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Social-ecological Heterogeneity Shapes Resilience of Small-scale Fisheries: An Interdisciplinary Analysis of the Mexican Chocolate Clam Fishery in Loreto, Mexico

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SOCIAL-ECOLOGICAL HETEROGENEITY SHAPES RESILIENCE OF SMALL-SCALE FISHERIES: AN INTERDISCIPLINARY ANALYSIS OF THE MEXICAN CHOCOLATE CLAM FISHERY IN LORETO, MEXICO

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An Abstract of the Dissertation Presented
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All benefits provided by natural systems are embedded within coupled social-ecological systems (SESs). Fisheries are clear examples of SESs: through fishing, humans affect ecosystem structure and functioning, and in turn, receive benefits, including sustenance, employment, and cultural value. Resilience, the ability to maintain structure and function in the face of change, is key to sustaining the social and ecological components of fisheries-related SESs and their interactions.

Many factors contribute to resilience, including heterogeneity. By identifying heterogeneity in these complex systems, we are better able to understand the capacity of fishery-related SESs to adapt to change, and contribute to management that sustains valuable benefits. In this dissertation, I ask: 1) How are SESs associated with marine fisheries shaped by environmental, social, and institutional heterogeneity, and 2) what are the implications of this variation for resilience and adaptive capacity of fishers and the SES, in the face of changing environmental and socioeconomic conditions?

To answer these questions, I employ an interdisciplinary approach focused on the Mexican chocolate clam (*Megapitaria squalida*) fishery in Loreto, Baja California Sur, Mexico. I conducted biological field studies, household surveys, interviews, ethnographic conversations, and developed fisheries models from my empirical work. Together, my results illustrate that management aligned with the biology of target populations and stakeholders' goals is critical to sustainable fisheries.

Heterogeneity among fishers affects their individual capacities to adapt to change. Maintaining a diversity of adaptive strategies is essential for individual adaptive capacity. Likewise, maintaining fishery heterogeneity, by ensuring all fishers are equipped to adapt, will strengthen community adaptive capacity. The Mexican chocolate clam provides diverse cultural and provisioning values to communities, and management that considers all benefits will be better equipped to account for the needs and knowledge of diverse stakeholders. Both formal and informal institutions shape fishing practices, and integrating them, via collaborative governance, would increase community participation in management and enhance fishery resilience.

My interdisciplinary approach acknowledges the intricate web of human-resource interactions shaping fisheries and reveals how heterogeneity shapes SES resilience. Management that supports diversity in all forms will be better equipped to contribute to the resilience of these highly valuable and dynamic systems.

DEDICATION

I dedicate this dissertation to my grandfather, Charles Anthony Taylor, who never failed to encourage my curiosity, and whose lifelong dedication to learning will always inspire me to keep asking questions.

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SES	Social-ecological system
YPR	Yield per recruit
SSB/R	Spawning stock biomass per recruit
SPR	Spawning potential ratio

CHAPTER 1

INTRODUCTION

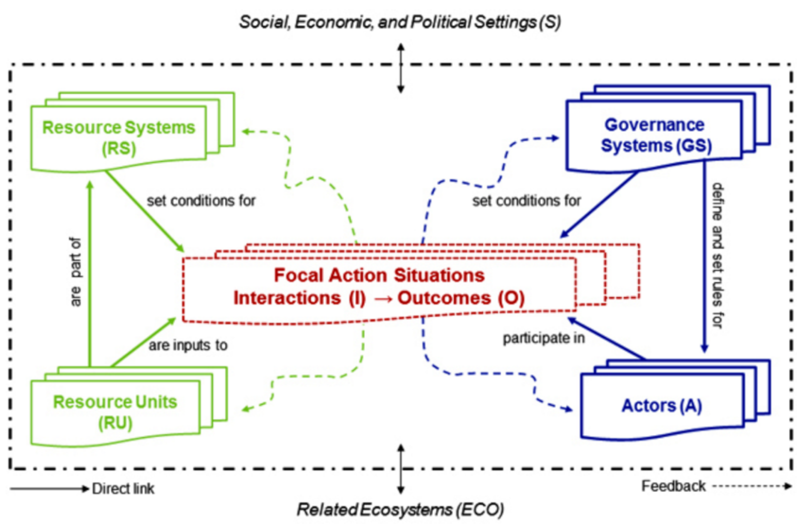
All benefits provided by marine ecosystems – including healthy food, clean water, and protection from coastal storms – are embedded within social-ecological systems (Millennium Ecosystem Assessment 2003, Kareiva et al. 2011). By social-ecological systems, I am referring to the reciprocal and multi-scaled interactions between people and nature, and the ecological, social and economic outcomes that emerge from those interactions (Berkes et al. 2003). Several frameworks for developing and guiding interdisciplinary research on the interactions between people and nature have been proposed, including vulnerability frameworks (Turner et al. 2003, Adger 2006), the sustainable livelihood approach (Morse and McNamara 2013), and the social-ecological systems framework (Ostrom 2009).

Understanding SES dynamics is key to sustaining vital interactions between humans and ecological systems and ensuring the continued delivery of valuable benefits, or ecosystem services, to human communities. The dynamics and trajectories of these systems are governed by three related attributes: resilience, adaptability, and transformability (Walker et al. 2004). Resilience is the capacity of a system to absorb or otherwise adapt to disturbance while retaining essentially the same structure and function (Gunderson and Holling 2001). Adaptability is a part of resilience. In SESs it refers to the human component's ability to influence and manage for resilience by making purposeful movements between stability basins or reshaping the stability landscape (Walker et al. 2004). Transformability is the capacity to create a new stability landscape when current conditions make the existing system untenable or undesirable.

Social-ecological systems framework

In Ostrom's social-ecological systems framework (2009) these linked systems are conceptualized as interacting subsystems, including resource systems, resource units, governance systems, and actors. Together, interactions within and among these subsystems (or what Leslie et al. 2015 refer to as "dimensions") produce emergent outcomes, at the level of the whole SES (Figure 1.1). Related ecosystems, as well as associated social, economic, and political settings, influence, but are not directly a part of, the core framework. These settings are assumed to be overarching and to influence interactions, although their placement outside of the framework minimizes their potential importance (Partelow 2016). The SES framework highlights the importance of connections in shaping system dynamics, and is useful for operationalizing interdisciplinary studies of SESs (Ostrom 2009, McGinnis and Ostrom 2014).

Figure 1.1. The Social-Ecological Systems Framework. Figure from McGinnis & Ostrom (2014), adapted from Ostrom (2009).



Resilience of coupled social-ecological systems

The capacity for systems to reorganize, adapt, and even transform is the cornerstone of current discussions of resilience in SESs (e.g., Boyd & Folke 2011, Biggs et al. 2015, Stoll et al. 2016). SES resilience recognizes that people and nature are interconnected systems (Folke et al. 2010). It is key to maintaining human well-being via the continued delivery of ecosystem services (Biggs et al. 2015).

Even within the widely-accepted definition of resilience as the ability of a system to maintain functioning in the face of disturbance (Folke et al. 2004), the concept has multiple meanings. It can be thought of as a metaphor related to sustainability, a characteristic of dynamic systems, or as a measurable attribute of systems *in situ* (Carpenter et al. 2001). Thus, in any discussion or study of resilience, it is necessary to first establish "resilience of what to what" (Carpenter et al. 2001). Unless specific sources of disturbance have been identified, general resilience is highly desirable in SESs, as it reflects the capacity to adapt to a variety of different stressors, including novel ones (Folke et al. 2010, Berkes and Ross 2013). General resilience also underpins specified resilience to a diversity of stressors, and thus is broadly applicable to many SESs (Berkes and Ross 2013).

Power differentials among stakeholders and managers also influence who defines resilience, how resilience is operationalized, and "for whom" resilience benefits (Lebel et al. 2006). Resilience at the community and individual scales may have conflicting definitions, goals, and priorities. Definitions of resilience may not represent the needs of all stakeholders within SESs, particularly where power differentials limit who is included in decision-making processes. Understanding and enhancing resilience in SESs requires sensitivity to power differentials and the conflicts that arise from unequal power among stakeholders (Biggs et al. 2015).

While there is no universally-agreed-upon set of criteria for assessing resilience in SESs, many researchers have identified characteristics thought to foster general resilience (Anderies et al. 2006, Walker et al. 2006, Biggs et al. 2015). These characteristics provide options and capacity for adapting to changing conditions. They include, but are not limited to, diversity and redundancy (Folke et al. 2004, Chapin et al. 2009), connectivity (Biggs et al. 2015), attention to slow variables and feedbacks (Carpenter et al. 2001), social capital (Adger et al. 2005), multilevel governance (Adger et al. 2005), and institutional learning (Biggs et al. 2015).

Biological diversity is a commonly-cited criterion for resilient SESs, and includes both response diversity and functional redundancy (Folke et al. 2004). Response diversity, the diversity of responses to environmental variability, and functional redundancy, the ability of multiple taxa to fulfil the same ecological role, are both critical to SES resilience (Elmkvist et al. 2003). Together, these two types of biological diversity reinforce ecosystems' capacity to withstand changing conditions, and provide options at the scale of the SES for adapting to change and disturbance (Folke et al. 2004, Worm et al. 2009, Pellowe and Leslie 2017). Relatedly, connectivity can enhance recovery following disturbance by providing links to sources of ecosystem recovery (Bernhardt and Leslie 2013), and facilitating information exchange among institutions and actors (Biggs et al. 2015).

Ecosystems, and the SESs associated with them, are complex adaptive systems, characterized by nonlinear dynamics and the capacity to exist in multiple states (Levin 1999). Human activities alter the dynamics of ecosystems, and expected increases in human use of natural resources will lead to greater uncertainty about the future of ecosystems and the services they provide (Folke et al. 2002). Human activities have already reduced the resilience of ecosystems around the world (Scheffer et al. 2001, Jackson et al. 2007). Attention to slow variables and feedbacks is critical if we are to support SES resilience and the capacity of these systems to produce the ecosystem services on which people depend (Folke et al. 2004). Changes in slow variables, such as exposure to stress over a long period of time with no noticeable change, can culminate in an abrupt shift as the system crosses a threshold (Folke et al. 2004). Such shifts can result in drastic changes in ecosystem services (Carpenter et al. 2001, Gordon et al. 2008, Bennett et al. 2009). Managing slow variables and feedbacks is key to maintaining ecosystem services (Biggs et al. 2015). This requires assessing the diversity of ecosystem services a given ecosystem provides (Gordon et al. 2008), as well as understanding and monitoring slow variables.

Institutions and social-ecological resilience

Establishing institutional capacity to respond to environmental and economic change is a critical element of resilient SESs (Ostrom 2005). Social capacity, institutional redundancy, and institutional learning all contribute to institutions' capacity to adapt as conditions change. Social capacity contributes to SES resilience by facilitating the learning and collective action needed to effectively manage resources (Ostrom 2000). Social capacity, which exists at both the individual and community scales, is enhanced by broadening stakeholder participation, improving communication among stakeholders, and supporting local actors' ability to manage their resources (Allison and Ellis 2001, Ramirez-Sanchez and Pinkerton 2009). Social capacity is critical in times of change, as it provides the means for stakeholders to exchange information and determine appropriate ways forward. Polycentric governance systems are characterized by multiple, nested institutions at the scale of the regional to the local, that coordinate with one another to manage local resources. When polycentric governance systems involve power sharing between formal institutions and local stakeholders, as in co-management systems, social capacity may be enhanced. Such arrangements can contribute to increased SES resilience, but careful attention must be paid to the distribution of power among stakeholders (Béné et al. 2009), and who benefits from increased resilience (Lebel et al. 2006). The wealthy are better poised to take advantage of the redistribution of power that occurs in co-management, and may take advantage of the opportunity to advance their own agendas at the expense of others, often the most vulnerable. Co-management that creates space for diverse local actors to exercise their agency and share power will result in equitable stakeholder participation in decision-making processes, improved communication among stakeholders and between local and central authorities, enhanced social capacity, and resilience that benefits all stakeholders.

Without buy-in from resource users themselves, resource management can be fraught with problems, including resistance and recurrent rule-breaking (Ostrom 2005, Aswani et al. 2017). Formal, top-down management of resources without the participation of local stakeholders is unlikely to lead to sustainable resource management. Polycentric systems, like co-management, contribute to effective community-based resource management by explicitly including the participation of local actors, and may be better able to contribute to long-term sustainable resource management than top-down management by a single central authority (Ostrom 2005, Aswani et al. 2017). Polycentric arrangements also involve institutional redundancy, where multiple institutions work in tandem to produce the same outcomes (Ostrom 2005). Polycentric and multilevel governance systems improve the fit of rules and regulations with local contexts, and enable institutions to adapt and respond to change at appropriate scales (Lebel et al. 2006, Carlisle and Gruby 2017). Institutional redundancy and the ability of institutions to adapt in accordance with local conditions are essential to sustainable resource management, and contribute to resilience in SESs (Ostrom 2005, Biggs et al. 2015, Aswani et al. 2017). Likewise, institutional heterogeneity, i.e., the diversity of systems of rules governing human behavior, can contribute to SES resilience (Ostrom 2005). Redundancy among institutions promotes learning and experimentation, and provides internal checks against resource exploitation. Institutional learning is a critical aspect of resilient SESs that is facilitated both by connectivity and social capital, and results in enhanced understanding of SES dynamics that is essential to the development of novel strategies for responding to disturbance and change (Berkes et al. 2003, Biggs et al. 2015).

Fisheries as social-ecological systems

Fisheries are clear examples of SESs: resource exploitation by humans can significantly affect system structure and functioning (Jackson et al. 2007), and impact the long-term sustainability of human-resource interactions (Basurto et al. 2013b, Partelow and Boda 2015). Small-scale fisheries can be conceptualized as complex adaptive SESs because of their emergent dynamics and the types of problems they present (Folke et al. 2005, Gelcich et al. 2010). Fisheries provide valuable services, including food, nutrition, and livelihoods, to hundreds of millions of people around the world (Food and

Agriculture Organization 2016), yet the resilience of these systems is threatened by overexploitation, pollution, environmental variability and climate change, among other stressors (Béné 2006, Halpern et al. 2012). It is estimated that 90% of people dependent on capture fisheries are involved in small-scale operations (Food and Agriculture Organization 2015). Small-scale fisheries play a critical role in alleviating poverty, and providing food and rural livelihood security (Food and Agriculture Organization 2016). Managing for fishery resilience can help ensure the continued delivery of these valuable services. As in other SESs, heterogeneity is a key characteristic of resilient fisheries, and understanding sources of heterogeneity in fisheries can shed light on how these SESs may respond to both short-term disturbance and long-term environmental change. By understanding SES responses to these changes, it also is possible to more strategically develop management strategies that enhance resilience and adaptive capacity in ways that are consistent with fisheries management objectives.

The SES framework places interactions and their resultant outcomes at the forefront. In this dissertation, I first identified these interactions (*e.g.*, harvest strategies, consumption), and then investigated how heterogeneity shapes system dynamics. My approach applies Ostrom's (2009) SES framework to study interactions between the clam fishery's ecological and social dimensions. This framework provides a template for addressing sustainability challenges and organizing transdisciplinary research agendas (Partelow 2016). In my work, the SES framework serves as a guide to identify important aspects of a small-scale fishery SES that affect resilience outcomes. To uncover the interactions shaping a small-scale fishery SES, I combined studies of the life history of a fished species, the ecological system of which that species is part, the actors directly and indirectly involved in the fishery, and the governance systems that shape fishing practices. This integration allowed me to understand SES dynamics and the factors contributing to SES resilience. In this dissertation, I undertook a series of studies designed to answer two guiding questions:

1. *How are social-ecological systems associated with marine fisheries shaped by environmental, social, and institutional heterogeneity?*
2. *What are the implications of this variation for resilience and adaptive capacity of fishers and the SES of which they are part, in the face of changing environmental and socioeconomic conditions?*

To answer these questions, I studied a model small-scale fishery, the fishery associated with the Mexican chocolate clam, *Megapitaria squalida*, in Loreto Bay National Park, a national marine park on the Gulf of California coast of Baja California Sur, Mexico. Over six years, I traveled to Loreto eight times, and spent a total of twelve months living in the region. During this time, I developed relationships with clam harvesters and their families, fisheries and national park officials, restaurant and other business owners, conservation organizations, and community members. I organized and participated in community outreach, and communicated my findings regularly with local contacts. I also developed and carried out field work for my four dissertation chapters. My chapters each focus on an interaction or set of interactions between the first-level core subsystems outlined in Ostrom's SES Framework (2009): resource systems; resource units; actors; and governance systems. By combining ecological and social science approaches, I seek to capture both the ecological aspects of a data-limited fishery, as well as its complex social landscape, which is so often missing from fisheries management (St. Martin et al. 2007). In the second chapter, I focus broadly on the links between all subsystems with special attention to the way in which fisheries management scenarios interact with clam life history to affect fishery and clam population outcomes. In the third chapter, I examine the resource unit-actor relationship, and seek to understand the social context of the species and fishery, with a study of the diverse ecosystem services values that Mexican chocolate clams provide to households in the Loreto Bay region. In the fourth chapter, I explore another aspect of the resource unit-actor relationship with a study of how heterogeneity among clam harvesters affects fishing practices and individual adaptive capacity. In the fifth chapter, I focus on the actor-governance system interaction, exploring how formal and informal institutions shape fishing practices, interact with one another, and affect the fishery's potential for collaborative, polycentric governance. Throughout this dissertation, I illuminate how heterogeneity in the fishery's ecological, social, and institutional realms influence the resilience and adaptive capacity of clam fishers and the SES of which they are part, particularly in the face of changing environmental and socioeconomic conditions.

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CHAPTER 2

SIZE-SELECTIVE FISHING LEADS TO TRADE-OFFS BETWEEN FISHERY PRODUCTIVITY AND REPRODUCTIVE CAPACITY

Abstract

Most fishing is inherently size-selective, in that fishers preferentially select a subset of the population for harvest based on economic incentives associated with different sized fish. Size-selective fishing influences the targeted population and fishery performance in multiple ways, including changing the reproductive capacity of the target population and altering fishery yield. Understanding how social-ecological variability, including size selectivity, affects target species populations is critical for fisheries management to optimize the benefits of fisheries and the ecological impacts on target populations. In this study, I use yield per recruit, spawning stock biomass per recruit, and length based spawning potential ratio models to explore how a range of size selectivity scenarios affect fishery and population productivity for Mexican chocolate clams, *Megapitaria squalida*, in Loreto, Baja California Sur, Mexico. My results suggest that alternate slot limits result in trade-offs between fisheries yield and reproductive productivity of the target population. A more restrictive slot limit reduces the proportion of the population available to harvest, resulting in higher reproductive capacity of the population and lower short-term fisheries yield than a less restrictive one, conditional on the same level of fishing mortality. However, in the long run, a more restrictive slot limit will likely lead to a higher number of recruits, larger stock size, and higher long-term fisheries yield relative to a less restrictive scenario. More restrictive slot limits also result in higher values for F_{max}, a proxy for rate of fishing mortality at maximum sustainable yield, and lower values for $F_{0.1}$, a precautionary rate of fishing mortality. My findings highlight that how people fish matters, perhaps as much as the quantity of fish harvested; size-selective fishing that aligns with the life history of target populations and stakeholders' goals is critical to sustaining fisheries and the valuable food and livelihoods they provide.

Introduction

Multiple types of social-ecological variability influence target species populations, including selective harvest by humans. Most fishing is inherently selective in that harvesters choose a subset of the target population to harvest, e.g., only large or mature individuals (Fenberg and Roy 2008, Zhou et al. 2010). Size-selective harvest, in which fishers preferentially target individuals of a certain size, is common, and can result in evolutionary shifts, reduction in species productivity, and fishery collapse (Darimont et al. 2009). Most fisheries selectively remove large-bodied individuals due to market demand, and the size of harvested individuals relative to maximum body size may be an indication of overfishing (Pauly et al. 2002).

Size-selective fishing affects target species by altering the reproductive capacity of the population. Harvesting fish before they mature is a precursor to overexploitation (Salas et al. 2007), and preferential harvest of large individuals can lead to evolutionary changes including smaller maximum body size and smaller size at maturity (Baskett et al. 2005, Fenberg and Roy 2008). Understanding how social-ecological variability, including size selectivity, affects target species populations is critical for fisheries management to optimize the economic and livelihood benefits of fisheries, while recognizing the important constraint posed by the need to sustain target stocks. Current fisheries management often relies on the evaluation of stock status, which presents challenges for situations in which target population and fisheries data are limited (Cope and Punt 2009). A range of methods for evaluating data-limited fisheries are emerging (Hordyk et al. 2015a). In this study, I use field studies to parameterize standard and widely used fisheries models including yield per recruit (YPR) and spawning stock biomass (SSB) models to explore how a range of size selectivity scenarios affects fishery and biological outcomes. I also employ a data-limited technique to estimate current exploitation patterns from length frequency data. This technique, spawning potential ratio (SPR), is a well-established biological reference point that is particularly useful for evaluating data-limited fisheries management, since it requires data inputs that are relatively easy to obtain, including length-based catch data and basic biological parameters.

The Mexican chocolate clam (*Megapitaria squalida*) is a harvested species in the Mexican state of Baja California Sur that provides an important source of food and livelihoods to coastal communities. Yet, it is a data-limited fishery lacking baseline biological data. Despite consistent landings over the past 20 years (Pellowe and Leslie 2017), fishers have observed reduced abundance of clam populations (Pellowe and Leslie, in review). The chocolate clam is one of the top species harvested in Baja California Sur, which is part of Mexico's Gulf of California region. This region provides 50-70% of Mexico's total annual fishing harvest by volume (Erisman et al. 2011, Azuz-Adeath and Cortés-Ruiz 2017). Despite the importance of the chocolate clam as a fished species in this region, fundamental questions about its ecology have not been well studied, such as its rate of growth, life span, and population size structure. Data-driven fisheries management is critical to the maintenance of this species as a source of food and livelihoods to communities in Baja California Sur.

