INVESTIGATING SOCIAL AND CULTURAL DRIVERS OF PACIFIC CORAL REEF RESILIENCE

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ABSTRACT

Coral reefs and their associated human communities are inextricably linked in social-ecological systems (SES). Globally, there are many cases of fisheries management failure when the human dimension is not properly incorporated into management planning. As such, a growing body of evidence suggests that fisheries should be managed for social-ecological resilience, or the ability of SES to resist, recover, and adapt from disturbance while maintaining structure, function, and feedbacks. However, few attempts have been made to use SES approaches in management design, that incorporate locally relevant sociocultural factors, at the scale in which fishing activities are determined. This dissertation focuses on coral reef fishing communities in the Pacific Islands, where indigenous communities have been established for centuries or millennia and which have a long history of both natural and social disturbances, making them especially suited for understanding how social-ecological resilience has been maintained over time.
I addressed the following questions: 1) from a Pacific Islands perspective, what are the relevant sociocultural factors that influence resilience and how can such factors be measured?; 2) what role do fisheries play in sharing networks, important structures for social-ecological resilience; and 3) which social-ecological indicators of resilience predict household fish catch?

In visioning exercises, members of place-based communities identified several factors that have largely been absent from resource management and conservation interventions, that could be broadly classified under the concepts of: “Connectedness to people and place” and “Indigenous and local knowledges, skills, practices, values and worldviews.” I assessed social cohesion, which is part of “Connectedness to people and place” in 18 communities in Fiji across a socioeconomic gradient using social network analysis (SNA) of resource sharing networks. I found that natural resources are widely shared, but that villages in closer proximity to a large, urban center had less cohesive sharing networks. Further, mean household fishing frequency was positively correlated with two measures of network cohesion. As such, fisheries management that takes sharing network properties into account should be prioritized to maintain social resilience. To determine drivers of household fishing, I used data collected from 20 villages across Fiji in structural equation models, and found that importance of fishing to income, household fish consumption, livelihood diversity, travel time to market, and coral reef area, all positively affected estimated household-level fish catch. These results contrast with findings

from other larger-scale studies in identifying that households further from markets had higher fishing frequency. My results highlight the role of middlemen in these small-scale fisheries, who have been largely overlooked as drivers of small-scale fisheries catch. Findings of this research demonstrate the importance of understanding how locally important sociocultural factors, at a fine spatial scale, influence coral reef SES. Such an understanding is necessary for designing successful small-scale fisheries management measures in participation with local communities.

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CHAPTER 1. INTRODUCTION.

Coral reefs play a significant role in the resilience of Pacific Island social-ecological systems. However, social, environmental, and climate change have caused worldwide declines in coral reef ecosystems (Gardner et al. 2003, Bruno and Selig 2007, Burke et al. 2011) and their associated fisheries (Newton et al. 2007, Mora et al. 2011), threatening social-ecological resilience. Increasingly, coral reefs have been managed with the goal of maintaining or building ecological resilience (McClanahan et al. 2012, Mumby et al. 2014), or the ability of a system to resist, recover, and adapt from disturbance while maintaining structure, function, and feedbacks (Holling 1973, Nyström et al. 2008, Gunderson et al. 2009). However, a growing body of evidence suggests that natural resources should not simply be managed for ecological resilience, but instead for social-ecological resilience, or the ability of SES to resist, recover, and adapt from disturbance while maintaining structure, function, and feedbacks (Adger 2000, Anthony et al. 2015). As such, managing coral reefs is a pressing challenge that will require substantial, interdisciplinary efforts (Aswani et al. 2015). The interdisciplinary challenge of coral reef management is not unique to coral reef systems and lessons in resource management can be learned from and transferred to other social-ecological systems worldwide.

Successful natural resource management depends on how and why decisions are made in the process of planning and the ability of interventions to change human behavior (Mascia et al. 2003). Management interventions that do not acknowledge the connections between social and natural dimensions often fail (Christie 2004, West 2006, Waylen et al. 2010, Keppel et al. 2012, Bennett and Dearden 2014, Sterling et al. 2017a, 2017b). A number of approaches have been proposed to address this oversight (e.g., Davidson-Hunt & Berkes 2003; Hicks et al. 2016), and social-ecological systems (SES) approaches have gained substantial traction in conservation discourse in recent years. SES approaches are characterized by recognition of complex interactions between humans and their biophysical surroundings, including reciprocal feedbacks between the social and ecological subsystems (Liu et al. 2007, Binder et al. 2013). In other words, SES approaches describe how natural dimensions influence and are influenced by social dimensions. SES research often seeks to better understand social-ecological resilience, or the ability for SES to maintain overall function after disturbance events (Folke 2006). SES approaches are particularly valuable, as they can highlight patterns that are not apparent with single disciplinary approaches, and these may offer important insights for conservation and management (Liu et al. 2007).

However, it has been widely noted that social-ecological studies struggle to adequately capture the complex nature of the social dimension (Davidson 2010, Hatt 2013, Fabinyi et al. 2014, Stojanovic et al. 2016). By focusing on tangible interactions between humans and environment, many SES frameworks ignore other processes and relations that mediate human-nature interactions, such as power relations, cultural beliefs, and values (Cote and Nightingale 2012, McKinnon et al. 2016). While various studies have descriptively documented aspects of human-environment interactions (such as Lepofsky et al. 2017), these are missing, for the most part, from studies guided by SES frameworks. Social variables that have been used in SES frameworks are often socioeconomic rather than sociocultural, perhaps because they are relatively easy to measure and quantify (Stojanovic et al. 2016, Annis et al. 2017).

For example, several recent studies have used socioeconomic variables to predict coral reef social-ecological system drivers. Human population density has been documented as a positive driver of fishing pressure (Williams et al. 2008, Brewer et al. 2012) and negative driver of reef fish biomass (Sandin et al. 2008, Mora 2008, Cinner et al. 2009b). Other social factors that affect fishing pressure and/or reef fish biomass include socioeconomic development (e.g., the presence of certain infrastructure and facilities) (Cinner et al. 2009b, Brewer et al. 2012) and fisheries management regime (i.e., traditional management, co-management, national parks) (McClanahan et al. 2006). Recent research has found an increase in fishing pressure (Brewer et al. 2012) and lower fish biomass (Cinner and McClanahan 2006, Cinner et al. 2013, Maire et al. 2016) closer to markets. Although these recent studies have made important contributions to our understanding of human dimensions of coral reef social-ecological systems, there are still gaps in our knowledge of the sociocultural factors important for sustainable resource management.

Given that many coral reef fisheries management projects are planned and implemented by biologists, it is not surprising that sociocultural factors have largely been left out of natural resource management planning. Biologists may lack an understanding of the multidimensional dynamic of human relationships to nature (especially those that are not tangible or that incorporate culture) or may lack the capacity to identify locally appropriate sociocultural components important for resource management (Bennett et al. 2016). Or, by focusing only on sociocultural factors that are directly linked to the environment, biologists may fail to incorporate factors that are important to people dwelling in nature and that indirectly influence how people relate to their surroundings.

In addition, because the social measures that have been examined as drivers are often at the geographic community level or higher (e.g., human population density, presence of large-scale infrastructure such as schools and roads), our understanding of what drives household-level behaviors is still lacking. Human communities, whether defined spatially or by social structure, are not homogeneous (Agrawal and Gibson 1999) and the variation of interests and behaviors of individuals or households within communities influences the state of resources (Kramer et al. 2009). Since human behaviors can be managed, it is especially important to understand what factors influence individual and household-level fishing activities (Aswani et al. 2015).

Finally, in the cases where household-level social factors have been included, sometimes easily measured characteristics are selected at the expense of being inadequate and/or inappropriate for the local cultural context (Sterling et al. 2017b). For example, "material assets" is an easily measured indicator that is commonly used as a proxy for wealth (Pollnac and Crawford 2000, McClanahan et al. 2008), yet may not be locally recognized as a significant component of well-being (Copestake et al. 2009). Similarly, social capital is commonly measured as the number of community groups a household is a part of (McClanahan et al. 2008, Cinner et al. 2009a), yet may not account for other forms of social connections that may be more common and/or more significant, such as resource sharing or informal cooperation. For example, across Melanesia, the *wantok* system exists, where goods and services are commonly reciprocated within groups that speak the same language (Belshaw 1965). Additionally, measures of education tend to focus on the level of formal schooling (Kittinger 2013a, Béné et al. 2016), which excludes the informal or non-Western modes of knowledge transmission that play a critical role in childhood development and learning (Lance 1996).

Goals of the dissertation

Given these gaps in our knowledge of social-ecological systems, the overarching goals of this study are to 1) advance our understanding of local visions of resilience to help inform the development of indicators of social-ecological resilience; 2) better understand the current structure of sharing networks, how different natural resources are shared within them, and whether there are certain fishing practices that are more associated with sharing; and 3) better understand drivers of resource extraction by utilizing culturally appropriate indicators at the appropriate scale.

The study focuses on the Pacific Islands, in which indigenous Pacific Islander communities have been established for centuries or millennia (Kirch 2017). In the Pacific Islands, human well-being is especially dependent on natural assets. In particular, fish consumption in the region is high, although with recent urbanization, there has been a shift to an increasingly modern diet of imported goods and less local foods, including fresh fish (Bell et al. 2009, Charlton et al. 2016). Across the region, biodiversity has declined and extinctions have occurred due to habitat loss and degradation, invasive species, overexploitation, pollution, disease and climate change (Jupiter et al. 2014b). However, the Pacific Islands have a long history of both natural and social disturbances, which make them especially suited for understanding how social-ecological resilience has been maintained over time (Connell 2013, Campbell 2015).

Outline of the dissertation

In Chapter 2, I describe a method for gaining a better understanding of local visions of social-ecological resilience, to inform the development of appropriate indicators for social-ecological resilience for the purpose of designing management interventions that improve conservation outcomes. A sample of sociocultural indicators of resilience is also provided.

In Chapter 3, I demonstrate how social cohesion, a category that was highlighted in Chapter 2, as being missing from indicator sets, can be measured through social network analysis. This chapter also investigates the role of marine resources in sharing networks and how sharing networks are impacted by market integration.

In Chapter 4, I use household level, place-based indicators (identified in Chapter 2), to determine sociocultural drivers of household fish catch. Specifically, I used measures of market integration, livelihood diversity, local ecological knowledge (LEK) and social cohesion to examine how they were directly or indirectly driving household catch, along with more standardly measured indicators.

Finally, in Chapter 5 I provide a synthesis of Chapters 2-4 and offer potential directions for future work that builds on these studies.

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CHAPTER 2. IMPROVING CONSERVATION OUTCOMES BY INCORPORATING CULTURALLY-GROUNDED INDICATORS INTO SOCIAL-ECOLOGICAL FRAMEWORKS.

To be submitted as:

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Existing social-ecological systems frameworks require additional sociocultural detail

Successful conservation interventions depend on how and why decisions are made in the process of conservation planning and the ability of interventions to change human behavior (Mascia et al. 2003). Conservation interventions that do not acknowledge the connections between social and natural dimensions often fail (Christie 2004, West 2006, Waylen et al. 2010, Keppel et al. 2012, Bennett and Dearden 2014, Sterling et al. 2017a, 2017b). A number of approaches have been proposed to address this oversight (e.g., Davidson-Hunt & Berkes 2003; Hicks et al. 2016), and social-ecological systems (SES) approaches have gained substantial traction in conservation discourse in recent years. SES approaches are characterized by recognition of complex interactions between humans and their biophysical surroundings, including reciprocal feedbacks between the social and ecological subsystems (Liu et al. 2007, Binder et al. 2013). In other words, SES approaches describe how natural dimensions influence and are influenced by social dimensions. SES research often seeks to better understand social-ecological resilience, or the ability for SES to maintain overall function after disturbance events (Folke 2006). SES approaches are particularly valuable, as they can highlight patterns that are not apparent with single disciplinary approaches, and these may offer important insights for conservation (Liu et al. 2007). While there has recently been a call for using SES frameworks to make conservation more effective (Glaeser et al. 2009, Ban et al. 2013), case studies of how SES frameworks are incorporated into conservation planning are scarce (but see Guerrero & Wilson 2017; Leenhardt et al. 2017).

SES approaches have made significant progress; however, critics have claimed that there is a tendency for them to treat the social and ecological as ‘separate-but-connected’ components, which in turn may reproduce and maintain a false dichotomy between the two (Lauer 2016). Instead, authors have advocated for a 'humans-in-nature' depiction, which would acknowledge that all organisms are interdependent and that their connections lead to the co-development of both nature and culture (Lauer 2016). This conceptualization is compatible with the worldviews of diverse communities, including those of many indigenous peoples (Salmón 2000) whose place-based ecological expertise is increasingly recognized for its potential value to conservation science (Berkes et al. 2000, Aswani and Hamilton 2004, Aswani et al. 2012, Lauer 2017).

Several frameworks have been developed to examine SES approaches. Binder et al. (2013) provide a comparison of the purpose and conceptualization of ten established frameworks. They find major differences in the perspectives of SES frameworks, such as whether: the model is foundationally anthropocentric or ecocentric; interactions between the ecological and social dimensions are unidirectional or include reciprocal links including feedback loops; and whether the framework is intended to be used broadly for analysis of the system or to act upon a specific goal (e.g., conservation, improve food security, disaster preparedness). SES frameworks and approaches may also struggle to adequately capture the complex nature of the social dimension (but see Bodin 2017). By focusing on tangible interactions between humans and environment, many SES frameworks ignore other processes and relations that mediate human-nature interactions, such as power relations, cultural beliefs, and values (Cote and Nightingale 2012, McKinnon et al. 2016). Although these criticisms have been widely echoed (Davidson 2010, Hatt 2013, Fabinyi et al. 2014, Stojanovic et al. 2016), there are still gaps.

A systematic review of community-based conservation case studies found that conservation interventions incorporating the local cultural context were more likely to succeed than those that did not (Waylen et al. 2010). This suggests that the criticisms of SES frameworks do indeed point to true limitations of current conservation interventions. Muhar et al. (2017) have suggested adapting SES to include social and cultural factors, including environmental worldviews, connectedness to nature, place attachment, and human-nature relationships. While various studies have descriptively documented these aspects of human-environment interactions (such as Lepofsky et al. 2017), these have largely been omitted from SES frameworks. Instead, social variables that have been used in SES frameworks are often socioeconomic rather than sociocultural, perhaps because they are relatively easy to measure and quantify (Stojanovic et al. 2016, Annis et al. 2017).

Given that many conservation projects are planned and implemented by biologists, it is not surprising that sociocultural factors have largely been left out of conservation planning. Conservation biologists may lack an understanding of the multidimensional dynamic of human relationships to nature (especially those that are not tangible or that incorporate culture) or may lack the capacity to identify locally appropriate sociocultural components important for conservation (Bennett et al. 2016). Or, by focusing only on sociocultural factors that are directly linked to the environment, biologists may fail to incorporate factors that are important to people dwelling in nature and that indirectly influence how people relate to their surroundings. It can also be difficult for non-social scientists to develop indicators for such components and determine the most appropriate approaches for measuring these indicators (Drew and Henne 2006).

In the cases where social factors have been included, sometimes easily measured characteristics may be selected at the expense of being inadequate and/or inappropriate for the local cultural context (Sterling et al. 2017b). For example, "material assets" is an easily measured indicator that is commonly used as a proxy for wealth (Pollnac and Crawford 2000, McClanahan et al. 2008), yet may not be locally recognized as a significant component of well-being (Copestake et al. 2009). Similarly, social capital is commonly measured as the number of community groups a household is a part of (McClanahan et al. 2008, Cinner et al. 2009a), yet may not account for other forms of social connections that may be more common and/or more significant, such as resource sharing or informal cooperation. For example, across Melanesia, the *wantok* system exists, where goods and services are commonly reciprocated within groups that speak the same language (Belshaw 1965). Similar systems of reciprocity exist is Fiji (*kerekere*) and Samoa (*fa'asamoa*) and elsewhere in the Pacific (Nanau 2011). Additionally, measures of education tend to focus on the level of formal schooling (Kittinger 2013a, Béné et al. 2016), which excludes the informal or non-Western modes of knowledge transmission that play a critical role in childhood development and learning (Lance 1996).

In the last decade, there has been considerable progress in measuring indicators of well-being for assessing outcomes of conservation interventions (McKinnon et al. 2016). While well-being outcomes have largely been assessed by economic or other material wealth indicators, there are accepted categories of well-being that include sociocultural components such as "Culture and Spirituality" and "Social Relations" (McKinnon et al. 2016). Kaplan-Hallam & Bennett (2017) highlight topics under each well-being category that potentially relate to conservation interventions. However, it should be noted that sociocultural indicators have to be place-specific in order to be relevant and appropriate. To make indicators context specific, Fabinyi et al. (2014) suggest engaging people on the ground and asking for their own interpretations of what resilience looks like in their places.

Here, we present a sample methodology that provides a general road map for how conservation practitioners can work with place-based communities to understand the sociocultural factors to include in SES frameworks (Fig. 2.1). We propose that biocultural approaches are most appropriate for such purposes. Gavin et al. (2015) define biocultural approaches to conservation as "conservation actions made in the service of sustaining the biophysical and sociocultural components of dynamic, interacting, and interdependent social–ecological systems." Sterling et al. (2017a) further describe biocultural approaches as starting with and building upon local cultural perspectives to fill existing gaps. The approach can help develop locally appropriate indicators of conservation or resource management success, by identifying sociocultural components critical for conservation but that are currently missing from most SES frameworks (Gavin et al. 2015, Caillon et al. 2017, Sterling et al. 2017a, 2017b). We use sociocultural to be inclusive of both social and cultural factors including beliefs, values, traditions, and behaviors. As we demonstrate, sociocultural factors can be used to develop biocultural indicators if they are developed using a biocultural approach and created for the purpose of sustaining both biophysical and sociocultural components of a SES.

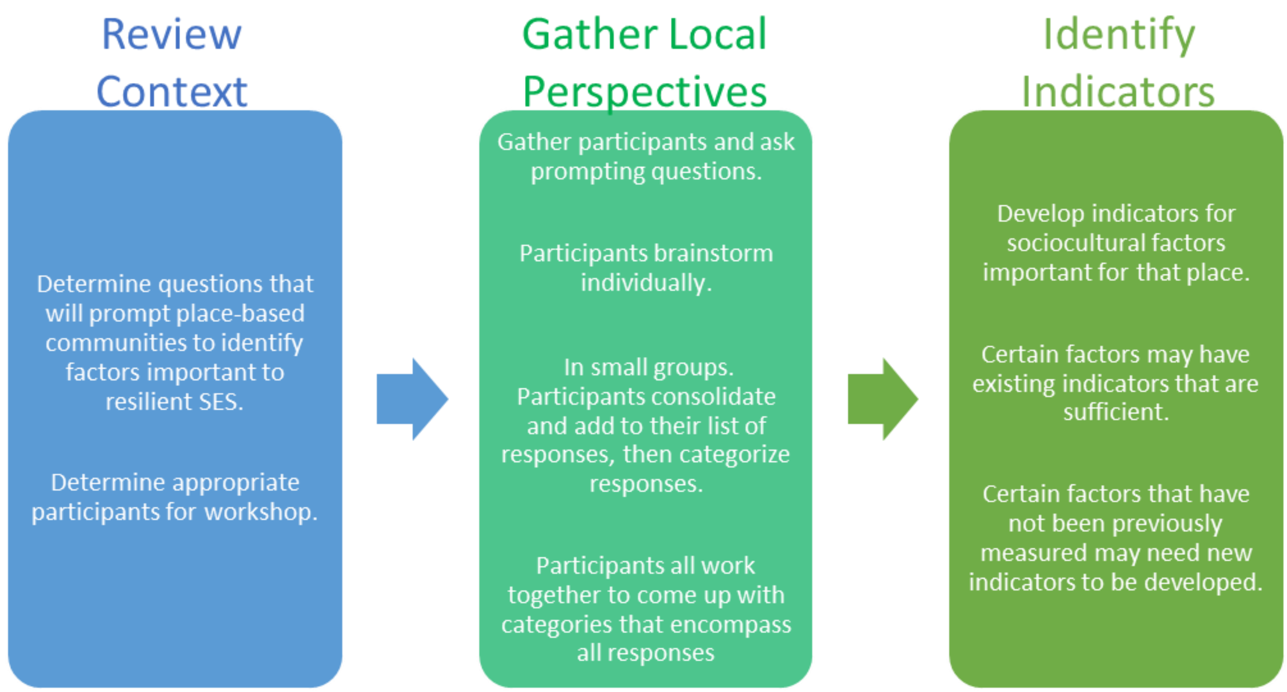

Figure 2.1. Process that led to identifying sociocultural factors in Pacific social-ecological systems and developing corresponding biocultural indicators.

We focus on Pacific Islands, in which indigenous Pacific Islander communities have been established for centuries or millennia (Kirch 2017). Across the Pacific, species endemism is high, but biodiversity decline and extinctions have occurred due to habitat loss and degradation, invasive species, overexploitation, pollution, disease and human-forced climate change (Jupiter et al. 2014b). The Pacific Islands have a long history of both natural and social disturbances, which make them especially suited for understanding how social-ecological resilience has been maintained over time (Connell 2013, Campbell 2015). Finally, like many indigenous communities globally, many Pacific Island worldviews do not conceive of human and non-human or natural domains as fundamentally separate (Strathern 1980, Charpleix 2017, Jupiter 2017). For example, many Hawaiians identify as descendants of their land and view caring for a place in the same way as caring for a family member (Pascua et al. 2017). Thus, conservation efforts that do not have an effective understanding of the social-ecological links in these worldviews often fail (Jupiter 2017).

Using a biocultural approach to identify sociocultural components of social-ecological systems

Biocultural approaches should first seek to understand local definitions of resilience and then develop indicators with communities of each of its locally defined components (Sterling et al. 2017a, 2017b). To identify local visions of social-ecological resilience, we conducted six workshops in Fiji, Hawaiʻi, the Marshall Islands, Solomon Islands, and French Polynesia. Workshop participants included a combination of cultural practitioners, government and non-governmental organization employees, and university students and faculty from the host countries as well as countries across the region, including Vanuatu and Papua New Guinea. In addition, we had two workshops with international researchers who all had worked extensively with communities in the Pacific Island region.

In each workshop, we prompted participants to think about and identify characteristics of resilient Pacific Island communities. Because resilience is a complex concept, we used a variety of locally relevant questions to approach the concept, with all interpretations of resilience incorporating ideas of environmental sustainability and long-term human well-being. For example, in Hawaiʻi, we asked participants what *ʻāina momona* (literally translates to "fat land," and represents a concept of abundant resources in a place) looks like in their places. In a region as vast and diverse as the Pacific Islands, we acknowledge that the participants were not representative of all communities or stakeholders. However, the general themes that emerged from the workshops are consistent with those addressed in studies conducted throughout the region and documented in the literatures of anthropology, sociology, and geography (Hviding 1996, D'arcy 2006, Bambridge 2016) (Fig. 2.2).

After brainstorming and creating an initial list of resilience characteristics, participants combined their responses and developed categories in which all the characteristics could be grouped. The development of categories and categorization of responses was done first in small groups and then with the whole workshop group in order to foster a more in-depth discussion. Although we recognized inherent overlaps (Fig. 2.2), we found that creating and naming category themes helped expand participants' brainstorming. It is not intended that efforts attempt to measure or monitor all the components of each category. Further, categories are important because, while each underlying characteristic may not be important to every community, there are a number of characteristics from each category that do apply to every community. For example, depending on the colonization and missionization history of a place, certain traditional practices under the “Connectedness to People and Place” category may be considered taboo to address. Similarly, depending on the nature of the social networks common in a place, certain “Connection to People and Place” components will be more relevant than others.

