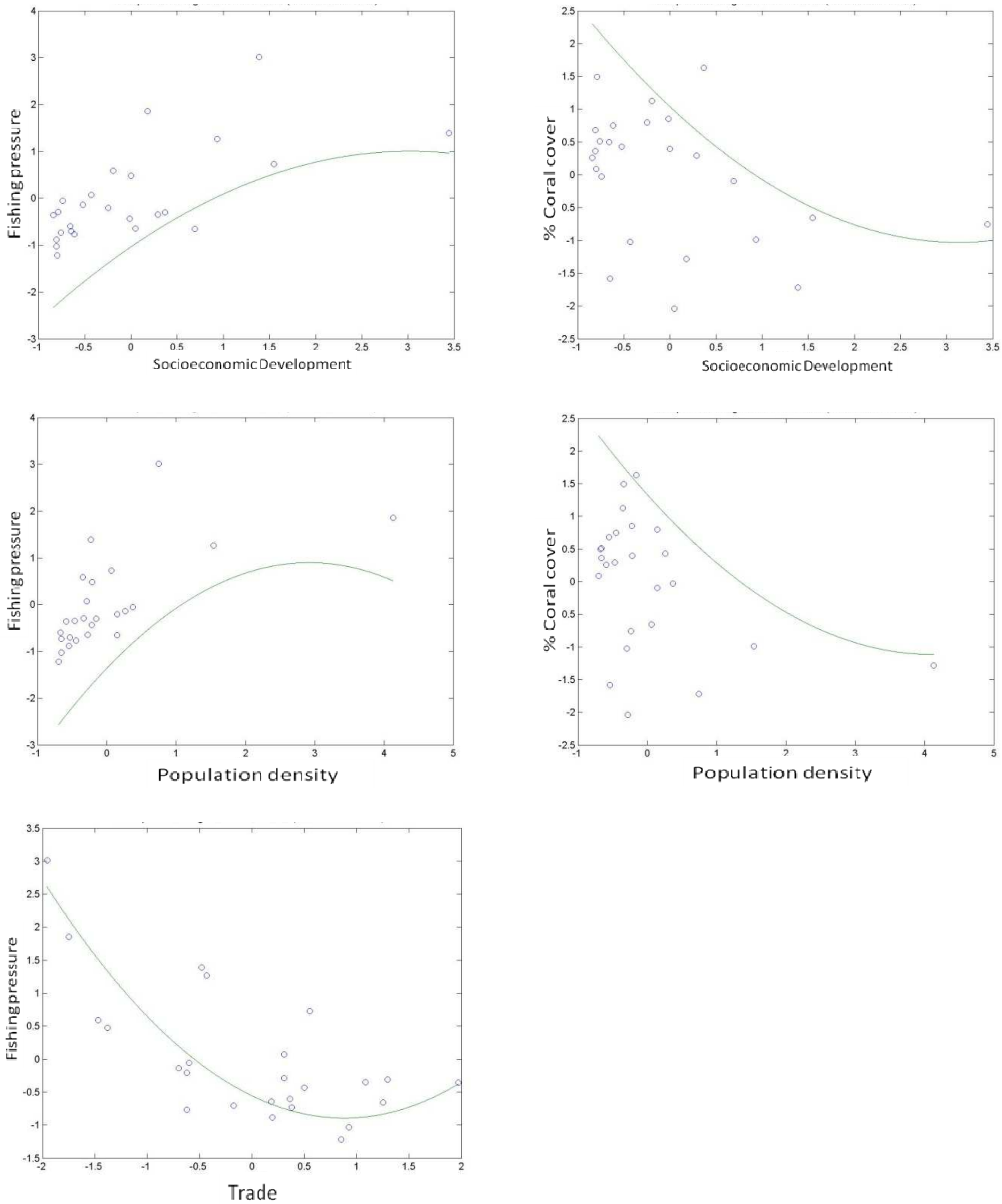
A)


Species Richness
Fishing pressure
Species Richness
% Coral cover
Species Evenness
Fishing pressure
Species Evenness
% Coral cover
AvTD
Fishing pressure
AvTD
% Coral cover


VarTD
Fishing pressure
VarTD
% Coral cover
Herbivore biomass
Fishing pressure
Herbivore biomass
% Coral cover
Non-target herbivore biomass
Fishing pressure
Non-target herbivore biomass
% Coral cover


Piscivore biomass
Fishing pressure
Piscivore biomass
% Coral cover
Non-target piscivore biomass
Fishing pressure
Non-target piscivore biomass
% Coral cover

B)


Fishing pressure
Socioeconomic Development
% Coral cover
Socioeconomic Development
Fishing pressure
Population density
% Coral cover
Population density
Fishing pressure
Trade

APPENDIX 6: SURVEY USED TO ELICIT FISHER AND MIDDLEMEN PERCEPTIONS

Field Survey questionnaire

Tom Brewer

PhD field period in Solomon Islands

Survey ID:____

Time of day:____

Surveyor name:____

Date:____

Halo, nem blo mi Tom, and dis wan hem Joe, hem bai helpem mi for save lelebt lo langus blo yu. Mi wanfala Scientist lo James Cook University lo Australia and mi doim study for fisheries department lo Solomon Islands.