In this study, I collected baseline biological data on chocolate clams via field studies, then developed and parameterized YPR, SSB/R, and SPR models in order to investigate current exploitation rates, and to explore how a range of slot limit scenarios could impact the fishery and fished population. To produce information relevant for managers to use in determining appropriate slot limits for the species, it is necessary to understand *how size-selective fishing affects fishery yield and the reproductive capacity of targeted clam populations.*

Methods

Study system

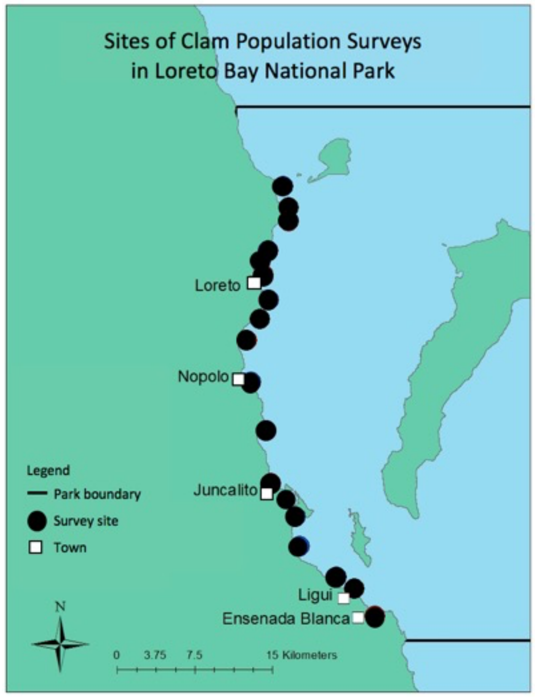
Mexico's Gulf of California region is renowned for its rich biological diversity and highly productive fisheries. In Loreto Bay National Park (LBNP), on the coast of the state of Baja California Sur, the Mexican chocolate clam (*Megapitaria squalida)* is an important food and income source and a symbol of communities' proud connection to the marine environment (Pellowe and Leslie, in prep). The clams live in soft sediment habitats from the intertidal to depths of 160m (Keen 1971). Fishers harvest clams by free or hookah diving, to depths of up to 10m. For many Loretano families, chocolate clam fishing provides supplementary food and income in times of scarcity. The species also serves as the primary income source for many fishing families.

Field studies

I conducted several field studies to parameterize the fisheries models I developed. These included subtidal population surveys, an enclosure study of clam growth and mortality, and measurements of clams from fishers' harvests.

In summer 2015, I conducted subtidal surveys at 17 sites along the coast of LBNP (Figure 2.1). At each site, I surveyed clam population density and size structure at three discrete depth categories: 0-5m depth, 5-10m depth, and 10-15m depth. Each site*depth was surveyed via two subtidal transects of 18-20m in length, with every meter sampled along its length using a 1m^2 PVC quadrat. Within each 1m^2 quadrat, all sediment was excavated to a depth of 20cm (i.e., deeper than the depth at which the largest chocolate clams burrow). All clams within each transect were measured and counted at depth and returned to the sediment. For each clam, I took an anterior-posterior measurement of shell length. Data on environmental variables, including depth, temperature, salinity, and sand grain size, were also collected at each site. Since fishing effort is generally greatest at shallow depths and lower at deeper depths (Pellowe, *unpubl. data*), I expected to find a difference in clam density among the depth classes, with the highest densities of chocolate clams in the 10-15m depth class. To test for the effect of depth class on clam density, I performed an ANOVA in R (R Core Team 2019).

Figure 2.1. Map of Loreto Bay National Park



From 2015-2016, I conducted a study of clam growth and mortality by marking clams and placing them in benthic enclosures at depths of 5m and 20m at a protected site in Ensenada Blanca, Loreto Bay (25.7234° N, 111.2387° W). At the start of the study, clams were collected via SCUBA from Ensenada Blanca, brought to the surface, and notched with a metal file on the mid-ventral edge of their shells. Except while being notched, clams were kept in seawater. Twelve 1m x 1m x 30cm enclosures were constructed using plastic-coated metal mesh. Six of twelve enclosures were placed at a depth of 5m, and the remaining six were placed at a depth of 20m. Enclosures were placed 2m from one another along two parallel transects at each depth. Each transect was dug into the sediment at least 10cm to prevent clams from burrowing, and to prevent predators from entering. Thirty notched clams ranging from 51mm to 86mm in length were placed within each enclosure at the start of the study. At the end of both four months and twelve months, clam growth was recorded by measuring the distance from the original notch to the new ventral shell edge. Total length, the longest possible anterior-posterior measurement of each clam, and mortality were also recorded. After four months, the 20m depth cages were removed due to logistical constraints; the 5m depth cages remained for the twelve-month duration. I performed an ANOVA in R (R Core Team 2019) to determine the effect of depth on clam growth after four months. During these four months (January to May), water temperatures at the 5m and 20m sites remained constant (Pellowe, *unpubl. data*).

Parameter estimation

I combined data from the above studies to parameterize fisheries models to examine the effects of size-selective fishing on fishery yield (yield-per-recruit, YPR), and on clam reproductive capacity (spawning stock biomass per recruit, SSB/R). Data used to parameterize the length-weight relationship and growth rate are available at github.com/kpellowe/clam-models. I parameterized the length-weight curve (Ricker 1975) using the equation:

Equation 2.1. Ricker length-weight equation.

$$W = a \cdot L^b$$

where, *L*=length, *W*=weight, and *a* and *b* are regression coefficients that are specific to each species. I parameterized coefficients *a* and *b* by fitting a linear model to length-weight data applied to measurements of clam length and wet weight from 2,485 clams harvested by fishers. Analyses were conducted in R (R Core Team 2019) using the package FSA (Ogle et al. 2019). For all clams, length was taken as an anterior-posterior measurement of the longest distance between shell edges, and wet weight was recorded using a portable digital scale. Clams ranged in length from 52mm to 110mm.

Mark-recapture measurements of clam length from *in situ* clam growth studies (n=311) were used to parameterize the von Bertalanffy growth equation (von Bertalanffy 1938), using a maximum likelihood approach (Wang et al. 1995):

Equation 2.2. von Bertalanffy growth equation.

$$L_r - L_m = [L_{inf} + \beta(L_m - \bar{L}_m) - L_m](1 - e^{-k\delta t})$$

where, L_r is length at recapture, L_m is length at marking, L_{inf} is asymptotic length, k is a species-specific constant, β is a regression coefficient, and δt is the time between marking and recapture. Length was measured in mm and growth was measured in units of mm/year. I parameterized coefficients L_{inf} , k, and β using a maximum likelihood approach (following Wang et al. 1995) applied to mark-recapture data from the growth study detailed above. My approach relied on Wang and colleagues' (1995) generalized classical von Bertalanffy growth model that assumes maximum length L_{inf} varies among individuals with a mean of L_{inf}. This method takes into account individual variability in the asymptotic length L_{inf}, and the unknown age-at-marking, and presents an asymptotically unbiased alternative to Faben's method (Wang et al. 1995). Analyses were conducted in R (R Core Team 2019) using the package FSA (Ogle et al. 2019).

Instantaneous natural mortality, *M*, was also estimated from the numbers of living clams at the beginning and end of the twelve-month growth study in the 5m depth enclosures, using the following equation:

Equation 2.3. Mortality equation.

$$N_{t+1} = N_t e^{-Z}$$

where, *Z* is instantaneous total mortality (assumed to be equal to natural mortality *M* when fishing mortality equals zero), N_t is sample population size at time *t*, and N_{t+1} is the sample population size at time *t*+1, with *t* measured in years.

Current selectivity, *S*, was estimated as the ratio of observed to predicted catch proportions (following Restrepo and Arrizabalaga 2007). For each 5mm size class from 0mm to 110mm, selectivity was estimated as the ratio of the proportion of clams of a given size class within the harvested sample, to the proportion of clams of a given size class within the *in situ* population.

Equation 2.4. Selectivity equation.

$$S = \frac{P_h}{P_s}$$

where, S is selectivity from 0 to 1 for a given size class, P_h is the proportion of that size class within the sample harvested population, and P_s is the proportion of a given size class of clams within the sample *in situ* population. For each slot limit treatment, selectivity was manually applied as the proportion of clams harvested below and above a given slot limit, based on current patterns of selectivity around the current minimum size of 64mm.

The current legal size limit for clams harvested in Loreto Bay is 64mm (SAGARPA 2015). Maturity curves were estimated based on similar well-studied species, *Mya Arenaria* (Dame 1996), and a known minimum size at maturity of 42mm in length, and a minimum spawning size of 50mm in length for *M. squalida* (Singh Cabanillas, J., Vélez-Barajas, J. y Fajardo-León 1991, Villalejo-Fuerte et al. 1996, 2000). Previous histological studies have found the sex ratio of *M. squalida* to be 1:1 M:F (Arellano-Martínez et al. 2006, Álvarez-Dagnino et al. 2017).

YPR and SSB/R models

I used length-based fisheries models to estimate stock parameters for the Mexican chocolate clam populations in Loreto Bay. Such models are often used in data-limited situations (Chen 1997). I used yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) as proxies for fishery status and population status, respectively. YPR is the expected yield per average individual recruited in the stock at a specific age or size and depends on the exploitation pattern (fishing mortality at age), size/age at recruitment, and natural mortality. YPR is commonly used in place of maximum sustainable yield (MSY) when the stock-recruitment relationship for a given target species is unknown (The Pew

Charitable Trusts 2016). *F* is the rate of fishing mortality (yr^{-1}). YPR_{max} is the maximum value of YPR and F_{max} is the *F* value associated with YPR_{max}. F_{max} is the fishing mortality rate that maximizes equilibrium yield per recruit (Hilborn and Walters 1992). F_{max} is the fishing mortality level often used to define growth overfishing (Cochrane 2002). $F_{0.1}$ is the fishing mortality rate at which the marginal yield-per-recruit (i.e., the increase in yield-per-recruit in weight for an increase in one unit of fishing mortality) is 10 percent of the marginal yield-per-recruit on the unexploited stock (The Pew Charitable Trusts 2016). The fishing mortality rate at which the slope of the yield-per-recruit curve is one-tenth the slope of the curve at its origin (Cochrane 2002). $F_{0.1}$ represents a conservative biological target. SSB/R is the expected lifetime contribution to the spawning stock biomass for a recruit of a specific age. For a given exploitation pattern, rate of growth, and natural mortality, an expected equilibrium value of SSB/R can be calculated for each level of fishing mortality (Hilborn and Walters 1992).

YPR and SSB models were run for each of 12 slot limit treatments (Table 2.1). These models can be found at github.com/kpellowe/clam-models. Slot limit treatments represent existing and plausible size limit scenarios, in which a minimum and maximum legal harvestable size are defined for chocolate clams in Loreto Bay (*personal observations*, KP). In addition to the current minimum legal harvest size of 64mm, two minimum harvest sizes lower than the current (44mm, 54mm), and one higher than current (74mm) were investigated. Each minimum size was tested both without a maximum size limit, as is the current policy, and with maximum sizes 80mm and 90mm. In many bivalve species, including clams, fecundity increases with increasing size (e.g., Lucas 1994). The addition of a maximum size prohibits harvest of the largest, most fecund individuals, thereby increasing the reproductive potential of the population. Slot limit treatments were modeled by manipulation of selectivity at age in fisheries model calculations. YPR and SSB/R were calculated for each slot limit treatment across the range of F=0 to F=1 at intervals of 0.1. F_{max}, a proxy for rate of fishing mortality at maximum sustainable yield, and $F_{0.1}$, a precautionary rate of fishing mortality, were also calculated for each treatment.

Table 2.1. Fishery and biological reference points for all slot limit treatments

Treatment	Minimum size (mm)	Maximum size (mm)	YPRmax	Fmax	F0.1
1	44	--	11.88	0.25	0.23
2	44	80	9.03	0.36	0.26
3	44	90	10.75	0.29	0.25
4	54	--	12.64	0.29	0.24
5	54	80	10.60	0.39	0.26
6	54	90	11.43	0.35	0.25
7	64	--	12.67	0.33	0.25
8	64	80	10.28	0.48	0.26
9	64	90	11.29	0.42	0.26
10	74	--	12.03	0.37	0.25
11	74	80	9.00	0.60	0.26
12	74	90	10.33	0.50	0.26

LB-SPR model

Length-based indicators were used to model the status of the Mexican chocolate clams under the current harvest scenario and slot limit treatment (following Hordyk et al. 2015b). The length based spawning potential ratio (LB-SPR) model estimates the selectivity-at-length and the ratio F/M, which in turn are used to calculate the spawning potential ratio, SPR. Input parameters for the calculation of SPR are the asymptotic length (L_{inf}), lengths at 50% (L_{50}) and 95% maturity (L_{95}), and the ratio of natural mortality and growth rate (*MK*). Biological parameters (Table 2.2), and the two years of length data collected from fishers' harvests were used to model spawning potential ratio, using the LBSPRfit function in the R package LBSPR (Hordyk 2019). The two years of length data were aggregated into a single dataset for the LB-SPR model. Results from the function yielded estimated population SPR as well as the selectivity of the fishery under the current management scenario. Since applications of the LB-SPR in other data-limited fisheries revealed significant model sensitivities to biological parameter inputs (e.g., Lennox et al. 2019), I tested the sensitivity of the model by calculating additional values of SPR using alternative values for asymptotic length (Table 2.3). I also compared current selectivity to target selectivity under the target ecological SPR of 0.4 (Walters and Martell 2004, Hordyk et al. 2015b).

Table 2.2. Biological and selectivity parameters for *M. squalida* used in models.

Parameter	Definition	Units	Value	Source
a	Length-weight constant	g wet weight	0.0021(0.090)	Field study data
b	Length-weight constant	g wet weight (mm)^-1	2.5445(0.021)	Field study data
Linf	Asymptotic size	mm	70.2742(0.074)	Field study data
k	von Bertalanffy growth coefficient	yr^-1	4.5622(0.65)	Field study data
B	von Bertalanffy growth constant	none	0.9130(0.0079)	Field study data
M	Natural mortality	unit year^-1	0.37	Field study data
m	Maturity constant	none	0.5	Estimated from similar species
L50	Length at 50% maturity	mm	42	Villalejo-Fuerte et al. 1996
L95	Length at 95% maturity	mm	50	Villalejo-Fuerte et al. 1996
M/k	M/k ratio	none	0.08110	
LS50	Length at 50% selectivity	mm	50	Field study data, at current slot limit
LS95	Length at 95% selectivity	mm	60	Field study data, at current slot limit

Table 2.3. Alternate biological and selectivity parameters and results of LB-SPR analyses.

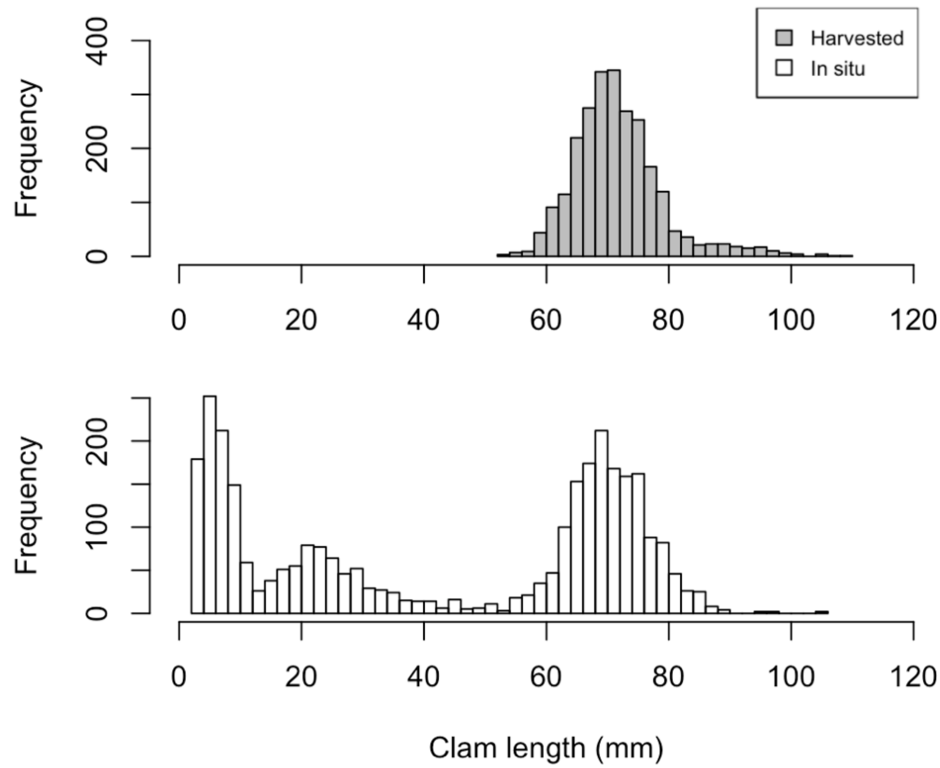
	Parameter							
	Linf	L50	L95	M	k	M/k	SPR	Description
Value	70.27	42	50	0.37	4.56	0.081	1	Model if Linf is set to value obtained from von Bertalanffy growth function
	110	42	50	0.37	4.56	0.081	0.02	Model if Linf is set to max length we observed in fishers' catch
	105	42	50	0.37	4.56	0.081	0.02	Model if Linf is set to max length we observed in *in situ* population

Results

Parameter estimation

Length-weight parameter estimates (and standard errors associated with log-transformed estimates) were calculated as: *a*=0.0021(0.090), *b*=2.5445(0.021). Growth parameter estimates (and their standard errors) were calculated as: L_{inf}=70.2742 (0.074); *k*=4.5622 (0.65); β=0.9130 (0.0079). I found no significant effect of depth on clam growth [F(1, 242) = 3.83, p>0.05]. Similarly, from the *in situ* population survey, I found no significant effect of depth on clam density [F(2,50) = 0.49, p>0.05]. I tested for the effect of depth on clam density at only sites with high fishing effort, and found no significant effect of depth on density [F(2,16) = 0.734, p>0.05]. I estimated the natural mortality rate, *M*, to be 0.32. Of clams measured from fishers' harvests, I found 11% were greater than or equal to 80mm in length, and 3% were greater than or equal to 90mm in length (Figure 2.2). Further, I found that sizes of harvested clams closely matched the size structure of the *in situ* adult population.

Figure 2.2. Histogram of clam lengths found in fishers' harvests and the *in situ* population. Clams were measured from fishers' harvests (n=2485), and *in situ* during clam population surveys (n=3043).



YPR and SSB/R models

My results show trade-offs between fisheries yield and biological condition of the target population. I used yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) as proxies for fishery status and status of the population, respectively. I found YPR and SSB/R curves by fishing effort varied among slot limit scenarios, with the highest YPR_{max} for Treatment 1 (minimum size 44mm and no maximum size), and the lowest for Treatment 11 (minimum size 74mm and maximum size 80mm; Table

2.1). Treatment 1 is the least constrained and most production-oriented, and Treatment 11 represents the most constrained and most conservation-oriented slot limit scenario.

I found that the YPR and SSB/R models for all treatments display trade-offs between fisheries yield and reproductive capacity of the target population. Figures 2.3-2.5 demonstrate these trade-offs with YPR and SSB/R curves for three slot limit scenarios: Treatment 1, the least restrictive scenario with minimum size 44mm and no maximum size limit; Treatment 7, the current slot limit of the Loreto chocolate clam fishery with minimum size 64mm and no maximum size limit; and Treatment 11, the most restrictive scenario with minimum size 74mm and maximum size 80mm. A more restrictive slot limit reduces the proportion of the population available to harvest, resulting in higher spawning stock biomass per recruit. A less restrictive slot limit increases the proportion of the population available to harvest, resulting in higher yield-per-recruit and lower spawning stock biomass across the range of fishing mortality scenarios. Values for the precautionary biological target F0.1 are relatively consistent across slot limit scenarios, ranging between 0.23 and 0.26 for all treatments. Values for F_{max} vary widely among treatments, with higher F_{max} values for the more restrictive slot limits.

Figure 2.3. YPR and SSB/R curves for Treatment 1. Yield per recruit (YPR) and spawning stock biomass by recruit (SSB/R) vary by fishing mortality (F) for Treatment 1, where minimum size is 44mm. At maximum yield-per-recruit, fishing mortality $F_{max} = 0.25$. $F_{0.1} = 0.23$.

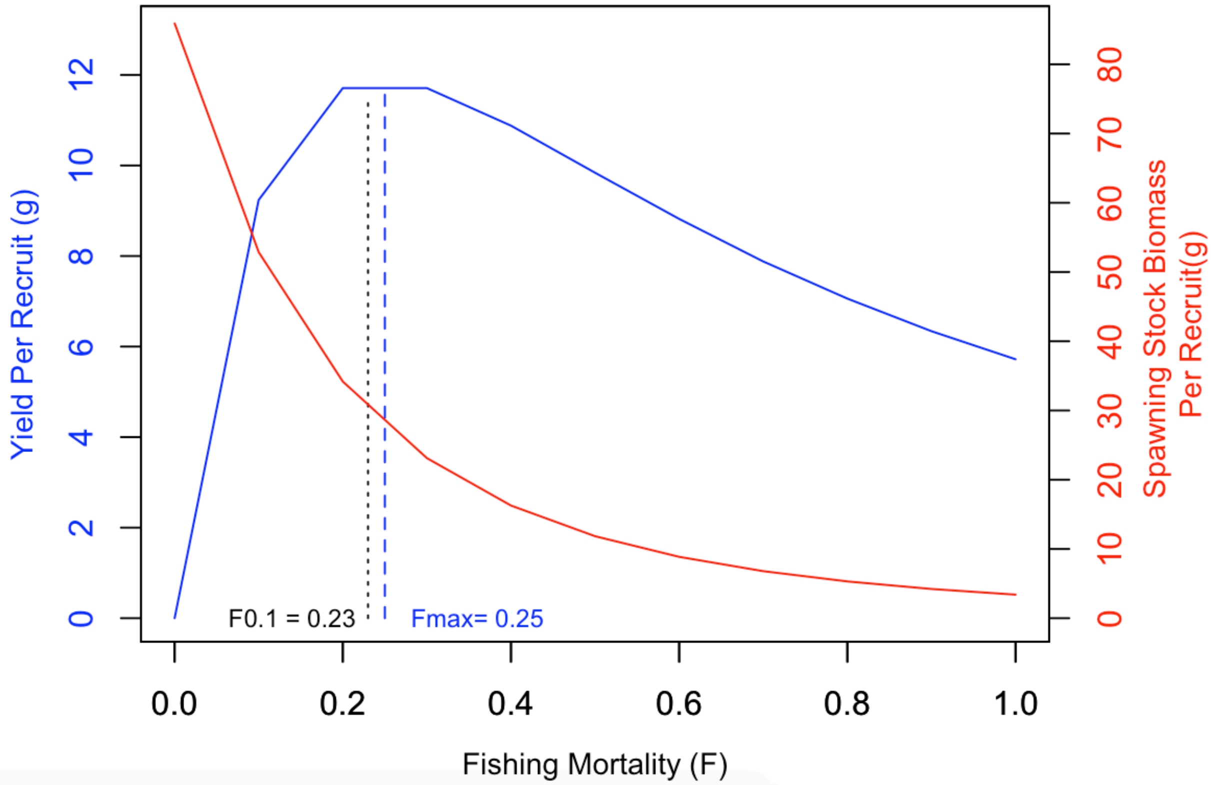


Figure 2.4. YPR and SSB/R curves for Treatment 7. Yield per recruit (YPR) and spawning stock biomass by recruit (SSB/R) vary by fishing mortality (F) for Treatment 7, where minimum size is 64mm. At maximum yield-per-recruit, fishing mortality F_{max} = 0.33. $F_{0.1}$ = 0.25.