After the workshops were completed, we consolidated categories and coded the responses, in order to group them into more general sociocultural factors and so that our findings from each workshop could be compiled. For example, *laulima* (Hawaiian), *solesolevaki* (Fijian), and *lale dron* (Marshallese) all represent similar concepts of “Cooperation and social cohesion” and were thus grouped together under the category “Connectedness to people and place.” We kept characteristics that were broad and not specific to a certain context in the form that they were presented, for the most part (e.g., transmission of knowledge between generations, access to healthcare, abundant resources).

We identified the sociocultural factors for which we were unaware of well-established, existing indicators. Based on the responses from the workshops, and our previous knowledge, we then developed example indicators to measure the status of these sociocultural factors (Table 2.1).

Table 2.1. Examples of sociocultural factors and associated indicators for consideration in conservation planning.

Category	Example sociocultural factor	How factor is related to conservation	Supporting citations	Example indicator
Connectedness to people and place	Religious or spiritual practices and connections to entities (living and non-living)	1. People may be more willing to conserve species or areas that contain important non-living entities if they have a spiritual connection to them. 2. Certain species may be totem species associated with identity or be associated with ancestors and/or deities. Such species may already be protected and could serve as umbrella species for other species occupying the same habitat. 3. Alternatively, species that are perceived to have special powers may be persecuted.	(Blicharska and Mikusiński 2014, Holmes et al. 2017)	Trend in the proportion of individuals that know their totem or ʻaumakua
	Following appropriate social and cultural norms associated with specific places	1. Harvesting particular resources in particular ways, observing spiritual prohibitions, and transmitting knowledge of specific sites, are all examples of cultural norms that may be associated with specific places. The status of such practices can reveal the relationship between a community and its places. Communities that have strong cultural norms tied to places may be more inclined to conserve such places and their associated biota. 2. Alternatively, people may be unwilling to participate in conservation activities that require them to alter practices that have been carried out for centuries	(Poepoe et al. 2007, Cohen and Foale 2013)	Perceptions of the degree to which community members follow [locally appropriate cultural norm]
	Connections within and between communities including relations within and between social groups	1. Certain connections may be maintained by exchange of a specific natural resource that needs to be accounted for if there are restrictions on species/areas in a conservation intervention 2. Individuals/communities with better connections and ability to rely on others for support may be less likely to exploit resources. 3. Connections between individuals/communities can allow for “natural” spread of ideas/knowledge/practice. Outcomes could be positive or negative for conservation depending on what is being spread.	(Bodin et al. 2014)	Perceptions of connectivity of networks inside and outside community and level of exchange of [resource/knowledge].

	Knowledge of traditional place names or landscape terms	1. Place names may connect people to ancestors who gave those names, making people less likely to alter tenure practices (i.e., sell off land or resources). 2. Place names can contain important information about the place that can help in mgmt./conservation 3. Songs/chants, stories may contain a place name and its significance to the community, but it is necessary to know the place name in order to locate such information.	(Lauer 2016, Lepofsky et al. 2017)	Trend in proportion of people who know names of culturally important places and their locations.
Indigenous and local knowledge, skills, practice, values and beliefs	Use of local biodiversity in cultural practices	1. Trend in the use of biodiversity may be an indicator of its abundance. If the trend in the use of a species decreases, its abundance may have decreased. If the trend in the use of species that are long-lived/slow to mature has increased (perhaps as a result of increasing populations) this is a cause for concern. 2. If specific species are required for certain cultural practices, users may be more inclined to conserve them for future use and to perpetuate their cultural practices.	(Garibaldi and Turner 2004)	Trend in the number of species of plants and animals used in traditional ceremonies
	Knowledge and practice of stories, songs, chants, dance, locally significant ceremonies, and other important cultural performances	Important language and knowledge of species/ecology may be embedded in cultural performances.	(Fernández-Llamazares and Cabeza 2017)	Trend in the number of people who know how to carry out or perform [a locally important cultural performance with embedded local ecological knowledge]

Local perceptions of key components of resilient social-ecological systems

All the responses to the visioning prompts could be grouped under one or more of the following categories:

1. Environmental state
2. Access to natural and cultural resources
3. Sustainability management
4. Connectedness to people and place
5. Indigenous and local knowledges, skills, practices, values and worldviews
6. Education
7. Healthy people
8. Access to financial resources, infrastructure, and services.

Many of the responses were cross-cutting and could be organized into more than one category (Fig. 2.1). Also, although to some it may appear as if there are categories that could be condensed, it was important to focus group participants that certain categories were stand-alone and not combined.

Many of the responses from the focus groups are frequently incorporated into SES frameworks (e.g., Environmental State, Healthy People). However, consistent with criticisms of SES, key cultural elements that were persistently brought up cannot easily be located on existing SES frameworks. Most of the missing sociocultural factors are found in the categories of "Connectedness to people and place (CPP)" and "Indigenous and local knowledges, skills, practices, values and worldviews (ILK)" (Table 2.1). Many of the factors under the ILK category have been recognized as important aspects in SES (Folke et al. 2003), yet there are few examples of them being adapted to the local context or developed into indicators for conservation planning purposes (but see Biedenweg et al. 2016). Similarly, while sense of place has been documented to play a large role in motivating stewardship, methods and indicators to measure people's connection to place has yet to be well developed (Masterson et al. 2017).

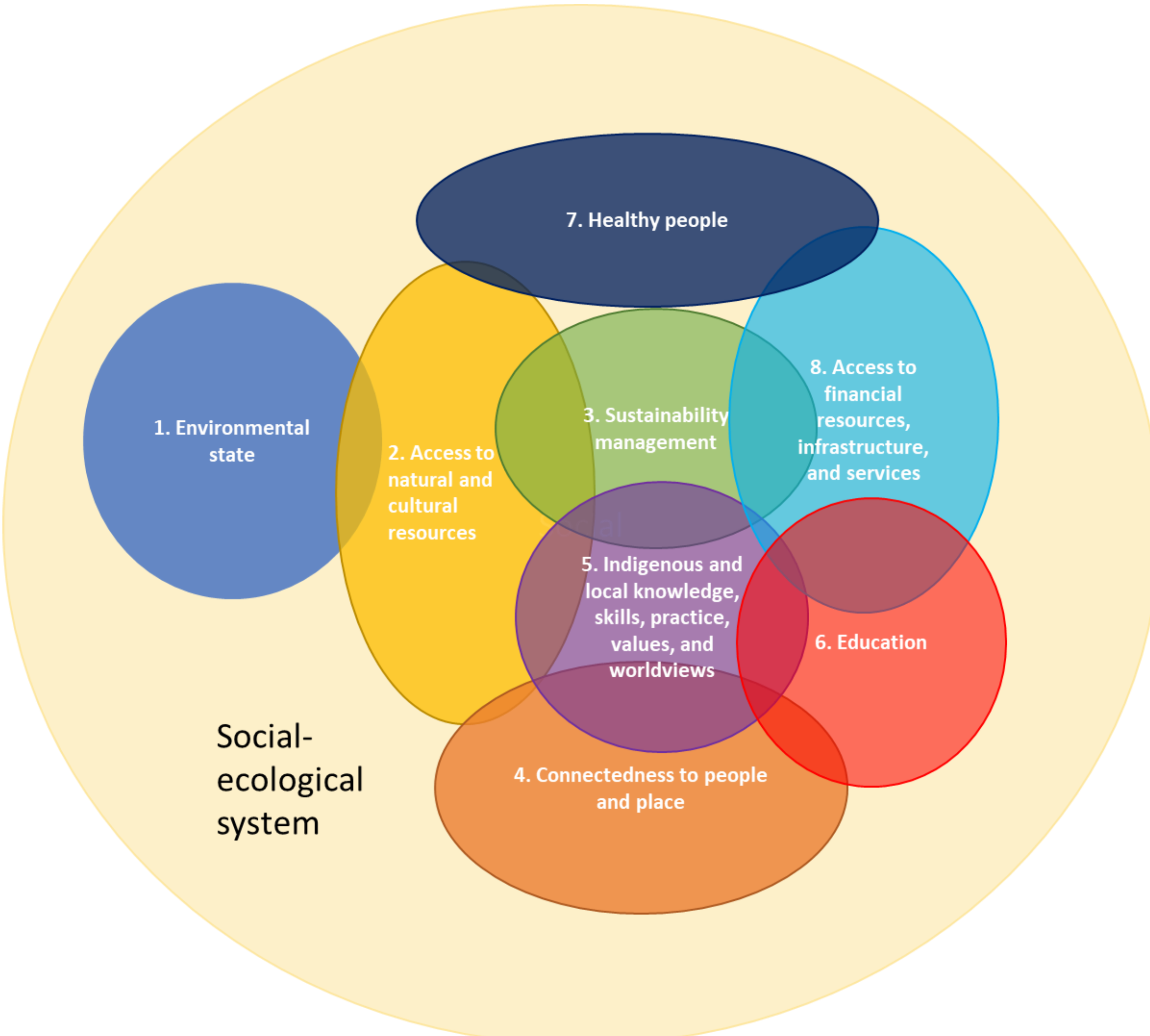

Figure 2.2. Categories of resilient SES components. Each category (i.e., circle) has a number of underlying components (Appendix 1). Overlaps represent areas where components may fit into more than one category.

Two main mechanisms link these sociocultural factors to conservation:

1. Many of the factors influence and drive attitudes and perceptions of species or places, and people's interactions with them. For example, in many place-based communities in Melanesia, people have strong connections to place, as they feel connected to ancestors who spent time or named those places (Lauer 2016). As a result of having a strong connection to place, people may be more inclined to support conservation interventions in such places (Masterson et al. 2017). However, this is not to say that a conservation

ethic existed in the past or is a traditional practice (Foale et al. 2011). For example, the value of species in place-based communities may be very different than that of external conservationists (Foale et al. 2016).

2. Other factors can inform conservation. Place and species names and the stories, songs, and performances in which they are embedded may contain important information about places and species of conservation interest. It should be noted, however, that this local ecological knowledge may not have evolved for conservation purposes (Foale et al. 2011).

Potential biocultural indicators

Using the responses from our workshops, we provide example indicators that could be used to monitor and evaluate the status of factors that are locally perceived to be integral components of SES (Table 2.1). However, biocultural indicator development is a complex process, and while our example indicators may serve as a starting point for use with communities that have inhabited the same place over generations, our indicators need to be locally adapted (even across the Pacific Islands). For example, for the indicator for "knowledge of performance," one would have to first understand the types of performances that are linked to species or places before assessing the "trend in number of people who know that type of performance." Similarly, before asking about "religious or spiritual connections to entities," the types of connections that exist in the local context would have to be known. If totem species are locally relevant, an appropriate indicator might be "trend in the number of people who know their totem species." With such indicators, it should be noted that knowledge and practice are different. For example, just because an individual knows of their totem does not equate to them having an active relationship with that species.

Because of the coupled nature of SES, some indicators measure both biophysical and sociocultural conditions. For example, the trend in the harvest per unit effort of culturally important species can indicate the status of a biological population and the use of local biodiversity in cultural practices. If harvest per unit effort decreases, the species may be decreasing in abundance and additional time is required to harvest in the same area or additional time is required to travel to a place where the species is still abundant. A decrease in harvest may also indicate that the species is culturally less important than it was previously. An increase in catch per unit effort may indicate that a species is increasing in abundance or that a more efficient gear is being used for harvest. A similar indicator that is widely used in fisheries is catch per unit effort (CPUE). Using a biocultural approach, such indicators will be specific to culturally important species.

Another example of a biocultural indicator that can measure both biophysical and sociocultural factors is the trend in the presence of certain types of local knowledge, such as the location of a certain species. If the knowledge within a community changes over time, this may indicate that the species is changing in abundance, there is a change in the frequency of use of this species, or that there has been a change in the transmission of this type of knowledge. The trend in the number of species or species varieties used for ceremonial practices may indicate similar changes.

To tease out the problem of having an indicator potentially measuring multiple conditions, multiple indicators need to be analyzed together. For example, to identify the driver of the change in local knowledge of a species, you would need to ask about frequency of use of that species, actual or perceived change in that frequency, as well as transmission of knowledge and perceived or actual change in transmission.

Conclusion

Although biocultural approaches may require larger investments of time, the process can be simple and not costly (Sterling et al. 2017a, 2017b). By incorporating multiple worldviews and knowledge systems, biocultural approaches can help better understand the sociocultural factors in SES. Sociocultural factors influence and drive attitudes and perceptions of species or places, and people’s interactions with them. Further, sociocultural components may help inform conservation by providing a source of deeper ecological understanding. Conservation success, where success is defined by improvements in biocultural outcomes, may lead to increased interest and long-term support from communities.

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Appendix 1. List of Well-being Elements and links to Supplemental Information

1 - Environmental state

Ecosystems include the ecological, biological, physical, chemical, and human components and their interrelationships, their functionalities and resilience to change.

1.1 Ability of ecological systems to reorganize or recover after disturbance

1.2 State/status of biologically and culturally important populations, species, and varieties

1.3 Proportion of native species in danger of extinction

1.4 Extent, range, and control of invasive species

1.5 State/status of non-biological culturally important resources (water sources, rock quarries, clay deposits, etc.)

1.6 Level of habitat diversity for land- and seascapes

1.7 Proportion of functionally intact ecosystem(s) across land- and seascapes

1.8 Status of ecosystem connectivity

1.9 Local perceptions of the aesthetics of environmental surroundings

2 - Access to natural and cultural resources

The ability to physically, appropriately, and equitably access a place for non-extractive or extractive sustainable use of natural and cultural resources. Access is sufficient to fulfill values and needs for subsistence, health, cultural, spiritual, aesthetic, emotional, or economic purposes. Recognition can be formalized by policy, law or through customary practices.

2.1 Access to and agency over a sufficient quality and quantity of local resources

2.2 Appropriate access to cultural resources are supported and recognised by local and/or national rules

2.3 Customary rights and tenure are supported by national or regional-level laws

2.4 Legal rights are known, respected and practiced

2.5 Customary rights and responsibilities are locally known, respected and practiced

2.6 Communities are able to access resources they are entitled to based on social relationships including kinship

2.7 Local authorities are able to manage or resolve conflict over resources

2.8 Knowledge of culturally significant places, sites, landscapes, and species

3 - Sustainability management

Sustainability management includes all processes and structures involved in extractive and non-extractive resource use, sustainability, and enforcement of rules, norms, and actions collectively involved in management of natural/cultural resources. Management coordinates, balances, and accounts for multiple resource users and uses of a place based on the best available knowledge which may stem from multiple sources. Sustainability management allows for responsiveness, accountability, prosperity, and empowerment.

3.1 Presence of a local sustainability ethos

3.2 Presence of a national sustainability ethos

3.3 Relevant boundaries are well-defined (i.e. land or seascape units, community boundaries, use-rights, decision-making processes)

3.4 Knowledge of socio-ecological connections, interdependence, and feedbacks

3.5 Stakeholders and stakeholder groups are appropriately identified

3.6 Decision makers and decision-making processes are well defined

3.7 Stakeholders are involved in decision making as appropriate, and decisions reflect local and traditional values

3.8 Equitable decision-making outcomes within or across social groups

3.9 Agency across local, regional, and national scales

3.10 Interactions between institutions are coordinated, both within the organisation and with others

3.11 Accountability across institutions and stakeholders

3.12 Transparent management, governance systems, or governance norms

3.13 Resource planning and management is targeted towards sustainability

3.14 Local compliance with resource management rules

3.15 Presence and implementation of appropriate consequences to rule breaking (relative to local norms)

3.16 Presence and implementation of conflict resolution mechanisms

3.17 Sustainable management of land and seascapes

3.18 Local perceptions of management outcomes

3.19 Presence of adaptive practice (practices informed by evidence, knowledge, experience)

3.20 Secure and sustainable funding or resources for sustainability management

4 - Connectedness to people and place

Connectedness to place has strong bearing on cultural identity, rootedness and belonging, sense of responsibility and stewardship, social engagement and natural resource management. Connectedness to place encompasses historical, physical, emotional and/or spiritual bonds between people and their local environment. It is often informed and driven by knowledge of events and history, and experiences of survival and thriving in place. Connection to people includes relationships based on material (e.g., food, resources, land) or immaterial (e.g., trust, labor, knowledge, time, social alliances) circulation among individuals and within and across households and communities. A highly-connected system is one in which there is trust, cohesion, respect, and a high degree of connectedness to place.

4.1 Knowledge of traditional place names or landscape terms

4.2 Local perceptions of ecological and environmental risks

4.3 Knowledge and practice of social and cultural norms related to place-based practices

4.4 Connections within and between communities and social groups

4.5 Knowledge and practice of individual and collective rights and obligations towards people and place

4.6 Knowledge and practice of genealogical connections related to rights, access, and management of land and seascapes

4.7 Relationships based on customary/familial connections across locations

4.8 Reciprocity and exchange within and between communities

4.9 Reciprocity between people and place

4.10 Cooperation and social cohesion

4.11 Intergenerational connections including practices of respect

4.12 Connection to ancestors

4.13 Religious or spiritual practices and connections to entities (living and non-living)

4.14 Makeup and extent of migration, diaspora, and other forms of mobility.

4.15 Effects of environmental, social and cultural change on identity

4.16 Engagement/activism in maintenance of place (local, national, or international)

5 - Indigenous and local knowledge, skills, practice, values, and worldviews

Indigenous and local knowledge, skills, practices, values and beliefs are dynamic, adaptive and transmitted across and between generations. They are embedded within a worldview and ethos, and often include spiritual connections to place, including to specific species, landscapes and ancestors.

5.1 Use of local biodiversity in cultural practices

5.2 Knowledge and practice of stories, songs, chants, and dances

5.3 Use and vitality of local language(s)

5.4 Knowledge and practice of culturally significant social interaction norms

5.5 Inter- or intra-generational transmission of knowledge, skills, practice, values, and belief

5.6 Innovation in knowledge and practice based on tradition

5.7 Indigenous and / or local knowledge are protected by legistlation, where appropriate (i.e. intellectual property rights)

6 - Education

Access to knowledge, networks and qualifications from formal educational systems includes appropriate and contextualized sources of knowledge, well trained and supported educators, and clean, safe, and inclusive facilities. This theme also includes scientific and technical information that may be useful to communities, such as for sustainable resource management, waste management, health and wellness, biosecurity etc. This theme notes that local forms of knowledge described in other themes play significant roles in education.

6.1 Quality of formal education

6.2 Access to and use of formal education pathways

6.3 Role of local knowledge in formal education

6.4 Role of local language in formal education

6.5 Local beliefs or values towards formal and informal education

6.6 Diverse (formal and informal) learning opportunities

6.7 Role of intergenerational knowledge transmission from community elders in formal and informal educational settings

6.8 Access to and use of vocational training

6.9 Access to and use of technical and scientific information

7 - Healthy people

Physical, emotional, spiritual, and mental health are critical components of the wellbeing of individuals, families, and communities and may be reflected in adaptability or resourcefulness in response to change. Knowledge of what supports healthy people exists across multiple dimensions of wellness.

7.1 Condition of physical health

7.2 Condition of spiritual health

7.3 Condition of emotional health

7.4 Condition of mental health

7.5 Self-sufficiency and resourcefulness of individuals and collectives

7.6 Adaptability or capacity to respond to shorter-term impacts (e.g. natural disasters) or longer-term impacts (e.g. climate change)

7.7 Individual or collective security and safety, especially related to perceived climate, ecological, or environmental risks

7.8 Health and wellness knowledge from diverse sources

7.9 Familial or community-based support for individual or collective health

8 - Access to Financial Resources, Infrastructure, and Services

The ability to access banks and credit, financial aid, and grant funding opportunities for communities to support activities they consider important to their wellbeing. This could include development of livelihood opportunities, conservation programs, and strengthening of connectivity. Where communities perceive a need, this may include proximity to roads, public transportation, water supplies, waste management, access to civic infrastructure (clinics, schools, and government offices), communication systems (phone networks, internet), and access to markets for trade and sustainable tourism.

8.1 Presence and quality of infrastructure

8.2 Access to and use of physical infrastructure and services

8.3 Adaptable, flexible, and/or resilient infrastructure or services

8.4 Access to and use of affordable housing

8.5 Access to and use of health infrastructure and services

8.6 Access to and use of transportation infrastructure and services

8.7 Access to and use of communication tools and infrastructure

8.8 Equitable access to and use of financial resources and services in vulnerable populations

8.9 Access to and use of markets

8.10 Access to and use of green infrastructure

8.11 Access to and use of sustainable energy sources

8.12 Access to and use of diverse sources of income generation

8.13 Locally or nationally recognized equity across gender for access to financial resources and infrastructure

8.14 Local ability to control, manage, or influence external funding sources

8.15 Financial or other resources derived from community members living overseas, in diaspora, or who have migrated

CHAPTER 3. THE ROLE OF MARINE RESOURCES IN INTRAVILLAGE SHARING NETWORKS ACROSS A SOCIOECONOMIC GRADIENT IN FIJI.

ABSTRACT

Social networks are important for community resilience in social-ecological systems. After a disturbance, social networks can provide a mechanism for coping. Strong social networks also increase the likelihood of collective action for community-based natural resource management. Reciprocity, a defining characteristic of Pacific Island culture, is critical for building and maintaining social network ties. There is little information on how contemporary social, economic, environmental, and climate changes will impact social networks. In order to predict how these changes may affect social networks, it is essential to better understand the current structure of sharing networks, how different natural resources are shared within them, and whether there are certain harvesting practices that are more associated with sharing. We conducted social network analysis for sharing networks in 18 villages in Fiji across a socioeconomic gradient. About half of ties were reciprocated, in line with what may be expected for generalized reciprocity, which is common in the region. Further, villages formed two clusters based on network characteristics: villages on the main island where the capital is located and villages located on other islands. The cluster on the main island was associated with less cohesive networks and more cash and purchased good ties. Villages not on the main island were more cohesive and had a greater proportion of ties from natural resources. Mean household fishing frequency was positively correlated with and material wealth was negatively correlated with average degree centrality and average distance, both metrics of network cohesion. Finally, fishers reported sharing the largest proportion of their catch when using gillnets. This study provides an example for how social network analysis can be conducted to better understand sharing networks. Such information is critical for effective fisheries management, which in turn can sustain the fisheries shown to support cohesive sharing networks.

INTRODUCTION

Social networks, social-ecological resilience, and collective action

Social capital, including trust, reciprocity and exchange, common norms, rules and sanctions, and network connectedness, is an important component of social-ecological resilience (Adger 2003, Berkes et al. 2003, Pretty 2003). Network connectedness, in particular, is important, as reciprocal exchange can serve as a coping mechanism that enables recovery after a crisis (Campbell 2015), and can support collective action, which is needed for successful community-based natural resource management (Ostrom 1990, Pretty 2003).

Social networks can be secured or enlarged through reciprocity, a defining characteristic of many Pacific Island cultures (Hau'ofa 1994, McMillen et al. 2014). Unlike specific reciprocity in which items of relatively equal value are exchanged simultaneously, generalized reciprocity, in which there is not an expectation for an immediate exchange in return, is the dominant form of reciprocity found across the Pacific (Sahlins 1972). Surplus production in Pacific food systems has allowed for customary, ceremonial feasting in which much intercommunity sharing takes place (Campbell 2015). Feasts have provided an opportunity to distribute surpluses, which has mediated seasonal shortages and contributed to a diversified diet and resource base, beyond what the ecology of a place provided (Campbell 2015). Such resource sharing has been critical for maintaining social and political ties, and creating deficits, or obligations that can be called upon during times of need (Campbell 2009). Although weakened, intra- and intercommunity networks still aid in coping and recovery after major disturbances in the region (Le Dé et al. 2018).