Mi laik aaskem yu lo samfala tingting blo yu aboutem solwata fisheries lo Solo (SI). Tufala main part lo survey blo mi aboutem fish markets and oketa samting wea save mekem gud or spoilem risoses blo yufala.

Bai mi no talem nem blo yu lo report blo mi bata bai mi usim oketa totok blo yu wetem oketa nara answers in sait lo riport. Hem nomoa and mi laik tok tangiu tumas for tekem taim blo yu for sidaun lelebet and stori wetem mi.Hem orait for totok dis time?

A: Demographics (ALL RESPONDENTS)

8. Gender (M / F)
9. What is your age? _____
10. Where do you live?
11. Province :___________ Ward:____________ Village:___________

12. Were you born in the village that you now live in? (Y/N)

13. If no then where were you born?

14. Nation _______

15. Province :_______

16. Ward : _________

17. Village: _________

18. What age were you when you moved to this village? ________

19. Why did you move to this village?

____
____

20. How many years of education have you received? _____

21. How many adults in your household?:___

22. How many children live in your household?:____

23. Are you married? (Y/N)

24. Are you the head of your household?(Y / N)

25. Do the children in your household go to school? (Y / N)

B: Fishing Gear (Artisanal and subsistence fishers)

I would like to know what sort of fishing gear you use to fish and how important it is to your fishing

26. Which of the following do you use for fishing or fishing related activities such as transporting fish to markets? (

Gear	Use?	How many do you own?
Transport and storage		
Car/Truck (taraka) /Tractor		
Taxi		
Public Transport (boat/bus)		
Outboard engine		
Fibreglass boat		
Wooden Canoe		
Esky (size)		
Other		

	Use?	How many do you own?
Fishing Gear		
Mask		
Dive torch (Dive tos)		
Poison rope (Poisin)		
Fishing line		
Deep sea line		
Fishing net		
Hand spear / sling		
Spear gun		
Fins / flippers		
Dynamite		
Other:		

c) Is your outboard currently working? (Y/N)

What size is your outboard motor (hp)?

1.________________

2.________________

C: Market chain analysis & target species (Artisanal fishers and middlemen)

Where do you catch or buy reef fish?

PR.	Ward	Place / Village	How many years have you been catching / buying reef fish here?	How many kilograms of reef fish do you catch or buy on a good/ average /bad trip?			How often do you catch / buy reef fish here (days per fortnight)			What transport do you normally use to catch or buy reef fish here?	Who catches the reef fish that you sell?	If you do not catch the fish, what price do you pay for the reef fish / kg	Why do you catch / buy fish here?

Reef fish Sale

27. W

here do you sell reef fish?

PR.	Ward	Place	How many years have you been selling fish here?	How many kilograms of reef fish do you sell on good/average/bad trip?			How often do you sell reef fish here on a good/average / bad month)			What transport do you normally use to get your reef fish to this market?	What price do you get per kg for fresh reef fish?	What price do you get per kg for fresh reef fish?	How much profit do you make on an average trip?			Why do you sell fish here?

Market	Do you use ice to keep fish fresh?	Where do you get your ice?	How much do you use for 1 esky for a trip to market?	How much do you pay for ice for 1 esky?	What do you think fisheries should do to make the market better?

28. Do you try to catch/buy particular fish to sell? (Y / N)

29. If yes which fish? (Use fish id book)

Type	**Local name**	**Common name**	**Latin name**	**Why do you target this fish?**	**Where do you sell this fish?**

30. Are you satisfied with the money you make from selling reef fish? *(*Y / N)

31. Would you like to make more money from selling fish? (Y / N)

32. If yes, then what could you do to increase the amount of money you make from selling fish?

____

____

33. If yes (to 24) then what is another way to make more money from selling fish without spending your own money?

____

____

34. Why don't you do this now?

____

____

D: Livelihoods (ALL RESPONDENTS)

35. What activity do you spend most of your time doing?

____

____

36. What activities do people in your household do for food and income?

Activity	**Check if yes**	**# of people**	**Rank of importance for income**
Fishing *(Fishing)*			
Gleaning			
Gardening			
Selling reef fish			
Selling other marine resources			
Selling garden products			
Informal economic activity (e.g. selling cigarettes)			
Government Employee			
Other salaried employment (regular pay			
Tourism			
Other			

E : Perceived causes of resource condition change, and impacts and response. (ALL RESPONDENTS)

37. What can affect the number of fish on the reef?

38. What can affect the number of beche-de-mer on the reef?

F: Recommendations (ALL RESPONDENTS)

39. What do you think people fishing should do to increase the number of fish on the reef?

____

____

40. What do you think village leaders should do to increase the number of fish on the reef?

____

____

41. What do you think the church should do to increase the number of fish on the reef?

____

____

42. What do you think fisheries centres should do to increase the number of fish on the reef?

____

____

43. What do you think provincial governments should do to increase the number of fish on the reef?

____

____

44. What do you think the ministry of fisheries should do to increase the number of fish on the reef?

____

____

45. What do you think NGO's and other international organizations should do to increase the number of fish on the reef?

____

____