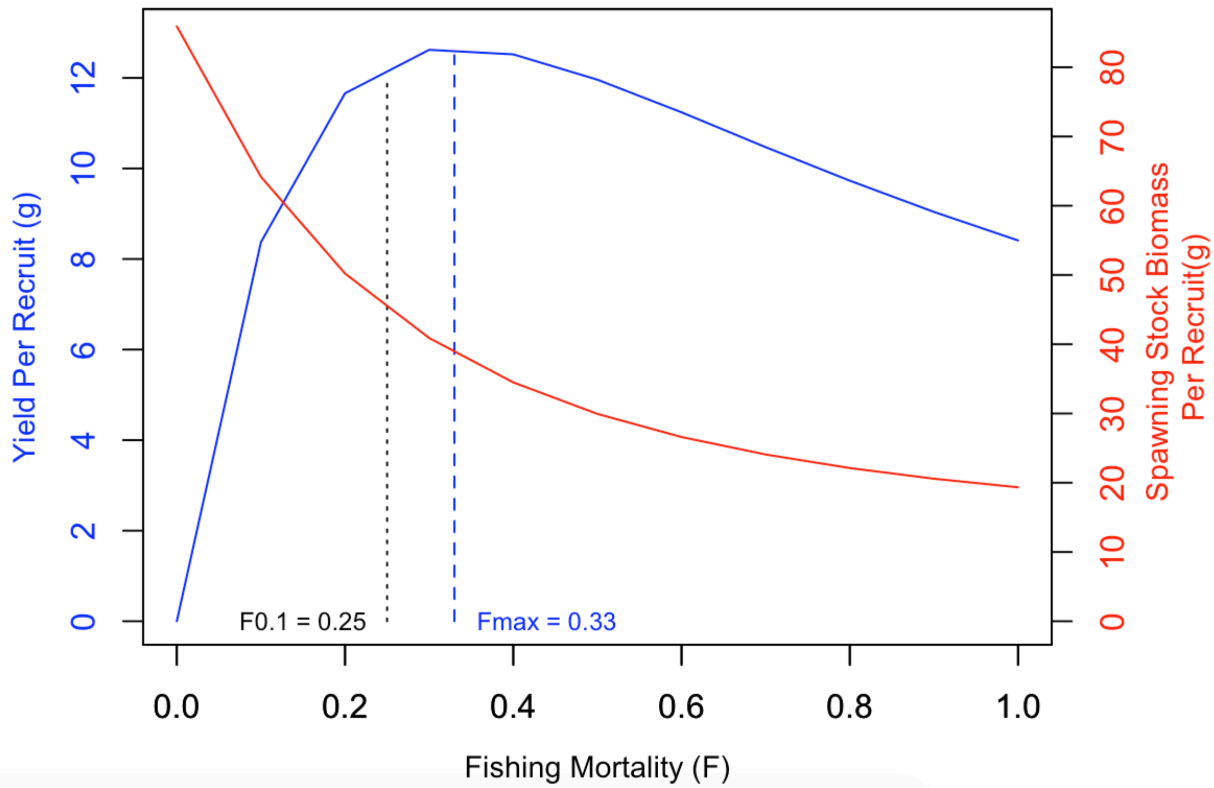
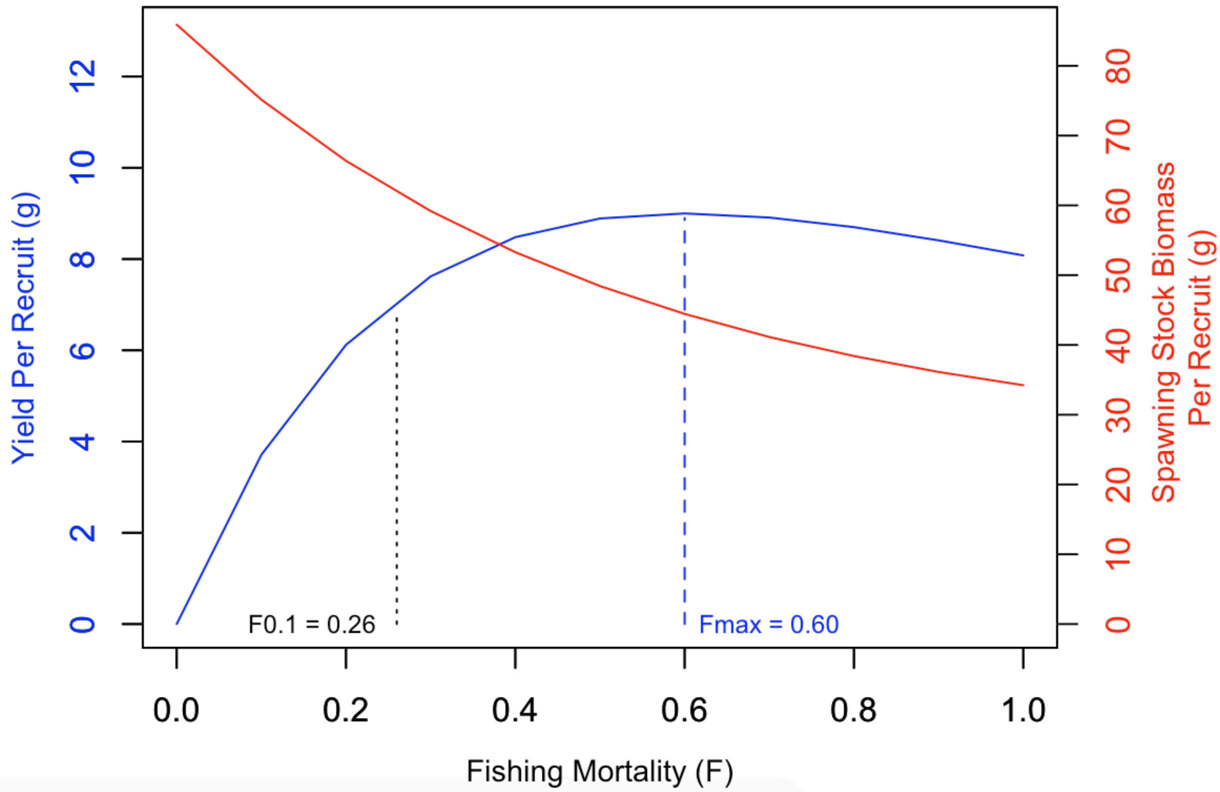


Figure 2.5. YPR and SSB/R curves for Treatment 11. Yield per recruit (YPR) and spawning stock biomass by recruit (SSB/R) vary with fishing mortality (F) for Treatment 11, where minimum size is 74mm and maximum size is 80mm. At maximum yield-per-recruit, fishing mortality F_{max} = 0.60. $F_{0.1}$ = 0.26.



Treatment 7 represents the current legally mandated situation in Loreto Bay, and has a more restrictive minimum size (64mm) than Treatment 1 (44mm), although neither scenario has a maximum size limit. The fisheries model results indicate that maintaining the current minimum size (64mm) and implementing a maximum size limit, as in Treatment 8 and 9, results in higher spawning stock biomass per recruit values, and higher F_{max} values. In scenarios with maximum size limits, reproductive potential of the population increases, maximum fisheries yield is lower, and higher values for F_{max} indicate that fishing effort can be increased, compared to scenarios with the same minimum size limit, but no maximum size limit.

LB-SPR model

I found with L_{inf} set to 70.27mm, the value obtained in the von Bertalanffy growth parameterization, SPR based on the current harvest pattern is 1.0, the maximum possible value (Table 2.3). However, I found that the model was highly sensitive to changes in the asymptotic size (L_{inf}), as has been found in other SPR analyses for different species (e.g., Lennox et al. 2019). Setting L_{inf} to 105mm or 110mm, the maximum lengths of chocolate clams observed in *in situ* population surveys and fishers' catch, respectively, resulted in SPR values of 0.02 and 0.02, respectively. Model estimates of maturity-at-length, based on biological parameters provided by Villalejo-Fuerte et al. 1996, and selectivity-at-length based on catch data show that chocolate clams reach maturity at a length smaller than the length at which they are selectively harvested (Figure 2.6). Comparison of current length-based harvest to the target ecological spawning potential ratio of 0.40 (Walters and Martell 2004, Hordyk et al. 2015b) revealed that the fishery could include smaller chocolate clams than those currently harvested and the clam population would meet the SPR ecological target (Figure 2.7).

Figure 2.6. Maturity and selectivity curves based on fishers' harvests. Maturity and selectivity curve modeled based on length-based data from 2,485 chocolate clams harvested by fishers. Under the current management scenario, selectivity (blue) is maximized at a length greater than the length at maturity (red), indicating that the clams reach maturation before being selectively harvested.

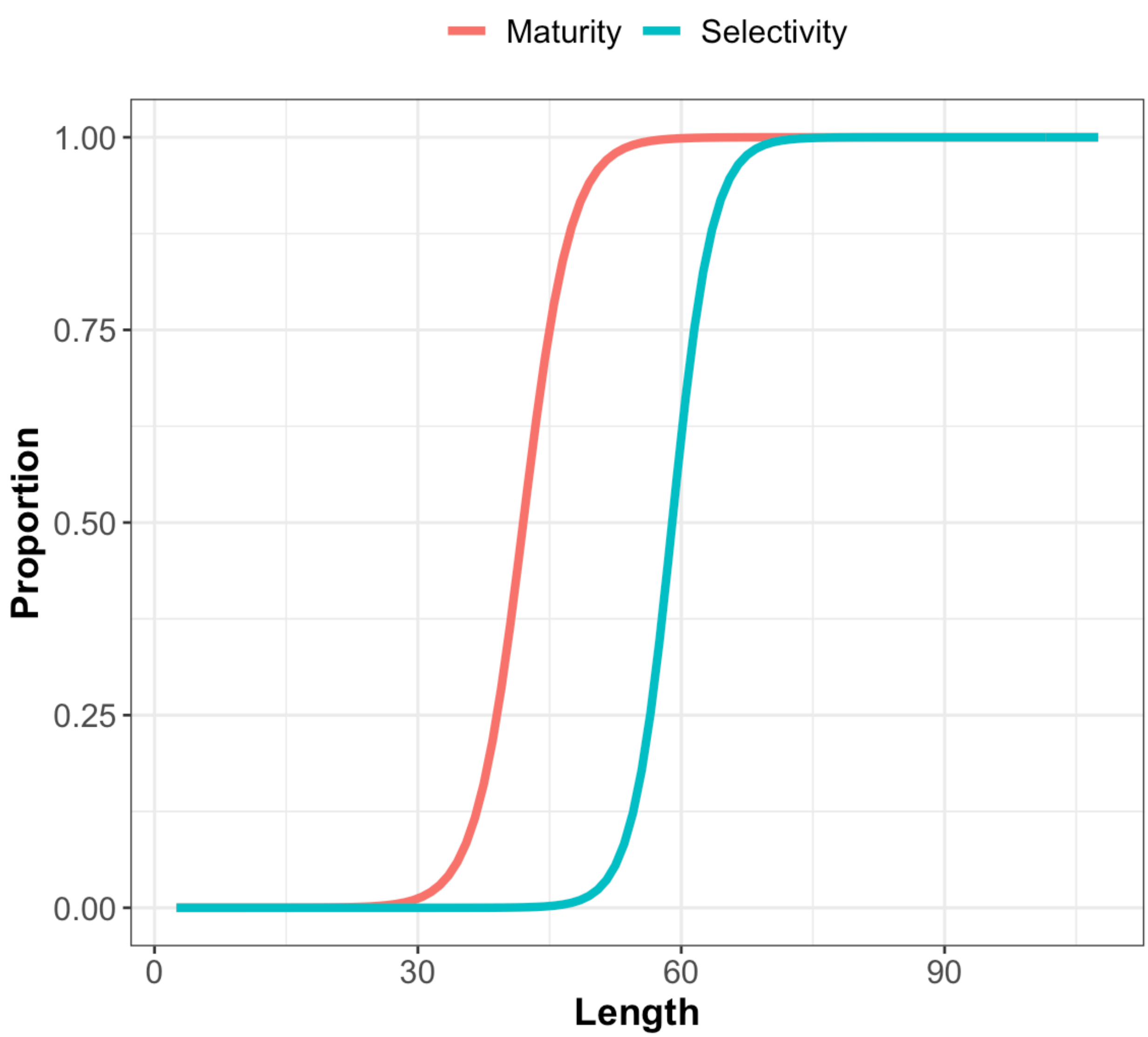
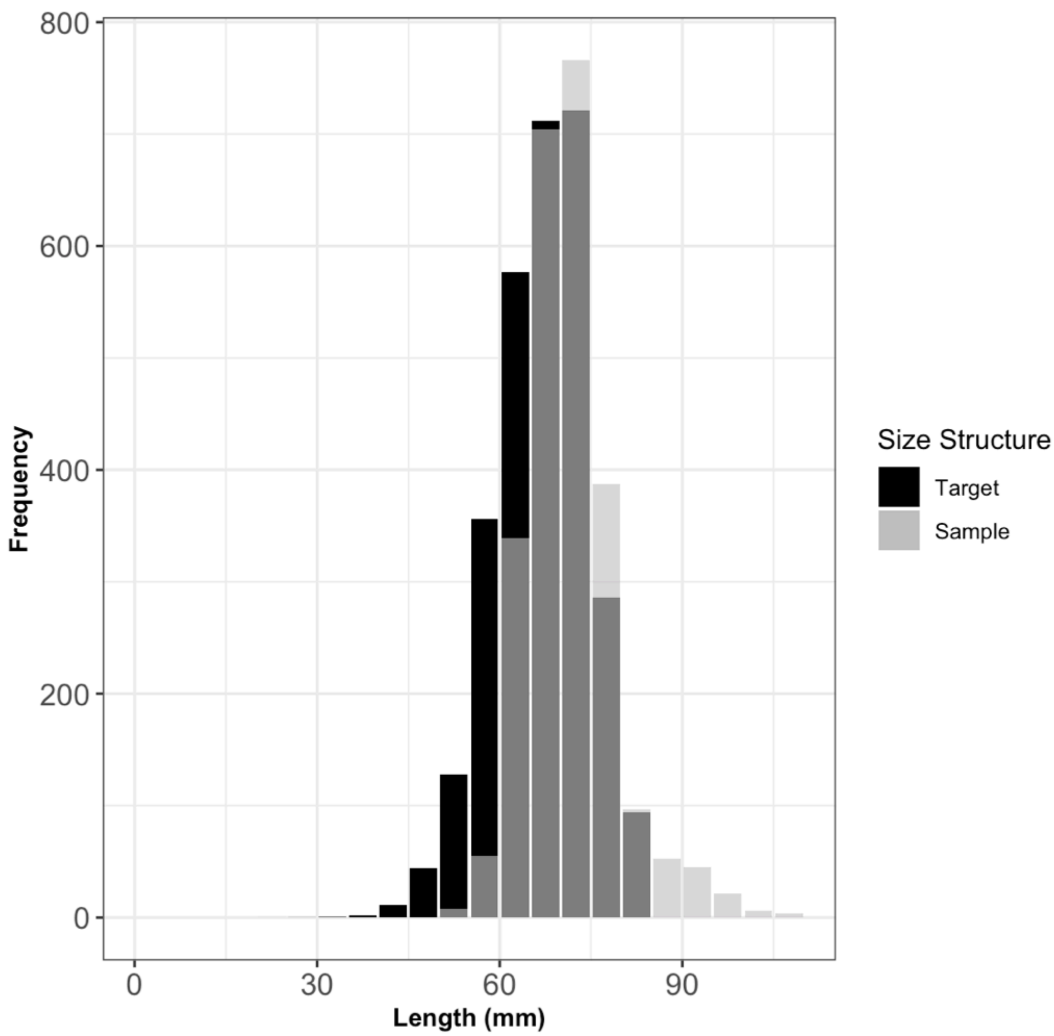


Figure 2.7. Target and sampled length frequencies from LB-SPR model. Target and sampled length frequencies of chocolate clams from length based spawning potential ratio model, where L_{inf} = 70.27mm. Light grey bars indicate the frequency of observed length groups (in 5mm bins) with a modeled spawning potential ratio of 100%. Black bars indicate the simulated target length frequency distribution of harvested population with 40% spawning potential ratio. Medium grey bars indicate overlap between the two. The current harvest pattern results in a higher spawning potential ratio than the ecological target of 40%, indicating that the minimum legal size could be reduced and the chocolate clam population would still meet ecological targets.



Discussion

These results indicate that how people fish matters, perhaps as much or more than how much they fish (Wilson 2006). Size-selective fishing interacts with the life history of target species to affect both fishery productivity and the biological health of the target population (Fenberg and Roy 2008). Setting appropriate slot limits for fisheries based on biological data may be as important to the ecological health of fished populations as setting appropriate fishing quotas. Past studies have found that how people fish, including gear type, is a significant factor in the ecological impacts of fisheries (Pauly et al. 2002). When fisheries management establishes size selectivity of harvest that is aligned with the biological characteristics of fished populations, it can lead to sustainable fisheries and a reliable source of food and livelihoods (Reddy et al. 2013).

This study synthesizes baseline biological data on chocolate clam populations that are foundational to a comprehensive study of the fishery for science-based fisheries management. I used data from field studies to parameterize several fisheries models to explore the effects of fishing effort and size-selective fishing on ecological and fishery outcomes. It would be beneficial for managers to consider trade-offs between fishery yield and the reproductive capacity of a target stock like those that I found before setting slot limits or other management measures. I found, through clam population surveys and measurements of clams from harvesters' catch, that clam fishers exhibit size-selective harvest for medium to large-sized clams. This selectivity is based on market demand, formal regulations, and community rules. The minimum legal harvest size of clams currently is 64mm in length. With no upper limit to size from either formal fishery regulations or community rules, the observed harvest indicates that the entire adult cohort larger than about 60mm in length is subject to harvest pressure.

I found that implementing a modest upper limit to size of 90mm on top of the current minimum legal size of 64mm would result in a slight decrease in maximum yield-per-recruit, and an increase in the associated spawning stock biomass per recruit, resulting in more precautionary fishery policy and a population with greater reproductive potential. In this scenario, the population could be fished with greater effort (i.e., higher fishing mortality) at maximum sustainable yield, and the addition of a maximum size would also result in a population able to sustain higher fishing effort in the long term. However, spawning potential ratio analysis indicates that SPR of the fishery is maximized under current patterns of selectivity, and a slight decrease in the minimum legal size may still result in a chocolate clam population that meets accepted ecological targets (Walters and Martell 2004). This result should, however, be considered with caution given the sensitivity of the LB-SPR model to changes in growth curve parameters, especially L_{inf}. This study reveals how changes to the minimum legal harvest size and the implementation of upper limits, i.e., shifts in size selectivity, can affect fishery and biological outcomes.

Managers' goals will determine which slot limit scenario is appropriate. Fisheries models aid in the identification of desired fishery productivity and ecological targets, and their tradeoffs, which assist managers in determining desirable slot limits and fishing mortality values that will result in a sustainable fishery. While fisheries models like the ones used in this study are useful for selecting slot limits based on fishery and conservation goals, they cannot address the issues of implementation and enforcement of such limits. Fisher adherence to changing fishery regulations poses a nontrivial challenge to the implementation of slot limits and should be considered in assessing model predictions and designing management measures like those explored here.

Future studies should examine the possible economic impacts of different slot limit scenarios. In Loreto, all clams, regardless of size, net the same unit price (Pellowe, *unpubl. data*), so economic yield can be expected to parallel the fishery yield results observed in this study. Thus, slot limits affect not only stock reproductive potential and fishery yield, but also economic yield. Future work on the economic potential of different slot limit scenarios will be valuable to fishery managers, and provide them with more information to decide whether a modification to the current slot limit would help to meet conservation, fishery, and economic goals.

Chocolate clams can occur at depths of 1-160m (Keen 1971), a range much wider than that at which harvest occurs. Harvest is restricted to depths that fishers can access via free or hookah diving, typically shallower than 20m. The contrast between the range of depths at which chocolate clams can occur and the depths exploitable by fishers may result in the *de facto* protection of a subset of the population. However, in my field studies, despite predicted lower fishing effort at deeper depths, I did not observe differences in clam densities between shallow (0-5 and 5-10m) and deeper (10-15m) areas. I also found no effect of depth on clam density at high fishing effort sites, where I would expect differences between shallow and deep areas to be most pronounced. It is possible that surveys deeper than 15m would have captured a significant effect of depth on clam populations. Assessing whether a significant proportion of the chocolate clam population is protected from harvest based on depth requires additional field studies.

Social-ecological variability, including size-selective fishing, as well as physical variables including sediment grain size and nearshore oceanography, affect the distribution of clams and other targeted marine resources (Menge and Sutherland 1987, Peterson 1991, Wilson 2006). Spatial variability is an important consideration in developing fisheries rules in many places. In Maine, for example, lobster fishery management is tailored to seven zones, based on spatial variability in lobster populations and fishers' behavior along the coast (Acheson et al. 2000, Steneck and Wilson 2001). My field study results indicate high spatial variability of clam population abundance and size structure within Loreto Bay (Fig. 1). I was unable to account for spatial heterogeneity in the models because the data collected at each site were not sufficient to enable modeling at a finer spatial scale. Consequently, I ran the fisheries models in this study on aggregate data for Loreto Bay. Future work could explore the feasibility of incorporating spatial heterogeneity into such models; that would require data collection at a scale more appropriate to the ecology of the area, i.e., the scale of a clam bank. Although fine-scale analyses and management may be more ecologically appropriate in areas with high spatial variability, it is unlikely, particularly in data-poor fisheries, that resources will be available for data collection at scales matching the spatial complexity of *in situ* populations. Consequently, I assert that even without fine-scale data, slot limit analyses based on known or assumed target species life history characteristics can help managers assess trade-offs among different slot limit scenarios.