Sharing networks and environmental change

Across the Pacific Islands, a substantial amount of coral reef resources is shared non-commercially (Kittinger 2013b, Vaughan and Vitousek 2013, Kittinger et al. 2015). However, social, environmental, and climate changes have caused worldwide declines in coral reef ecosystems (Gardner et al. 2003, Bruno and Selig 2007, Burke et al. 2011) and their associated fisheries (Newton et al. 2007, Mora et al. 2011). While it is expected that reef fish stocks will not be able to keep up with current consumption rates in most Pacific Islands by 2030, it is uncertain how the change in the resource base will affect sharing networks (Bell et al. 2009). For example, if coral reef resources from a coastal community have traditionally been traded for terrestrial resources from an upland community, how will a decline in reef resources influence this traditional sharing relationship? Will reef resources be substituted with alternative goods or will the relationship cease to exist?

Sharing networks and socioeconomic change

It is also uncertain how socioeconomic transformation--including urbanization, globalization, and integration into cash economies--has and will continue to impact sharing networks (Gurven and Jaeggi 2015). Studies have found commercialization of resources and market integration to be associated with reduced sharing (Behrens 1992, Ruddle et al. 1992, Baird and Gray 2014, Kasper and Mulder 2015). In some urban areas, food sharing has decreased, as wage earners have less time for fishing and farming and purchase most of their food (Mccubbin et al. 2017). In other places, wealth accumulation resulting from market integration has been associated with more sharing, as households with more income were more central in networks, likely because they could afford to share more than households solely dependent on subsistence (Dombrowski et al. 2013).

While rich ethnographies exist, there are few quantitative descriptions of food transfer patterns in the Pacific Islands (Gurven 2004). Especially lacking are studies of how sharing networks are being altered by changing social and environmental conditions. A more detailed understanding of the current characteristics of sharing networks and studies on how they are changing could help to maintain or increase social-ecological resilience by providing information on human behavior of resource extraction and exchange, necessary for natural resource management and conservation planning (Aswani et al. 2017).

There has recently been growing interest in using ecosystem service assessments for decision making in natural resource management (Ruckelshaus et al. 2015). Ecosystem service assessments seek to measure provisioning, regulatory, supporting and cultural benefits of ecosystem goods and services (Millenium Ecosystem Assessment 2005). However, cultural benefits, such as resource sharing, are hard to measure, so they are not usually considered in resource management planning (Pascua et al. 2017). Measures of cultural services provided by reefs often include recreation, aesthetic, and livelihood benefits, but do not capture important benefits, such as the building and maintenance of networks resulting from coral reef resource sharing (Moberg and Folke 1999). Although resource sharing through social networks is highly important to many communities, resource managers are not always informed of the benefits beyond food and resource provisioning that may result from sharing networks. Thus, resource management that does not take into account the benefits of social networks may have low compliance if resource users disregard management in order to continue the practices that allow them to share resources. Alternatively, resource management that obstructs sharing practices may weaken social resilience if such management is followed (Severance et al. 2013, Vaughan and Vitousek 2013). For example, certain harvesting methods may be more associated with sharing than others and restrictions on such methods may have low compliance if fishers value the benefits of using the gear to be greater than the risks resulting from noncompliance. Or, a spatial fishing ground closure which causes reductions in surplus catch may reduce fish sharing in a network.

Assessing social networks

Social network analysis (SNA) provides a method for quantitatively and qualitatively describing sharing networks (Borgatti et al. 2013). SNA can be used to understand properties of individual actors (Dombrowski et al. 2013), dyads (two connected actors) (Nolin 2010, Jaeggi et al. 2016), or whole networks (Mertens et al. 2015). SNA has been used to study different types of networks including sharing of food and natural resources (Nolin 2010, Dombrowski et al. 2013, Koster and Leckie 2014, Reedy and Maschner 2014, Mertens et al. 2015, Ziker et al. 2016), information (Crona and Bodin 2006, Cohen et al. 2012), or a combination of items in multiplex networks (Baggio et al. 2016). Of these types of networks, information sharing networks have been most studied for the purposes of natural resource management.

This study examines resource sharing networks using a whole network approach to 1) describe characteristics of intra-village sharing networks in coastal villages in Fiji, 2) identify the role of marine resources in sharing networks, and 3) examine differences in characteristics across a gradient of market integration.

Research Questions

1. What is the structure of coastal community sharing networks in Fiji?

We predict that generalized reciprocity will be common, as has been documented elsewhere in the Pacific Islands (Sahlins 1972, Severance et al. 2013). As such, social network metrics of reciprocity will be less than one in the sharing networks. Further, we predict that the majority of ties in the networks will be from sharing of natural resources.

2. What is the role of marine resources (fish and invertebrates) in sharing networks?

We predict that a large proportion of ties in sharing networks will be marine resource sharing, given the coastal locations of the villages and their close proximities to fishing grounds. Further, it is expected that a higher percentage of the catch will be shared from more efficient gear types, as sharing from larger yields can occur at a lower marginal cost (Kaplan and Gurven 2005). Further, we expect that in reciprocated ties, marine resources will be exchanged for terrestrial resources.

3. How do socioeconomic factors impact sharing networks?

We predict that households in villages closer to urban centers will be less connected and will have a smaller proportion of their ties from sharing of natural resources as a result of having more salaried employment and less surplus of natural resources harvested.

METHODS

Household surveys

This study was part of a larger project which sought to identify sociocultural drivers of social-ecological resilience in indigenous Fijian coastal villages (Dacks et al. 2018, Ticktin et al. 2018). The project surveyed households across 18 villages in four districts in Fiji from August to November 2014 (Fig. 3.1). Districts were selected to represent a range of sociocultural, economic, and ecological conditions.

Household surveys were conducted to understand household level socioeconomics, fishing and farming activities, ecological knowledge, resource sharing, and material assets (Table 3.1). In villages with fewer than 20 households, we invited all households to be surveyed. In larger villages, we surveyed a random sample of 20 households (Appendix 1 contains a list of villages with number of households and percentage surveyed). We conducted a total of 289 household surveys. All survey activities were approved by the University of Hawaiʻi Institutional Review Board, Fiji Ministry of Education, local Provincial Offices, and highest-ranking village elders within each community. Surveys were conducted with heads of households, which were defined as those who made household decisions. A household was defined as a group of people who regularly shared meals. Household interviews were structured surveys lasting approximately 45 minutes. Focus group discussions, participatory mapping exercises, and interviews with the village headmen were also conducted to better understand and triangulate village level characteristics of resource management and market connections. All interviews were conducted in the Fijian language.

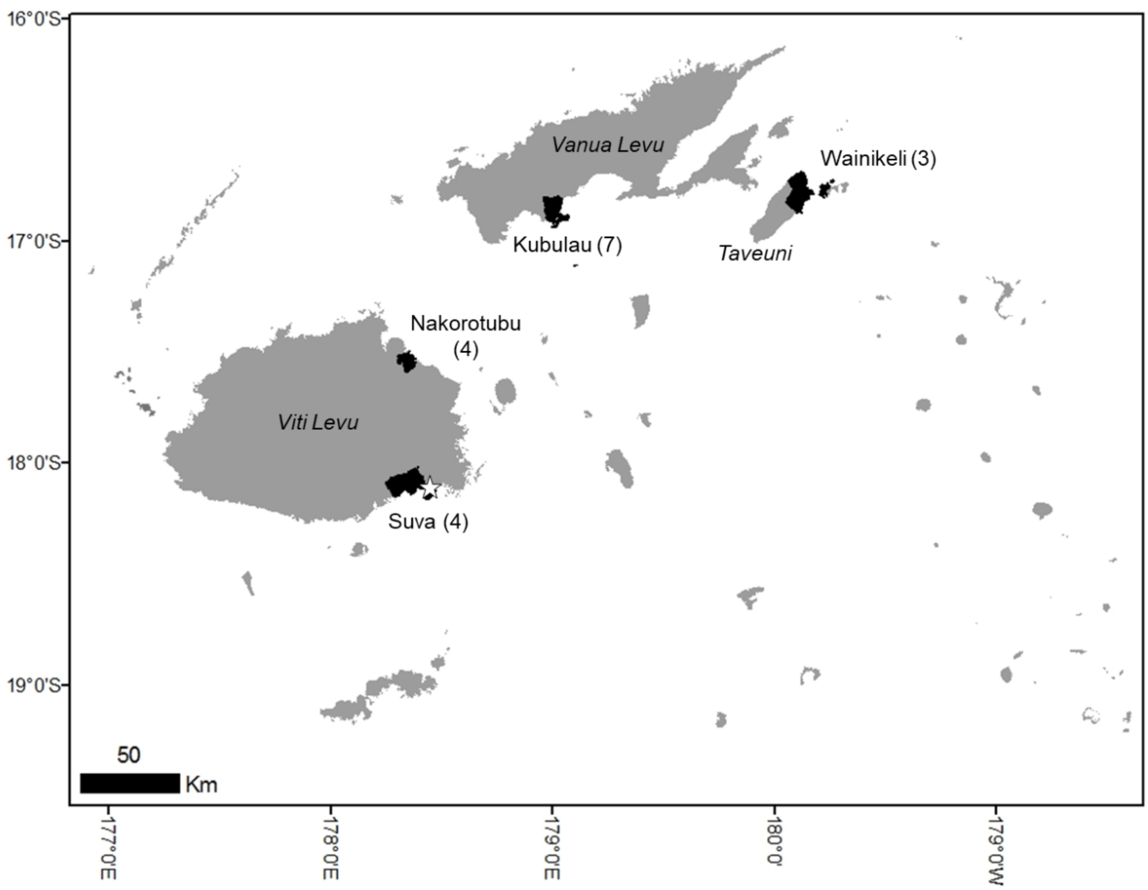

Figure 3.1. Map of the Fiji Islands. Italicized names mark the three largest islands in the archipelago. Areas shaded in black are the four study districts. The star indicates the location of the capital city, Suva. Numbers in parentheses denote the number of villages surveyed.

Social network surveys

A social network analysis of resource sharing between households in each village was conducted to measure social cohesion. In order to assess the whole network, we sampled ≥80% of households that were listed by the village headmen as being part of the village and were present in the village during the days of surveying. In villages where we surveyed ≥80% of households (described above), social network questions were simply incorporated into the household survey. In villages where we conducted household surveys with ≤80% of households, additional households were given only the social network survey, so that the total number of households that were given the social network questions was ≥80%. We conducted social network surveys in a total of 374 households. In each survey, respondents were asked to provide the names of the other households in which they received or gave resources (e.g., marine resources, terrestrial resources, prepared food, purchased goods, cash) within the previous two weeks. Respondents were asked to provide more than one name for each household listed, to ensure that households could later be identified from the village household list. In most surveys, a second surveyor verified the respondents' listed households in real time.

Social network analysis

The resources shared were classified into five categories: marine resources, terrestrial resources, prepared food, purchased goods, and cash. Most marine resources listed were fish. Terrestrial resources were mostly agricultural crops. Data were entered in a format that allowed link attributes to be identified (i.e., ties could be identified by the type of resource that was being shared). As such, the networks are actually multiplex networks, made up of layers of different types of sharing. Links were transformed into binomial format because the number of types of resources being shared was not of interest for this study. Because sharing could have been indicated by the giver or the receiver, we used the union of both responses, a method that minimizes the number of false negatives (Nolin 2010). However, this method also maximizes the number of false positives, but we assumed that respondents were more likely to be forgetful than dishonest (Nolin 2010). For each network, we calculated the proportion of ties represented by each resource type.

Social network calculations were done using UCINET software (Borgatti et al. 2002). Households that included non-permanent members of the village (e.g., teachers, nurses, religious leaders) were omitted from the analyses. In addition, isolates (i.e., nodes that were not tied to any other nodes) that were not interviewed were removed from all networks before analysis because it was likely that these households had been out of the village for the period of time that was asked about in the survey. We calculated two metrics of cohesion at the whole network scale:

average degree centrality and average distance (Table 3.2) (Borgatti et al. 2013). Degree centrality (the sum of the number of households the respondent's household shared with or received resources from) was used to measure the household’s centrality. For the purposes of this analysis, we calculated degree from an undirected graph because we did not need to distinguish between giving and receiving of resources. Average degree centrality was then calculated using the degree of the households within each village. Geodesic distance, or the number of edges between two nodes, was calculated for each dyad (also using an undirected graph). Since fragmentation was zero in all networks (i.e., all distances were defined), average distance was appropriate to use as an additional measure of cohesion (Borgatti et al. 2013). Reciprocity, or whether a giving link was matched with a receiving link, was calculated using the directed graphs of each multiplex network. We checked for marine for terrestrial goods exchange (or vice versa) in each reciprocal dyad.

Ordination

Nonmetric multidimensional scaling (NMDS) was used to produce two-dimensional ordinations to visualize the similarities in the network structures of each village. For the ordination, metrics were first standardized using Wisconsin double standardization and distances were based on Bray-Curtis similarity measures. Socioeconomic variables were then fit onto the ordination plot and the significance of their fits were tested using permutation methods. All ordination analyses were conducted using the vegan package (Oksanen et al. 2013) for R (R Development Core Team 2015). Network metrics were regressed against socioeconomic variables that had significant fits in the ordination.

Table 3.1. Descriptions of socioeconomic and network metrics. Network metrics were used in Nonmetric multidimensional scaling (NMDS) and socioeconomic metrics were overlaid onto the ordination. †not used in NMDS

Type	Indicator	Description	Form of metric used in ordination
Network	Degree centrality	The sum of the number of households the respondent's household shared with or received resources from. The degree centrality of each node in a network was calculated and averaged.	Average of households in each village
	Distance	The number of edges between two nodes. The distance between each node in a network was calculated and then averaged.	Average of dyads in each village
	Proportion of marine ties	The proportion of the total ties in the network that are from sharing of marine resources (e.g., fish, invertebrates, seaweed).	Proportion of whole network
	Proportion of terrestrial ties	The proportion of the total ties in the network that are from sharing of terrestrial resources (e.g., root crops, vegetables, coconuts, etc.)	Proportion of whole network
	Proportion of cash or purchased good ties	The proportion of the total ties in the network that are from sharing of cash or purchased goods (e.g., sugar, flour, soap, kerosene).	Proportion of whole network
	Reciprocity	The proportion of dyads that are reciprocated in the network (i.e., the proportion of dyads for which both a giving and receiving tie are present).	Proportion of whole network†
	Marine-terrestrial reciprocity	Of the reciprocated dyads, the proportion in which a marine resource is exchanged with a terrestrial resource.	Proportion of whole network†
Socioeconomic	Market integration	The number of times a member of the household visits a town annually.	Average of households in each village
	Livelihood diversity	The number of livelihood sources employed by the household, which includes sources of income and livelihoods which procure food and/or handicrafts for cultural offerings.	Average of households in each village
	Fresh seafood consumption	Average number of days per week the household consumes fresh seafood.	Average of households in each village
	Material wealth	Sum of the number of appliances owned by the household from the following list: radio, television, DVD player, mobile phone, generator, refrigerator/freezer, washing machine, laptop/tablet	Average of households in each village
	Fishing days	Sum of the number of annual days members of the household participated in fishing activities.	Average of households in each village
	Importance of fishing for village livelihoods	The proportion of households that listed the sale of marine resources as their top income source	Proportion of whole village
	Importance of agriculture for livelihoods	The proportion of households that listed the sale of an agricultural product as their top income source	Proportion of whole village

RESULTS

Structure of sharing networks

Network maps for each village are displayed in Fig. 3.2. In all of the village sharing networks, fragmentation was zero, meaning there are no unreachable households in any of the village networks. Sharing of marine resources, terrestrial resources, and prepared food made up most of ties; on average, each of these resource types made up approximately 30% of ties (Table 3.2). Among all networks, sharing was reciprocated in approximately half of the dyads (mean reciprocity = 0.54 ± 0.08 s.d.). Average distance, or the average path length, was 2.2 ± 0.6 s.d. and ranged from 1.3 to 3.4 (Fig. 3.3a). Average degree centrality, the average number of households a single household either shares or receives from, was 6.9 ± 1.8 s.d. and ranged from 4.2 to 9.5 households (Fig. 3.3b).

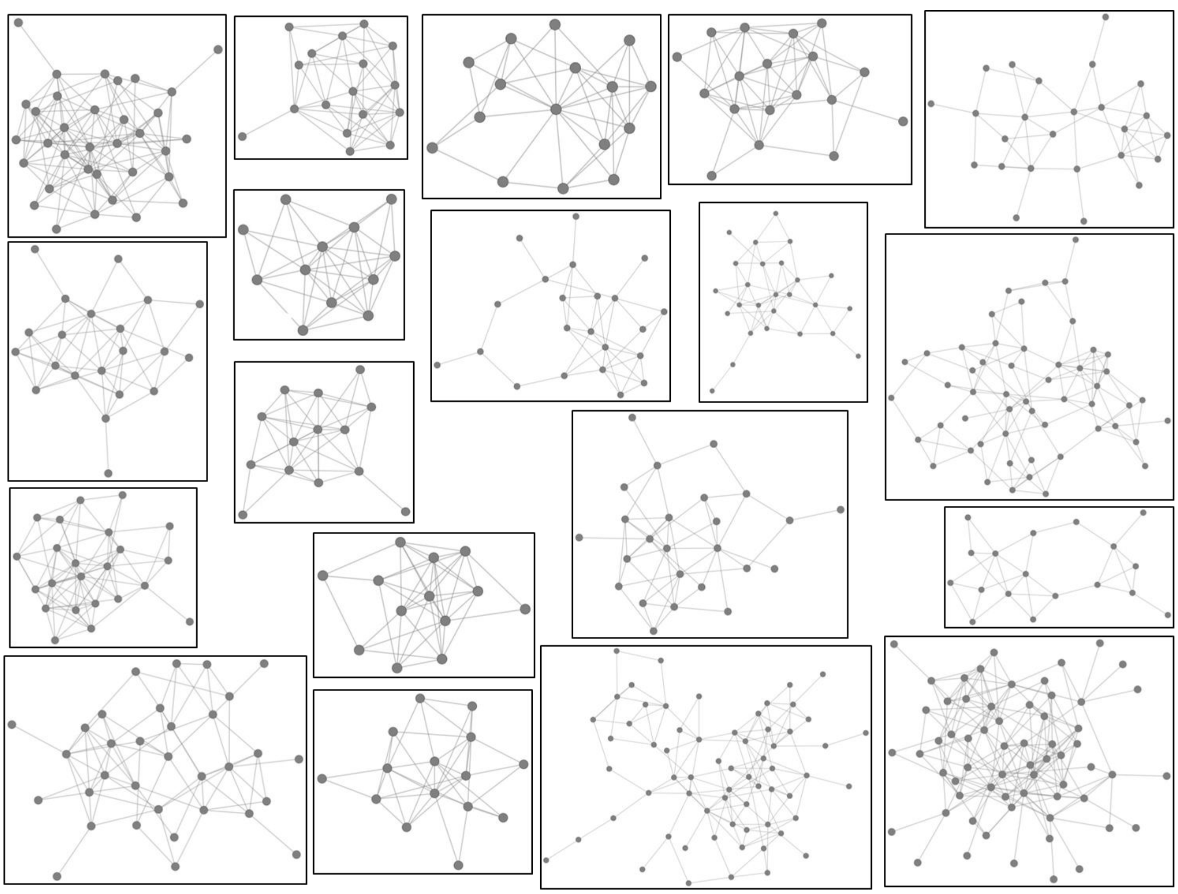

Figure 3.2. Undirected social network maps for each village. Each node represents a household and ties between nodes represent sharing of marine resources, terrestrial resources, prepared food, purchased goods, and/or cash.

Table 3.1. Summary of network metrics. Metric descriptions are provided in Table 3.1.

District	Village	Number of households	Mean degree centrality	Mean distance	Reciprocity	Number of ties	Proportion of marine resource ties	Proportion of terrestrial resource ties	Proportion of prepared food ties	Proportion of cash ties	Proportion of purchased good ties	Marine-terrestrial reciprocity
Kubulau	Kiobo	13	6.46	1.5	0.62	117	0.42	0.37	0.18	0.00	0.03	0.57
	Kilaka	35	9.06	2	0.48	293	0.25	0.30	0.27	0.01	0.18	0.35
	Navatu	25	9.48	1.8	0.58	201	0.46	0.32	0.14	0.00	0.07	0.64
	Raviravi	18	8.24	1.7	0.64	125	0.45	0.24	0.28	0.00	0.03	0.73
	Natokalau	15	7.73	1.7	0.57	135	0.35	0.41	0.23	0.00	0.01	0.76
	Waisa	12	9.50	1.3	0.59	142	0.22	0.32	0.35	0.01	0.10	0.70
	Namalata	19	7.68	1.8	0.47	135	0.41	0.16	0.36	0.01	0.06	0.57
Nakorotubu	Verevere	27	4.69	2.6	0.42	117	0.21	0.20	0.43	0.06	0.11	0.46
	Saioko	22	4.18	2.6	0.51	98	0.23	0.19	0.41	0.00	0.16	0.41
	Naocobau	17	7.25	1.7	0.60	124	0.27	0.12	0.29	0.01	0.31	0.28
	Namarai	30	4.88	2.4	0.36	102	0.19	0.28	0.24	0.02	0.27	0.50
Suva	Kalokolevu	74	5.87	3.4	0.55	340	0.18	0.31	0.36	0.03	0.12	0.37
	Waiqanake	58	5.96	3	0.50	305	0.21	0.22	0.30	0.02	0.26	0.51
	Togalevu	19	4.44	2.6	0.56	79	0.11	0.33	0.25	0.08	0.23	0.37
	Muaivuso	33	5.64	2.5	0.54	182	0.23	0.23	0.35	0.03	0.16	0.43
Wainikeli	Waitabu	21	5.62	2	0.68	96	0.32	0.47	0.52	0.02	0.15	0.51
	Vidawa	18	9.29	1.6	0.56	106	0.24	0.32	0.38	0.01	0.06	0.46
	Korovou	60	7.60	2.6	0.56	414	0.12	0.43	0.36	0.00	0.08	0.48

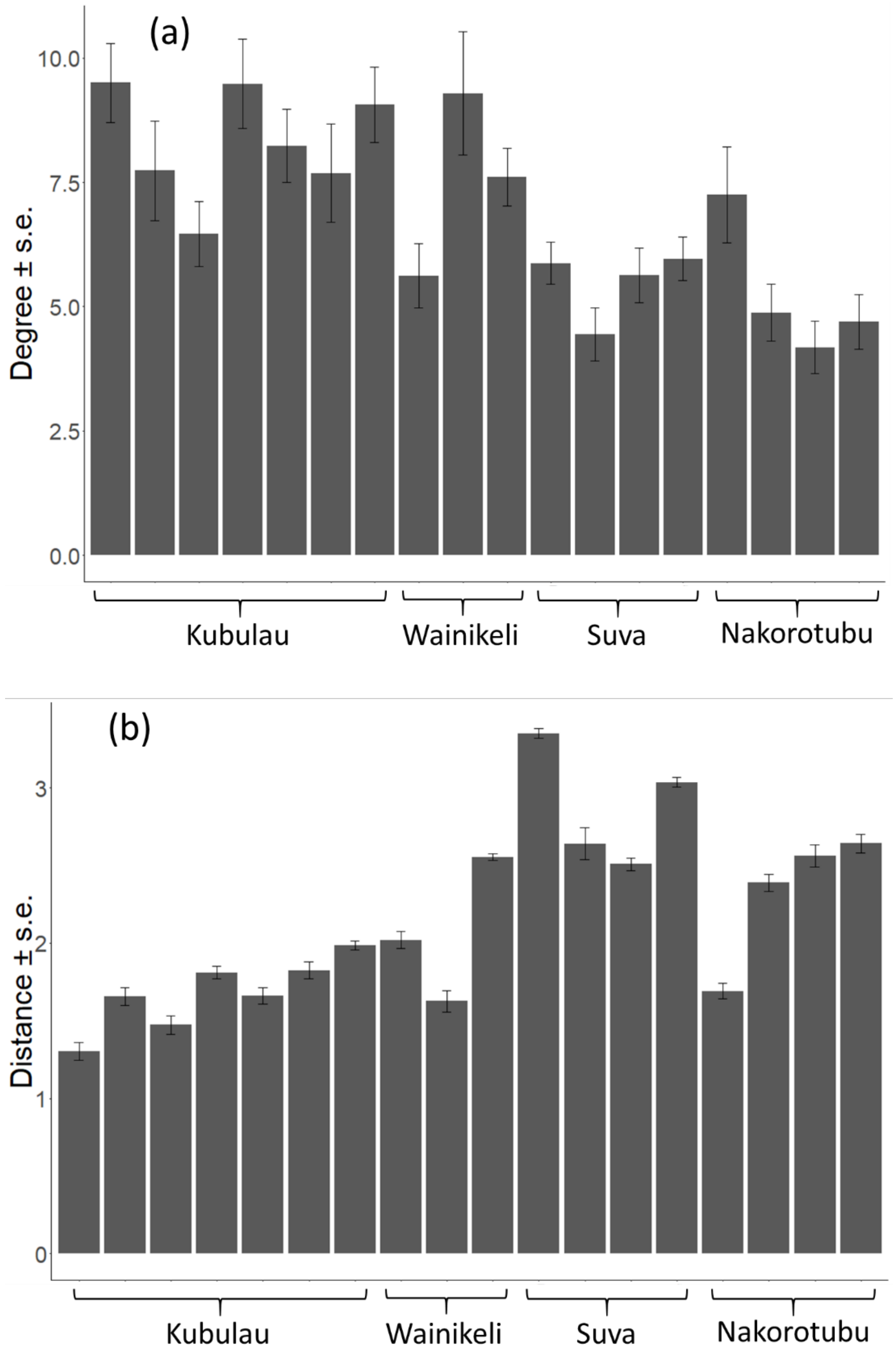

Figure 3.3. Barplots of a) average degree centrality and b) average distance in each village sharing network. Error bars indicate ± s.e.

Role of marine resources in networks

Of the three main resources shared (marine, terrestrial, and prepared food), marine resources made up the smallest proportion of ties, on average (0.26 ± 0.11 s.d.). However, we probably underestimated both marine and terrestrial resource ties because marine and terrestrial resources are likely to be used in prepared foods and counted instead in that category of ties. Forty-six percent of ties were of marine resource sharing in the village with the highest proportion of marine ties. When asked to estimate the disposition of typical catches using different gear types, fishers reported that 20-30% of their catch is shared, but this varies by gear type (Fig. 3.4). Gillnets have the highest estimated percentage of catch being used for sharing. Night spearfishing has the lowest estimated percentage of catch being used for sharing and is the gear with the highest estimated percentage used for selling. Among reciprocated ties, approximately half of dyads are marine resources exchanged for terrestrial resources or vice versa (mean= 0.51 ± 0.13 s.d.).

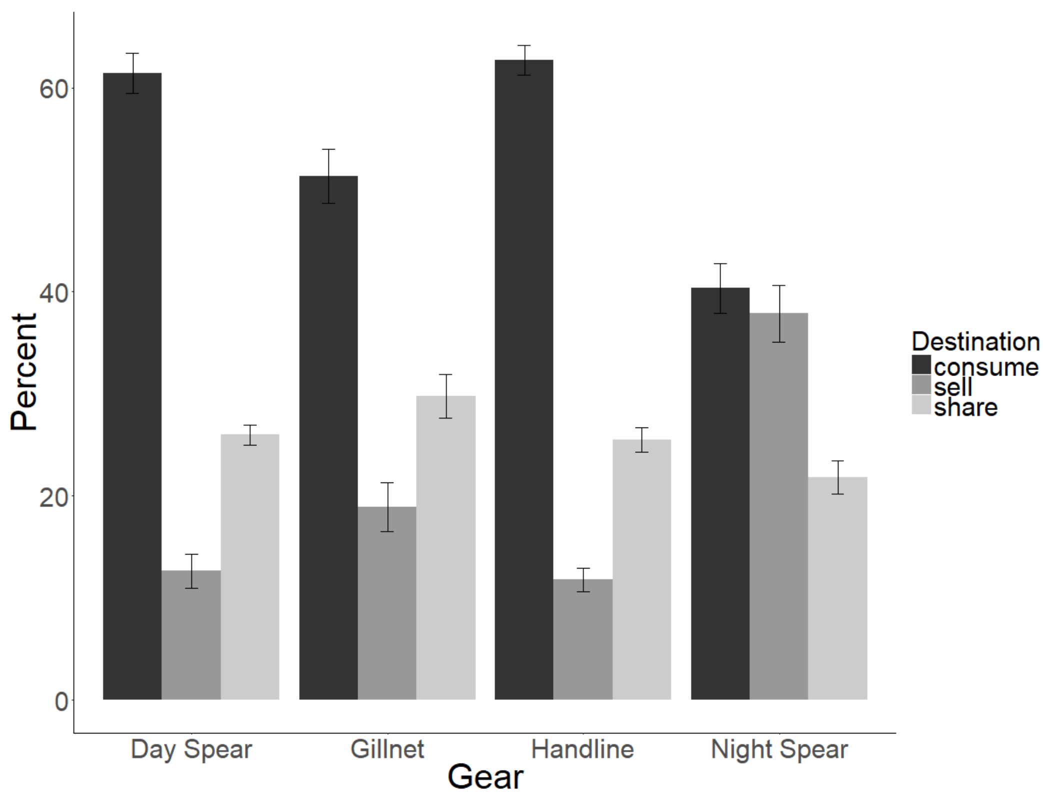

Figure 3.4. Barplots of disposition of catch for different gear types based on estimates across all sites. Error bars indicate ± s.e

Socioecononic factors influencing network characteristics

Village network metrics (average degree centrality, average distance, % of ties from marine, terrestrial, and bought/cash) were plotted in multidimensional space (Fig. 3.5). Two clusters were apparent with different characteristics: cluster 1 had higher average degree centrality, lower average distance, higher proportion of marine/terrestrial ties, and lower proportion of purchased goods and cash; while cluster 2 was less connected with more cash-based sharing. Cluster 1 is made up of all the villages in Kubulau and Wainikeli. Cluster 2 is made up of all the villages in Suva and Nakorotubu (both districts on the main island of Viti Levu). Village socioeconomic data was fitted onto the ordination (only significant variables shown, where $p < 0.05$), where smaller angles between arrows and social network metric represent stronger correlations and the length of the arrow is proportional to the correlation with the ordination axes. The overlaid socioeconomic data on the ordination show that villages with a higher mean annual household fishing days and higher mean household fresh seafood consumption are correlated with higher proportions of marine resource ties in their social networks and higher average degree centrality. Households with higher material wealth and market integration are more correlated with larger average distance metrics and a higher proportion of bought resources and cash in their social networks.

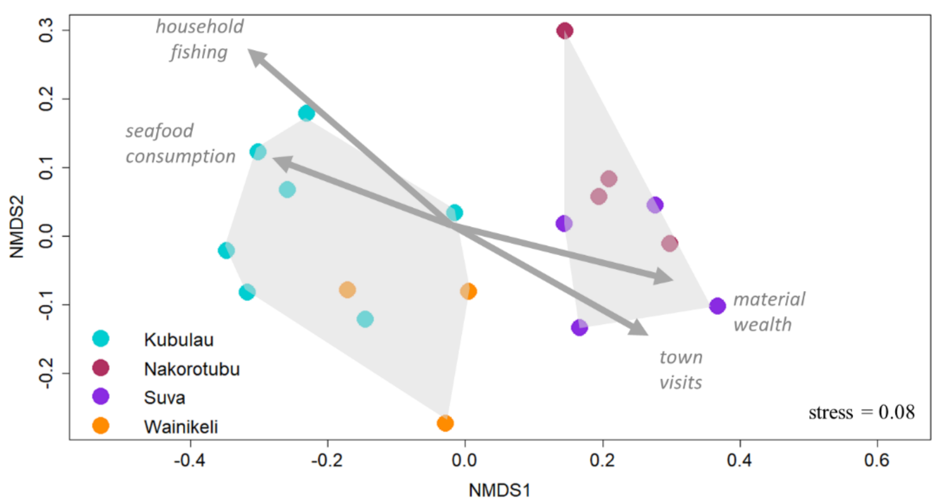

Figure 3.5. NMDS plot of networks characteristics (black text) with significant village socioeconomic conditions fitted as environmental variables (blue text). District in which the village is located is indicated with different colored points.

Mean annual fishing days was significantly, positively correlated with both average degree centrality ($p < 0.01$, $R^2 = 0.35$) and average distance ($p < 0.01$, $R^2 = 0.37$) (Figs. 3.6, 3.7). Mean material wealth was significantly, negatively correlated with both average degree centrality ($p = 0.02$, $R^2 = 0.29$) and mean network distance ($p = 0.01$, $R^2 = 0.33$) (Figs. 3.6, 3.7). Additionally, average distance was significantly, positively correlated with mean market integration ($p<0.01$, $R^2 = 0.37$) and mean fresh seafood consumption ($p = 0.01$, $R^2 = 0.33$) (Fig. 3.7).

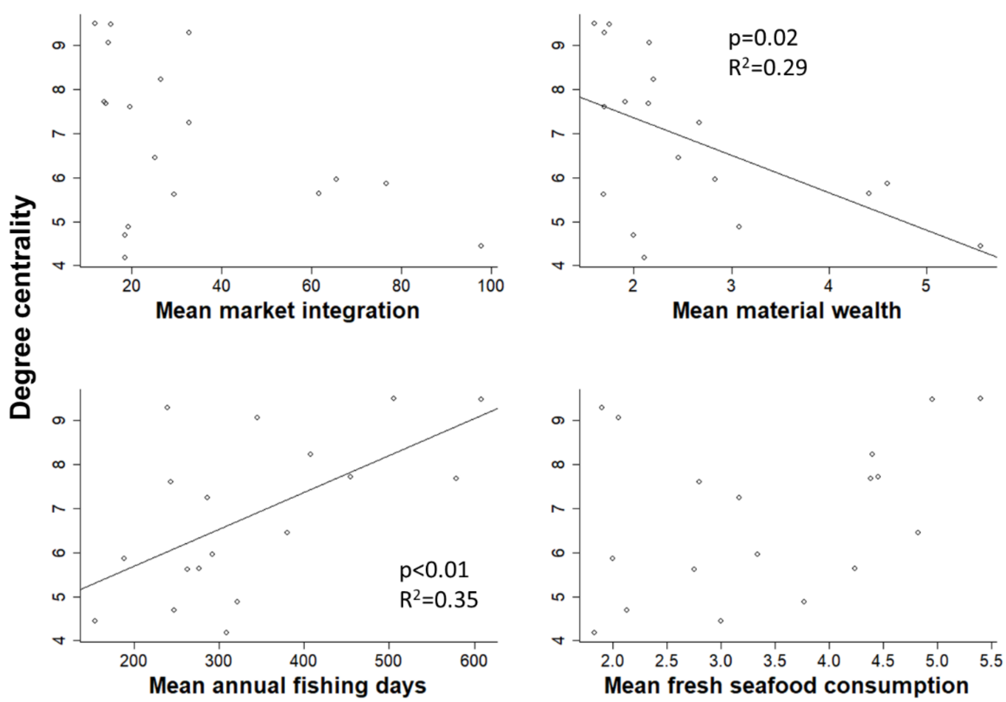

Figure 3.6. Village level socioeconomic characteristics as explanatory variables for average degree centrality.

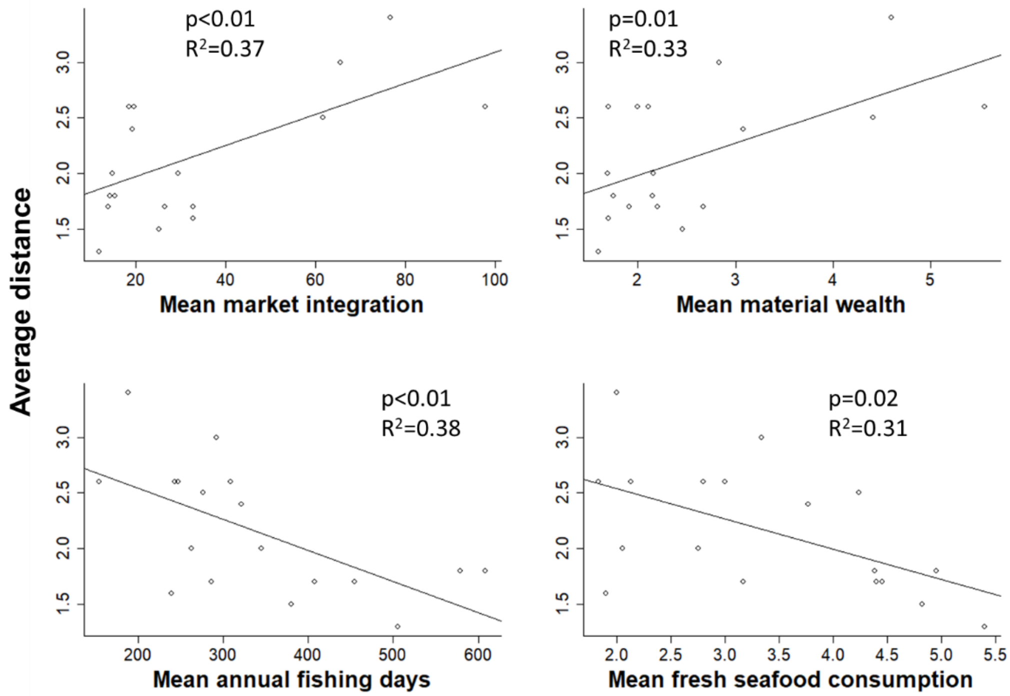

Figure 3.7. Village level socioeconomic characteristics as explanatory variables for average distance.

DISCUSSION

The goal of this study was to better understand the current structure of sharing networks, how different natural resources are shared within them, and whether there are certain fishing practices that are more associated with sharing. The results can help guide resource management planning for social-ecological resilience in the face of socioeconomic and environmental changes.

Reciprocity

The range of reciprocity values measured in this study (0.36-0.68) is slightly higher than the range observed in food sharing networks throughout South America (0.2-0.5) (Kaplan and Gurven 2005), though the average of our networks (0.54) is lower than a food sharing network in coastal Indonesia (0.67) (Nolin 2010). In networks where generalized reciprocity is observed, it is expected for reciprocity to be less than one because there is flexibility in both the timing and equivalency of returns. Thus, it is possible that a return of a gift was not observed in the limited time period that we asked about (two weeks) and/or a gift in return may not have been one of the material resources that we asked about. For example, in Tsimane' communities in Bolivia, households may provide labor, childcare, or sick care in return for meat (Jaeggi et al. 2016). In Hawai'i, fish is still shared with households that provided child care, even after the children are grown (Vaughan and Vitousek 2013). In the Pacific, maintaining sharing "deficits" is important for maintaining political, social, and kinship ties that can be called upon for help in times of need, such as after natural disasters (Sahlins 1972, Campbell 2015).

In the reciprocal ties in which marine resources were one of the goods shared, terrestrial goods were the goods exchanged in about half of dyads. Again, it is possible that additional exchanges were not observed because they occurred beyond the two-week period we asked about. It is likely that marine-terrestrial reciprocity is greater in intervillage networks, as specialization is expected to be greater at the village level than the household level. In informal focus group discussions in each village, respondents mentioned specific resources for which their village was known, consistent with descriptions of *solevu* sharing networks in Fiji, in which specialization was based on the ecology of the islands on which villages were located (Thaman 1990). For example, one of the villages in this study is located slightly upland, in close proximity to freshwater streams and is known for having abundant freshwater clams, while other villages right on the coast are more known for certain species of fishes, and others villages mentioned being known for their yams. In many of these discussions, however, respondents mentioned that while they still engage in inter-village exchange with similar villages as they have in the past, the exchanged resources are no longer the "known for" resources and, in some cases, have been replaced with purchased goods (i.e., kerosene, sugar, soap) and/or cash.

The future of coastal sharing networks with declining fish stocks

Fishing frequency is a strong predictor of two measures of social network cohesion. This is not surprising, because households that fish more frequently are likely to have larger catches, and having a "larger packet size" has been shown to be a strong predictor of sharing because sharing can occur at a lower marginal cost (Kaplan and Gurven 2005). For example, hunting households that are high meat producers in sharing networks in South America share more meat than hunting households that produce less meat (e.g., Jaeggi et al. 2016). For the same reason, it makes sense that gillnet harvests are the gear type with the greatest estimated proportion shared, as gillnets have a high gear efficiency, with a high catch per unit effort in Fiji (Dacks et al. 2018). Further, gillnets require multiple people to operate, so catches are likely to be shared with those individuals who helped set the net, and/or bring in the catch (i.e., cooperative acquisition described by Kaplan & Gurven 2005). Finally, gillnets are one of the more expensive gear types used in Fiji, that often need to be used together with a boat. If a net is owned by a household that is not conducting the fishing, the operators may share a portion of the catch with the net-owning household. If a boat was borrowed for the gillnet use, a portion of the catch may also have been shared with the boat owner. However, gillnets are a gear associated with causing physical damage to coral reefs (Mangi and Roberts 2006), have a low species and size selectivity (Dalzell et al. 1996), and have been documented to catch species that are important for coral reef resilience (Cinner et al. 2009c).

Globally, coral reef fisheries are experiencing major declines (Newton et al. 2007, Mora et al. 2011) due to social, environmental, and climate changes (Gardner et al. 2003, Bruno and Selig 2007, Burke et al. 2011). Current reef fisheries management practices to sustain coral reefs and their fisheries include spatial and seasonal closures, species restrictions, size restrictions, and gear restrictions (Jupiter et al. 2014a). It is crucial that any resource management planning takes into account not just provisioning benefits, such as food and income, provided by resources but also cultural benefits that resources provide in building and maintaining social networks. Otherwise, management is not likely to be effective and may threaten social cohesion. For example, in American Samoa and the Commonwealth of the Northern Marianas Islands, legislation allowing for traditional, subsistence, and recreational fishing and prohibiting fishing for sale, barter, and trade threatened social networks by considering customary sharing as “trade or barter” (Severance et al. 2013). In this study, we observed gillnet catches to have the highest estimated proportion used for sharing, compared to other gears. Gillnets may seem like an appropriate gear to restrict, but based on our findings, banning gillnets could also result in less fish sharing. Alternatives to a gillnet ban could be restricting small mesh size gillnets, as is the case in some community management plans (e.g., WCS 2012).

Regardless of management, it is likely that reef resources will decline in the near future due to climate change impacts (Bell et al. 2009). However, social-ecological systems are adaptive, and there is evidence to suggest that sharing networks can still thrive despite changes to the resource base (Baggio et al. 2016). For example, tuna and coastal pelagic fish (e.g., *Decapterus spp*., *Selar crumenophthalmus*) now play important roles in several Pacific Islands, where coral reef fish have historically been dominant resources in sharing networks (Glazier et al. 2013, Severance et al. 2013, Vaughan and Vitousek 2013, Kittinger et al. 2015, Roeger et al. 2016).

The future of coastal sharing networks with increased market integration

In this study, the villages on the same island as the capital city were associated with a lower proportion of ties from natural resources in their sharing networks, higher proportion of ties from cash and purchased goods, and had lower measures of network cohesion. This result indicates that networks with higher market integration may not simply keep the same structure and substitute natural resources for purchased goods. Instead, it appears as though market integration both weakens the structure of the network and alters the goods being shared. This observation is consistent with observations in urban Funafuti on the Pacific Island of Tuvalu, where imported foods are not shared as extensively as local foods (Mccubbin et al. 2017).

However, a lower level of intracommunity sharing does not necessarily mean that a household is more vulnerable. For example, in urban areas where wage earners have less time for fishing and farming and purchase most of their food, food sharing may actually threaten food security if a household purchases a higher quantity of food (i.e., so there is a surplus that can be shared) at the expense of it being of lower nutritional value (Mccubbin et al. 2017). In addition, adaptive capacity could actually increase if lower levels of intracommunity sharing result from more diversified livelihoods and/or more sharing with individuals or groups outside the community (Baird and Gray 2014).

Finally, although households may not have high measured market integration (i.e., they had a low number of annual trips to town), they still may have been indirectly connected to markets via intermediaries. Middlemen purchasing marine resources can be widespread, allowing for the substantial sale of fish and invertebrates in areas far from town (Crona et al. 2010, Ferrol-Schulte et al. 2014, Dacks et al. 2018). In this study, we found surprisingly high cohesion even in villages where fish are documented to be sold regularly to middlemen (Dacks et al. 2018). This suggests that market integration does not always result in decreased sharing. Similar observations can be seen in Hawaiʻi, where market integration is high, and where the majority of nearshore fisheries catch is used for household consumption or sharing, not selling (Delaney et al. 2017). Similarly, Poe et al. (2015) found that profit maximization is not a dependable predictor of subsistence behaviors, as fishers do not always maximize profits when determining the sale and subsistence portions of their catch.

CONCLUSION

Marine resources are important goods in sharing networks and resource management that takes sharing network properties into account should be prioritized to ensure the sustainability of resources to be used not only for subsistence and sale, but also as material to be gifted in sharing networks. The safeguarding of social networks has the potential to maintain collective action and increases the chances of social-ecological recovery after a disturbance.

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CHAPTER 4. DRIVERS OF FISHING AT THE HOUSEHOLD SCALE IN FIJI.

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ABSTRACT

Coral reefs sustain millions of people worldwide, yet in recent years, social, environmental, and climate change have caused major declines in coral reef fisheries. Small-scale coral reef fisheries research has largely focused on community-level drivers of fishing, ignoring the heterogeneities that exist within communities. We used social-ecological indicators from 20 coastal villages in Fiji to identify potential fine-scale, context-appropriate drivers of estimated household fish catch. Indicators were developed based on a review of the literature, discussions with local experts, and a pilot study. Using structural equation models, we found that importance of fishing to income, household fish consumption, livelihood diversity, travel time to market, and coral reef area all positively affect estimated household-level fish catch. Our results contrast with findings from other larger scale studies by identifying that households further from markets had higher fishing frequency. We highlight the role of middlemen in these small-scale fisheries, who have been largely overlooked as drivers of fisheries catch. Our findings emphasize the need for household-level analyses to better understand the complexities in coral reef social-ecological systems to more effectively manage small-scale fisheries in communities.