Future work also should aim to establish rules of thumb for slot limit scenarios, so that managers of data-limited fisheries can make informed management decisions based on species life history and minimize the need for extensive biological data collection. Rules of thumb for slot limits would need to account for size at first reproduction and frequency of reproduction (*i.e*., seasonal spawning), as well as the life history types of target species, including whether the target species is short- or long-lived, mobile or sedentary, and whether the species has indeterminate growth (Christie et al. 2018). A large slot limit will likely lead to loss of reproductive potential, and the long-term health of the population may suffer. Slot limits may lend themselves particularly well to data-limited fishery management, since expanding or decreasing the range of sizes available to harvest has predictable outcomes. Lowering the minimum size will generally lead to higher fishery yield and lower reproductive potential of the target population, while implementing a maximum size limit will generally increase the population's reproductive potential and decrease fishery yield. Thus, a precautionary approach to management for a data-limited fishery should require a more conservative, or narrower, range of sizes subject to harvest.

This approach resulted in information on slot limit scenarios that is currently missing from stock assessments and has direct relevance to the management of this species. Knowledge of the distribution and life history characteristics of fished taxa, and how fishing activities influence population dynamics, is foundational to marine resource management. Thus, these results will be shared with local resource managers for consideration in designing future management scenarios for the fishery. I also acknowledge the tension between the widespread use of stock assessment methods in developed nations, and the historical and ongoing data collection required for such methods. The resources required for such data collection do not exist for many fisheries around the world, particularly in developing nations. Approaches to assessing data-limited fisheries include assessment of trends from fisheries-dependent data (i.e., landings data), and extrapolation from similar species (Honey et al. 2010). Since there is inherent uncertainty in data-limited approaches, a precautionary approach must be taken (Pilling et al. 2008). The core finding of this work— that slot limits are useful management tools for meeting fishery and ecological goals, and that they contain inherent tradeoffs – can be applied broadly in data-limited scenarios.

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CHAPTER 3

ECOSYSTEM SERVICE LENS REVEALS DIVERSE COMMUNITY VALUES OF SMALL-SCALE FISHERIES

Abstract

The ocean provides benefits to coastal communities around the world, however, the depth and complexity of people's interactions with marine ecosystems are not well understood. An ecosystem services approach can help untangle complex human-ecosystem interactions, and inform resource management that accounts for the needs, values, and knowledge of diverse stakeholders. In this study, I conducted 48 household surveys to assess community values related to a top fished species, the Mexican chocolate clam, *Megapitaria squalida*, in Loreto, Baja California Sur, Mexico. I found that this species provides a diverse suite of values to households, and that the production of cultural values by a fished species can equal or outweigh its provisioning value. I contend that fisheries management that considers the range of ecosystem services a species generates will be better equipped to protect the diverse values it provides to coastal communities, account for local ecological knowledge, and enhance community resilience.

Introduction

All benefits provided by natural systems – including healthy food, clean water, and protection from coastal storms – are embedded within social-ecological systems (SESs; Ostrom 2009). These linked systems are conceptualized by Ostrom (2009) as interacting subsystems, and include the resource systems, resource units, governance systems, and actors. Together, interactions within and among these subsystems produce emergent outcomes, at the level of the whole SES. This framework is useful for operationalizing interdisciplinary studies of SESs (Ostrom 2009, McGinnis and Ostrom 2014). SESs operate everywhere humans depend on natural resources, and resilience is key to sustaining these interactions, for the benefit of both ecosystems and dependent human communities (Folke et al. 2004, Bernhardt and Leslie 2013). Resilience refers to the ability of a system to absorb disturbance and still retain its basic structure and function (Gunderson and Holling 2001, Adger et al. 2005). Social-ecological system resilience recognizes that people and other species are part of interconnected, interdependent systems. Feedbacks within and among these systems influence their overall dynamics (Folke *et al*., 2010). A resilient SES has the capacity to sustain a desired set of ecosystem services in the face of both short- and long-term stressors, such as hurricanes and climate change (Biggs *et al*., 2012). Thus, understanding and managing for SES resilience is key to meeting both current and future resource needs.

The ocean provides many benefits to coastal communities, including food, income, and recreational opportunities (Halpern et al. 2012), yet the depth and complexity of interactions within marine social-ecological systems are not well understood (Villasante et al. 2013). The ecosystem services approach is a useful tool for understanding the connections between humans and ecosystems that goes beyond income and food provision to include cultural and social values (Chan et al. 2012). Ecosystem services reflect the economic, social, cultural, and use values an ecosystem provides to people, and are often assessed using economic valuation techniques (Daily et al. 2000, Turner and Daily 2008). The Millennium Ecosystem Assessment (2005) outlines four categories of ecosystem services: supporting--those services that make it possible for ecosystems to continue providing the other three types of services (e.g., primary production); provisioning (e.g., food); regulating (e.g., water purification); and cultural (e.g., recreation and sense of place). Economic approaches have been useful in integrating ecosystem-related values into decision making, yet they fail to encompass dimensions of value that cannot be quantified in economic terms, including many cultural and non-use values (Chan et al. 2011, 2012).

A full consideration of the values associated with ecosystem services will better equip managers of marine ecosystems to address the needs and perspectives of diverse stakeholders (Chan et al. 2012). Managing for a diverse set of ecosystem services can also result in SESs that are resilient to a variety of unexpected changes. Resource management with an overly-narrow focus on a limited set of ecosystem services can lead to unexpected regime shifts and sudden losses of other ecosystem services (Gordon et al. 2008, Bennett et al. 2009). Thus, cataloguing the complete suite of values marine ecosystems produce is a crucial step in managing for resilience. Resilience applies to the entire SES, not just the ecological subsystem, and resilience indicators are related to the system's ability to provide ecosystem services (Carpenter et al. 2001). A thorough understanding of ecosystem services yields information not only about the social landscape of the system, but also sheds light on resilience indicators important to the overall SES.

Fisheries are clear examples of SESs: resource exploitation by humans can significantly affect system structure and functioning, and impact the long-term sustainability of human-resource interactions (Basurto et al. 2013b, Partelow and Boda 2015). Fisheries provide valuable services, such as food and livelihoods, to coastal communities, yet the resilience of these systems is threatened by overexploitation, pollution, and environmental variability, among other stressors (Béné 2006, Halpern et al. 2012). Managing for fishery resilience can help ensure the continued delivery of these valuable services. Fisheries management has come a long way in acknowledging and understanding the heterogeneity of ecological systems, but a parallel understanding of variety within social systems is often missing (St. Martin et al. 2007). Meeting the challenge of fisheries management requires moving beyond assessments of environmental variables and species interactions to develop a better understanding of sociocultural values and local knowledge of coastal communities and fishers (St. Martin et al. 2007).

People's interactions with marine ecosystems, particularly within fisheries, are deep and complex (Villasante et al. 2013). An ecosystem services approach can illuminate important connections between people and nature, and help untangle complex interactions shaping fishery SESs. In some cases, a coastal community's relationship with a single species can reflect local values and ecological knowledge that can help shape management that enhances system resilience. On the Gulf of California coast of Baja California Sur, Mexico, the town of Loreto relies on fishing and tourism to support the local economy. These activities are primarily focused on the marine park the town hosts, Loreto Bay National Park. The National Park is home to many species, but none is more characteristic of the region than the Mexican chocolate clam, *Megapitaria squalida*. The clam is one of the top species harvested by biomass in Loreto (Pellowe and Leslie 2017), and is a local culinary specialty, with a rich history of use by the local community.

Fisheries management of chocolate clams in Loreto Bay National Park focuses on the formal, permitted fishery, which provides income to fishers and food to local households. However, I hypothesize that relationships between people and nature are far more diverse and complex than is currently captured by management. I predict that the values chocolate clams provide in Loreto go beyond the provisioning services generated by the fishery to include cultural values as well. This study elicits data on the suite of ecosystem services provided by chocolate clams to households in this region, using a set of values adapted from previously identified landscape and ecosystem service values (Rolston and Coufal 1991, Reed and Brown 2003, Raymond and Brown 2006). This information is essential to an understanding of resilience, since SES resilience relates directly to the maintenance of the services people value (Carpenter et al. 2001). An understanding of both provisioning and cultural services is required for stewardship of chocolate clams that both accounts for the diverse values they provide to communities in the region, and captures the complexity of humans' relations to marine resources. In this study, I use household surveys to assess the range of provisioning and cultural values that chocolate clams provide to households in Loreto. I also assess community perceptions of change related to chocolate clams, and explore how fishery management might better account for the diverse values the species provides to stakeholders, and enhance community resilience.

Methods

Study site

The town of Loreto, Baja California Sur, Mexico, lies along the sea between the *Sierra de la Gigante* mountains and the Gulf of California. Loreto is home to roughly 19,000 people, and the town's economy depends on fisheries and tourism centered around the marine park it hosts (INEGI, 2017). Loreto Bay National Park (LBNP) is one of the largest marine protected areas in Mexico with an area of 2,065 square kilometers. The park contains varied marine and estuarine habitat types, including rocky reefs, seagrass beds, mangroves, and sandy habitats (Eco-Alianza, 2017). The waters of LBNP are home to 800 marine species, yet none is more characteristic of the region than the Mexican chocolate clam, *Megapitaria squalida* (Figure 3.1). Chocolate clams are soft-sediment burrowers that inhabit sandy-bottom habitat from the intertidal to depths of 160m (Keen 1971). In Loreto Bay, chocolate clams are an important source of food and income for local fishing communities; they are among the top five species harvested by total biomass, and among the top ten by total value (Pellowe and Leslie 2017).

Figure 3.1. Image of chocolate clams.

Chocolate clams are in demand year-round, sometimes despite seasonal bans on harvest. The clams are a long-standing culinary tradition in the region, headline the menu of local restaurants, and are the focus of an annual gastronomic festival held on Loreto's waterfront. The chocolate clam also serves as a symbol of community pride and connection to the sea; murals around Loreto Bay depict smiling clams reminding locals to fish responsibly. For many families in the region, chocolate clam fishing provides supplementary food and income in times of limited resources, and serves as a safeguard against scarcity.

Surveys

From February to May 2019, I administered 48 surveys to residents of Loreto, Baja California Sur, Mexico to assess community perspectives on a range of ecosystem services. Surveys completed less than 25% (12 or fewer questions answered out of 48) were removed from the sample. The participant population included adult community members (at least 18 years of age) residing in Loreto, Baja California Sur, Mexico at least six months of the year. Survey participants were recruited via snowball sampling, beginning with contacts established during previous fieldwork in this region. Due to variable literacy in the region, surveys were administered in-person in a quiet, semi-private setting, and took approximately 10-20 minutes to complete. Questions were read aloud to participants and recorded by the researcher (KP).

Surveys were confidential and collected information on the socioeconomic characteristics of households, how frequently members of their household harvest, buy, sell, and consume chocolate clams, changes they have observed in the availability, market demand, quantity, quality, and size of chocolate clams over time. Participants were then asked, using a three-item Likert scale, to indicate whether they agreed, disagreed, or neither agreed nor disagreed with a set of statements, each relating to an ecosystem service they and their household received from chocolate clams. Surveys were designed to elicit both use and non-use values. Values assessed in the survey included: general (self), general (community), life sustaining (self), life sustaining (ecological), economic (self), economic (community), tourism, subsistence, scientific/learning, recreation, aesthetic, future use, historic, cultural, individual identity, community identity, existence, and intrinsic values (see Table 3.1 for full list of statements used to determine ecosystem service values). This list of services is adapted from foundational work by Rolston and Coufal (1991), who identified ten basic landscape values: life support, economic, scientific, recreation, aesthetic, wildlife, biotic diversity, natural history, spiritual, and intrinsic. This list was later expanded by others to include subsistence, cultural, and therapeutic values (Reed and Brown 2003, Raymond and Brown 2006). I have adapted these lists, which were designed to capture values at the ecosystem scale, to include values that could be produced by an individual species.

The ecosystem services of tourism, scientific/learning, recreation, and aesthetic values were assessed each with two survey questions, and an average as taken from the two responses to determine whether participants identified these values from chocolate clams. Additionally, I assessed the following values both at the individual and the community level through two separate questions: general, economic, future use, and identity. For open-ended survey questions, including questions on the nature of changes observed, and participants' perspectives on why changes had occurred, responses were coded into categories. These categories emerged from analysis of participant responses by the researcher who conducted the surveys (KP). The number of responses within each emergent category was tallied.

Table 3.1. Value statements used to identify participants' identification of ecosystem service values. Participants' agreement with each statement indicated their belief that chocolate clams provide the associated ecosystem service value. Intrinsic value was reverse-coded.

Ecosystem service value assessed	Value statement
General	Chocolate clams are important to me and my family.
	Chocolate clams are important to my community.
Life sustaining	Chocolate clams help sustain me and my family.
	Chocolate clams help sustain other animals in Loreto Bay.
Economic	Chocolate clams provide income to my household.
	Chocolate clams are important to the local economy.
Tourism	Tourists spend money on chocolate clams when they visit Loreto.
	Chocolate clams are a tourist attraction of Loreto.
Subsistence	Chocolate clams provide some of my family's basic needs.
Scientific/Learning	Chocolate clams are important for scientists to study.
	Chocolate clams should be protected so that people can learn about them.
Recreation	Chocolate clams are important for recreation, including exercise and fun.
	It is fun or relaxing to look for or harvest chocolate clams.
Aesthetic	Chocolate clams are beautiful.
	Chocolate clams contribute to the unique beauty of Loreto.
Future Use	Chocolate clams should be conserved for future generations.
	Chocolate clams should be conserved because I or my family might want to harvest them in the future.
Historic	Chocolate clams are important because of their history in this area.
Cultural	Chocolate clams are important to the culture of this area.
Individual Identity	Chocolate clams are an important part of who I am as an individual.
Community Identity	Chocolate clams are an important part of what it means to be a Loretano or to live in this area.
Existence	Even when I don't use chocolate clams, I like to know they are there.
Intrinsic	Chocolate clams have value primarily because they provide benefits to people. (Reverse-coded)

Results

I found that 17% of survey participants were originally from Loreto, with many originating from other cities in Mexico. The average length of time participants had lived in Loreto was 17 years, and the longest length of time was 64 years. Mean household size was 2.4, with a mean monthly household income of $2020.18 U.S. Dollars. Participants reported collecting or harvesting chocolate clams 5.9 times per year on average, buying chocolate clams on average 17.4 times per year, and eating chocolate clams 18.0 times per year. None of the participants reported clamming as a source of income, however, participants reported selling chocolate clams 1.4 times per year on average. Forty percent of participants responded, "yes" when asked whether they had ever collected chocolate clams for any purpose. The participants who indicated that they regularly harvest or used to regularly harvest chocolate clams, had 7.3 years of harvest experience, on average, with a range of 1.5 to 20 years of experience. All participants had, on average, 15.4 years of experience buying chocolate clams, with a range of experience from 1 to 82 years.

Seventy percent of survey participants said they had noticed at least one change in chocolate clams over time in terms of the market demand, quantity, quality, size, price, and/or availability of the species (Table 3.2). The nature of changes observed varied among participants, with clear patterns of response. Those who noticed changes in market demand said that demand had increased and production had declined. Participants who had observed changes in the quantity or quality of chocolate clams cited reductions in quantity, and lower or variable quality. Those who cited reduced quality referred to reductions in the individual sizes of clams harvested, and possible impacts of pollution. Among those participants who noticed changes in the size over time, all observed that clams had gotten smaller. Those who had noticed changes in price said that price had gone up. In terms of availability, 50% of participants had noticed change in terms of decreased or seasonally-variable availability. Despite this, no participants said that the changes they had observed had directly affected their household. When asked whether they had any thoughts on why these changes had occurred, participant responses fell into four main categories, in order of most to least cited: fisheries management, overfishing, increased demand, and environmental change (Table 3.3).

Table 3.2. Changes in chocolate clams observed by survey participants, percentage of participants that have noticed each change, and if available, nature of change observed. N=40.

Type of change	Percentage of respondents that have noticed this change	Nature of change (number of responses)
Any	70	N/A
Market demand	48	Demand has increased (4) Production has declined (3) More difficult to find (1) Sold in more restaurants (1)
Quantity or quality	40	Quantity has decreased (8) Quality is lower/more variable (4) Quantity has increased (1)
Size of individual clams	35	Size has decreased (10)
Price	45	Price has gone up (16)
Availability	50	Availability has decreased (11) Availability is more seasonally variable (6)

Table 3.3. Participant perspectives on why changes have occurred fell into four primary categories: fisheries management, overfishing, increased demand, and environmental change.

Do have any thoughts on why these changes have occurred?		
Reason	**Times cited**	**Example**
Fisheries management	9	"It's because of poor management of the clam", "It's because of the cooperatives that use a compressor to harvest"
Overfishing	9	"The uncontrolled exploitation"
Increased demand	4	"It's a tourist town, and this is the dish that represents our town"; "There is more consumption now"; "Supply and demand- there are more people in Loreto now"
Environmental change	3	"The temperature- sometimes it's too warm"

All but one ecosystem service value assessed was reported by survey participants: economic (self). This is consistent with the lack of reported income from clamming among those surveyed. Relatedly, only 3% of participants reported life sustaining value (self) from chocolate clams, and 10% reported subsistence value, although several participants noted that while their household did not receive these values from chocolate clams, other households in the community do. While households surveyed did not receive economic value from chocolate clams, 95% agreed that chocolate clams provide economic value to the community, and 70% agreed that chocolate clams provide life sustaining value to other animals. The ecosystem service values with the highest rates of agreement among participants, in addition to community economic value, included: cultural (98% agreement), general (community, 95% agreement), existence (90% agreement), tourism (89% agreement), and future use (community, 88% agreement). A full report of values assessed and responses can be found in Table 3.4.

Table 3.4. Ecosystem service values assessed and percentage of survey participants who gave each of four possible responses to a corresponding value statement. For values with two corresponding statements in surveys, response percentages were averaged. These included: tourism, scientific/learning, recreation, and aesthetic values. n=40.

Ecosystem service value assessed	**Percentage of total**			
	Agree	**Disagree**	**Neither agree nor disagree**	**Prefer not to answer**
General, Self	45	15	38	3
General, Community	95	0	5	0
Life sustaining, Self	3	80	15	3
Life sustaining, Ecological	70	5	20	5
Economic, Self	0	95	3	0
Economic, Community	95	0	5	0
Tourism	89	0	11	0
Subsistence	10	80	10	0
Scientific/Learning	79	4	16	1
Recreation	43	21	35	1
Aesthetic	77	7	15	1
Future Use, Self	45	30	25	0
Future Use, Community	88	3	5	3
Historic	85	3	13	0
Cultural	98	0	3	0
Identity, Self	10	65	23	3
Identity, Community	73	13	15	0
Existence	90	5	5	0
Intrinsic	15	65	20	0

Discussion

Chocolate clams provide a host of ecosystem services to households in the Loreto region that include both provisioning and cultural services. As bivalves, chocolate clams also provide regulating services in the form of water filtration (Millennium Ecosystem Assessment 2005). Considerations of ecosystem services in chocolate clam management are implicit and restricted to fishery-specific indicators. However, I find that the provisioning services that derive from the fishery are only a few of more than a dozen values the species provides to households in the Loreto region. In addition to economic value generated by the chocolate clam fishery, I find that this species also contributes to tourism, scientific/learning, recreation, aesthetic, historic, cultural, community identity, and existence values. This finding supports my first hypothesis that chocolate clams provide a diversity of both provisioning and cultural values to the community of Loreto. None of the participants in the survey rely on income from chocolate clam fishing, yet nearly half of all participants indicated that they have collected chocolate clams at some point in the past, and a third said that they collect clams at least once per year. These results indicate that harvest of chocolate clams is a relatively common activity among residents of Loreto, and that the fishery itself is much more heterogeneous than is currently accounted for in management.

Formal management of the chocolate clam involves the distribution of fishing permits and setting of quotas for harvest of clams with a hookah compressor, a gasoline-powered compressor that pumps air through a thin, plastic tube to a diver on the ocean floor. Prior to 2016, a local ordinance allowed residents of Loreto to harvest small quantities of chocolate clams for personal and familial consumption via the traditional harvest method of free diving, holding one's breath and diving to the ocean floor, sometimes with fins. The local ordinance was a clause that permitted subsistence harvest up to a modest catch limit without a permit. In 2016, due to an inconsistency with state-level fisheries laws specifying that only finfish can be harvested without a permit for subsistence purposes, the local ordinance guaranteeing Loreto residents access to chocolate clams as a subsistence resource was ended. This change resulted in a local social movement called, "*Sí, al Autoconsumo de la Almeja Chocolata*", in which two Loreto schoolteachers organized a day of protest and invited all Loreto residents to free dive for clams at a public beach. In early 2019, when the household surveys for this study were administered, the local ordinance had not been re-established and its loss appeared to remain forefront of the minds of many Loreto residents.

I find that fisheries management can affect not only the stakeholders directly engaged in resource extraction, but also the broader community. In coastal communities, like Loreto, where relatively few members are regularly harvesting a species, the values that species provide to coastal communities can be diverse and significant. However, accounting for diverse ecosystem services and stakeholder perspectives in management is not easy. Fisheries management in Baja California Sur is improving in its ability to integrate the heterogeneity of ecological systems into policies, but the sociocultural richness of fisheries systems and coastal communities remains largely unaccounted for (see for example, Leslie et al., 2015). The assessment of ecosystem services can help inform ecosystem-based management that better incorporates this sociocultural richness (Rosenberg and McLeod 2005). However, translating ecosystem service assessments into policy has many challenges, including reconciling the legitimacy of diverse knowledge types, and finding pathways to turn such knowledge into action (Posner et al. 2016).

As hypothesized, participants in the study noticed changes over time in the form of increased market demand, reduced quantity, lower or variable quality, smaller size, higher price, and reduced availability of chocolate clams. Participants proposed several causes of observed changes, including fisheries management, overfishing, increased demand for chocolate clams, and environmental change. However, participants did not believe that these changes had impacted them directly. This finding seems contrary to my hypothesis that observed changes in clam populations have impacted the delivery of ecosystem services. Three participants explicitly noted that while they were not personally affected by the changes they had observed, they believed other households in their community were affected. Among survey participants, there was wide recognition of the community value of the chocolate clam. I found that the ecosystem services I assessed that focused on community benefits, including general importance, economic, life sustaining, future use, and identity values, all had higher average rates of agreement than the associated question that asked about these values from the household perspective.