Key words: coral reef fisheries; livelihoods; local ecological knowledge (LEK); market access; social-ecological systems; social network analysis; subsistence fisheries

INTRODUCTION

Fish play a significant role in the resilience of Pacific coral reef social-ecological systems. On the human side, fish provide a major source of protein (Bell et al. 2009, Teh et al. 2013, Charlton et al. 2016), are shared in complex social networks (Severance et al. 2013, Vaughan and Vitousek 2013, Kittinger et al. 2015), are central to cultural identity (D'Arcy 2006, Friedlander et al. 2013, Veitayaki et al. 2014), and provide an important source of income (Moberg and Folke 1999, Teh et al. 2009). On the ecological side, herbivorous fishes help keep algal levels in check (Hughes et al. 2007), maintaining open space for recruitment of reef-building taxa, which in turn enhances the resilience of coral reef ecosystems (Cheal et al. 2010). The preservation of higher trophic levels (e.g., sharks, groupers, jacks) helps maintain ecosystem balance (Heithaus et al. 2008). Coral reefs with lower densities of top predators have been found to have higher numbers of coral-eating crown-of-thorns starfish (*Acanthaster planci*; Dulvy et al. 2004) and lower coral and coralline algae cover (Sandin et al. 2008).

Social, environmental, and climate change have caused worldwide declines in coral reef ecosystems (Gardner et al. 2003, Bruno and Selig 2007, Burke et al. 2011) and their associated fisheries (Newton et al. 2007, Mora et al. 2011). Recent studies have made important contributions to our understanding of human dimensions of coral reef social-ecological systems. Human population density has been documented as a positive driver of fishing pressure (Williams et al. 2008, Brewer et al. 2012) and negative driver of reef fish biomass (Mora 2008, Sandin et al. 2008, Cinner et al. 2009). Other social factors that affect fishing pressure and/or reef fish biomass include socioeconomic development, e.g., the presence of certain infrastructure and facilities (Cinner et al. 2009, Brewer et al. 2012) and fisheries management regime, i.e., traditional management, comanagement, national parks (McClanahan et al. 2006). Recent research has found an increase in fishing pressure (Brewer et al. 2012) and lower fish biomass (Cinner and McClanahan 2006, Cinner et al. 2013, Maire et al. 2016, McClanahan et al. 2016) closer to markets. Though our understanding of how social systems are linked to coral reef ecosystems has greatly improved, our understanding of what drives household-level fish catch is still lacking because the social measures that have been examined as drivers of fishing pressure are at the geographic community level or higher, e.g., human population density or presence of large-scale infrastructure such as schools and roads. Human communities, whether defined spatially or by social structure, are not homogeneous (Agrawal and Gibson 1999), and the variation of interests and behaviors of individuals or households within communities influence the state of resources (Kramer et al. 2009). Because behaviors can be managed, it is especially important to understand what influences individual and household-level fishing activities (Aswani et al. 2015).

In the Pacific, where human well-being is especially dependent on natural assets and kinship ties (Pascua et al. 2017, Sterling et al. 2017), factors that influence household fishing levels may include dependence on fish as a food source, importance of fishing to income, livelihood diversity, local ecological knowledge, and connectedness. Fish consumption in the region is high, though with recent urbanization, there has been a shift to an increasingly modern diet of imported goods and less local foods, including fresh fish (Charlton et al. 2016). One reason for this shift has been the increase in salaried incomes in urban areas, which is associated with a reduced dependence on fishing (Charlton et al. 2016). However, although there may be reduced dependence on fishing at the household level, other studies have found greater total fishing pressure closer to towns (Brewer et al. 2012). Proximity to markets or towns, commonly used as an indicator of market access (Brewer et al. 2012, Maire et al. 2016), has included measurements beyond simply distance, such as population size (Brewer et al. 2009), but is not a complete measure of access to market because it has not taken into account transportation availability and does not consider all forms of monetary transactions. Middlemen, for example, are important intermediaries who provide links to markets, reducing the time and effort of fishers to market their catch. Although the role of middlemen has been documented in small-scale fisheries (Crona et al. 2010, Brewer 2011, Mangubhai et al. 2016), middlemen have been largely overlooked as drivers of fisheries catch. Because fish are not always sold in towns, a measurement of fishing income may be a better indicator of the influence of market integration on household fishing.

Artisanal fishers, like many rural residents in developing countries, have a high number of livelihood strategies (Allison and Ellis 2001, Cinner et al. 2010). The relationship between livelihood diversity and household-level catch is less certain. Although scenario-based studies show that increased livelihood diversity may increase a fisher's willingness to exit a fishery, there is a lack of evidence to show that fishers with more livelihoods have lower fishing effort

(Brugère et al. 2008, Cinner 2014). In addition, in the Pacific, given the high levels of subsistence activities, it is important to consider all sources of livelihood rather than just those generating income (Campbell 2015). For example, households may partake in mat weaving not for selling, but for customary exchange or to contribute to cultural functions.

Local ecological knowledge (LEK) refers to knowledge systems encompassing world views, cultural practice, and beliefs that have developed over centuries and are constantly evolving (Berkes 1999). Examples from across the Pacific indicate that for centuries, LEK has influenced individual and community scale marine resource use (Johannes 1978, Veitayaki 2002). It is important to note that knowledge embedded within LEK systems has been used both to maximize efficiency of harvests (Foale 1998) and to restrict harvesting (Johannes 1978, Friedlander et al. 2013). Foale et al. (2011) highlight that applying knowledge for the purpose of conservation was never needed in places that were sparsely populated and did not experience resource depletions. Regardless of how LEK has been applied, there is increasing acknowledgement that LEK is invaluable for developing effective place-based natural resource management (Berkes et al. 2000, Poepoe et al. 2007, Thornton and Maciejewski Scheer 2012).

Resource sharing, including through reciprocal exchange, is one of the four important features of social capital identified by Pretty (2003). Resource sharing occupies a very important part of Pacific Island culture and facilitates maintenance of traditional linkages (Veitayaki 2002, Nabobo-Baba 2011, McMillen et al. 2014). In the context of these linkages, several studies have shown the extent and socio-cultural significance of fish sharing networks across the Pacific (Severance et al. 2013, Vaughan and Vitousek 2013, Kittinger et al. 2015). The spatial extent of exchange can be great and may stretch across island groups as in Micronesia, where coolers of reef fish are sent from outer islands to family members on the main islands (Oles 2007). In American Samoa and the Commonwealth of the Northern Marianas Islands, customary exchange was identified as a major driver of fishing effort (Severance et al. 2013).

We aim to better understand the drivers of household fish catch by asking (1) what direct and indirect social indicators drive household fish catch?; and (2) what is the role of proximity to town in influencing household fishing levels in areas in which middlemen are widespread? We address these questions using household-level, context specific, empirical data. We focus on Fiji where coastal communities are located in close proximity to reefs, communities have rights to manage these reefs (Matthews et al. 1998, Clarke and Jupiter 2010), and reef fisheries are highly important to local livelihoods (Teh et al. 2009). Despite their importance, many of Fiji's inshore reef fisheries are now threatened from overfishing, destructive and illegal fishing, and pollution, leading to socioeconomic hardship including loss of income and diet changes (Turner et al. 2007, Teh et al. 2009). In addition, road development, a government priority in the last decade, has greatly increased market access in many areas (Asian Development Bank 2015). As a result, stakeholders and managers are currently interested in better understanding drivers of fish catch in order to better manage marine resources throughout Fiji. We predicted that market access, LEK, livelihood diversity, seafood consumption, importance of fishing to income, reef area, and connectedness will be directly and indirectly correlated with estimated fish catch (Table 4.1, Fig. 4.1).

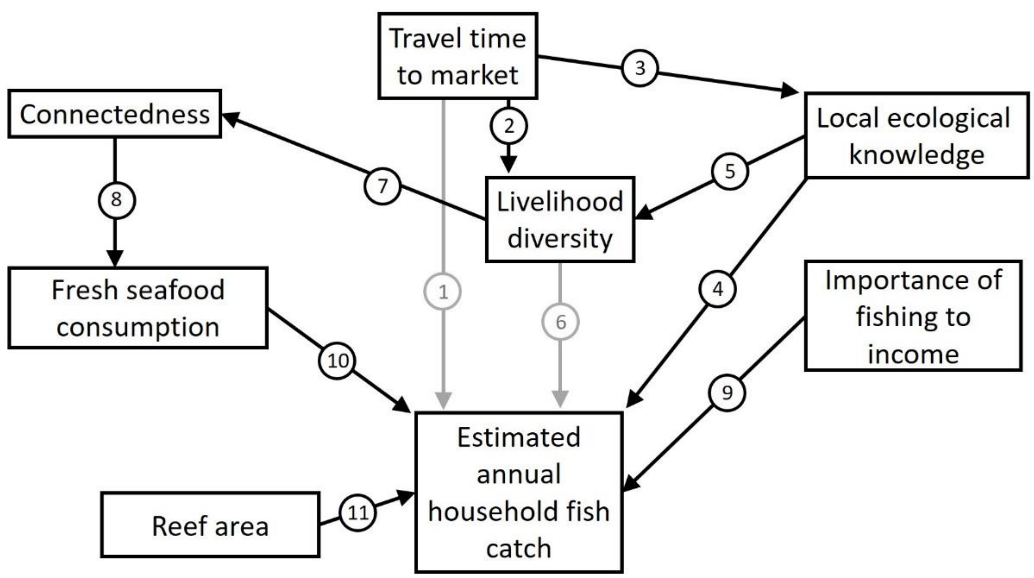

Figure 4.1. Hypothesized structural equation model of social ecological drivers of household fishing catch. Black arrows are positive and grey arrows are negative effects. Hypothesized links are described in Table 4.1.

METHODS

Study site

Fiji is an archipelago consisting of over 300 islands, many of which are surrounded by fringing and barrier coral reefs. The population is just under 900,000 and about half of the country lives in rural areas (FBoS 2007). Most of the indigenous rural population lives in villages that comprise one or more tribes (*yavusa*; Ravuvu 1983). Rural villages rely heavily on their terrestrial and marine natural resources for subsistence and sale (Rawlinson et al. 1995, WCS 2012).

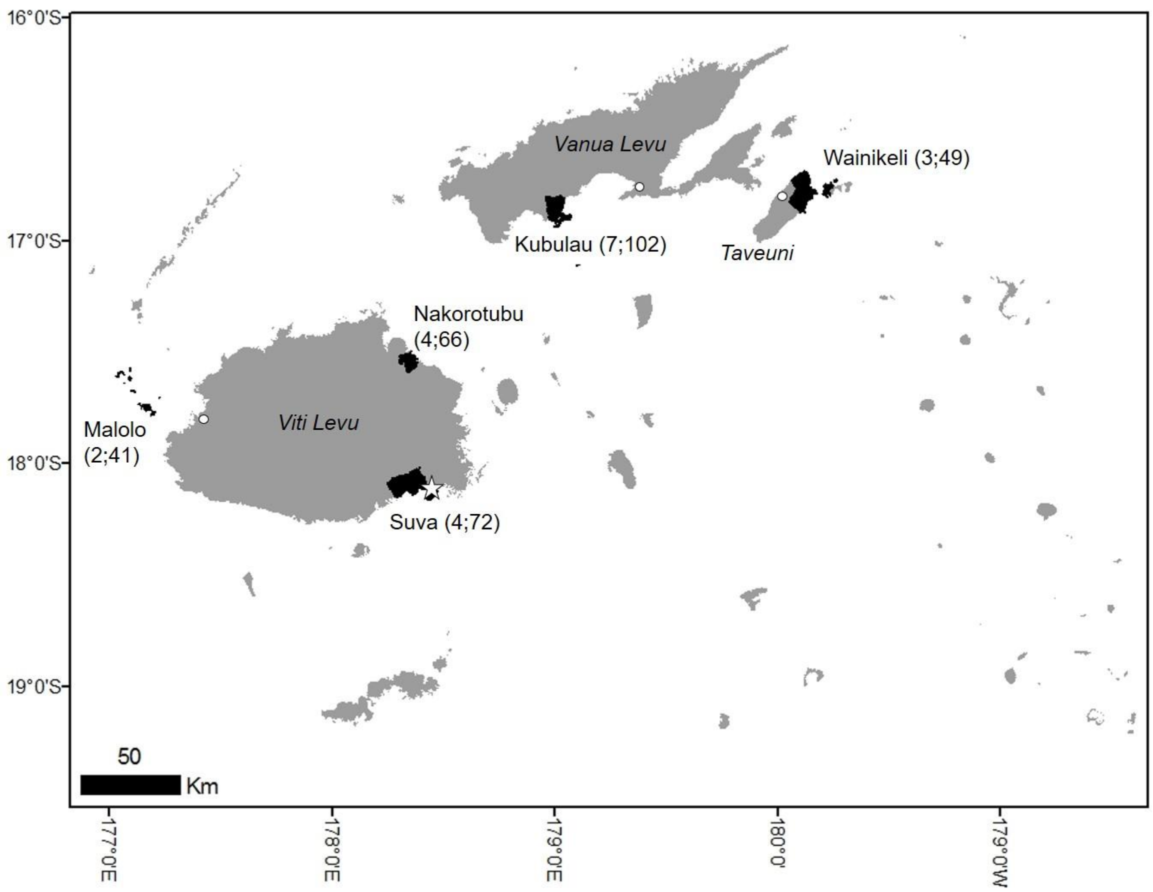

Figure 4.2. Map of the Fiji Islands. Italicized names mark the three largest islands in the archipelago. Areas shaded in black are the five study districts. Markets where villagers from the study sites visit to sell and buy goods are marked with circles (towns) and star (capital city, Suva). Numbers in parenthesis denote the number of villages surveyed followed by the number of households surveyed.

Although the national government recognizes the subsistence fishing rights, fishing grounds are legally owned by the national government with open access granted for subsistence with certain gear types, and fishing licenses are required for trade or sale (Matthews et al. 1998). However, customary fishing grounds (*qoliqoli*), extending to the outer reef, are informally divided into smaller units (*kanakana*) that are fished by single or multiple villages, with access granted by the chief of that village. Though not legally recognized, customary management over the *qoliqoli* and *kanakana* is still practiced in most rural areas in Fiji (Clarke and Jupiter 2010, Sloan and Chand 2016).

Urbanization, globalization, and integration into cash economies have all impacted traditional social structures and customary resource use. Access to markets has increased purchasing power, changing reliance on natural resources for food and income (Ravuvu 1988, Turner et al. 2007). School and church fees, medical and transportation costs, and purchase of imported goods has increased the need for income generating activities (Matthews et al. 1998). There is now less respect for the traditional roles of hereditary chiefs in mandating and enforcing natural resource management with recent national legislation and access to markets (Minter 2008, Jupiter et al. 2010, Sloan and Chand 2015).

Household surveys

To identify potential social drivers of fisheries catch, we conducted research in 20 indigenous Fijian coastal villages across five districts in Fiji from August to November 2014 (Fig. 4.2, Appendix 1). Districts were selected to represent a range of socio-cultural, economic, and ecological conditions.

In villages with fewer than 20 households, we invited all households to be surveyed. In larger villages, we surveyed a random sample of 20 households (Appendix 1 contains a list of villages with number of households and percentage surveyed). We conducted a total of 330 household surveys (Fig. 4.2). All survey activities were approved by the University of Hawai‘i Institutional Review Board, Fiji Ministry of Education, local Provincial Offices, and highest ranking village elders within each community. Surveys were conducted with heads of households, which were defined as those who made household decisions. A household was defined as a group of people who regularly shared meals. Household interviews were structured surveys lasting approximately

45 minutes. Questions covered topics including socioeconomics, fishing and farming activities, ecological knowledge, resource sharing, and material assets (Table 4.2). Focus group discussions, participatory mapping exercises, and interviews with the village headmen were also conducted to better understand and triangulate village-level characteristics of resource management and market connections. All interviews were conducted in the Fijian language.

Social network surveys

A social network analysis of resource sharing between households in each village was conducted to measure connectedness, an important component of social capital. To conduct the social network analysis, households in each village were asked to provide the names of the other households in which they received or gave resources (e.g., fish, crops, prepared food) within the previous two weeks (Appendix 2). In order to assess the whole network, we sampled ≥ 80% of households. In villages where we surveyed ≥ 80% of households with household surveys, these questions were simply incorporated into the household survey. In villages where we conducted household surveys with ≤ 80% of households, additional households were given only the social network survey, so that the total number of households that were given the social network questions was ≥ 80%.

Social network calculations were done using Visone software (Brandes and Wagner 2004). Degree centrality (the sum of the number of households the respondent's household shared with or received resources from) was used to indicate the household's connectedness. For the purposes of this analysis, we calculated degree from an undirected graph because we did not need to distinguish between giving and receiving of resources.

Social indicators

We measured a suite of social indicators in our household surveys based on a review of the literature and discussions with local experts from universities and nongovernmental organizations (Table 4.2). Survey questions that measured indicators of LEK were developed from a pilot study that was conducted in 2013 (Appendix 2). We calculated proximity to market as the distance along a road and/or boat path to town, as well as travel time to town and market trip frequency to take into account factors that are not represented in a simple distance measure, such as speed, frequency, and price of travel mode. Livelihood diversity was measured by the

Table 4.1. Descriptions and justifications of links in hypothesized structural equation model (Fig. 4.1). The path number refers to the labeled model paths in Fig. 4.1.

Path	Descriptions of hypothesized links	Justification in the literature for hypothesized link
1	Households that have better access to markets may be more inclined to sell a portion of their catch and thus fish at higher levels.	An increase in fishing pressure has been found closer to markets (Brewer et al. 2012).
2	Households that have better access to markets may have a higher chance of being formally employed in a full time position and thus not have the time or economic need to participate additional livelihoods.	Households in more densely populatied areas that were involved in formal employment had fewer supplementary occuptations (Cinner and Bodin 2010).
3	Households that have better access to markets may have lower levels of LEK.	Increasing market integration has led to a loss of local knowledge (Cullen et al. 2007) and breakdown in customary practices (Cinner and Aswani 2007).
4	Households with a greater knowledge of local fish may be using this knowledge to fish at higher levels.	LEK has been used to increase the efficiency of harvests (Johannes 1981) and maximize catches (Foale 1998). In Fiji, master fishers of the *gonedau* clan have been documented to have extensive knowledge of fish taxonomy (Thaman 2008).
5	Households with a greater knowledge of local fish may have higher levels of LEK in other areas which may enable them to have a higher number of livelihoods.	Fishers with increased knowledge of coastal resources have been found to have higher occupational diversity (Cinner et al. 2010).
6	Households whose needs are met with a variety of sources may be less reliant on any one source, such as fishing, and their household catch will be lower than households with smaller livelihood diversities.	Households may spread their needs across a diversity of livelihood sources to reduce risk (Allison and Ellis 2001).
7	Households with more livelihoods may have greater connectedness if they have more skills and products to potentially share.	
8	Households that are more connected within their networks may have higher fishing levels because they may be catching a surplus of fish that is shared with other households.	Customary exchange has been identified as a major driver of fishing effort (Severance et al. 2013).
9	Households that depend more on fishing for an income source may have higher fishing levels.	
10	Households who depend more on fish as a food source will have higher fishing levels.	Bell et al. (2009) documents the strong reliance on fish for protein in the Pacific. However, fishing pressure has been shown to decrease as dietary dependency lessens (Turner et al. 2007).
11	Households with more accessible reef area to fish may have higher fishing levels because there is a greater amount of habitat to support the resource base.	

number of income sources the households had, as well as by the total number of livelihoods, which included nonmonetary sources used for food and cultural offerings. Importance of fishing to income was based on the respondent's ranking of their income sources.

To measure local ecological knowledge (LEK), we developed an LEK index that included standardized metrics of knowledge transmission (20%), knowledge of fish identification (40%), and knowledge of fish ecology (40%; Appendix 2). We measured knowledge transmission by asking whether or not the respondent formally or informally teaches fish names to the younger generation(s). We measured knowledge of fish identification by asking for 20 local fish names (fishes were a combination of common and rare species; higher scores were given to specific names, lower scores were given to general or family names). We measured knowledge of fish ecology by asking about fish diets and the timing of spawning for groupers (family Epinephelidae), emperors (family Lethrinidae), and parrotfishes (family Labridae). Together these fish families were chosen based on their diverse functions, but also because they are important for subsistence, sale, and cultural events. Because there is documented information of some fish diets (http://www.fishbase.org), points were given to responses that match existing data for fish families. Because timing of spawning may vary spatially and temporally (Schemmel and Friedlander 2017), points were given to any response and no points were given to those who responded that they did not know. These scores provide an index of LEK but not a comprehensive measure (Zent and Maffi 2009). Because small differences in the index are not meaningful, we then ranked the scores from low to high based on three broader groupings.

To assess material wealth, the number of assets from a list of appliances were tallied using methods modified from McClanahan et al. (2008). Total reef area was calculated by overlaying the GIS layers of coral reef locations made available by the Millennium Coral Reef Mapping Project (Andréfouët et al. 2006) in ArcMap 10.4.1 (Esri 2016) onto a layer identifying reefs that are commonly fished. The second layer was created by asking respondents (in household interviews and focus groups) to identify on a map the reefs that they frequently access to harvest fish. We did not include all reefs within fishing grounds in the calculation of reef area because in some districts, distant reefs are not accessed. Though we intended to calculate the reef area from the *kanakana*, we calculated reef area at the district level because there was significant overlap in the use of fishing grounds between villages in the same district; households fished in areas outside of their *kanakana*, so *kanakana* area does not accurately reflect the size of the reefs being accessed.

Table 4.2. Descriptions of potential social-ecological indicators of household fishing catch. †Dependent variable

Indicator	Description	Survey method
Travel time to town	Travel time (minutes) to reach the town in which most villagers travel to for buying and selling goods, using the most commonly utilized mode of transportation	Key informant interview
Distance to town	The distance (km) traveled by the most commonly utilized mode of transportation to the town in which most villagers travel to for buying and selling goods.	Measured from Google maps
Market frequency	The number of times in a year that a member of the household visits town.	Household survey
Income diversity	The number of income sources employed by the household	Household survey
Livelihood diversity	The number of livelihood sources employed by the household, which includes sources of income and livelihoods which procure food and/or handicrafts for cultural offerings.	Household survey
Local ecological knowledge	Index made up of standardized scores based on responses to questions about fish identification, fish diets, timing of fish reproduction, and transmission of this knowledge (Appendix 2).	Household survey
Formal education	Highest level of formal education attained by adults in household	
Connectedness	The sum of the number of households the respondent's household shares with or receives shared resources from.	Household survey
Material wealth	Sum of the number of appliances owned by the household from the following list: radio, television, DVD player, mobile phone, generator, refrigerator/freezer, washing machine, laptop/tablet	Household survey
Annual household catch†	Product of the annual number of household fishing days (summed across all gear types) and the catch per unit effort for the different gear types (calculated using community catch logs).	Household survey; Catch logs
Fresh seafood consumption	Average number of days per week the household consumes fresh seafood.	Household survey
Reef area	Total area of accessible reef in district fishing grounds.	Household surveys; Focus groups; Millennium Coral Reef Mapping Data (Andréfouët et al. 2006)

Estimated annual household catch

We estimated total annual household catch from trip frequency estimates and catch per unit effort (CPUE) for each gear type. Two fishers each from 13 villages across Fiji completed training on recording catches in logbooks. Of these 13 villages, eight are located in four of the five districts in which household surveys took place. Fishers recorded all fishing landings in their village, in a haphazardly chosen 24-hour period once to twice a month over a six-month period and recorded information for each fishing trip, including gear type used. The biomass of individual fishes was estimated using the allometric length-weight conversion:

$$W = aFL^b \tag{1}$$

where parameters a and b are species-specific constants, FL is fork length in cm, and W is weight in grams. Length-weight fitting parameters were obtained from Kulbicki et al. (2005). Total biomass was calculated by taking the sum of the biomass of all individual fish caught per trip. Catch per unit effort for each gear type was determined as:

$$CPUE = total\ biomass * number\ of\ fishers^{-1} * fishing\ time^{-1} \tag{2}$$

in which fishing time was in hours. To calculate fishing time, we subtracted the travel time from the total time of the fishing trip because we were interested in using CPUE to estimate catch, rather than using it to compare CPUE between sites or how CPUE changed over time, for which it would be important to include travel time. Trips in which multiple types of gear were used, or in which invertebrates were harvested, were not included for the purposes of calculating gear-specific CPUE. CPUE estimates were calculated for each trip and then averaged for each gear type across all sites. For gillnet fishing, a catch per set, rather than a catch per time period was calculated. CPUE estimates were within the range of other estimates in Fiji (Appendix 3). Using the CPUE estimates, annual household catch for each gear type was estimated as:

$$\begin{aligned} Estimated\ annual\ household\ catch \\ = CPUE_{gear} * mean\ fishing\ time_{gear} \\ * annual\ household\ fishing\ trips_{gear} \end{aligned} \tag{3}$$

Information on the frequency of household fishing trips was recalled for each gear type in the household interviews. Estimated household catches for handline fishing, day spearfishing, and night spearfishing were calculated separately for each gear type by multiplying the household's estimated number of annual fishing trips by the catch per unit effort and the mean trip time (the latter two metrics were calculated using the catch logs described above). For estimating household catch from gillnet trips, number of annual household gillnetting trips was multiplied by mean catch per set. Total estimated annual household catch was calculated by summing the estimated annual household catch of each gear type used.

We recognize that our indirect estimates of household catch are inflated compared with other catch landing data, disaggregated by gear, for Fiji (e.g., Bell et al. 2009). Recall bias has been shown to cause overestimation of fishing frequency, especially when multipliers are used, e.g., extrapolating weekly frequency to calculate an annual frequency (Vaske et al. 2003), as fishers are not likely to fish every week given poor weather, sickness, or events, e.g., weddings, that require travel out of the village. However, it is reasonable to assume that this recall bias is consistent across respondents, gear, and sites and, because our model seeks to assess the variation within household catch, and not predict the actual household catch; therefore, the likely inflation of estimates should not affect the model.

Statistical analyses

All potential drivers of fisheries catch were regressed against estimated annual household catch using general linear mixed models, with village as a random effect. We used structural equation modeling (Grace 2006) using the lavaan program (Rosseel 2012) in R (R Development Core Team 2015) to model drivers of fishing. We chose structural equation modeling over multiple regression because we wanted to take a systems approach, differentiate between direct and indirect drivers of fishing pressure, and because we expected that some of our potential drivers would be correlated (Cullen et al. 2007, Cinner et al. 2007; Appendix 4). We first specified a hypothesized model based on published literature and our existing knowledge of the system (Fig. 4.1). Because the households were not a simple random sample of villages in Fiji, we used a model in which households were nested within villages. We used modification indices to identify missing paths, which may help to improve the model (Grace 2006), yet did not find any that were grounded in theory or existing knowledge, so no modifications were made. Nonsignificant drivers (determined by examining p-values) were then sequentially eliminated and the best-fit model was determined from comparing all models using Akaike's Information Criterion (AIC; Grace 2006; Appendix 5).

Table 4.3. Descriptive statistics of potential social-ecological indicators of household fishing catch. †Dependent variable.

Indicator	Mean	SD		Min.	Max.
Travel time to town	143.4	94	minutes	30	300
Distance to town	56	29.4	km	16.7	92.9
Annual town visits	32.1	40.3	visits $year^{-1}$	0	364
Livelihood diversity	7.8	2.2		2	14
Income diversity	5.2	2.2		1	11
Local ecological knowledge	4.9	2		0	8.7
Connectedness	6	2.5		1	14
Estimated annual household catch†	4638.5	3846.1	kg	0	15023
Importance of fishing to income	1.24	1.38		0	4
Seafood consumption	3.2	2	days $week^{-1}$	0	7
Material wealth	2.7	1.9		0	7
Reef area	25.7	20.3	km^2	1.4	52.2

RESULTS

Over 96% of households interviewed participated in some fishing activity and 33% of households reported fishing as one of their top three income sources (Table 4.3). Our household surveys revealed a large amount of variation in household-level measures (Fig. 4.3, Appendix 1). Travel time to town, livelihood diversity, LEK, connectedness, importance of fishing to income, and fresh seafood consumption were all positively correlated ($p<0.05$) with estimated mean annual household catch (Fig. 4.4).

Fresh seafood consumption averaged 3.2 days $week^{-1}$ and ranged from 0 to 7. The number of livelihoods averaged 7.8 and ranged from 2 to 14 (Fig. 4.3). Fishing, farming of taro (*Colocasia esculenta*), kava (*Piper methysticum*), and coconut (*Cocos nucifera*), along with formal employment were the most common livelihood sources. However, different livelihood sources provided the top source of income in different villages. For example, in villages close to urban areas and large resorts, about half of households listed formal employment as their top income source. In contrast, over half of households in the remaining villages responded that farming is their top livelihood source. Less common sources of livelihood included handicrafts, small businesses, and remittances.

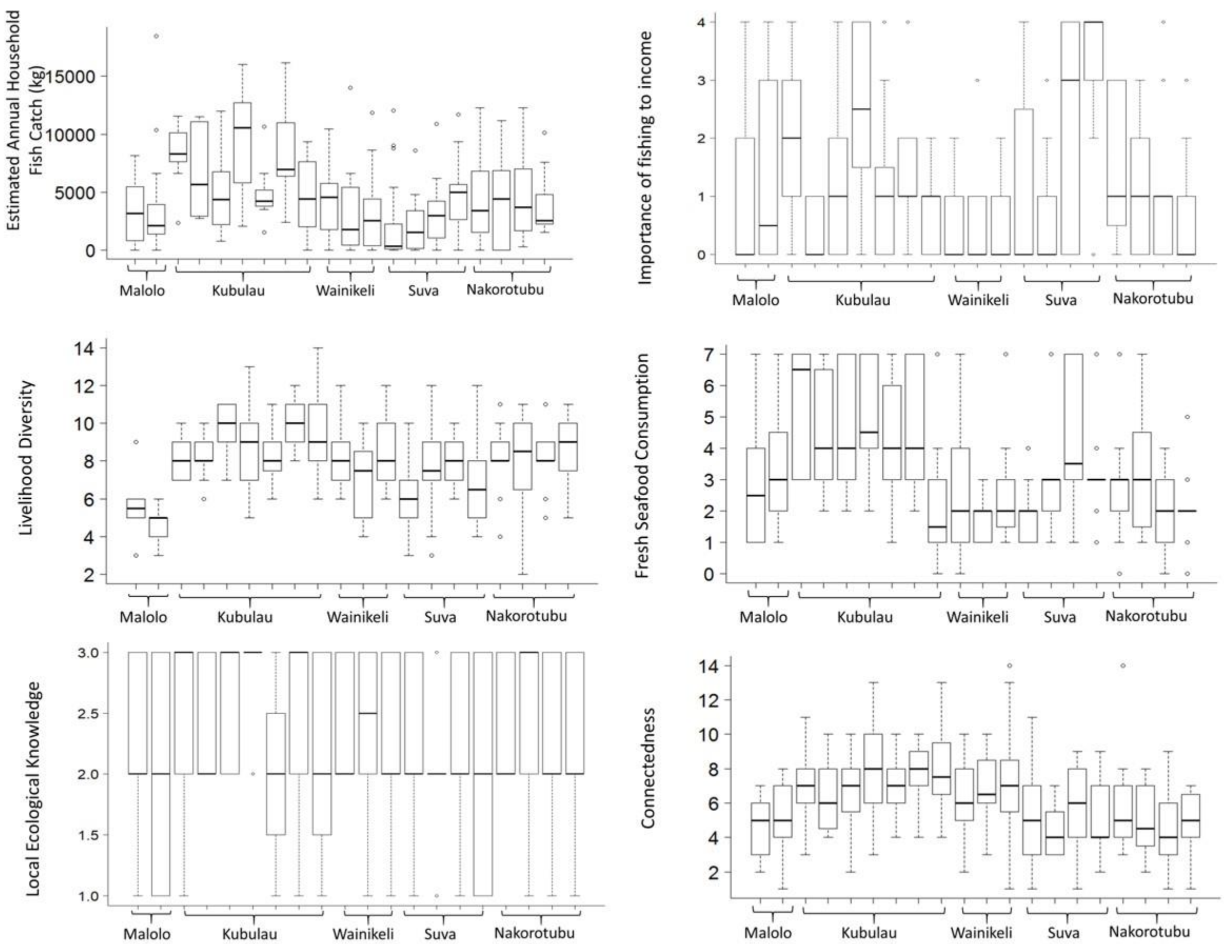

Figure 4.3. Variation in social indicators within and among villages. Districts are indicated on the x-axis. Boxplots show median value (solid band), fist quartile (bottom of box), third quartile (top of box), values that fall within 1.5 times of the interquartile range (dotted lines), and outliers (points).

Despite the variation in LEK, certain kinds of LEK were common across households. Most respondents had some knowledge of local species names, some knew about target fish diets, but few knew of fish spawning times. Of those that knew of spawning times, most only knew of grouper spawning periods, possibly the result of a recent national campaign to avoid eating groupers during their spawning season.

In the best fit structural equation model ($\chi2 = 0.61$, Fig. 4.5), importance of fishing to income, livelihood diversity, fresh seafood consumption, total reef area, and travel time to market all had direct significant positive effects on estimated mean annual household fish catch (Appendix 5). Travel time to market was a direct driver of livelihood diversity and was thus also an indirect driver of estimated household fish catch. Overall the model explained approximately one third of the variation in estimated household fish catch ($R^2 = 0.31$). Fish catch sold had the strongest effect (standardized path coefficient = 0.27) on estimated household fish catch.

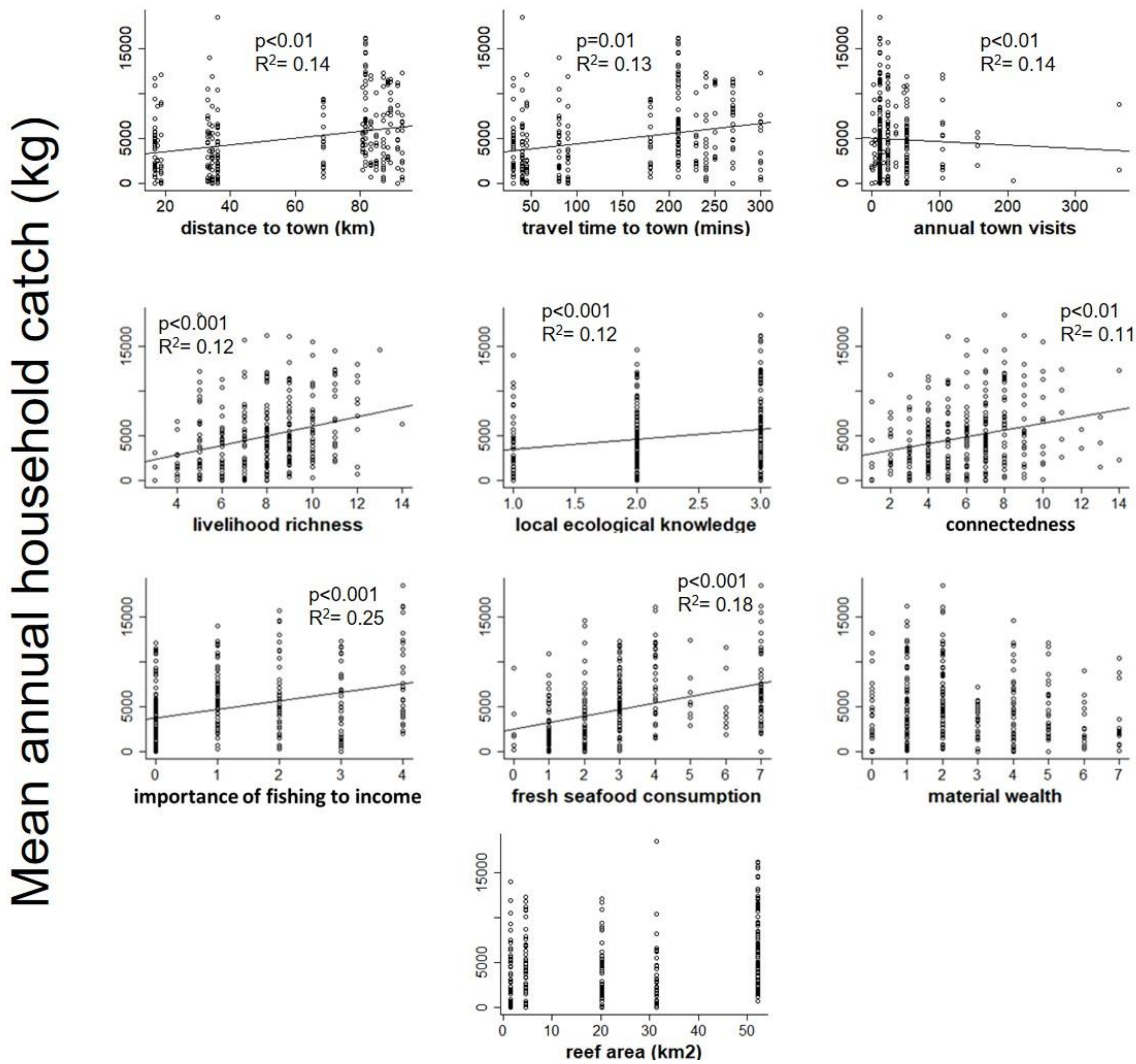

Figure. 4.4. Single variable regressions (with district as random variable) of potential drivers of household fishing. All relationships are statistically significant ($p < 0.05$) where regression lines are present.

DISCUSSION

By using fine-scale, context appropriate social-ecological indicators and assessing their potential role in driving household-level fishing, we found trends that have not emerged in larger scale analyses on this topic. For example, in contrast to other studies that have found fishing pressure to increase with increasing proximity to markets (Brewer et al. 2012), we found that households further from town have higher fishing frequencies.

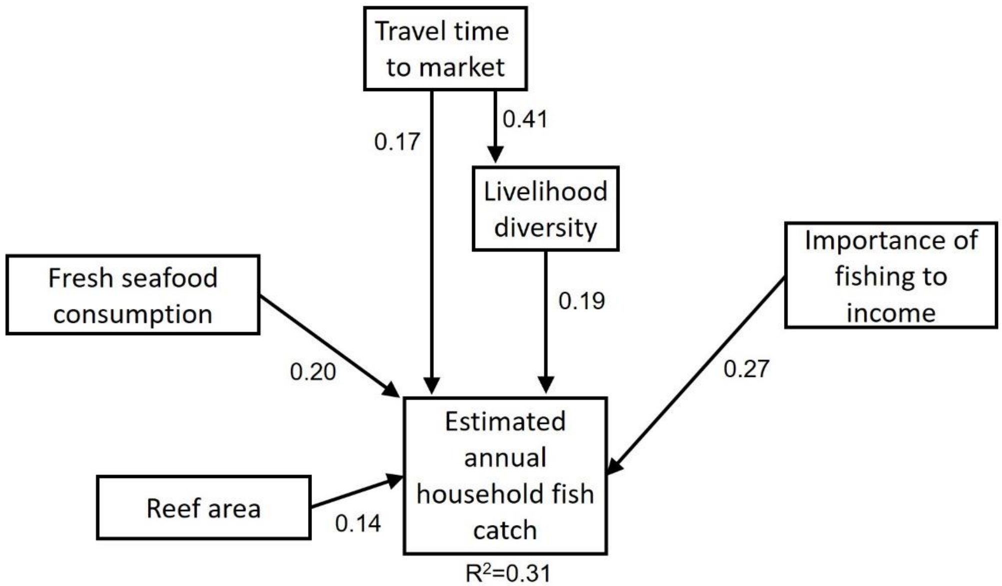

Figure. 4.5. Best fit structural equation model of social-ecological drivers of household fishing catch. All paths are positive and significant ($p < 0.05$). Values are standardized path coefficients. Additional model statistics can be found in Appendix 5.

Distance to market and middlemen

Market integration, defined by distance to town and/or markets, has been found to be a negative driver of reef fish biomass (Cinner and McClanahan 2006, Cinner et al. 2013, Maire et al. 2016, McClanahan et al. 2016) and positive driver of fishing pressure (Brewer et al. 2012). Instead of relying on a single measure, we collected several indicators of market integration (distance to market, distance to fish sale location, travel time to market, frequency of market visits, importance of fishing to income, and population of nearest town). Of these, the best predictor was importance of fishing to income, a measure not based on proximity to market. Adding the population of the nearest town did not improve the model. Travel time to market was a significant positive driver of estimated household fish catch, meaning that households in villages further from towns had the highest fishing frequencies. The widespread presence of middlemen in Fiji may be one explanation for this finding. Middlemen buy goods, e.g., seafood and crops, directly from producers, e.g., fishers and farmers, and in turn sell to retailers or consumers. The role of middlemen in rural coral reef fisheries have also been reported elsewhere (Crona et al. 2010, Brewer 2011). In Fiji, middlemen are based in or regularly visit rural areas, essentially bringing markets to rural villages (Mangubhai et al. 2016). The presence of middlemen in rural areas may help to explain why we found that households further from markets had higher estimated annual catches (Fig. 4.1). In Kubulau District, the district furthest from towns in this study, 75% of fishers sell fish directly to middlemen.

We were unable to accurately include a measure of distance to middleman in the model because households are not linked to a single middleman or place of fish sale. Some households may only sell fish to middlemen at times when cash is unexpectedly needed, e.g., funerals, or when larger sums of money are needed, e.g., church contributions or school-related expenses. Other households regularly sell at both the market and to middlemen. They decide between the two based on their yield or species of fish caught. Our data suggests that household decisions about whether and where to sell fish is dynamic. Assuming that sites further from markets are less at risk of overharvesting can lead to ineffective policies and insufficient funding for management of remote sites, particularly where middlemen may act as moving markets. Further information on the presence and role of middlemen in Pacific Island communities could facilitate effective management adapted to the realities and diversity of local circumstances. Value chain analysis, which maps the flow of goods and their values as they pass between actors, do consider the role of middlemen, and are increasingly useful in the management of small-scale fisheries (Thyresson et al. 2013, Wamukota et al. 2014).

Drivers of estimated household fish catch

Resource managers must have a comprehensive understanding of how social and ecological systems are connected at a local level to avoid bolstering social resilience at the expense of ecological resilience, or vice versa. Our research suggests that introducing additional income generating sources may be successful in increasing livelihood diversity of households, but may not reduce fishing levels, and therefore will not likely increase ecological resilience. Like many rural residents in developing countries, fishers commonly have diversified livelihoods to compensate for the seasonality and high variability inherent in small-scale fisheries (Allison and Ellis 2001, Cinner et al. 2010). Past studies suggest that households with high livelihood diversity may have increased resilience to disturbances, e.g., natural disasters or economic shocks, because they are able to spread risk across each of their livelihood sources (Allison and Ellis 2001). However, we found livelihood diversity was a significant positive driver of estimated annual household catch, indicating that households with more livelihood sources may also be catching more fish. This finding contradicts the assumptions of projects that introduce alternative livelihoods as a means to relieve fishing pressure, which are often popular with conservation agencies (Wright et al. 2016). Reviews of alternative livelihood projects, however, have shown that introducing additional income sources does not necessarily reduce resource extraction (Jupiter et al. 2014, Roe et al. 2015) because sometimes households do not find the introduced livelihood as a suitable substitute (Wright et al. 2016). In the Pacific, where fish and fishing are central to culture and identity, alternative livelihoods may not provide resources needed for traditional events, allow individuals to carry out their traditional roles, or provide opportunities for knowledge transmission. Instead, alternative livelihood sources may just serve as supplemental income (see also Sievanen et al. 2005).

It is important to note that our measure of livelihood diversity is simply the number of livelihood sources, and does not take into account how much income each livelihood provides nor the quantity of nonmonetary goods a livelihood source may generate. However, we found the importance of fishing for income to be a stronger driver of household fishing than household consumption of fish. This suggests that efforts to reduce fishing for consumption may have less impact at reducing total catch than efforts to reduce fishing for income.

Although LEK was not a significant predictor in the structural equation model, it is significantly, positively correlated with estimated household fish catch (Fig. 4.4). This means that households with more LEK catch more fish. In our interviews, 37% of respondents said that they are not passing down the knowledge of local fish names, a form of LEK. Many of these respondents noted that they are not doing so because there is not an opportunity to do so (e.g., they do not go fishing with their children, children prefer watching television) or because they think their children learn the things they need to know at school. LEK has influenced natural resource use for centuries (Johannes 1978, 1981, Berkes 1999) and has potential to guide formal and informal contemporary place-based management (Berkes et al. 2000, Thornton and Maciejewski Scheer 2012). However, market influences may motivate fishers to use their LEK to increase harvests, e.g., target spawning aggregations of grouper or harvest gravid mud crabs, rather than to protect resources.

Although LEK and connectedness were not the strongest predictors of household fishing in our study, both influence fishing (Fig. 4.4) and should be further examined in future studies. Other, less structured types of surveys could be used to assess a broader suite of LEK that may influence fishing activities. For example, future surveys could examine the role of LEK in fishing practices by asking questions about how fishers determine fishing locations or the time at which they target certain species, along with asking about their fishing practices at these locations or times. In addition, although trust, exchange, norms, and connectedness make up social capital, we only measured exchange as a component of social capital. A more detailed examination of social networks that assesses metrics besides degree (number of connections per house) or incorporates other types of exchange, e.g., information, could better document the role of social capital in driving household fishing.

Future studies should also consider reef productivity along with reef area. The standing biomass can be influenced by natural environmental factors or anthropogenic factors and will impact CPUE, thus influencing fish catch. Finally, although we have investigated the drivers of estimated household catch, we acknowledge that it is not only the absolute biomass of fish extracted that will impact the ecology of reefs, but also the composition of the catch, which may be related to gear types used. A basic exploratory analysis of household social factors associated with different gear types can be found in Appendix 6. Trophic level, size, and reproductive status of individual fish in catches are important to consider when assessing sustainability of fishing practices (Jennings and Kaiser 1998, Friedlander and DeMartini 2002, Graham et al. 2005, Mumby et al. 2006). Further studies should examine if and how social indicators are related to additional catch characteristics.

Importance of considering household-level characteristics

In contrast to studies that have used socioeconomic surrogates of fishing pressure (Mora 2008, Williams et al. 2008, Brewer et al. 2012), we used reported fishing activity to estimate household fishing levels. However, we also measured commonly used fishing pressure proxies (population density, mean number of boats per household, and mean number of refrigerators per household). Consistent with Weeks et al. (2010), we found that although the more easily measured metrics may be effective at generalizing total fishing pressure at a high spatial scale, they do a poor job of characterizing more heterogeneous fishing patterns found in communities. For example, we found that the villages that had the highest levels of household fishing were those with few boats and almost no refrigerators (Fig. 4.6). If managers are aiming to develop regulations that focus on local-level fishing, a broad understanding of mean fishing levels in an area may not be helpful, given the large variation in household fishing catch (Fig. 4.3, Appendix 1) and commonly used proxies may even misguide managers on the levels of fishing occurring in an area.