While participants in this study did not receive direct economic value from chocolate clams, nearly all agreed that the clam provides economic value to the community. Other values with nearly unanimous agreement among survey participants included cultural, existence, tourism, and future use values. Many locals recall childhood memories of collecting chocolate clams during family trips to the beach, learning to dig for clams in the sand with their toes, or holding their breath to grab a clam from the ocean floor (Pellowe, *unpubl. data*). While chocolate clams were not important to the individual identity of most participants, three quarters of participants agreed that the clam is an important part of what it mean to be a member of the Loreto community. Considering the suite of cultural ecosystem services the clam provides to Loreto households, and its contribution to local identity, it may be helpful to consider the chocolate clam a cultural keystone species. Cultural keystone species are "culturally salient species that shape in a major way the cultural identity of a people" (Garibaldi and Turner 2004). Such species are defined by the key role they play in defining cultural identity, and are characterized by their high cultural significance. The concept of the cultural keystone species highlights the importance of communities' relationship to place, and the management and conservation status of these species may be a starting point for understanding community resilience to change (Garibaldi and Turner 2004). In Loreto, managing for chocolate clams' diverse values might include protecting habitat, regulating water quality, and privileging low impact fishing practices, such as the traditional free-diving method of harvesting chocolate clams, over the more intensive hookah compressor method. These practices would serve not only to conserve chocolate clams and the benefits they provide to Loreto households, but would also benefit other marine species in Loreto's nearshore waters.

The social and cultural values of species and ecosystems shape human-nature interactions, yet are often overlooked in decision-making and design of marine management (Chan et al. 2011). If such values are not explicitly understood and accounted for, they are likely to be poorly represented in natural resource policy (Klain, S.; Chan 2012). Assessing these values and incorporating them into management creates robust policies that protect valuable ecosystem services in the face of unexpected change. Managing for a narrow set of ecosystem services may not only ignore other important values that a species or ecosystem provides to human communities, but can also reduce SES resilience (Gordon et al. 2008, Bennett et al. 2009). Understanding the full suite of ecosystem services provided by species or ecosystems is a critical step in designing management that supports and enhances the resilience of SESs in a changing world.

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CHAPTER 4

HETEROGENEITY AMONG CLAM HARVESTERS IN NORTHERN MEXICO SHAPES INDIVIDUAL ADAPTIVE CAPACITY

Abstract

Variability driven by environmental shifts, biological processes, and socio-economic fluctuations is inherent in natural resource-based sectors, including fisheries. In navigating these changes as opportunities for transformation, individual decisions play a key role. Understanding individual adaptive capacity, the ability to cope under changing or novel circumstances, and considering how community-level adaptive capacity is affected as individuals react to change, may allow a better understanding of adaptive capacity in a rapidly changing world. Fishers employ a range of adaptive strategies to cope with the inherent variability of their work. In Loreto Bay National Park, Baja California Sur, Mexico, the Mexican chocolate clam is an important source of food and livelihoods, and is harvested by a diverse group of fishers. Understanding the full spectrum of fishers, their decision-making processes, and adaptive strategies is essential both for anticipating fishery outcomes and predicting the capacity of different types of fishers to adapt to environmental and economic change. I use semi-structured interviews with clam harvesters to ask, *1) what types of fishers exist within the chocolate clam fishery, 2) how do they differ in their adaptive strategies, and 3) what are the implications of diverse fisher types on individual adaptive capacity?* I find that fishers of chocolate clams in this region operate within both the formal and informal sectors, have varied fishing strategies, and can be characterized into four discrete types. I also find that heterogeneity among fishers affects their individual capacities to adapt to changing conditions and disturbances, and may affect both economic and ecosystem-related fishery outcomes. Maintaining a diverse suite of adaptive strategies is essential for individuals to cope in the face of future disturbance and change. Likewise, maintaining heterogeneity in the fishery, by ensuring

multiple fisher types are equipped to adapt to future change, will strengthen adaptive capacity within the fishery and community.

Introduction

Environmental variation is inherent in natural resource-based sectors, including fisheries (Stoll et al. 2017). This variability is driven by changes in environmental and biological processes, as well as socio-economic shifts based on market dynamics and consumer demand (Adger 2000, Crona et al. 2015). In navigating these changes as opportunities for transformation, individuals have a key role to play (Westley et al. 2013). Individual agency, or the capacity for individuals to make their own decisions and act independently, can be vital in shaping the dynamics of the broader social-ecological system (SES) (Biggs et al. 2010, Westley et al. 2013, Frawley et al. 2019a). Individual agency is shaped by an individual's perceptions and cognitive processes, societal structures, as well as individual environmental and socio-economic circumstances (Emirbayer and Mische 1998). Understanding how individuals make decisions and adapt is key to predicting how they will fare under changing conditions in the future (Coulthard and Britton 2015). Heterogeneity among fishers has consequences both for the sustainability of fished populations and for fishers' individual capacities to adapt to future change (Coulthard and Britton 2015, Stoll et al. 2017, Frawley et al. 2019b). Adaptive capacity is defined by the ability of systems to design or change their structure in response to environmental or socioeconomic variability such that they maintain the ability to cope under new circumstances (Adger et al. 2005, Armitage and Plummer 2010). Likewise, adaptive capacity of individuals is related to their ability to withstand change (Stoll et al. 2017). Monitoring adaptive responses and considering how community and system-level adaptive capacity is impacted as individuals react to change may allow a deeper understanding of feedbacks, trade-offs, and potential improvements to approaches for assessing and building adaptive capacity (Aswani et al. 2015, Cinner et al. 2015).

Adaptive strategies contribute to adaptive capacity, and strategies fishers employ include changes in how, when, where, and what is fished (Wilson 2006, 2017). Strategies involving changes in fishing activities include changing harvest method (Cinner et al. 2015), engaging in seasonal fishing effort (Sievanen 2014), changing the intensity of fishing activity (Stoll et al. 2017), changing or rotating harvest locations (Sievanen 2014, Young et al. 2018), and fisheries portfolio diversification or shifting to high-value fisheries (Perry et al. 2011, Stoll et al. 2017). Fisheries portfolio diversification reduces the risk to fishers of inter-annual variation in stock abundance and market value (Kasperski and Holland 2013, Finkbeiner 2015, Cline et al. 2017), and is a signal of fishers' adaptive capacity. Maintaining or expanding alternate sources of income, via livelihood diversification (Ellis 1998, 2000, Allison and Ellis 2001, Béné 2009, Galappaththi et al. 2019), or relying on social networks, can help fishers navigate times when primary target species are scarce (Löfgren 1972, Perry et al. 2011, Boag et al. 2018). Another common adaptation strategy among fishers is mobility, or moving to follow sources of income (Pinsky and Fogarty 2012, Ferse et al. 2014, Sievanen 2014, Young et al. 2018). Additional strategies include proactive approaches such as altering habitat to accommodate desirable species (Boag et al. 2018), and wait-and-see approaches in which changes in behavior are delayed until additional information is collected (Perry et al. 2011; see Table 4.1 for full description).

Table 4.1. Adaptive strategies employed by small-scale fishers around the world.

Adaptive Strategies		
Type	Input required	Strategy
How to fish	Tactical	Multiple harvest methods[1]
When to fish	Informational	Seasonal fishing effort[2]
Where to fish	Informational	Rotate harvest location[2]
What to fish	Tactical	Fisheries portfolio diversity[3,4]
How and when to generate income	Informational and Tactical	Livelihood diversity[5,6]
		Reliance on social networks[3,7]
Where to generate income	Informational	Mobility (seasonal or long-term)[2]
Proactive	Informational	Seeding, changing environment[8]
Wait	None	Wait and see[3]

[1]Cinner et al. (2015), [2]Sievanen (2014), [3]Perry et al. (2011), [4]Stoll et al. (2017), [5]Allison and Ellis (2001), [6]Béné (2009), [7]Löfgren (1972), [8]Boag et al. (2018)

Each adaptive strategy has input requirements that may not be feasible for all fishers. For example, new information or knowledge may be needed before a fisher can change harvest times or locations (Wilson et al. 2013). To expand or move into new fishing areas, fishers may be required to obtain additional permits, longer-range fishing vessels, and may have higher fuel requirements to power vessels beyond their current fishing range. Financial capital inputs including fishing gear, as well as informational inputs may be required before a fisher can expand harvest methods or diversify fishing portfolios (Stoll et al. 2016, 2017). The ability to diversify is also increasingly bound by regulatory enclosure (Murray et al. 2010). Variation among fishers in terms of social and economic capital, as well as factors such as culture, perception, and individual risk profiles, influence which adaptive strategies they adopt (Frawley et al. 2019b). This variation affects each fishers' individual ability to adapt to disturbance and change, and may also have consequences for the broader adaptive capacity of the fishery SES (Walker et al. 2004, Folke et al. 2010).

Understanding the full spectrum of fishers, their decision-making processes, and their adaptive responses, is essential both for anticipating fishery outcomes and predicting the capacity of different types of fishers to adapt to future change. I focus on a small-scale fishery on the Gulf of California coast of Baja California Sur, Mexico, where fishers experience temporal and spatial variability in resource abundance, environmental conditions, and market demand (Pellowe and Leslie 2017). In this chapter, I ask, *1) what types of fishers exist within the chocolate clam fishery of Loreto Bay National Park, 2) how do they differ in their adaptive strategies, and 3) what are the implications of diverse fisher types on individual adaptive capacity?* This chapter focuses not only on the formal fishery, but also on the less visible informal sector that is often excluded from fisheries management. The inclusion of these fishers is critical to comprehensive fisheries studies, particularly in cases where the number of informal fishers is equal or larger than the number of formal fishers. I argue that: 1) there are multiple, discrete fisher types, characterized by harvest strategy and status of inclusion in the formal fishery; 2) fisher types employ different suites of strategies to adapt to economic and/or environmental change; and 3) adaptive strategies requiring financial capital inputs are more common among fishers engaged in the formal fishery than the informal fishery, due to the economic barriers formal fishers have had to overcome to obtain permits, and because of the formal fishery's recognition of a high-yield fishing method.

Study area

In the region of Loreto Bay National Park, Baja California Sur, Mexico, there is diversity among fishers in terms of their demographic characteristics and harvest strategies. The Mexican chocolate clam, *Megapitaria squalida*, is a culturally and economically important species in this region that provides food and income to many households. The clam can be found in the shallow waters along the coast, requires little equipment to harvest, and for many households serves as a safeguard in times of scarcity. Many locals have childhood stories of digging in the sand with their toes or learning to dive in the clear waters of the Gulf of California, searching for chocolate clams. The traditional method of harvest remains free diving. This technique involves holding one's breath and diving to the ocean floor to search for clams buried in the sand. The technical inputs of free diving are very low. Although not required, many free-diving fishers use a mask, snorkel, fins, and in some cases, a float constructed of empty milk cartons to hold their catch. Many fishers still use this traditional technique, but the method formally recognized for legal, permitted harvest is hookah diving. Hookah diving requires a boat outfitted with a gasoline-powered air compressor, which pumps air through long plastic tubing to a diver at the ocean floor. The hookah technique allows fishers to access deeper depths, and to remain on the ocean floor for up to four hours at a time. Compared to the 60-90 second breath holds of the most experienced free divers, hookah diving's extended periods at depth allow for efficient and high-yield harvests. The costs of obtaining the boat, motor, and compressor required for application for a chocolate clam permit are high, and are prohibitive for many fishers. For this reason, many chocolate clam fishers in this region operate outside of the formal, permitted fishery (Pellowe, *pers. obs*.). The informal sector of the fishery, which accesses clams exclusively via free diving, is a large and heterogeneous group that falls outside the purview of fisheries management.

Methods

From May to August 2015, I conducted in-depth, semi-structured interviews (Bernard 2017) with 35 chocolate clam fishers in Loreto, Juncalito, Ligüí, and Ensenada Blanca, Baja California Sur, Mexico. To understand the full spectrum of fishers involved in the fishery, care was taken to recruit and interview both permit-holding and non-permit-holding fishers. At the time of the interviews, there were approximately 20-25 fishers harvesting clams under a permit (independent permit holders or cooperative members), and an estimated 50-75 fishers harvesting clams without a permit in this region. Twenty-two of 35 interviews were audio recorded, three of these recordings were of non-permit-holding fishers. Most non-permit-holding fishers declined to be recorded, many citing a fear of being connected to the data shared during the interview, and receiving sanctions related to their extralegal activities. Interview participants were recruited via snowball sampling (Morgan 2008), beginning with contacts established during previous fieldwork in this region, and a list of contact information for chocolate clam permit holders as of May 2015. I identified the remaining interviewees by asking each participant to recommend other clam fishers in the region. Many non-permit-holding fishers were wary to participate in an interview, or to recommend others. This led to a smaller number of interviews with non-permit-holding fishers than with permit-holding fishers.

Interviews were conducted in Spanish, the first language of participants. Interviews occurred in person, lasted between 30 minutes and two hours, and took place on the beach or at participant's homes. All interviews were confidential due to the sensitive legal nature of fishing without a permit. Fishermen ranged in age from 28 to 55, and had lived in the Loreto Bay region between 15 to 54 years. Interviews were guided by a set of open-ended questions, and collected data on fishers' socioeconomic characteristics, reliance on clam fishing as a source of income, other sources of income, frequency of clam harvest, and effort. I used descriptive questions (Schatzman and Strauss 1973, Spradley 1979) to ask fishers about the factors influencing their fishing decisions, including where, when, and how they harvest clams. I also collected information on other species harvested, changes fishers had observed in the clam fishery over time, and whether their harvest practices and target species had changed over time.

Written notes, including quotes of fishers' responses, were recorded by two interviewers during each interview (Schatzman and Strauss 1973). Since many participants declined to have their responses audio recorded, and recorded interviews were heavily skewed towards permit-holding fishers, I relied upon the written responses captured by interviewers for qualitative data analysis. I employed an inductive approach (Strauss 1987) to define fisher types and to code fisher characteristics and adaptive strategies, with themes and categories emerging from analysis of interview notes by the primary researcher who conducted the interviews (KP). Typologies were constructed based on emergent themes from interview data, and included primary harvest method, type of operation, and permit status.

Results

My observations and interviews with clam fishers indicate that there are two major and two minor fisher types. These are: 1) *libres*, non-permit-holding, free-diving fishers; 2) *buzos de compresor*, permit-holding, hookah-diving fishers; 3) *permisionarios libres*, permit-holding, free-diving fishers; and 4) *contratados*, non-permit-holding, hookah diving fishers who contract their skills to permit holders (Table 4.2). The first type of fishers, *libres* (n=13), harvest chocolate clams primarily via free-diving with a mask, snorkel and fins. They operate independently, and do not harvest chocolate clams under a permit. The second type of fishers, *buzos de compresor* (n=17), harvest chocolate clams using a 7-9m fiberglass boat with outboard motor called a *panga*, outfitted with a gasoline-powered compressor for hookah diving. This type of fisher holds a permit for fishing chocolate clams and operates either independently under his own permit, or is a member of a formal fishing cooperative. *Permisionarios libres* (n=2) and *contratados* (n=3) are rare, but differ from the first two groups in important ways. Like *buzos de compresor*, *permisionarios libres* hold permits for chocolate clams, operate either independently or as cooperative members, and harvest clams from a boat, but do so via free-diving with mask, snorkel, and fins. *Contratados* do not hold their own permits and are not members of cooperatives, but harvest clams as independent contractors for permit holders or formal cooperatives for a daily rate. They harvest clams from a boat using hookah equipment that is owned by the permit holder or cooperative that they contract their skills to. Fishers using the free diving method reported collecting, on average, 422 clams per harvest day, while compressor divers' reported collecting 2740 clams per harvest day.

Table 4.2. Types of fishers associated with the Mexican chocolate clam fishery. Typologies were created based on permit status, primary gear type, and type of operational arrangement.

Fisher Type	n	Permit	Gear type	Operational Arrangement
Libres	13	No	Snorkel	Independent
Buzos de compresor	17	Yes	Fiberglass boat, hookah compressor	Independent or Cooperative member
Permisionarios libres	2	Yes	Fiberglass boat, snorkel	Independent or Cooperative member
Contratados	3	No	Hookah compressor	Contractor

Fishers reported that one of the primary benefits of having a permit is being able to easily sell higher volumes of catch for better prices. Three *buzos de compresor* stated these as their primary reasons for fishing under a permit (Participants 11, 14, 22). These benefits of holding a permit were echoed by *libres*, many of whom said they would prefer to obtain a permit because it would expand the market they are able to sell to, and increase the value of their product. However, Participant #32 stated that he remains unpermitted due to the "many roadblocks"; "we are illegal [fishers] because we do not have an option," he said. One *buzo de compresor* (Participant 15) stated, "Everyone wants to get a permit. Many don't have the equipment required, but they still [harvest clams]." The expense of obtaining the equipment necessary to apply for a chocolate clam permit was a primary reason given by participants.

Interview participants varied in their reliance on chocolate clam fishing as a source of income. Five participants (14%) reported that their sole source of income is chocolate clam fishing, while 21 participants (60%) reported that 100% of their income comes from fishing. On average, 82% of participants' income comes from fishing overall, and of this, 41% of income comes from chocolate clam fishing (chocolate clam income is nested within fishing income). These percentages did not vary considerably among fisher types (Table 4.3). Sixteen of the 35 participants (46%) reported having additional, non-fishing sources of income throughout the year. Two participants reported that 100% of their income comes from fishing, but that they take additional jobs when needed. Additional sources of income reported included park monitoring, education, construction and masonry, transport and sale of potable water, glass manufacturing, tourism, bus/truck driving, agriculture, landscaping, and restaurant work.

Table 4.3. Measures of the percentage of fishers' economic dependence on fishing, perceptions of change, and number of adaptive strategies.

Measure	Total	*Libres*	*Buzos de compresor*	*Permisionarios libres*	*Contratados*
Percent of income from chocolate clams	41	45	36	40	50
Percent of income from all fishing	82	77	85	65	100
Percent of participants that have noticed changes in ocean in past 20 years	80	77	82	50	100
Percent of participants that have noticed changes in clam populations	60	77	41	50	100
Average number of adaptive strategies	3.0	2.6	3.5	2.5	2.7

When asked whether they had observed changes in the ocean over the past 10-20 years, 80% of participants said yes. Sixty percent said that these included changes in chocolate clam populations, including declines in the abundance and size of clams. Two participants said that they believed the changes in clams were cyclical, rather than long term. Participants reported seasonal variability in market demand for chocolate clams, as well as seasonal shifts in environmental conditions in Loreto Bay National Park, including changes in water temperature and wind strength and direction throughout the year. Eight fishers expressed the belief that free diving has a lower impact on clam populations than does hookah diving, and that the expansion of hookah diving is a primary reason for the declines in clam populations they have observed. Participant 30 stated, "If there weren't compressors in Loreto Bay, the clams would never disappear." He believes that compressors and the hookah divers who use them are responsible for the declines in clam populations that he has observed. Participant 10 echoed this sentiment: "If everyone dove with a compressor like that, the clams would be gone." He does not want to use equipment to fish, but he is trying to get a permit so that he can avoid problems with the authorities.

All participants reported engaging in at least one adaptation strategy, and the most adaptive strategies reported by an individual fisher, a *buzo de compresor*, was five. The most common strategy reported was rotating harvest sites (Table 4.4). Ninety-seven percent of participants (34 out of 35) reported rotating harvest locations on a daily to monthly basis. Fishers switched among harvest locations when clams became scarce, appeared too small, or when environmental factors, including wind and waves, limited their access to certain sites. Individual fishers reported harvesting from two to nine different clam banks over the course of a typical year, indicating high spatial variability in fishers' harvest activities. Other adaptation strategies commonly reported included maintaining diverse fishing portfolios (63%), and engaging in seasonal fishing effort of chocolate clams (63%). Seasonal fishing effort, i.e., temporal variability in chocolate clam effort throughout a typical year, was reported by all types of fishers except *permisionarios libres*. Recall, however, the small number of *permisionarios libres* in my sample (n=2). Sixty-two (62%) percent of *libres*, 77% of *buzos de compresor*, and 33% of *contratados* reported varying their fishing effort seasonally throughout a typical year. Rotating harvest location and engaging in seasonally variable fishing effort are strategies that require informational, but not necessarily financial capital inputs.

Table 4.4. Adaptive strategies reported by chocolate clam fishers by type.

Adaptive Strategies Reported		Total	*Libres*	*Buzos de compresor*	*Permisionarios libres*	*Contratados*
Type	Strategy	Percent Reported				
Change fishing	Multiple harvest methods	31	0	41	50	67
	Seasonal fishing effort	63	62	76	0	33
	Rotate harvest location	97	92	100	100	100
	Fisheries portfolio diversity	63	38	82	50	67
Change income	Livelihood diversity	49	62	35	50	0

Participants' adaptation strategies were related to fisher type. Higher percentages of *buzos de compresor* report using multiple harvest methods (41%) and maintaining diverse fishing portfolios (82%), compared to *libres* (0% and 39%, respectively). Conversely, 62% of *libres*, almost double that of *buzos de compresor* (35%), report maintaining diverse livelihoods. Although interview questions were not designed specifically to capture data on mobility, reliance on social networks, proactive approaches, or wait-and-see strategies, it is likely that many participants engage in these approaches in addition to the strategies explicitly reported. In addition, despite interviews not being designed to capture proactive approaches, seeding of small clams was a strategy reported by three participants (9%). No participants explicitly reported wait-and-see approaches; however one participant, a *buzo de compresor*, reported relying on social networks during times of financial hardship.

Discussion

I found that heterogeneity among fishers affects their individual capacities to adapt to changing conditions and disturbances, and may affect both economic and ecosystem-related fishery outcomes. Fishers of chocolate clams in Loreto Bay National Park operate within both the formal and informal sectors, have various combinations of methodologies and operations, and fall into four discrete groups. I found differences in the adaptive strategies used by fishers of these different types. Adaptive strategies employed by fishers worldwide include using multiple harvest methods, changing spatial distribution of effort via rotation of harvest sites, maintaining alternate sources of income (both fisheries and livelihood portfolio diversity), and redistributing effort among the fisheries in which they participate (Fuller et al. 2017). Fishers also rely on social networks during times of scarcity (Löfgren 1972), move to other locations to follow sources of income (Sievanen 2014), and engage in proactive approaches to seed or encourage the growth and survival of desirable species (Boag et al. 2018). Understanding how individuals make decisions, and what options they have for responding to changing conditions is critical for understanding individual resilience (Coulthard and Britton 2015). Limits to individual agency affect not only how fishers interact with their resources, and the adaptation strategies they adopt, but also the success of local resource management (Bennett et al. 2018).