An example of this occurred in Fiji after Cyclone Winston, which hit February 2016. In a postcyclone survey conducted to estimate impacts of fisheries dependent communities, village leaders were asked to rank their villages' top livelihood source before the cyclone (Chaston Radway et al. 2016). We asked the same question, in some of the same villages, at a household-level and found that village-level results inflate the importance of fisheries in villages. If these village-level results are used to guide resource allocation for fishing gear replacement, villages might end up with more fishing gear than they had before the cyclone, and as a result, fishing levels could increase at a time when reefs are particularly vulnerable.

We understand that resources are not always available for household surveys, especially in times of crisis, such as after a major disaster. However, when possible, household-level surveys should be a priority. Our household surveys revealed a large amount of variation in household-level measures (Fig. 4.3), which is not surprising given the heterogeneities that exist within a community. Instead of trying to aggregate at a community level, a more accurate, yet challenging way to understand the diverse interests and behaviors of different actors is to focus on understanding "patterns of difference" within a community (Agrawal and Gibson 1999). Factors that may affect how decisions are made about fishing and the fate of fisheries resources that could not be represented in this type of quantitative analysis, and require a more nuanced study, include household responsibilities based on religion, traditional roles, and relationships with other households and communities (Veitayaki et al. 2014).

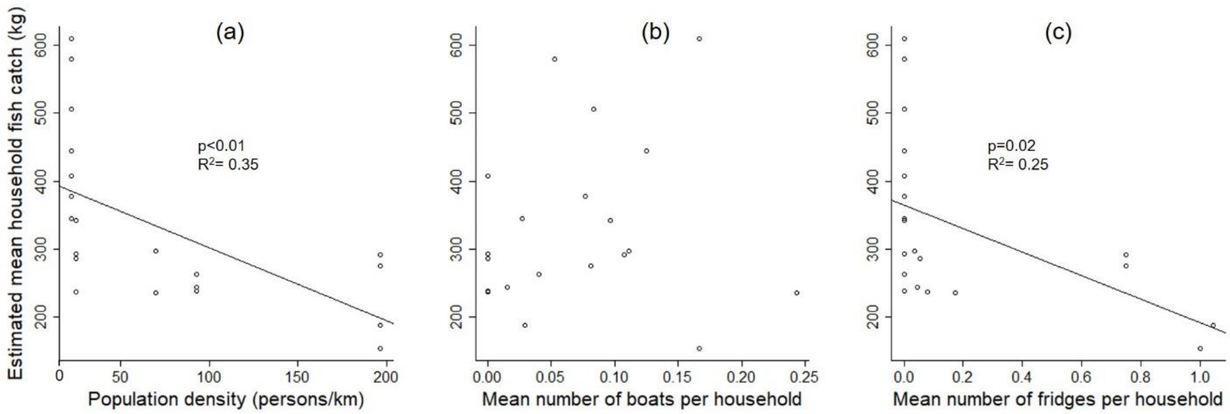

Figure 4.6. Mean household fish catch and commonly used proxies of fishing pressure: (a) population density in persons/km of coastline, (b) mean number of boats per household, and (c) number of refrigerators per household. Relationships are statistically significant ($p < 0.05$) where regression line is present. In Fig. 4.6b and 6c the y-axis does not cross the the x-axis at 0 to better display the low values of mean number of boats and fridges per household.

CONCLUSION

For effectively managing small-scale coral reef fisheries, it is necessary to move beyond a community-level understanding of drivers of fishing and consider the drivers of individual or household behaviors (Aswani et al. 2015). Simple measures of social factors that are being applied worldwide have greatly improved our understanding of how human dimensions are related to resource use, but not all of these measurements are appropriate at smaller spatial scales, which is the scale at which most management decisions are made. Finer-scale data better captures the variation of fishing within a community and the nuances that affect how decisions are made about fishing and the use of fisheries resources, and as such will allow for a better idea of the implications of different management measures.

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Appendix 2

Table A1.1. Descriptive statistics of potential social-ecological indicators of household fishing catch by village

District	Village	Number of households	Percent of households surveyed	Travel time to town (minutes)	Distance to town (km)	Annual town visits	Livelihood diversity	Income diversity	Local ecological knowledge	Social capital	Estimated annual household catch (kg)	Importance of fishing to income (rank)	Seafood consumption (days week^{-1})	Material wealth
Malolo	Cubi	27	78%	40	36	22	4.7	3.1	1.9	5.0	3,484	1.4	3.4	2.8
	Solevu	115	17%	40	36	32	5.5	3.9	2.1	4.4	3,545	0.9	3.1	4.9
Kubulau	Kilaka	37	54%	180	69	15	9.4	6.3	2.1	7.8	4,879	0.7	2.1	2.2
	Kiobo	13	92%	210	83	25	9.7	6.6	2.5	6.7	5,347	1.3	4.8	2.5
	Namalata	19	68%	210	82	14	9.8	7.5	2.6	7.8	8,499	1.4	4.4	2.2
	Natokalau	16	75%	250	89	14	8.2	5.7	2.4	6.4	6,714	0.5	4.5	1.9
	Navatu	30	67%	210	82	15	8.8	6.4	2.8	7.9	9,624	2.4	5.0	1.8
	Raviravi	18	83%	210	81	27	8.3	5.5	2.0	6.9	4,728	1.1	4.4	2.2
	Waisa	12	83%	270	89	12	8.2	6.2	2.5	7.0	8,353	2.1	5.4	1.6
Wainikeli	Korovou	65	31%	90	35	20	8.3	5.6	2.1	7.5	3,011	0.6	2.8	1.7
	Vidawa	21	57%	80	34	33	7.6	4.6	2.4	6.7	4,047	0.5	1.9	1.7
	Waitabu	25	68%	80	33	30	8.2	5.4	2.3	6.3	4,554	0.6	2.8	1.7
Suva	Kalokolevu	69	29%	45	19	77	6.3	3.1	2.2	5.0	3,029	1.1	2.0	4.6
	Muaivuso	37	54%	30	17	62	8.1	4.4	2.3	5.6	3,369	2.0	4.2	4.4
	Togalevu	18	67%	45	18	98	8.8	4.9	2.1	4.6	2,944	0.8	3.0	5.6
	Waiqanake	56	36%	30	17	66	7.0	4.2	1.9	5.3	5,193	3.1	3.3	2.8
Nakorotubu	Namarai	31	58%	270	91	19	8.5	5.8	2.5	5.4	5,288	1.0	3.8	3.1
	Naocobau	18	72%	300	93	33	8.5	6.5	2.4	5.8	4,748	1.5	3.2	2.7
	Saioko	20	95%	240	87	19	8.2	6.1	2.2	4.4	4,573	0.9	1.8	2.1
	Verevere	25	64%	230	85	19	8.7	6.5	2.3	4.9	3,873	0.5	2.1	2.0

Appendix 3

Section 1: Lessons learned from LEK questions from pilot survey; Section 2: Pilot survey; Section 3: Questions about local ecological knowledge (LEK) in the household survey; Section 4: Explanation of how total LEK score was calculated; Section 5: Social network analysis section from the household survey.

<u>Section 1</u>

Our pilot survey can be found, starting on the following page. The local ecological knowledge questions that were tested can be found in section IV. The questions were designed to ask about aspects of knowledge and practice. Below, we describe what we learned from three of these marine related pilot questions and the changes that were made for the final survey.

1. *Do you plan your fishing activities according to:*

Weather?

Moon phase?

Flowering plants?

Other:

In this question, almost every fisher mentioned at least one method, and it was thus difficult to determine a method to assess this question. We created a new question to assess practice in which we asked respondents whether or not they teach fish names to younger generations and why they do or do not partake in this practice.

2. *How many types of parrot fish can you name?*

In this question, we presented respondents with photos of different species of parrotfish, including some photos of the same species but in different phases. We found that most people only had 2-3 names for parrotfish as a species complex. We revised this question to include species from several different families that had documented names in some dialects.

3. *Have you noticed changes in the timing of fish reproduction? [probe: migration, egg production, spawning]*

We learned that many respondents had a hard time understanding what we were even asking about. We learned that it is somewhat common knowledge that some fish aggregate, but most of our respondents were unaware of the biological processes occurring during aggregations. From this experience, we made many changes to the spawning questions, including adding a description of fish aggregations. After we explained aggregations, we asked if the respondent knew of this behavior. If they did not, we did not ask further questions. If they did, we asked about the three species complexes and then an open-ended question in which we asked if they knew the timing of any other species or had anything else about spawning that they wished to share. The majority of the respondents knew about spawning times for groupers (likely due to a recent national campaign) and were clear in that they did not know about times for other species.

Investigating the complexities of coral reef social-ecological systems

Household Surveys

Interviewer:	
Interviewee:	
Name of house:	
Village name:	
Date:	

I. LIVELIHOOD OPTIONS

Check all sources of income from which your household derives salary. [Must ask all]. Next, give interviewee 20 beans and ask them to distribute them among income sources to reflect each source's contribution (score) to total income. All sources that are checked must also have a score.

	Income source	Score
☐	Fishing (*saltwater* finfish, shellfish)	
☐	Fishing (*freshwater* finfish, shellfish)	
☐	Farming	
☐	Copra	
☐	Sea cucumbers	
☐	Handicrafts (weaving, baskets, mats, masi, sasa, fans, etc.)	
☐	Wages/salary from employment	
☐	Remittances	
☐	Land lease	
☐	House rent	
☐	Own business	
☐	Other (specify): ______________________	
☐	Other (specify): ______________________	
☐	Other (specify): ______________________	
	TOTAL SCORE (should add to 20)	

II. AGRICULTURE

Check all crops that are grown by members of this household. For every checked crop, ask how many varieties of the crop are grown. Also indicate if the crop is used for subsistence, sale, or to give away (can check more than one). If the crop is sold, indicate the location of sale.

crop	Number of varieties (list)	subsistence	sale	takitaki	If resource sold, market location
☐ Eggplant					
☐ Banana					
☐ Bele					
☐ Sugarcane					
☐ Cassava					
☐ Chillies					
☐ Coconut					
☐ Copra					
☐ Taro					
☐ Citrus					
☐ Ota					
☐ Pawpaw					
☐ Pumpkin					
☐ Rourou					
☐ Plantain					
☐ Kava					
☐ Sweet Potato					
☐ Yam					
☐ Breadfruit					
☐ Ivi					
☐ Vutu					
☐ Other:					
☐ Other:					
☐ Other:					

2a. Do you use chemical: (check if yes) ☐ fertilizers? ☐ pesticides? ☐ herbicides?

III. FISHING

Check all fishing activities performed by members of this household. For every checked method, ask the frequency of the activity and, as done previously, indicate what the harvest is used for.

Fishing method	frequency	subsistence	sale	takitaki	If resource sold, market location
☐ **Hand line**	☐ More than once a week ☐ Once every 1-2 weeks ☐ About once a month ☐ Less than once a month				
☐ **Spear fishing (snorkeling)**	☐ More than once a week ☐ Once every 1-2 weeks ☐ About once a month ☐ Less than once a month				
☐ **Gill net**	☐ More than once a week ☐ Once every 1-2 weeks ☐ About once a month ☐ Less than once a month				
☐ **Cast net**	☐ More than once a week ☐ Once every 1-2 weeks ☐ About once a month ☐ Less than once a month				
☐ **Fish basket**	☐ More than once a week ☐ Once every 1-2 weeks ☐ About once a month ☐ Less than once a month				
☐ **Other:**	☐ More than once a week ☐ Once every 1-2 weeks ☐ About once a month ☐ Less than once a month				
☐ **Other:**	☐ More than once a week ☐ Once every 1-2 weeks ☐ About once a month ☐ Less than once a month				
☐ **Other:**	☐ More than once a week ☐ Once every 1-2 weeks ☐ About once a month ☐ Less than once a month				

3a. How often do you fish to contribute to an event (church, feast, relatives, etc):

☐ Once a week ☐ Once a month ☐ Less than once a month ☐ Never ☐ Other:

3b. Do you plan your fishing activities according to:

☐ Weather? ☐ Moon phase? ☐ Flowering plants? ☐ Other:

IV. LOCAL KNOWLEDGE

How many varieties of taro can you name?	1. 2. 3. 4.	5. 6. 7. 8.	9. 10. 11. 12.
How many uses of *[important plant]* can you think of?	1. 2. 3. 4.	5. 6. 7. 8.	9. 10. 11. 12.
Can you name the types of trees that grow in or around your taro?	1. 2. 3. 4.	5. 6. 7. 8.	9. 10. 11. 12.
How many types of parrot fish can you name?	1. 2. 3. 4.	5. 6. 7. 8.	9. 10. 11. 12.

4b. What do you do to your plantation after harvest:

☐ Let it lay fallow. If so, how long? ____________ ☐ Till remaining plant matter into soil

☐ Plant a cover crop ☐ Burn ☐ Other: ______________

4c. Have you planted any new crops or varieties in the last 10 years that are more resistant to salt, cyclones, or drought? ☐Yes ☐No

If yes, which ones? ____

4d. Have you noticed changes in the timing of plant maturation? [probe: budding, flowering, fruiting]

☐ Yes. Explain:____

☐ No.

4e. Have you noticed changes in the timing of fish reproduction? [probe: migration, egg production, spawning]

☐ Yes. Explain:____

☐ No.

V. MARKET ACCESSIBILITY

5a. How often do you buy things from the market?

☐ More than once a week ☐ Once a week ☐ More than once a month ☐ Other:

5b. How often do you buy things from the village canteen?

☐ Once a week ☐ Once a month ☐ Less than once a month ☐ Other:

5c. How do you travel to the nearest market? (check all that apply)

☐ Bus ☐ Carrier ☐ Boat ☐ Other:

5d. How long does it take to reach the nearest market?

☐ Less than 1 hour ☐ 1-2 hours ☐ 2-4 hours ☐ More than 4 hours

5e. How much does it cost to travel to the nearest market? (one way)

Transportation method:	Cost:
Transportation method:	Cost:
Transportation method:	Cost:

VI. MATERIAL ASSETS

Check all that apply for the household.

House construction:	☐ Tin ☐ Wood ☐ Brick ☐ Traditional materials ☐ Other: ____________________
Toilet facility:	☐ Pit ☐ Water seal ☐ Flush ☐ Other: ____________________
Appliances:	☐ Radio ☐ Television ☐ DVD player ☐ Mobile phone ☐ Laptop/tablet ☐ Other: ____________________
Lighting:	☐ Kerosene ☐ Lamp (battery/rechargeable) ☐ Electrical lights ☐ Candles ☐ Other: ____________________
Cooking energy:	☐ firewood ☐ kerosene ☐ gas ☐ Other: ____________________
Own transportation:	☐ bilibili ☐ non-motorized boat ☐ boat with outboard engine ☐ vehicle ☐ Other: ____________________

VINAKA VAKALEVU!!! ☺☺☺

Section 3

Below are questions about local ecological knowledge (LEK) from the household survey. Note, this is an English translation of these questions. The actual survey was translated into the Fijian language and conducted in Fijian by native speakers.

Traditional Ecological Knowledge

For these questions, we do not aim to document your specific detailed knowledge, we are just trying to get a sense of what types of knowledge exist in this village. As with all of our questions, there are no right or wrong answers. If you do not know something, do not be ashamed to say "I don't know;" we are not here to judge you.

1. Do you usually go fishing? YES NO

2. *We have several photos of fish found in Fiji. [Give respondent first set of cards] How many can you name? Please provide whatever name you know of- we are aware that names may be different throughout the country, so please give a local name if that's what you know. [Write down names with the number that corresponds with the number on the fish card]*

Respondents were presented photos of the following species:

Family	**Genus and species**
Acanthuridae	Acanthurus xanthopterus
Belonidae	Tylosurus crocodilus
Carangidae	Carangoides ferdau
Chaetodontidae	Chaetodon lunula
Gerreidae	Gerres erythrourus
Gerreidae	Gerres oblongus
Haemulidae	Plectorhinchus chaetodonoides
Labridae	Cheilinus fasciatus
Labridae	Cheilinus undulatus (adult)
Labridae	Cheilinus undulatus (juvenile)
Lethrinidae	Lethrinus nebulosus
Lethrinidae	Lethrinus olivaceus
Lethrinidae	Monotaxis grandoculis
Lutjanidae	Lutjanus argentimaculatus
Lutjanidae	Lutjanus bohar
Scaridae	Bolbometopon muricatum
Scaridae	Chlorurus bleekeri
Serranidae	Cephalopholis argus
Serranidae	Epinephelus merra
Serranidae	Plectropomus leopardus

3. Have you taught these names to anyone in a younger generation?
YES NO

Why or why not?

You may know that fish come together, in groups, to reproduce.
4. Do you know the *time of year* when this occurs for any fish species?

***[If yes]* What about for: [note response and circle number that corresponds to level of knowledge]**

Groupers?____
0 1 2

Parrotfish? ____
0 1 2

Emperorfish? ____
0 1 2

Any other species?_____
0 1 2

5. As you probably know, different fish eat different things. Do you know what the following fish eat?

Groupers?____
0 1 2

Parrotfish? ____
0 1 2

Emperorfish? ____
0 1 2

Section 4

Scoring:

Fish identification [Question 2]:

- 1 point for every answer that corresponded to the correct species name
- 0.5 points for every answer that corresponded to the correct general/family name - 0 points given to answers that were known to apply to different species

Transmission [Question 3]: - 1 point for YES

- 0 points for NO

Timing of fish spawning [Question 4]:

- Because timing of spawning may vary spatially and temporally:
- 1 point for any response
- 0 points for "do not know"

Fish diets [Question 5]:

- 0 points if respondent did not know any diet items
- 1 point for every correct diet item mentioned
- 0.5 points subtracted for every incorrect item mentioned (only subtracted from scores greater than zero).

Total LEK score:

0.2*Transmission + 0.4*Fish identification + 0.4*(Timing of fish spawning + Fish diets)

Section 5

Below are the questions from the social network section of the household survey. Note, this is an English translation of these questions. The actual survey was translated into the Fijian language and conducted in Fijian by native speakers.

Social Networks

In the next set of questions, we ask who you share resources with. We know that sharing is very common in many cultures, including here in Fiji. In Hawai'i, scientists have shown that the fish caught in one community may be widely dispersed to other parts of the island and beyond. Maintaining relationships can help in times of trouble. However, with recent social and environmental changes, many things are changing. We are interested in if/why/how sharing is changing. In this section, we will ask you to provide names of people. We just want to remind you that there are no right or wrong answers to these questions AND that we will not be sharing your personal information with anyone. We are not judging you.

[Surveyor then shows respondent an example of a network map (on last page) to explain how this data will be used]

27. In the past **two weeks**, to who have you **provided** resources **in this village**? (list more than one name OR name and house name for each listed- ex.: Jone, father of Mere)

- What is your relationship with whom you have provided?
[Eg. immediate family, non-immediate family, clan, church, chief, etc.)

-What resource was shared?
[e.g., fish, root crops, money, sugar]

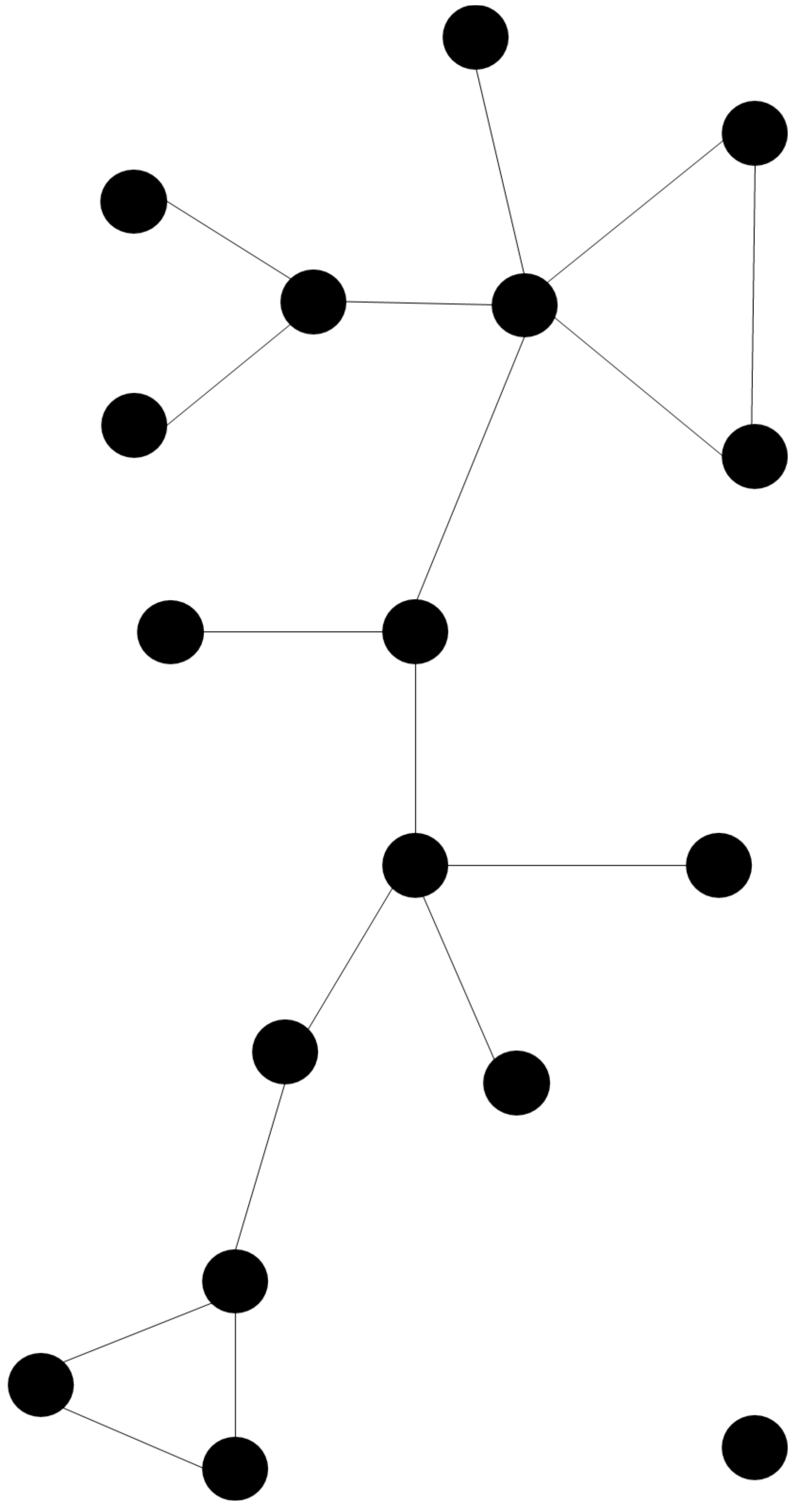
Name 1	Name 2	Relationship	Resource (s)

28. In the past **two weeks**, from who have you **received** resources from **in this village**? (list more than one name OR name and house name for each listed- ex.: Jone, father of Mere)

- What is your relationship with the providers?
[Eg. immediate family, non-immediate family, clan, church, chief, etc.)

-What resource was shared?
[e.g., fish, root crops, money, sugar]

Name 1	Name 2	Relationship	Resource (s)



Appendix 4

Table A3.1. Comparison of catch per unit effort (CPUE) estimates in Fiji from this study and other studies. Table is adapted from Teh et al. 2009.