All fishers in this study reported at least one adaptive strategy. On average, they maintain three adaptive strategies, suggesting that chocolate clam fishers engage in a suite of behaviors that buffer them against environmental change and dynamic markets. Spatial variability in fishing effort, a strategy requiring informational inputs, was reported by nearly all fishers interviewed. This spatial variability, which took the form of rotating harvest locations, occurred on a daily to monthly basis. Seasonal variation in fishing effort was another common strategy, reported most often by fishers with fishing portfolios composed of multiple, seasonal target species. Fishers in Baja California Sur experience highly seasonal fisheries, due in part, to environmental variability (Pellowe and Leslie 2017). Many clam fishers in this study harvest chocolate clams seasonally as a complement to the other fisheries in which they participate.

I found that in some cases, the rate at which participants reported adaptive strategies was related to fisher type. Higher percentages of *buzos de compresor,* permit-holding, hookah-diving fishers, reported using multiple harvest methods and maintaining diverse fishing portfolios, compared to *libres*, the non-permit-holding free-diving fishers. This finding supports my hypothesis that the adaptive strategies requiring financial capital inputs – including fisheries portfolio diversity and multiple harvest methods – are more common among fishers engaged in the formal fishery than the informal fishery. Access to financial capital enhances fishers' abilities to diversify their livelihoods and adapt to change without putting additional strain on fished resources (Bennett et al. 2014, Haque et al. 2015). Maintaining options and flexibility is at the core of adaptive capacity (Folke et al. 2010). Almost twice as many *libres* maintain non-fishing sources of income as do *buzos de compresor*. This finding could be attributed to *libres*' lower daily harvests and fishing income compared to fishers who harvest clams via hookah diving. Small-scale fishers worldwide experience poor or variable market access (Haque et al. 2015), and informal fishers may be the most vulnerable to market dynamics. *Libres*' status as non-permit-holding fishers prevents them from selling their catch to restaurants, and they receive orders less reliably. One of the primary benefits of having a permit, according to fishers in my study, is the ability to easily sell high volumes of catch for better prices. The lower harvest rates, less reliable demand, and lower prices paid to informal fishers may explain why such a large proportion of *libres* maintain diverse livelihood portfolios to supplement clam income with income from other sources.

Despite informal fishers' desire to access formal markets and avoid sanctions, they are constrained by their lack of financial capital, which prevents them from obtaining a permit. The application process for a chocolate clam permit and quota, necessary for harvesting chocolate clams legally, requires proof of ownership for a fiberglass *panga*, motor, and hookah compressor. Although many informal fishers would prefer to be permitted, many also stated that they prefer the traditional free diving method over hookah diving. Fishers whose primary method of harvest is hookah diving collect nearly seven times more clams per harvest day as do free-diving fishers. This difference in harvest efficiency and effort may have significant ecological consequences for the fishery. The current system of permitting encourages the adoption of high-yield fishing methods, and leads to underreporting of catch by informal fishers who lack the financial capital needed to obtain a permit. Fishers attribute observed declines in the abundance and size of clam populations to the expansion of hookah diving, and a common belief among fishers is that free diving has a lower impact on clam populations.

The current system of permitting results in *de facto* encouragement to adopt higher-impact harvest methods, and in higher rates of unreported catch and thus inaccurate estimates of overall fishing effort in Loreto Bay's chocolate clam fishery. Inaccuracies in the data informing management may lead to inappropriate quota limits and declines in chocolate clam populations. Many fishers believe that the shift towards hookah diving has resulted in higher fishing pressure and changes in chocolate clam populations. This finding is consistent with recent emphasis on the need for conservation policy that is aligned with local ethics, values, and motivations (Chan et al. 2006, Lubchenco et al. 2016, Nyborg et al. 2016). Alienation of the informal sector (*libres* and *permisionarios libres*), via formal sanctions and exclusion from decision-making processes, has also led to tension between formal and informal groups. Appropriate marine management requires deepened participation of diverse actors, including marginalized groups, and shifts in the power balance among actors (Araujo et al. 2017). Increased participation of marginalized groups, like informal fishers, requires redefining how institutions operationalize participation. Formal mechanisms to increase the participation of marginalized groups are often obstructed by powerful groups that define the meaning of participation (Castro et al. 2016, Araujo et al. 2017). Effective marine management requires knowledge of the local context, including the decision-making processes of diverse actors, and their individual abilities to adapt to change, as well as policies that take into account local ethics, values, and motivations (Bennett et al. 2018).

Observed differences among fishers in individual adaptive capacity can lead to various levels of individual vulnerability to future environmental or socioeconomic change. A comprehensive understanding of this heterogeneity in fishers' adaptive capacity is necessary for management strategies that address the needs of diverse fishers. Heterogeneity among fishers' adaptive capacity has also been found in other systems economically dependent upon the fisheries sector (Steneck et al. 2011, Cline et al. 2017, Stoll et al. 2017). In many of these cases, fisheries portfolio diversification represents a primary adaptive strategy that varies widely among individual fishers (Cline et al. 2017, Stoll et al. 2017). Barriers to fisheries portfolio diversification, including the difficulty of obtaining permits, influence fishers' individual adaptive capacities, and have consequences at the fishery scale. Reductions in economic diversity limit adaptive capacity, and leave both fishers and fisheries vulnerable to future economic and environmental change (Steneck et al. 2011). Mediating such vulnerability requires policies that support social, biological, and economic diversity.

Conclusion

Fishers are adept at solving problems and adapting to the inherent variability of the marine environment in which they work (Acheson 1981). The variability fishers commonly experience is due to changes in environmental and biological processes, as well as market dynamics and demand (Adger 2000, Crona et al. 2015). The chocolate clam fishers I interviewed actively employ adaptive strategies, and make fishing and livelihood decisions in response to changing conditions. Fisher type is in many cases related to fishers' access to financial resources, influencing and potentially limiting the adaptive strategies they engage in. While informal fishers engage in almost as many adaptive strategies as formal fishers, the strategies they employ generally require less input of financial capital. Informal fishers obtain higher percentages of their total income from chocolate clam fishing than formal fishers, yet are subject to highly variable demand and lower prices. They are thus particularly vulnerable to the environmental and economic variability inherent in the fishery. Informal fishers often lack the resources to obtain permits, are excluded from fishery decision-making processes, and are subject to costly sanctions for fishing without a permit. Such fishers are keenly aware of changes in chocolate clam populations and worry about how increased use of hookah diving will affect clams and their own livelihoods. As one *libre* (Participant 9) stated, "as the sea is used up, so I will be too." These fishers buffer themselves against vulnerabilities by maintaining diverse livelihood portfolios, and engage in various strategies to adapt to change. Maintaining a diverse suite of adaptive strategies is essential for individuals to cope in the face of future disturbance and change. Likewise, maintaining heterogeneity in the fishery, by ensuring multiple fisher types are equipped to adapt to future change, will strengthen adaptive capacity at the fishery and community levels.

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CHAPTER 5

THE INTERPLAY BETWEEN FORMAL AND INFORMAL INSTITUTIONS AND THE POTENTIAL FOR CO-MANAGEMENT IN A MEXICAN SMALL-SCALE FISHERY

Abstract

Understanding how institutions operate is crucial to the protection of marine ecosystems and the communities that depend on them. I define institutions broadly as the rules, norms, and practices that govern resource users' interactions with common-pool resources, and recognize that both formal and informal institutions govern marine fisheries and other coastal and ocean resources around the world. Institutional diversity can enhance social-ecological system resilience by providing multiple ways of responding to disturbance or change. Identifying institutions and their effects on fishing practices is key to improving management for sustainable fisheries. In this study, I use a case study approach focused on the institutions guiding fishing activities of an economically and culturally important marine species: the Mexican chocolate clam, *Megapitaria squalida*, in Loreto Bay National Park in Baja California Sur, Mexico. By synthesizing long-term observations and semi-structured interviews with fishers and other key stakeholders, I identify the formal and informal rules and norms governing fishing behavior, explore their effects on fishing practices, and illuminate ways in which formal and informal institutions may work in tandem. I find that both formal and informal institutions shape fishing practices within the chocolate clam fishery. Some reinforce one another, and others are in conflict. The diverse institutions governing the chocolate clam fishery create a complex web of sometimes conflicting rules and social norms that fishers navigate every day. I contend that greater community participation in management, via polycentric and collaborative governance that accounts for and legitimizes local norms in a system like co-management, would foster enhanced sustainability of the chocolate clam fishery and the benefits it provides to coastal communities.

Introduction

Coastal ecosystems provide innumerable benefits to humans, including food, livelihoods, and recreational opportunities (Halpern et al. 2012). All benefits provided by the ocean, and other natural systems in which humans interact, are embedded within social-ecological systems (SESs) (Ostrom 2009). The continued delivery of these benefits requires management of people's interactions with marine species and the ecosystems of which they are a part. Institutions define how people interact with and manage common-pool resources, like fisheries, and understanding how they operate is crucial to the success of resource management (Ostrom 2005, Basurto and Coleman 2010). Institutional heterogeneity, i.e., the diversity of systems of rules governing human behavior, shapes SES dynamics, and diverse institutional arrangements can enhance SES resilience (Ostrom 2005). In fisheries, institutions can be defined as the organizational structures that bound fisheries management, or they can be thought of more broadly as the rules, norms, and practices governing interactions between people and fished resources (Ostrom 2005). The success of institutions depends on monitoring and enforcement at the local level (Ostrom 1990).

Around the world, both formal and informal institutions, including social norms (Ehrlich and Levin 2005), guide the interactions of resource users with resources (Agrawal and Gibson 1999). As defined by Ostrom (Ostrom 2000), and cited by Nyborg and colleagues (Nyborg et al. 2016), a social norm is a "predominant behavioral pattern within a group, supported by a shared understanding of acceptable actions and sustained through social interactions within that group," and can be considered a form of informal institution (Ehrlich and Levin 2005). Formal and informal institutions can interact, contradict, and overlap. Both types are equally likely to contribute to sustainable management, or to resource overexploitation (Agrawal and Gibson 1999). Understanding both types, as well as their interplay, can reveal how resource users engage with their common-pool resources (Etiegni et al. 2017). Identifying what informal institutions exist and creating pathways for coordination with formal institutions, via nested and polycentric governance systems, can lead to effective community-based resource management (Aswani et al. 2017). Without buy-in from resource users themselves, formal, top-down institutions for management of resources can be fraught with problems, including resistance and recurrent rule-breaking (Ostrom 2005). Polycentric systems, systems in which multiple decision-making authorities cooperate and maintain conflict resolution mechanisms, can lead to better institutional fit, risk mitigation, and enhanced adaptive capacity (Carlisle and Gruby 2017). For these reasons, polycentric systems may be more effective than top-down management by a single central authority (Ostrom 2005).

Sustainable governance of natural resources is more likely to be achieved through decentralized and participatory governance (Aswani et al. 2017). Co-management is one such example of participatory governance that implies the sharing of power and responsibility between local resource users and government authorities (Allison and Ellis 2001, Carlsson and Berkes 2005, Berkes 2009). Co-management can exist within polycentric systems of governance, and has been proposed as an effective solution to sustainable resource management, particularly where power is equitably distributed among local actors (Béné et al. 2009). Success in co-management depends on local leadership, strong social networks, monitoring and enforcement of regulations, and participation of fishers in local markets (Gutiérrez et al. 2011). In addition to the sharing of power, co-management is also a knowledge partnership between local and state actors, and through mutual learning, co-management can facilitate formalized adaptive management (Berkes 2009, Armitage et al. 2011). The integration of traditional, informal rules and social norms into formal governance of natural resources, contributes to management that is better equipped to adapt to future change (Cinner and Aswani 2007). Traditional ecological knowledge incorporates adaptive processes, and it has been argued that it is similar in many ways to adaptive management (Folke et al. 1998, Berkes et al. 2000, Moller et al. 2016). The challenge of effective management of SESs requires the appreciation of diverse knowledge systems, adaptive communication between actors, and the integration of local knowledge and practice into participatory governance (Turner et al. 2016).

Institutional arrangements play a key role in shaping the resilience of the coupled SESs associated with small-scale fisheries in Baja California Sur (BCS), Mexico (Basurto 2005, Basurto et al. 2013a, Leslie et al. 2015). Identifying and characterizing both formal and informal institutions, and their influence on actors' fishing behavior, is a crucial step in understanding how institutions shape fishery dynamics and contribute to sustainable or unsustainable practices, and has direct management implications. Informal institutions reveal ways in which local ecological knowledge contributes to fishers' decisions regarding their common-pool resources (Basurto 2005). A study of the diverse institutions shaping fishing practices can help identify potential avenues for co-management in a system currently governed by top-down, non-participatory governance. In Loreto Bay National Park, on the Gulf coast of BCS, I asked: 1) What institutions, both formal and informal, govern fishing behavior in an economically and culturally important fishery; 2) How do diverse institutional arrangements shape fishing practices; 3) Where do informal and formal institutions overlap or come into conflict; and 4) What does this institutional overlap or conflict reveal about the potential for participatory governance in the fishery? I predicted that: 1) multiple formal and informal institutions operate simultaneously, with diverse effects on fishing practices; 2) there is both overlap and conflict among formal and informal institutions; and 3) addressing the conflicts will pave the way for participatory, adaptive management, with the potential for polycentric governance that better accounts for local ecological knowledge. I employed a case-study approach involving long-term participant observations and interviews with diverse stakeholders to better understand the institutions governing fishing practices in a Mexican small-scale fishery.

Background and study area

This study took place in Loreto Bay National Park, a national marine park on the Gulf of California coast of Baja California Sur, Mexico. Loreto Bay National Park encompasses five islands and five coastal towns; Loreto, Nopoló, Juncalito, Ligüí, and Ensenada Blanca. In this region, the Mexican chocolate clam, *Megapitaria squalida*, is a species with high economic and cultural significance (López-Rocha et al. 2010, Pellowe and Leslie 2017), and the fishery provides an important source of food and income to communities. The fishery is formally regulated using permits and catch quotas, issued by the Comisión Nacional de Acuacultura y Pesca (CONAPESCA), an arm of the Mexican government responsible for regulating fisheries and aquaculture at the state level. Monitoring and enforcement of formal fisheries regulations is carried out by officials of CONAPESCA, Loreto Bay National Park, and Fondo para la Protección de los Recursos Marinos (FONMAR). FONMAR participates in occasional monitoring of fishing activities in Loreto Bay, but it is primarily responsible for the sportfishing sector.

Legal harvest of chocolate clams requires a species-specific permit issued by CONAPESCA. Obtaining a permit requires an applicant to show proof of ownership of a boat, often a 7-9m fiberglass *panga*, an outboard motor, and a gasoline-powered air compressor, which is used for hookah diving. When mounted on a boat, the compressor pumps air down to a diver on the ocean floor, allowing for extended periods of harvest at depth. With a permit, fishers also must obtain a quota, which delineates which areas and how much a fisher can harvest in a given time period. Both a permit and quota are required for legal harvest of chocolate clams in Loreto Bay National Park. The high costs associated with the permit application, including the gear required, are a barrier to entry for many chocolate clam harvesters who would otherwise enter the formal fishery. Many of these non-permit-holding fishers harvest chocolate clams close to shore using the low-cost method of free diving, with a mask and snorkel.

The chocolate clam's use as a traditional food in the Loreto region dates to the precolonial era, when the indigenous Pericú people dove for shellfish (North 1908), including chocolate clams, buried them on the beach, and cooked them under bonfires of beach brush (Laylander 2000). Prior to 2016, a local *usos y costumbres* clause, a clause protecting traditional uses and customs, allowed community members to harvest modest quantities of chocolate clams without a permit, for personal and familial consumption. Selling clams collected under the clause was prohibited, but the clause allowed community members to maintain cultural traditions surrounding the species. In 2016, a conflict was discovered between the clause in practice in Loreto, and a state-level law that guarantees resource rights under *usos y costumbres* for finfish species, but does not specify shellfish. In order to conform with state law, the *usos y costumbres* clause for chocolate clams was removed, and legal community access to the resource without a permit was interrupted. Effectively, this change made free diving for chocolate clams, the traditional method of harvest, illegal, since only permit-holders, all of whom were required to own the equipment for hookah diving, were allowed to harvest chocolate clams. In response, two schoolteachers in the town of Loreto started a protest movement called, "*Sí, al autoconsumo de la almeja"*, "Yes, to the self-consumption of the clam". A day of protest was organized, and all community members were invited to join together for a day of chocolate clam harvest at a public beach in protest of the loss of access to what was perceived as a traditional public resource. In 2019, at the conclusion of conversations related to this study, the *usos y costumbres* clause had not been re-established for chocolate clams in Loreto Bay National Park, due to continued conflict with state law.

Methods

To better understand the institutions governing fishing practices, and to estimate their effects on harvest, I employed a case study approach focused on four communities along the coast of Loreto Bay National Park; Loreto, Ligüí, Juncalito, and Ensenada Blanca. Five years of observations of fishing practices, ethnographic conversations (Spradley 1979) with fishermen, community members, and enforcement officials, and 35 semi-structured interviews with fishermen (Berg 2004, Etiegni et al. 2017), were used to identify the institutions governing fishing activities in the chocolate clam fishery, and to understand how they shape fishing practices, and relate to ecological, economic, and fisheries-related outcomes. Observations of fishing practices and conversations with fishers, community members, and enforcement officials took place over the course of eight trips to the region, each lasting between ten days and three months, from 2014 to 2019. Ethnographic conversations occurred when and where the opportunity arose, with questions guided by the informant and related to themes emerging from participant observation (Spradley 1979). Notes were taken both during and after the conversation took place.

From May to August 2015, I conducted 35 semi-structured interviews with clam harvesters. I recruited participants using snowball sampling (Morgan 2008), beginning with contacts established during previous fieldwork in the region. Additional participants for interviews were identified by asking each participant to recommend other clam harvesters in the region. Interviews were conducted in Spanish, the first language of participants, and a language I speak with professional proficiency. Interviews lasted between 30 minutes to two hours, and took place in a location of the participants' choosing, often at the beach, or in participants' homes. Interviews were guided by a set of open-ended questions (Schatzman and Strauss 1973, Strauss 1987) that were informed by questions pilot tested during informal conversations in 2014. Interviews collected information on the factors influencing participants' fishing decisions, including what factors affect their decisions of where, when, and how to harvest chocolate clams on any given harvest day. I translated interview responses from Spanish to English, and from fishers' responses, I used an inductive approach (Strauss 1987) to identify institutions governing fishing practices in the chocolate clam fishery. The informed consent document and interview questions can be found in Appendices 1 and 2. I conducted qualitative analyses (Strauss 1987) of the impacts of various institutions on fishing practices and behavior, with themes emerging from analysis of interview responses by the primary researcher who conducted the interviews (KP). Institutions were identified from fishers' citation of factors influencing their fishing decisions. These included social norms, community or group rules, formal rules, and formal and informal vigilance and rule enforcement.

Observations of fishing practices occurred over a five-year period, and included accompanying fishers while they harvested clams, as well as my own experiences of vigilance and enforcement while I conducted other studies of clam populations in Loreto Bay National Park. While conducting clam population surveys at 17 sites spanning the coast of the marine park, I noted formal and informal vigilance if enforcement officials or fishers approached the boat, and questioned my activities. I also observed fishers engaging in informal monitoring of other fishers while accompanying and observing fishers while they harvested clams. This type of informal monitoring was typically carried out by hookah fishers in boats, and was directed towards free diving fishers. Informal monitoring involved questioning the activities of the apparent offender, informing them that they must have a permit to fish chocolate clams, and giving a verbal warning. Combining fishers' and community members' accounts of institutions from ethnographic conversations and interviews, and observations of rules in practice and rule enforcement, I identified formal and informal institutions governing fishing activities in the Mexican chocolate clam fishery. I also analyzed qualitatively how these institutions shape fishing practices, support or contradict one another, and influence harvest.

Limitations of this study include possible cultural misunderstandings and language translation errors during conversations and interviews. My study approach, combining observations, ethnographic conversations, and semi-structured interviews, results in a qualitative understanding of institutional effects that provides important insights about the role of institutions in shaping fishing practices.

Results

Types of institutions

I found that both formal and informal institutions regulate fishing practices in Loreto Bay National Park's chocolate clam fishery (Table 1), and affect fishing practices in various ways. Some institutions support and replicate one another, and others are in direct conflict. This creates a complicated institutional web that fishers must navigate on a daily basis to make decisions about their harvest practices. Formal institutions identified in this study include: requirement of boat, motor, and compressor ownership to obtain a permit; requirement of permit and quota to legally harvest clams; spatially specific harvest areas outlined in permit; legal minimum size (64mm) for clams harvested (SAGARPA 2015); requirement of permit to sell to restaurants; and prohibition of harvest during seasonal bans, or *vedas*. Informal institutions include: enforcement of permit and quota; harvest of medium to large clams; respect for others' harvest areas; rotation of harvest areas when clams become scarce or too small; harvest by free divers in shallow, nearshore waters, and harvest by hookah divers in deeper waters; subsistence harvest as a right of community members; free diving as the traditional and ecological harvest method; and seasonal fishing effort in accordance with environmental variability.

Table 5.1. Rules and norms governing fishing activities in the chocolate clam fishery, the effects of rules and norms, and sanctions for noncompliance. The symbol "*" indicates rules that are not often enforced.

	Rules and norms	Effect	Sanctions for noncompliance
Formal	Ownership of boat, motor, and compressor required to obtain permit	Expansion of hookah diving as harvest method; High barrier to entering the formal fishery; High number of fishers without permits	Permit not issued
	Permit required to legally harvest clams	Number of permits regulated	Monetary fine; Confiscation of fishing catch, equipment, and vehicle
	Quota required to legally harvest clams	Volume of catch regulated for permit holders	Monetary fine; Confiscation of fishing catch, equipment, and vehicle
	Area-specific permits	Spatially-defined harvest areas for permit holders	Harrassment; Verbal warning
	Legal minimum size limit	Fishers throw back small clams (<64mm)	Monetary fine*
	Only permit holders may sell to restaurants	Non-permit holders do not receive reliable, large orders; They sell directly to consumer	Monetary fines for fisher and restaurant
	Veda (Seasonal ban)	No harvest during ban	Monetary fine; Confiscation of fishing catch, equipment, and vehicle
Informal	Enforcement of permit and quota	Reduction in extralegal fishing close to towns	Harrassment, Verbal warning; Report to authorities
	Harvest only medium to large clams	Fishers throw back small clams	Harrassment; Social pressure
	Respect other fishers' harvest areas	Fishers generally stick to their own clam banks	Harrassment; Verbal warning
	Rotation of harvest sites	Fishers rotate harvest areas when clams become scarce or appear too small	Social pressure
	Free divers harvest in shallow, nearshore waters; Hookah divers harvest in deeper waters further off the coast	Spatially distinct fishing areas for free divers and hookah divers	Social pressure; Verbal warning
	Subsistence harvest is a traditional right of community members	Unreported, small harvests of clams from nearshore waters are common	Occasional verbal conflict
	Free diving is the traditional and ecological method of harvest	High number of fishers who prefer free diving as a harvest method	Occasional verbal conflict
	Seasonal fishing effort	Lower fishing effort during spawning	Little to none

Effects on fishing practices

The requirement of ownership of boat, motor, and compressor to obtain a permit, together with the requirement of a permit and quota to legally harvest chocolate clams has resulted in regulation by fishing authorities of the number of permits issued and the volume of allowable catch harvested by permit holders. The equipment requirements have created a barrier to entry for the formal fishery, with the intent of allowing fishing authorities to regulate how and how much people fish. However, the equipment requirement has also resulted in the expansion of hookah diving as a method of harvest for chocolate clams. At the same time, the high barrier to entry of the formal fishery has created a high number of non-permit-holding clam fishers, thereby reducing the authorities' ability to track who is catching what and where, since unpermitted harvest is both unregulated and unreported.

Area-specific permits have resulted in the spatial distribution of harvest activities throughout Loreto Bay National Park, and the minimum legal size restricts harvest to clams larger than 64mm in length. Formal institutions also affect total fishing effort of permit- and non-permit-holding fishers. Only permit-holding fishers may legally sell their catch, and local restaurants, the biggest buyers of chocolate clams, must require fishers to show their permits prior to making a sale. The inability to sell to restaurants has led to lower and less reliable orders for non-permit-holding fishers, and thus, fishing effort that is lower and temporally variable. Formal institutions also enact seasonal bans, or *vedas*, which result in total prohibition of harvest during a designated time period, usually for one to two months in both the spring and fall.

The informal enforcement of permit and quota has led to a reduction in extralegal fishing close to towns, with many non-permit-holding fishers traveling to remote beaches where the risk of vigilance is low. Informal rules also encourage minimum size restrictions on clams harvested, and respect for other fishers' harvest areas. These rules result in fishers throwing back smaller clams from their harvests, and generally sticking to their own clam bank, whether an area close to their home, or one where they have a history of harvest. Local vigilance of one's own clam bank further enforces this informal rule. The understanding that free divers harvest in shallow, nearshore waters, and hookah divers harvest in deeper waters further from shore, is an informal norm that is widely understood among harvesters. When followed, this norm results in spatial separation of the two harvest methodologies, and in general, spatial variability in fishing activities and effort.

Unreported, small harvests of clams from nearshore waters are common, and are a result of an informal norm that subsistence harvest is a traditional right of community members. These small harvests are less common during formal *vedas*, because the sale of fresh clams is conspicuous and more likely to draw the attention of authorities. A related norm dictates that free diving is a traditional, low impact alternative to hookah diving, and is ecologically preferable. Fishers whose primary method of harvest is hookah diving collect, on average, almost seven times more clams her harvest day than do fishers who free dive (Pellowe and Leslie n.d.). Many fishers have a personal preference for free diving as a harvest method, refuse to hookah dive for chocolate clams, and engage in extralegal harvest in keeping with the informal norm that free diving is a more sustainable method of harvest. Finally, fishers also reduce their fishing effort seasonally when they notice clams spawning, resulting in lower fishing effort during spawning periods, which coincide with formal *vedas*.

Institutional overlap

I found that formal and informal institutions overlap in several aspects, including in the enforcement of permit and quota, compliance with area-specific harvest, minimum size, and seasonal harvest. Formal fisheries regulations require a permit and quota to harvest chocolate clams, and compliance is enforced through formal vigilance by fisheries authorities and informal vigilance by fishers on other fishers. Fisheries and marine park officials conduct routine monitoring of harvest activities, which includes approaching fishers and requesting their permit to verify that they are in compliance with formal rules and regulations. Similarly, fishers participate in informal vigilance in which they monitor the activities of other fishers, and harass, verbally warn, and sometimes report rule breakers to authorities. In their mutual enforcement of permit and quota, formal and informal institutions reinforce one another, and impose sanctions on those who participate in extralegal harvest of chocolate clams.

Permits for harvesting chocolate clams are spatially explicit, outlining which clam banks the permit holder can harvest. This formal rule is upheld by the informal rule of respect for other fishers' harvest areas. Although fishers also engage in rotation of harvest sites, I find that they often maintain a preferred set of clam banks, and rotate harvest sites within these banks. Preferred clam banks are often ones in which the fisher has both experience and ecological knowledge of clam populations. In the case of permit-holding fishers, these banks are also ones from which their permit allows them to harvest. Formal and informal institutions also overlap in terms of size limits on harvestable clams. Both formal rules and informal norms related to clam size encourage taking only medium to large clams, and leaving small clams in place. Informally, the distinction in size classes is subjective, and is sometimes measured by the number of clams a fisher can fit in his hand. For example, I have observed fishers explaining that three clams in the hand is the minimum size of clams that should be harvested. If four or more clams can fit in the hand, the clams are too small and should not be taken. The formal fishery has a minimum legal size of 64mm in length (SAGARPA 2015), which roughly coincides with the informal measure described above. Any clams smaller than this minimum legal size may not be harvested. Both formal and informal rules dictate that clams smaller than the acceptable minimum size should be tossed back into the water. The informal norm of fishers rotating harvest sites when clams become scarce or too small, indirectly supports the preferential harvest of larger clams, and thus, the minimum legal size.

Another area in which there is overlap between formal and informal institutions is in the seasonality of harvest. Seasonal bans, known as *vedas*, are formally-imposed regulations delineating periods of time during which no clam harvest is allowed in Loreto Bay National Park. Similarly, informal norms discourage harvest of clams during spawning times. Fishers recognize spawning when they see clams releasing a milky substance into the water. During these times, harvest is discouraged. This informal norm pre-dates and overlaps with the formal imposition of seasonal (spring or fall) bans, which are designed to occur during the period of clam spawning.

Institutional conflict

I found direct conflict between the requirement of permit and quota to harvest chocolate clams, both formal and informally enforced, and the informal norm of subsistence harvest as a traditional right of community members. The former has resulted in the regulation of the number of permits and catch volume of permit holders, and its enforcement via both formal and informal monitoring. These formal rules have reduced extralegal fishing activities, at least visibly and close to towns. Meanwhile, the local norm that chocolate clams are a community resource and that harvesting them is a traditional right, has made small harvests by individuals for personal or familial consumption common. Consequently, the recent loss of access to such small harvests by those who do not hold permits has led to division among community members as well as between some community members and fisheries authorities. Discontent surrounding loss of the right to harvest chocolate clams via free diving for personal consumption under the *usos y costumbres* clause compounds some fishers' unwillingness to conform to formal fisheries regulations. Further, the informal norm of free diving as a traditional and ecological method of harvest is in direct conflict with the equipment requirements of obtaining a permit. Meant to create a barrier to entering the formal fishery, the equipment requirements have resulted in many fishers continuing to harvest clams extralegally, while being unable or unwilling to obtain the equipment required for a permit.

Discussion

Both formal and informal institutions shape fishing practices in the chocolate clam fishery of Loreto Bay National Park, Mexico. These have diverse effects on fishing activities, and produce a complex matrix of institutional arrangements that shape the decisions of clam fishers on a daily basis. Among institutions, I found several instances where different institutions reinforce one another. However, tensions between formal and informal institutions threaten the capacity for collaborative governance. Institutional conflicts are the result of incongruences between the objectives of formal fishing authorities and the local ecological knowledge and traditions of resource users. A lack of attention to the social context of fisheries SESs can lead to resource management that ignores local norms, rules, and values (Cleaver 2002). Failing to account for local norms and values in formal governance can lead to noncompliance with formal regulations and in many cases, higher rates of exploitation than desired or anticipated (McClanahan et al. 2006, Cinner and Aswani 2007). I argue that greater community participation in marine resource management, together with the development of participatory, adaptive, and multilevel governance of chocolate clams and other marine resources, is necessary to account for local ecological knowledge, and to sustain small-scale fisheries and the communities reliant on them in Loreto Bay National Park.

Formal and informal institutions coexist and shape fishing practices in small-scale fisheries in Baja California Sur (Basurto 2005, Cinti et al. 2014), and elsewhere around the world. They are equally likely to contribute to the sustainability or collapse of natural resources, and understanding both types, as well as their interplay, is crucial for the design of effective and appropriate resource management (Agrawal and Gibson 1999). In addition to merely identifying the types of institutions operating within a system, their content and effect, as well as their social context, are necessary pieces of information to understand how formal and informal institutions interact (Cleaver 2002, Chuenpagdee and Jentoft 2007). Even where there are apparent conflicts between formal and informal institutions, coordination is possible and necessary for effective co-management (Etiegni et al. 2017). Co-management is the formal sharing of power and responsibility between government authorities and local resource users (Carlsson and Berkes 2005, Berkes 2009).

I found several overlaps between informal and formal institutions governing harvest of chocolate clams in Loreto Bay National Park. Currently, these institutions, including monitoring efforts by both fisheries officials and fishers themselves, are not coordinated. They represent independent efforts to monitor the same fishing activities for the same types of rule-breaking behavior and carry sanctions that are different, but often linked. Informally, rule-breaking behavior (e.g., harvesting clams without a permit or harvesting from another's clam bank) results in harassment and verbal warnings. However, if rule-breaking behavior continues and includes the violation of formal rules, fishers engaging in informal monitoring will report the offender to fisheries authorities, resulting in formal sanctioning, such as fines and confiscation of fishing equipment. Informal sanctioning of rule-breaking behavior usually flows in the direction of permit-holder to non-permit-holder. The success of institutions depends on the existence of mechanisms to monitor and enforce rules at the local level (Ostrom 1990, Dietz et al. 2003). Local-scale monitoring of fishing activities is already happening in Loreto Bay National Park, however, coordination with formal monitoring efforts is lacking. The development of mechanisms to link these disparate monitoring activities is key to effective enforcement of common-pool resource rules (Dietz et al. 2003), and could be a step towards participatory and polycentric management.

Formal and informal institutions also correspond in that they both encourage spatially explicit harvest, and the harvest of only medium to large clams. Area-specific permits issued by the fishing authority CONAPESCA, together with a social norm of respect for others' fishing areas, create spatial distribution of fishing effort throughout Loreto Bay National Park, diffusing fishing effort across the bay, and reducing the likelihood of overexploitation in specific clam banks. The minimum legal size set by CONAPESCA also corresponds with the informal norm that small clams should not be harvested. While operationalization of a minimum size differs between formal and informal institutions, their impacts on fishing activities are mutually supportive. Formal coordination between state-level fishing authorities and local clam fishers would result in multi-level governance that takes advantage of pre-existing local institutions to further the objectives of both state agencies and local resource users. Achieving this, however, demands the formal sharing of decision-making authority and responsibility, and a fundamental shift in the balance of power between the state and local stakeholders.

In addition to these potential avenues for coordination, there is also conflict between state-level fishing regulations and the local norms surrounding chocolate clam harvest. Formal, state-level institutions issue permits and quotas for chocolate clams and determine who can legally fish, and when, where, and how much they can harvest. They also outline sanctions for rule breaking, which include fines and confiscation of equipment. These sanctions deter many non-permit-holding fishers from engaging in harvest of chocolate clams, at least close to towns where the risk of both formal and informal monitoring is higher. The high costs of the equipment required to obtain a permit have created a barrier to entry for the formal fishery, allowing fishing authorities to regulate the number of users and catch volumes. But, the equipment requirement has resulted in the expansion of hookah diving, which, as a fishing method, is significantly higher impact in terms of the number of chocolate clams that can be harvested per fishing day, compared to the traditional method of free diving (Pellowe and Leslie n.d.). In addition to the expense of the equipment and permit needed to harvest chocolate clams legally, the loss of community members' access to chocolate clams as a subsistence resource via the removal of the local *usos y costumbres* clause, has resulted in a high number of clam fishers engaging in extralegal fishing practices, with catch that is unreported.

Noncompliance with formal regulations does not mean that fishing activities are unregulated, however (Ostrom 2000, Etiegni et al. 2017). In other fisheries contexts where there is low compliance among fishers with formal regulations, informal set of rules and social norms, often based on fishers' local ecological knowledge and experience, govern fishing practices (Etiegni et al. 2017). A social norm in Loreto Bay National Park dictates that chocolate clams are a public resource and should be accessible to all community members. Many fishers also believe that free diving, as the traditional method, is a better way to harvest chocolate clams and has lower impacts on chocolate clam populations. These norms are in direct conflict with formal rules and regulations. Feelings of discontent with chocolate clam management, and the desire for diverse community participation in decision-making processes, are widespread among community members in the region (Pellowe and Leslie n.d.). Community participation is critical for effective fisheries management (Coffey 2005). A lack of fisher participation in management decision-making processes leads to reduced acceptance of rules and regulations, with negative consequences for the sustainability of target species populations (Pita et al. 2012).

Addressing these issues, and building the foundation for participatory, adaptive, multi-level management in Loreto Bay National Park, is crucial for fisheries governance that protects the benefits provided by chocolate clams to local communities, but will not be without its challenges. Norms can play a powerful role in fostering collective action among resource users (Ostrom 2000, 2005, Ehrlich and Levin 2005, Nyborg et al. 2016). However, when heterogeneous and divergent norms exist within the same community, as is the case in the Mexican chocolate clam fishery, collective action may be harder to achieve. When the community of resource users is heterogeneous, observes different and conflicting institutions, processes for coordinated community participation in management require careful attention to, and processes for ensuring a balance of power not only between government agencies and fishers, but also among fishers themselves. Ideally, co-management redistributes power from government agencies to the community of resource users. However, Bené and colleagues (Béné et al. 2009) found that, in practice, co-management can lead to a redistribution of power that privileges certain actors over others, allowing them to advance their own agendas at the expense of the majority of fishers, often the most vulnerable. Co-management provides resource users with a greater say in resource allocation, and the wealthy are better positioned to take advantage of these opportunities. Thus, co-management, if not implemented carefully, can lead to greater inequity by creating opportunities for local elites to control resources (Béné et al. 2009). Managers must make sure that space is created for all resource users, including the poor and vulnerable, to access the benefits and rights associated with co-management, and to demonstrate their agency and share power.

Conclusions

Systems of rules governing use of commons resources are crucial to the long-term delivery of services to human communities (Ostrom 1990), and understanding the institutions that shape fishing practices helps elucidate the structure and dynamics of the fishery SES. Knowing how both formal and informal institutions affect fishing practices and interact with one another in Loreto Bay National Park's chocolate clams fishery is invaluable for informing resource management of this species, and protecting the immense cultural and economic values it provides to communities in this region (Pellowe and Leslie n.d.). Multi-level, polycentric governance with an emphasis on learning and knowledge sharing and development, can lead to effective management of marine fisheries when combined with community participation (Wilson 2017), such as in co-management. In co-management, power is formally shared among a centralized government and fishing communities, and includes allocation of rights that determine who can make decisions about resource use (Pinkerton et al. 2014). In the study region, the current disenfranchisement of many chocolate clam harvesters and other community members decreases the likelihood of cooperation and reduces adherence to formal fisheries rules. Collaboratively defined institutions are urgently needed in the Loreto Bay National Park region, in order to increase community and fisher buy-in of fisheries management institutions. Governance challenges in fisheries, like those seen in the Loreto region, can be lessened by explicitly identifying, understanding, and incorporating local stakeholder values into the policy process (Song et al. 2013).

Achieving polycentric co-management in Loreto Bay National Park will not be possible without changes in state-level fisheries regulations that make possible the formal sharing of decision-making power and monitoring and enforcement responsibilities between state fishing institutions and local fishers. It will be especially important to include those fishers who are currently excluded from the formal fishery due to the high financial barriers to entry. Increased community participation in management could pave the way for the formal and informal institutions that govern fishing practices in the chocolate clam fishery, to coordinate efforts, compromise, and find common ground in management that meets the objectives of fisheries agencies, as well as the fishers directly impacted by fisheries policy. An example of a management policy that represents common ground between formal and informal institutions is the creation of a formal avenue whereby fishers who choose to free dive can obtain a permit to harvest chocolate clams without owning hookah equipment. An understanding of the diverse institutions shaping small-scale fisheries, their effects on fishing practice, their interactions, and the cultural contexts in which they operate, is an essential step in informing community-based resource management that is collaborative, polycentric, and suited to adapt to the challenges of a changing world.

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CHAPTER 6

CONCLUSION

Understanding resilience in social-ecological systems

Studying complex, adaptive social-ecological systems (SESs), and identifying sources of resilience, is key to sustaining the many benefits these systems provide to communities around the world. There is no universal set of criteria for assessing resilience in SES, however, many scholars have identified system characteristics that foster general resilience. General resilience is the capacity to withstand a variety of known and novel stressors (Folke et al. 2010, Berkes and Ross 2013). Resilient SESs are characterized by diversity and redundancy (Folke et al. 2004, Chapin et al. 2009), connectivity (Biggs et al. 2015), attention to slow variables and feedbacks (Carpenter et al. 2001), social capital (Adger et al. 2005), multilevel governance (Adger et al. 2005), and institutional learning (Biggs et al. 2015). Heterogeneity underpins many of the features that characterize resilient systems.

Through my interdisciplinary approach, I find that the Mexican chocolate clam fishery of Loreto, Baja California Sur, Mexico is shaped by various forms of heterogeneity within the environmental, social, and institutional realms. The fishery for the Mexican chocolate clam is size selective; a minimum legal size of 64mm in length, together with local norms that favor larger clams, and market demand, result in the preferential harvest of clams larger than about 60mm in length. The size selectivity of the fishery affects fisheries and economic yield, as well as the reproductive capacity of the clam population. These, in turn affect the future provision of a variety of benefits, or ecosystem services, that the clam provides to communities in the Loreto region. The Mexican chocolate clam delivers a diversity of ecosystem services to the local community, ranging from food, income, and tourism to aesthetic beauty and community identity. Many diverse stakeholders are affected by changes in clam availability and abundance, particularly those who are directly involved in harvest. Multiple types of fishers are involved in the Mexican chocolate clam fishery, and individual variability among fishers affects fishing decisions and the adaptive strategies that fishers use to cope with changing ecological and economic conditions. Individual heterogeneity among fishers leads to differences in fishers' individual adaptive capacity. Current fisheries management supports the needs and adaptive capacities of some fishers, but excludes others. In addition, fishers' daily fishing decisions are shaped by a complex web of formal and informal institutions. Many of these institutions bolster one another and lead to similar outcomes for fishing behavior, however, others are in direct conflict. Reconciling these tensions requires formal mechanisms for coordination and conflict resolution that would enhance the ability of management to sustain the Mexican chocolate clam fishery.

A more complete understanding of sources of heterogeneity, and the impacts of such variability on fishery and community outcomes in small-scale fisheries, like the Mexican chocolate clam fishery, is critical for the design of future management that supports resilience and adaptive capacity. In this dissertation, I have described several complementary studies of social-ecological variability, insights into the current state of system resilience, and avenues whereby management could better support and enhance the resilience and adaptive capacity of the SES associated with the Mexican chocolate clam fishery in Loreto. A better understanding of the links between heterogeneity and resilience in the fishery will contribute to management that protects and supports the continued delivery of the many economic and socio-cultural values that Mexican chocolate clams provide in the Loreto region. The suite of studies I employ in this dissertation also provide a guide for operationalizing interdisciplinary studies of social-ecological systems to better understand their resilience.

Complexity of human-nature interactions

People's interactions with marine ecosystems are more diverse, deep, and complex than is captured by most fisheries management. Fisheries management has improved in its ability to account for ecological variability, but its capacity to assess and integrate social variability into management is lacking (St. Martin et al. 2007). Fisheries provide numerous benefits to coastal communities, including provisioning services such as food and income, as well as a host of cultural services including historic value, recreation, and community identity. Protecting these benefits through management that matches local conditions requires SES research that account for both ecological and social complexity.

"Complex adaptive systems [...] are composed of elements, called agents, that learn or adapt in response to interactions with other agents" (Holland 2014:24). Agents can be humans, fish, or any other entity capable of making choices or responding to its environment (Wilson 2017). Small-scale fisheries can be considered complex adaptive SESs because of their emergent dynamics and the types of problems they present (Folke et al. 2005, Gelcich et al. 2010). Attention to slow variables and feedbacks is a necessary for understanding and predicting the dynamics of complex adaptive systems, and is a key characteristic of resilient SESs (Carpenter et al. 2001). Fisheries are shaped by processes occurring in the ecological and social realms. Therefore, fisheries management that fails to account for the social context of fisheries SESs can lead to resource management that ignores local norms, rules, and values (Cleaver 2002), and inadequately accounts for the slow variables and feedbacks that shape long-term outcomes.

How people fish matters

Social-ecological variability, including size-selective fishing, impacts the spatial and temporal distribution of fished species and the values they provide to coastal communities. Most fisheries are inherently size-selective in that fishers preferentially harvest a subset of the population, most often the largest individuals. Size selective fishing affects target species by altering the reproductive capacity of the population. Harvesting fish before they mature is a precursor to overexploitation (Salas et al. 2007), and preferential harvest of large individuals can lead to evolutionary changes including smaller maximum body size and smaller size at maturity (Baskett et al. 2005, Fenberg and Roy 2008). Understanding how social-ecological variability including size selectivity affects target species populations is critical for fisheries management to optimize the economic and livelihood benefits of fisheries, with the reproductive capacity of target stocks.

Fishers of the Mexican chocolate clam preferentially harvest medium to large individuals. Using fisheries models developed from my empirical field work in Loreto, I find that how people fish matters, perhaps as much as the quantity of fish harvested. Size-selective fishing that aligns with the life history of target populations and stakeholders' goals is critical to sustaining fisheries and the valuable food and livelihoods they provide. Slot limits, or rules related to the minimum and maximum sizes of individuals that may be harvested, lend themselves particularly well to data-limited fishery management, since expanding or decreasing the range of sizes available to harvest has predictable outcomes. Lowering the minimum size will generally lead to higher fishery yield, and lower reproductive potential of the target population. Implementing a maximum size limit will generally increase the population's reproductive potential, and while short-term fishery yield will decrease, high population abundance over time means that the fishery will be able to sustain higher levels of fishing effort long term. Thus, a precautionary approach to management for a data-limited fishery that requires a more restrictive, or narrower, range of sizes subject to harvest, will result in the best long-term sustainability outcomes.