Fishery	CPUE mean (± s.e.)	Reference
Hand line	2.27 kg $line^{-1}$ h^{-1}	Dalzell et al. 1996
Hand line	1.41 ± 0.31 kg $fisher^{-1}$ h^{-1}	Rawlinson et al. 1995
Hand line	2.75 ± 0.41 kg $fisher^{-1}$ h^{-1}	this study
Spear	1.2 kg $fisher^{-1}$ h^{-1}	Dalzell et al. 1996
Spear	1.51 kg $fisher^{-1}$ h^{-1}	Dalzell et al. 1996
Spear	2.07 ± 0.31 kg $fisher^{-1}$ h^{-1}	Kuster et al. 2006
Spear (day)	2.97 ± 0.70 kg $fisher^{-1}$ h^{-1}	this study
Spear (night)	3.80 ± 1.10 kg $fisher^{-1}$ h^{-1}	this study
Gillnet	18.9 kg set^{-1}	Dalzell et al. 1996
Gillnet	31.8 kg set^{-1}	Dalzell et al. 1996
Gillnet	24.76 ± 8.68 kg set^{-1}	this study

Appendix 5

Table A4.1. Correlation matrix of potential explanatory variables significance levels are indicated by: $p < .01$ ‘**’, $p < .05$ ‘*’

	Reef area	Distance to town	Town population	Travel time to town	Annual town visits	Income diversity	Livelihood diversity	Local ecological knowledge	Social capital	Estimated annual household catch	Importance of fishing to income	Material wealth
Reef area												
Distance to town	0.32**											
Town population	-0.35**	-0.49**										
Travel time to town	0.22**	0.98**	-0.43**									
Annual town visits	-0.13*	-0.39**	0.43**	-0.34**								
Income diversity	0.11	0.42**	-0.30**	0.44**	-0.09							
Livelihood diversity	0.11	0.36**	-0.26**	0.41**	-0.09	0.81**						
Local ecological knowledge	0.08	0.18**	-0.12*	0.19**	0.03	0.17**	0.14*					
Connectedness	0.24**	0.14*	-0.36**	0.15*	-0.15*	0.19**	0.28**	0.19**				
Estimated annual household catch	0.30**	0.29**	-0.22**	0.28**	-0.04	0.37**	0.29**	0.21**	0.25**			
Importance of fishing to income	0.14*	-0.08	0.19**	-0.07	0.14*	0.19**	0.00	0.26**	0.02	0.35**		
Material wealth	-0.05	-0.33**	0.45**	-0.33**	0.32**	-0.14*	-0.07	-0.06	-0.15**	-0.16**	-0.08	
Seafood consumption	0.33**	0.15**	-0.12*	0.13*	-0.03	0.17**	0.12*	0.32**	0.18**	0.39**	0.38**	-0.06

Appendix 6

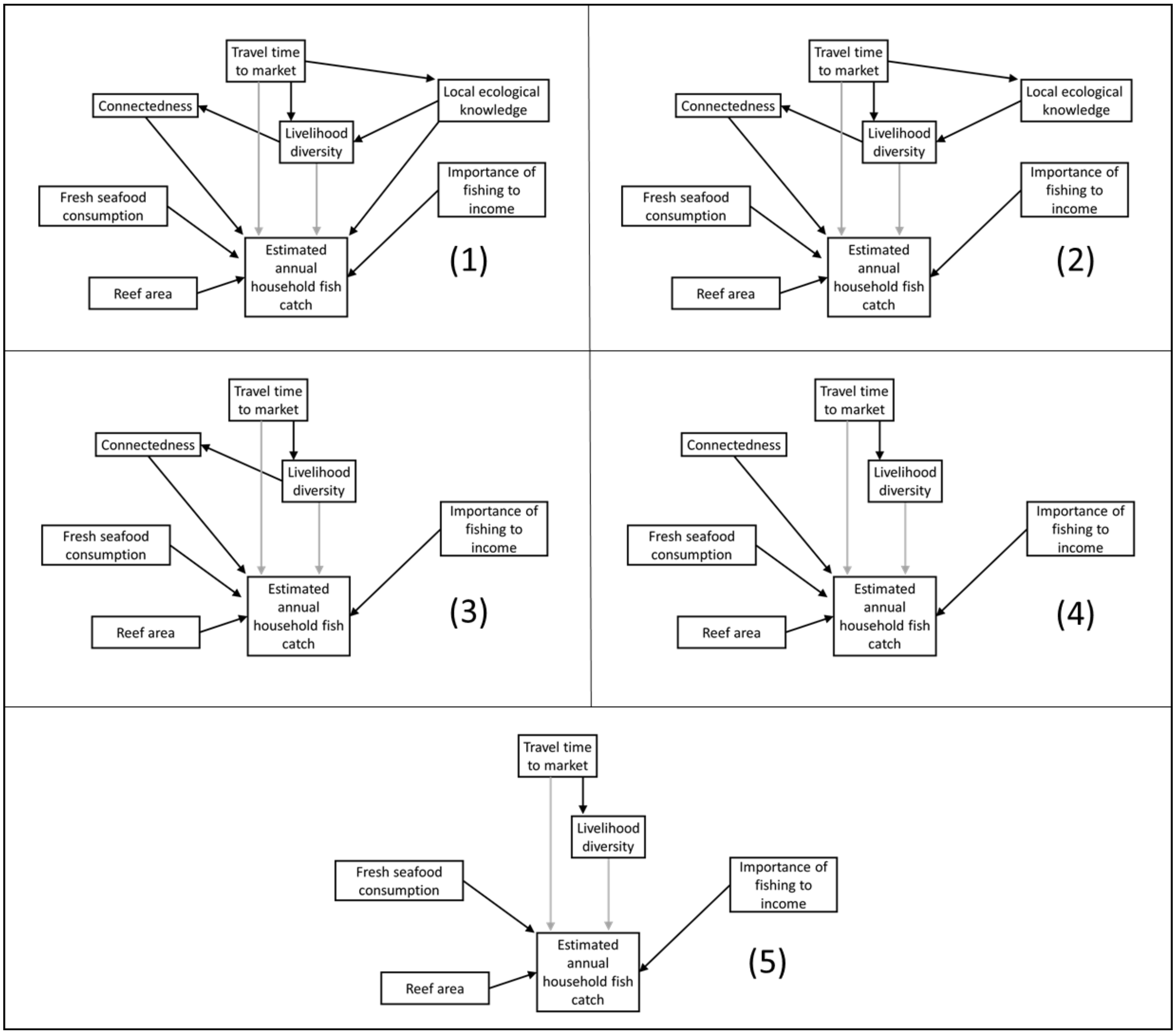


Figure A5.1. Comparison models. Model 1 is the hypothesized model and each subsequent model has had a non-significant variable removed. Model statistics are compared in Table A3.1 below.

Table A5.1. List of AICc scores and other model statistics from candidate models.			
Model	AICc	R2	P-value (chi-square)
1	13535.7	0.29	<0.01
2	10458.8	0.31	<0.01
3	9828.44	0.31	<0.01
4	9821.92	0.32	<0.01
5	8454.59	0.31	0.61

Table A5.2. Summary statistics of final model.

	Unstandardized effect size	Standardized effect size	SE	p-value
Effect on estimated household catch:				
Seafood consumption	0.37	0.199	0.113	0.001
Importance of fishing to income	0.738	0.272	0.177	<0.001
Livelihood diversity	0.335	0.186	0.111	0.002
Reef area	0.261	0.142	0.127	0.04
Travel time to town	0.068	0.168	0.025	0.007
Effect on livelihood diversity:				
Travel time to town	0.091	0.407	0.028	0.001

Appendix 7

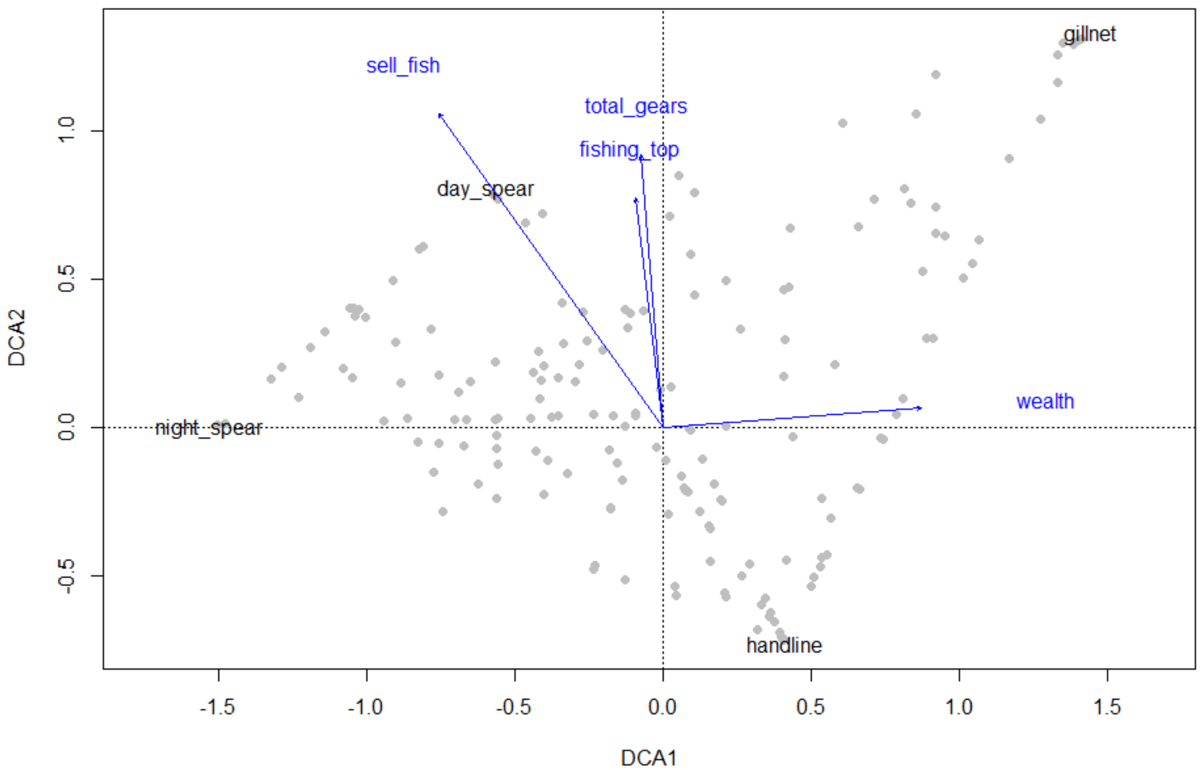


Figure A6.1. Results of detrended correspondence analysis (DCA) of household gear use assemblages. Household annual frequency of gear use (days) was plotted in multidimensional space. Axis 1: eigenvalue= 0.42, Axis 2: 0.35. Household socioeconomic data was fitted onto the ordination (only significant variables shown, where $p<0.05$), where smaller angles between arrows gear types represent stronger correlations and the length of the arrow is proportional to the correlation with the ordination axes.

The plot of the results of the detrended correspondence analysis was homogeneous, with no clear clustering of households (Axis 1: eigenvalue= 0.42, Axis 2: 0.35) (Fig. 4.7). The overlayed socioeconomic data on the ordination showed that households with a top income source of fish or that sell any amount of fish are correlated with higher amounts of spear use. Households with higher numbers of gears are more correlated with spear and gillnet use than with handline use. Similarly, households with the highest measures of wealth were most correlated with households with higher gillnet usage.

CHAPTER 5. CONCLUSION.

Synthesis

The overarching goals of this dissertation were to 1) advance our understanding of local visions of resilience to help inform the development of indicators of social-ecological resilience; 2) better understand the current structure of sharing networks, how different natural resources are shared within them, and whether there are certain fishing practices that are more associated with sharing; and 3) better understand drivers of resource extraction by utilizing culturally appropriate indicators at the appropriate scale.

In Chapter 2, I used a biocultural approach to understand local visions of resilience. The approach allowed for an increased understanding of local perspectives of social-ecological resilience in the Pacific Islands. I led a working group that used the resulting compilation of factors to develop measurable indicators that can be used to assess and monitor social-ecological resilience. While there are studies that have listed sociocultural factors as important for well-being and/or resilience, there were few existing useable indicators prior to this study. Further, existing indicators that had been used to measure "connectedness" may not have adequately capture connections important to place-based communities. Indicators developed using a biocultural approach, such as the examples provided in Chapter 2, are likely to indicate more meaningful processes and states to communities. If communities see that what is important to them is being incorporated into resource management or conservation, they may be more likely to support such interventions (McCarter et al. 2018).

In Chapter 3, I described how social network analysis can be used to measure social cohesion, a concept that has been documented to be important for resilience in the literature, and that was also mentioned extensively in visioning exercises described in Chapter 2. I used social network analysis to assess sharing networks in villages along a gradient of socioeconomic conditions. To date, there have been very few studies on contemporary sharing networks in the Pacific (Gurven 2004). Further, this chapter provides an example of the potential impacts of socioeconomic change on sharing networks. I found differences in the structure and composition of villages on the main island (where the capital is located) and villages on other islands. Not only were villages less cohesive on the main island, but they also had fewer ties from natural resources and more ties from cash and purchased goods. I also found mean household fishing frequency to be positively correlated with and mean household wealth to be negatively correlate with two measures of network cohesion. This chapter highlighted that natural resources are not simply important for providing food and income, but also for social cohesion. Thus, the sustainable management of resources is important for more reasons than are usually cited and when natural resources are substituted with other goods, social cohesion may suffer.

While fishing activities were associated with more cohesive networks in Chapter 3, it is known that overfishing is a major driver of coral reef decline. As fishing is a local driver, it is one that can be managed (unlike climate change associated drivers). In order to effectively manage, it is important to understand human behavior, especially at the individual and household level, where decisions are made. While there have been large advances in our understanding of the human dimension, culturally appropriate, household-level studies are lacking. In Chapter 4, I used several indicators (several of which match with factors from categories developed in the visioning exercises described in Chapter 2), along with more standard drivers to model the predictors of household fishing catch. The importance of fishing to income, household fish consumption, livelihood diversity, travel time to market, and coral reef area, all positively affect estimated household-level fish catch. By finding a positive correlation between livelihood diversity and household fish catch, this chapter supports the notion that additional or alternative income generating projects (which have been popular with NGOs and governments) are not likely to curb fishing efforts. This is likely for reasons related to factors under the "Connectedness to People and Place" and "Indigenous and local knowledges, skills, practices, values and worldviews" categories, described in Chapter 2. In the Pacific, where fish and fishing are central to culture and identity, alternative livelihoods may not provide resources needed for traditional events, allow individuals to carry out their traditional roles, or provide opportunities for knowledge transmission. Instead, alternative livelihood sources may just serve as supplemental income.

Further in Chapter 4, by finding a positive correlation between proximity to town and household fishing (i.e., households further from towns had higher estimated catches), this chapter highlights the role of middlemen in small-scale fisheries, who have been largely overlooked as drivers of fisheries catch. It is interesting to note, however, that while importance of fishing to income was a driver of household fishing, the proportion of households that ranked fishing as their top income source (i.e., essentially a village-level importance of fishing to income) was not significantly correlated with the network variables that were used in the ordination in Chapter 3, that produced two clear clusters of villages. This suggests that while the commercialization of marine resources may drive household fishing, it is not commercialization, but the proximity to urban centers that negatively impacts social cohesion. However, if the commercialization of marine resources is such to drive fishing to unsustainable levels, declining catches or a resulting reduction in fishing frequency could negatively impact social cohesion. They key is sustainable management, for which it is necessary to incorporate context appropriate indicators (which brings us full circle, back to Chapter 2).

Management Contributions

Sociocultural factors may have been ignored in resource management and conservation planning in the past because their influence on coral reef resilience is indirect, rather than direct. Further, if social scientists were not involved in the resource management or conservation planning, the skills needed for identifying the relevant sociocultural factors and the development of appropriate indicators may have been lacking. The remainder of this section details the contributions each chapter makes for the incorporation of sociocultural factors in planning for the sustainable management of coral reefs.

Chapter 2

This chapter provides a methodology for better understanding local visions of resilience that can be used to develop locally appropriate indicators. Similar approaches can be used in other locations. In this chapter, we identified “Connectedness to People and Place” and “Indigenous and local knowledges, skills, practices, values and worldviews” as two categories that are important to Pacific Island visions of social-ecological resilience, but for which existing indicators are few. Management institutions may choose to focus attention on developing locally appropriate indicators to measure factors in these categories. We provide a sample of measurable indicators for the above-mentioned categories that can be used, if appropriate, or can be referenced for the development of indicators in other locations.

Chapter 3

In this chapter, I demonstrate how social cohesion can be quantified to capture meaningful social processes. Social network analysis, or other analyses of resource sharing can provide measurements of social cohesion in a relatively simple manner. Only two questions were used to generate data for the social network analyses.

This chapter provides further evidence that natural resources are not only important for food security and income generation, but also for social cohesion. Thus, managing for sustainability is critical, and cultural practice, which is often overlooked, should be considered as a strong component of sustainability. This chapter also highlights the different role fisheries play in the sharing networks of villages of differing market proximities, which should be considered in management planning. Finally, by highlighting that some harvesting practices are more associated with sharing practices than others, this chapter makes the case for understanding the disposition of catch, as certain management practices could undermine sharing practices.

Chapter 4

This chapter highlights sociocultural factors that influence household fishing that should be considered when managing fishing activities. It also provides additional evidence that households within communities are heterogeneous. Thus, village level averages may not accurately reflect the factors that influence fishing behaviors.

This chapter highlights the role of middlemen in bringing markets to rural areas. Thus, it is not only communities in close proximity to urban markets that should be considered at risk to commercialization of resources. Finally, the chapter provides evidence that counters the concept of income generation projects' ability to reduce fishing pressure

Limitations

Although this research was conducted in the Pacific Islands, much of it in Fiji, in particular, the respondents in the workshops described in Chapter 2 and the Fijian villages in Chapters 3-4 where the research took place, were not randomly selected. Thus, our results cannot be interpreted as representative over the vast and diverse Pacific Islands region, or the entire country of Fiji. However, the general themes that emerged from the workshops (Chapter 2) are consistent with those addressed in studies conducted throughout the region and documented in the literatures of anthropology, sociology, and geography (Hviding 1996, D'arcy 2006, Bambridge 2016). The research in Chapters 3-4 could have benefitted from the inclusion of additional periurban villages, that are somewhere between rural and urban. Additional samples, with increased variation may have also allowed for additional variables to be incorporated into the final model.

Recommendations for future research in this area

Linking social and ecological systems

The initial goal for the structural equation model in Chapter 4 was to link the sociocultural variables to resource state (e.g., fish biomass). However, this proved impossible given the following: 1) it was impossible to distinguish the fishing grounds of villages within the same district, as villagers fished on the reefs of each other's fishing grounds; 2) the ecological data was collected for a different purpose and did not coincide sufficiently with fishing areas of respondents, therefore, when trying to match households to reefs, there were several households that did not match to any of the surveyed reefs; 3) further, since reefs could not be identified by village, when trying to match households to reefs, there was no way of connecting reefs in no fishing areas to households, which was desired because the characteristics of certain households and villages may have made for more effective management in such areas.

In order to link social and ecological data, it is essential that a biocultural approach is taken from the start, to identify the relevant ecological units. Not only will this approach allow for the integration of different types of data, but it will also likely provide results that are more meaningful to the people that rely on the ecological systems of focus.

Feedback loops in social-ecological systems

A question that I have repeatedly received as I have presented this work concerns the direction of my hypotheses and subsequent models. For example, people have asked whether local ecological knowledge (LEK) drives household fish catch or whether it is the other way around. Similarly, do households that fish more frequently share more or is it because households share more, they need to fish more frequently? It is likely that these types of processes are feedbacks, so the question can be asked in either direction. There is a lack of empirical data on feedback loops in social-ecological systems (Kittinger et al. 2012). Future work can use tools such as structural equation modeling to fill such gaps.

Social network analyses

To increase our understanding of intravillage sharing networks, the methods used in the social network analysis conducted in Chapter 3 could be enhanced by gathering volume estimates of resources that were shared and expand the items asked about to include information/knowledge, labor, and time (e.g., childcare, sick care). This would allow for a more complete understanding of the value of shared resources. Future studies could also expand the network analysis to examine not only sharing within villages, but also between villages. A true network analysis of intervillage sharing would be a very large undertaking, as it would be necessary to follow up with the links to the different villages. As such, other methods would probably be necessary to make such a study feasible.

Local Ecological Knowledge

Although it has been documented that LEK has influenced individual and community scale marine resource use for centuries (Johannes 1978, Veitayaki 2002), the contemporary role of LEK in resource use has been debated, as such knowledge systems have been used both to maximize efficiency of harvests (Foale 1998) and to restrict harvesting (Johannes 1978, Friedlander et al. 2013). Regardless, there is increasing acknowledgement that LEK is invaluable for developing effective place-based natural resource management (Berkes et al. 2000, Poepoe et al. 2007, Thornton and Scheer 2012). Thus, it is important that remaining LEK is respected and where it has been lost, the production of new LEK is supported. Further, future research should examine how LEK influences resource use. For example, under what circumstances is LEK used to maximize harvest in an unsustainable manner and when is it used with future generations in mind? I expect that LEK is used for sustainability purposes once a conservation ethic has been developed, which may not occur until resource depletion is experienced. In an increasingly connected Pacific, however, is it possible for places which have already experienced depletion to communicate their experiences? During my graduate study, I have been privileged to witness and participate in several events in which Pacific Islanders from different island groups were able to meet in each other’s places and not just share, but also experience the results of different pasts. I believe that the exchange of ideas *in situ* is one of the most powerful methods for communicating the potential futures that lie ahead and the actions that can enable or disable such trajectories.

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Appendix 8. Human Studies Program Exemption Approval.

Office of Research Compliance
Human Studies Program

UNIVERSITY *of* HAWAIʻI®
MĀNOA

June 28, 2013

TO: Rachel Dacks
Principal Investigator
Biology Program

FROM: Denise A. Lin-DeShetler, MPH, MA
Director

SUBJECT: CHS #21391- "Investigating the Complexities in Coral Reef Social-Ecological Systems in Fiji"

This letter is your record of the Human Studies Program approval of this study as exempt.

On June 28, 2013, the University of Hawai'i (UH) Human Studies Program approved this study as exempt from federal regulations pertaining to the protection of human research participants. The authority for the exemption applicable to your study is documented in the Code of Federal Regulations at 45CFR 46.101(b)(Exempt Categories 2, 4).

Exempt studies are subject to the ethical principles articulated in The Belmont Report, found at http://www.hawaii.edu/irb/html/manual/appendices/A/belmont.html.

Exempt studies do not require regular continuing review by the Human Studies Program. However, if you propose to modify your study, you must receive approval from the Human Studies Program prior to implementing any changes. You can submit your proposed changes via email at uhirb@hawaii.edu. (The subject line should read: Exempt Study Modification,) The Human Studies Program may review the exempt status at that time and request an application for approval as non-exempt research.

In order to protect the confidentiality of research participants, we encourage you to destroy private information which can be linked to the identities of individuals as soon as it is reasonable to do so. Signed consent forms, as applicable to your study, should be maintained for at least the duration of your project.

This approval does not expire. However, please notify the Human Studies Program when your study is complete. Upon notification, we will close our files pertaining to your study.

If you have any questions relating to the protection of human research participants, please contact the Human Studies Program at 956-5007 or uhirb@hawaii.edu. We wish you success in carrying out your research project.

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