Knowledge of the distribution and life history characteristics of fished taxa, and how fishing activities influence population dynamics, is foundational to marine resource management. I also acknowledge the tension between the widespread use of stock assessment methods in developed nations, and the historical and ongoing data collection required for such methods. The resources required for such data collection do not exist for many fisheries around the world, including many fisheries in Baja California Sur. Approaches to assessing data-limited fisheries include assessment of trends from fisheries-dependent data (Hordyk et al. 2015b), and extrapolation from similar species (Honey et al. 2010). Since there is inherent uncertainty in data-limited approaches, a precautionary approach must be taken (Pilling et al. 2008). My core finding— that slot limits are useful management tools for meeting fishery and ecological goals, and that they contain inherent tradeoffs – can be applied broadly in data-limited scenarios. When size selectivity is aligned with the biological characteristics of fished populations, it can lead to sustainable fisheries and a reliable source of food and livelihoods (Reddy et al. 2013). A precautionary approach that directs social-ecological variability using slot limits will result in sustainable fishing, and enhance SES resilience by safeguarding target populations and the valuable services they provide.

Diverse community values

Ecosystem services reflect the economic, social, cultural, and use values an ecosystem provides to people, and are often assessed using economic valuation techniques (Daily et al. 2000, Turner and Daily 2008). Economic approaches have been useful in integrating ecosystem-related values into decision making, yet they fail to encompass dimensions of value that cannot be quantified in economic terms, including many cultural and non-use values (Chan et al. 2011, 2012). A full consideration of the values associated with ecosystem services will better equip managers of marine ecosystems to address the needs and perspectives of diverse stakeholders (Chan et al. 2012). Managing for a diverse set of ecosystem services can also result in SESs that are resilient to a variety of unexpected changes, i.e., SESs with high general resilience. Resource management with an overly-narrow focus on a few ecosystem services can miss important changes in other services that signal a loss of system resilience. This can result in unexpected regime shifts and sudden losses of other ecosystem services (Gordon et al. 2008, Bennett et al. 2009). Thus, cataloguing the complete suite of values marine ecosystems produce is an essential step in managing for resilience. Meeting the challenge of fisheries management requires moving beyond assessments of environmental variables and species interactions to develop a better understanding of sociocultural values and local knowledge of coastal communities and fishers (St. Martin et al. 2007).

Using household surveys, I assessed the range of both provisioning and cultural values that households in Loreto receive from Mexican chocolate clams. I also explored how management might better account for the diverse values the species provides to stakeholders and enhance community resilience. I found wide recognition among survey participants of the community value of Mexican chocolate clams. The ecosystem services I assessed related to community benefits, including general importance, economic, life sustaining, future use, and identity values, all had higher average rates of agreement among participants than did associated questions that asked about these values from the household perspective. Nearly all agreed that the clam provides immense economic value to the community, and that Mexican chocolate clams are an important part of what it means to be a member of the Loreto community.

Considering the suite of cultural ecosystem services the clam provides to Loreto households, and its contribution to local identity, the Mexican chocolate clam may be considered a cultural keystone species. Cultural keystone species are "culturally salient species that shape in a major way the cultural identity of a people" (Garibaldi and Turner 2004). Such species are defined by the key role they play in defining cultural identity, and are characterized by their high cultural significance. The conservation status of cultural keystone species may be a starting point for understanding community resilience to change (Garibaldi and Turner 2004). In Loreto, managing for Mexican chocolate clams' diverse values might include delineating protected areas of habitat, regulating water quality, and privileging low impact fishing practices, including the traditional free-diving method of harvesting Mexican chocolate clams, over the more intensive hookah compressor method. These practices would serve not only to conserve Mexican chocolate clams and the benefits they provide to Loreto households, but would also benefit other marine species in Loreto Bay National Park's waters. Acknowledging and understanding system heterogeneity, by cataloguing the full suite of ecosystem services provided by species like the Mexican chocolate clam, is a critical step in designing management that supports and enhances the resilience of fisheries-associated SESs in a changing world.

Diverse fishers and individual adaptive capacity

Fishers are adept at solving problems and adapting to the inherent variability of the marine environment in which they work (Acheson 1981). The variability fishers commonly experience is due to changes in environmental and biological processes, as well as market dynamics and demand (Adger 2000, Crona et al. 2015). Fishers around the world employ a range of strategies to adapt to the inherent variability of their work. These adaptive strategies include using multiple harvest methods, altering the spatial distribution of their fishing effort by rotating harvest sites, maintaining alternate sources of income via both fisheries and livelihood portfolio diversity, and redistributing effort among the fisheries in which they participate (Fuller et al. 2017). Fishers also rely on social networks during times of scarcity (Löfgren 1972), move to other locations to follow sources of income (Sievanen 2014), and engage in proactive approaches to seed or encourage the growth and survival of desirable species (Boag et al. 2018). Understanding how individuals make decisions, and what options they have for responding to changing conditions is critical for understanding individual resilience (Coulthard and Britton 2015). Limits to individual agency affect not only how fishers interact with their resources, and the adaptation strategies they adopt, but also the success of local resource management (Bennett et al. 2018), and thus, SES-scale resilience.

The Mexican chocolate clam provides a multitude of benefits to communities in the Loreto region, and is harvested by a diverse group of fishers. Understanding the full spectrum of fishers, their decision-making processes, and adaptive strategies is essential both for anticipating fishery outcomes and predicting the capacity of different types of fishers to adapt to future environmental and economic change. Through semi-structured interviews with clam harvesters in this region, I find that fishers of Mexican chocolate clams operate within both the formal and informal sectors, have varied fishing strategies, and can be characterized into four discrete types: 1) *libres*, non-permit-holding, free-diving fishers; 2) *buzos de compresor*, permit-holding, hookah-diving fishers; 3) *permisionarios libres*, permit-holding, free-diving fishers; and 4) *contratados*, non-permit-holding, hookah diving fishers who contract their skills to permit holders. I found differences in the adaptive strategies used by fishers of these different types.

The Mexican chocolate clam fishers I interviewed actively employ adaptive strategies, and make fishing and livelihood decisions in response to changing conditions. Fisher type is in many cases related to fishers' access to financial resources, influencing and potentially limiting the adaptive strategies they engage in. While informal fishers engage in almost as many adaptive strategies as formal fishers, the strategies they employ generally require less input of financial capital. Informal fishers obtain higher percentages of their total income from Mexican chocolate clam fishing than formal fishers, yet they are subject to highly variable demand, lower prices, and due to the low impact fishing method they use, have lower daily harvests. Informal fishers are thus particularly vulnerable to the environmental and economic variability inherent in the fishery. They often lack the resources to obtain permits, are excluded from fishery decision-making processes, and are subject to costly sanctions for fishing without a permit. Such fishers are keenly aware of changes in Mexican chocolate clam populations and worry about how increased use of hookah diving will affect clams and their own livelihoods.

The formal acknowledgement of diverse fisher types would decrease illegal fishing, improve catch reporting, and lead to better data for fisheries managers to assign quotas that accurately account for current fishing effort. The creation of new avenues for entering the legal fishery and reporting catch, particularly for those fishers who cannot afford or prefer not to use hookah equipment, would also enhance social capital, a key component of resilient SESs, and result in management that better matches the social landscape of the fishery. Maintaining a diverse suite of adaptive strategies is essential for individuals to cope in the face of future disturbance and change. Likewise, maintaining heterogeneity in the fishery, by ensuring multiple fisher types are equipped to adapt to future change, will strengthen adaptive capacity within the fishery and community, and enhance SES resilience.

Institutional coordination and pathways towards co-management

Systems of rules governing use of commons resources are crucial to the long-term delivery of services to human communities (Ostrom 1990), and understanding the institutions that shape fishing practices helps illuminate the structure and dynamics of fisheries-related SESs. Both formal and informal institutions shape fishing practices in the Mexican chocolate clam fishery of Loreto, Mexico. Combining five years of observations of fishing practices, ethnographic conversations with fishers, community members, and enforcement officials, and semi-structured interviews with fishers, I found that these institutions have diverse effects on fishing activities, and produce a complex matrix of institutional arrangements that shape the daily fishing decisions of clam harvesters. I found instances both of reinforcement among institutions, as well as institutional conflict. Conflicts were the result of incongruences between the objectives of formal fishing authorities and the local ecological knowledge and traditions of resource users. A lack of attention to local norms and values in the design of common-pool resource governance can lead to noncompliance with formal regulations and higher rates of exploitation than desired or anticipated (McClanahan et al. 2006, Cinner and Aswani 2007).

Multi-level, polycentric governance with an emphasis on learning and knowledge sharing and development, can lead to effective management of marine fisheries when combined with community participation (Wilson 2017), such as in co-management. In co-management, power is formally shared among a centralized government and fishing communities, and includes allocation of rights that determine who can make decisions about resource use (Pinkerton et al. 2014). In the Loreto region, the current disenfranchisement of many clam harvesters and other community members decreases the likelihood of cooperation and reduces fishers’ adherence to formal rules and regulations. Collaboratively defined institutions are urgently needed in the Loreto region, and would help increase community and fisher trust in fisheries management institutions. Governance challenges in fisheries, like those seen in

Loreto's Mexican chocolate clam fishery, could be lessened by explicitly identifying, understanding, and incorporating local stakeholder values into the policy process (Song et al. 2013).

Achieving polycentric co-management in Loreto will not be possible without the addition of state-level fisheries regulations that enable the sharing of decision-making power and monitoring and enforcement responsibilities between state fishery institutions and local fishers. Inclusion of those fishers currently excluded from the formal fishery will be particularly important for aligning formal and informal institutions. Increased community participation in management could pave the way for formal and informal institutions to coordinate efforts, compromise, and find common ground in management that meets the objectives of both fisheries agencies and the fishers directly impacted by policy. A potential management policy that would represent common ground between formal and informal institutions is the creation of formal avenues for free diving fishers to obtain a permit to harvest Mexican chocolate clams without owning hookah equipment. Gaining an understanding of the diverse institutions shaping small-scale fisheries, their effects on fishing practice, their interactions, and the cultural contexts in which they operate, is an essential step in informing community-based resource management that is collaborative, polycentric, and suited to adapt to the challenges of a changing world.

Coordination between informal and formal institutions and the creation of polycentric co-management would also result in increased social capital and institutional learning, two features of resilient SESs. Such coordination would create institutions that are better equipped to learn and adapt to changing economic and ecological conditions. A system like co-management, by sharing of decision-making and enforcement power between fisheries authorities and local stakeholders (Carlsson and Berkes 2005, Berkes 2009), increases social capital, which further facilitates learning, and contributes to collective action (Ostrom 2000). Social capital is strengthened by diverse stakeholder participation in decision-making processes, and by the empowerment of local actors to manage their own resources.

Social capital is critical in times of change, as it facilitates communication among stakeholders that enables them to exchange information and make decisions about how best to respond to change. Heterogeneity within institutions can enhance SES resilience by providing multiple ways of responding to change, and by creating redundancy that is essential for SES' ability to retain their structure and function in the face of disturbance. However, in order to ensure the continued delivery of common-pool resources and the values they provide to human communities, diverse institutions must work in tandem.

Heterogeneity shapes the Mexican chocolate clam fishery

Accounting for variability in multiple forms—among fishers and other local stakeholders, institutions, fished species, and environmental and market conditions—can increase understanding of SES resilience, and help SESs prepare for future disturbance and change. Considering how social-ecological variability shapes fishery economic and biological outcomes, and adapting fisheries management to protect the reproductive capacity of target populations and ensure future abundance, can lead to sustainable fishing practices and increased SES resilience, as I found in Chapter 2. Taking account of the diverse ecosystem services fished species provide, including, in particular, sociocultural and community values that are often unaccounted-for when considering the benefits of fisheries, can help inform management that fosters general resilience and is robust to a diversity of stressors. Fished species can also contribute to local community identity, a value that has immense importance for community sense of place, and for shaping human-nature interactions, as I found in Chapter 3. Individual actors have a key role to play in determining system-level resilience outcomes. The maintenance of a diverse set of livelihood strategies increases fishers' individual capacities to adapt to economic and environmental change, however not all fishers are equally as positioned to adopt adaptive strategies. Encouraging diversity among actors, and supporting diverse actors' abilities to adapt in response to change, is important for enhancing SES-scale adaptive capacity and resilience, as I found in Chapter 4. Supporting resilience in the Mexican chocolate clam fishery requires management that explicitly accounts for and encourages heterogeneity, while understanding that certain types of heterogeneity, i.e., multiple, diverse institutions, require coordination to ensure the best outcomes for ecosystems and people, as I found in Chapter 5.

People's interactions with small-scale fisheries are far more diverse, deep, and complex than is captured by traditional fisheries management. Uncovering the social richness of fisheries, and considering informal aspects of fisheries by including fishers engaged in the informal sector, as well as the informal rules and norms shaping fishing practices, is necessary to reveal the richness of human-nature interactions that shape individual and fishery resilience. In addition to revealing how various forms of heterogeneity can be managed to enhance individual and SES resilience, my complementary studies also expose additional paths whereby other characteristics of resilience could be bolstered and enhanced in Loreto's Mexican chocolate clam fishery, including social capital and institutional learning. Improving the fit of fisheries management to the social-ecological context of small-scale fisheries requires acknowledgement of the depth and complexity of people's interactions with marine ecosystems. My interdisciplinary approach reveals how studying environmental, social, and institutional heterogeneity, and reimagining fisheries management to account for such variability, can help ensure the continued delivery of the diverse benefits that small-scale fisheries, like the Mexican chocolate clam fishery, provide to coastal communities like Loreto.

Future research

This dissertation, and the suite of interdisciplinary studies I employed, are an example of how the SES framework (Ostrom 2009) can be used to operationalize studies of social-ecological systems to better understand their resilience. The findings of this work point to the importance of including the social and institutional realms, in addition to the ecological, when studying fisheries dynamics, and devising future management. Resolving tensions between different types of knowledge is an ongoing issue in interdisciplinary studies, and will require careful attention to definitions of resilience in various contexts. Future work that explicitly accounts for the historic, economic, and political contexts of small-scale fisheries would expand on the work developed in this dissertation and capture additional depth and complexity in the human-nature relationships shaping fisheries SESs (Sáenz-Arroyo et al. 2005, González-Mon et al. 2019). Future studies focused on the role of small-scale fisheries and fished species in shaping individual and community identity will be important for advancing understandings of the depth of human connections to marine ecosystems, and for identifying the community impacts of common-pool resource management. Expanding studies of environmental, social, and institutional heterogeneity to include spatial and temporal analyses, would better account for the dynamism of small-scale fisheries, and contribute to the identification and understanding of slow variables and feedbacks. An understanding of slow variables and feedbacks are critical to the management of complex, adaptive systems like small-scale fisheries, and their inclusion in future analyses of the type described in this dissertation, would enable better predictions of how SESs will be affected by future change and disturbance.

There is also a need to better understand how micro-level processes, including the individual decisions of fishers and the ability of fishers to access permits, affect macro-level outcomes at the fishery scale, such as target species abundance and total fishing effort. Integrating empirical data from field studies into computer models, like agent-based models (Helbing and Balietti 2015), can help identify how micro- and macro-level processes are linked, and would provide important insights into the relationship between individual and system resilience. Parameterizing agent-based models with empirical data would contribute to a more comprehensive study of small-scale fishery resilience that acknowledges the nested and multi-level nature of complex adaptive SESs. Modeling that integrates the types of interdisciplinary data collected in this dissertation would also permit the exploration of causal relationships shaping SESs dynamics. These are themes I plan to explore in my future research.

Concluding thoughts

The study of social-ecological system dynamics requires an interdisciplinary approach that incorporates multiple, complementary studies that are each disciplinarily and theoretically rooted. Such work calls for multidisciplinary expertise, and collaboration and communication across disciplines. However, difficulties in communication between disciplines and among diverse actors creates challenges for information exchange, and can hinder decision-making processes (Dietz 2013, Partelow et al. 2019). This is a particular problem in conservation and sustainability science, where well-informed decisions must often be made quickly and efficiently (Bodin 2017). To facilitate the rapid and effective decision-making that is required in our changing world, there is a need for the next generation of conservation and sustainability scholars to have interdisciplinary training. This will facilitate communication and knowledge exchange, and allow scholars to integrate information from diverse disciplines into decisions that will shape the future of our world. In my own experience as an interdisciplinary conservation scientist, I have found that while it is at times challenging to reconcile the epistemologies of my ecological and sociological trainings, my interdisciplinary expertise has made me more attentive to the depth of interactions that shape and influence SESs, and has given me access to wider range of options for conceptualizing and approaching questions of sustainability.

Through the process of developing this dissertation, I have also found that creating fisheries management that enhances resilience and supports the continued delivery of valuable ecosystem services will require an interdisciplinary perspective that acknowledges the complexity of human-nature interactions. Research and management should also treat fisheries as the complex, adaptive systems they are, with an eye to uncertainty and emergent dynamics. With such an approach, conservation scientists like myself will be better able to engage with other scientists, policymakers, managers, and stakeholders, to share knowledge, make decisions, and design future management that supports and protects the abilities of fisheries SESs to continue providing the values on which so many rely.

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APPENDIX A: SEMI-STRUCTURED INTERVIEW INFORMED CONSENT FORM

Documento de consentimiento informado

Mi nombre es Kara Pellowe y soy una estudiante de la Universidad de Brown en los Estados Unidos. Estoy realizando un estudio sobre la pesca de la almeja chocolata. Quería hablar con usted para entender como los pescadores de almejas (almejeros) deciden pescar almejas, la cantidad de almejas que pescan, las otras especies que pescan además de almejas, y sus decisiones sobre los permisos de pesca.

La entrevista puede tardar 20-60 minutos. Después de la entrevista, voy a guardar la información en un lugar seguro para proteger su confidencialidad con todo el peso de la ley de los Estados Unidos. No grabaré ninguna información de identificación en la entrevista que permitiría a cualquier persona a enlazar su identidad con los datos compartidos en la entrevista.

Su participación es completamente voluntaria. Puede retirarse del estudio o parar la entrevista en cualquier momento, por cualquier razón. Con su permisión, la entrevista será audio-grabada.
Hay algunos riesgos de participación. Compartir información personal puede ser incómodo. Pescar sin permiso puede resultar en la perdida de propiedad personal o ingresos. Pero, las entrevistas serán anónimas y ninguna pieza de información identificable será grabada. Además, puede omitir cualquier pregunta o pedir que paremos el audio-grabado.

No hay beneficios directos para usted de participar en el estudio. Pero cuando el estudio se haya completado, le daré mapas temporadas mostrando los horarios y lugares donde la pesca de almejas es más alto.

Si da consentimiento a participar en este estudio, recibirá una copia de este documento de consentimiento para guardar.

Para más información sobre esta investigación o para cualquier pregunta, por favor, póngase en contacto con Kara Pellowe en kara_pellowe@brown.edu en cualquier momento, o por teléfono local

613.111.25.69 cuando estoy en México. También puede contactar a mi colega local, Hector Trinidad en el teléfono 613.121.10.34 o por correo en hector.trinidad@ecoalianzaloreto.net o a mi profesora la Doctora Heather Leslie en heather_leslie@brown.edu.

Si tiene alguna pregunta sobre sus derechos como participante, puede contactar la Oficina de Protecciones de Investigaciones de la Universidad de Brown en +001 401.863.30.60 o RPO@brown.edu.

APPENDIX B: SEMI-STRUCTURED INTERVIEW QUESTIONNAIRE

Número de entrevista:

Número para grupo:

El entrevistador ha leído el documento de consentimiento?

¿Está de acuerdo de participar?

¿Tiene 18 o más años?

1. ¿De dónde es usted, originalmente? ¿Por cuantos años ha vivido en Loreto?
2. ¿Cuántas personas hay en su casa? ¿Cuántos años tienen ellos? ¿Cuántos años tiene usted?
3. ¿Qué proporción de sus ingresos provienen de la pesca? ¿Qué otras fuentes de ingreso tiene?
4. ¿Qué proporción de sus ingresos provienen de la pesca de almejas chocolatas? Esto cambia por temporada?
5. ¿Pesca usted almejas chocolatas todo el año?
6. ¿Con qué frecuencia pesca usted chocolatas? (Diariamente, semanalmente, mensualmente, por temporada?)
7. ¿Ha notado usted alguna temporada de abundancia de chocolatas? ¿Cuáles meses han parecido tener la mayor abundancia de almejas chocolatas?
8. ¿Qué factores influyen la decisión de cuando y con que frecuencia va usted a pescar almejas chocolatas?
9. ¿Qué factores influyen la decisión de dónde va usted a buscar almejas chocolatas?
10. ¿Alterna usted los lugares donde pesca almejas? ¿Con qué frecuencia cambia de lugares o bancos? ¿Cómo decide cuando va a cambiar de banco?
11. ¿En cuáles bancos pesca almejas durante el año? En el último año, qué proporción de su tiempo pasó pescando almejas en cada banco? ¿Esto ha sido diferente en años previos? (Mostrar mapa)

12. ¿Aproximadamente cuantas almejas pesca usted en un viaje? ¿Esto cambia por banco? ¿Y por temporada?¿Puede estimar el total de chocolatas que pesca en un año?
13. ¿Cual es la metodología principal que utiliza usted para sacar almejas chocolatas (hookah, buceo libre, SCUBA, de la orilla)?
14. ¿Por qué utiliza esta metodología para pescar almejas?
15. ¿Piensa usted que su conocimiento de las almejas chocolatas afecta la manera en que las pesca? ¿Cómo? (metodología, temporada, zonas)
16. ¿Qué factores influyen su decisión de obtener o no obtener un permiso para pescar almejas chocolatas?
17. ¿Hay otras especies que pesca usted durante el año? ¿Cuales son?
18. ¿Qué estima usted que es la proporción de tiempo que pasó capturando cada especie en el último año? ¿Cambian las proporciones según la temporada? ¿Esto ha sido diferente en años previos? ¿Cómo?
19. ¿Ha cambiado la composición de especies desde que usted comenzó a pescar en Loreto?

APPENDIX C: HOUSEHOLD SURVEY INFORMED CONSENT FORM

Informed Consent Form—English

You are invited to participate in a research study conducted by Kara Pellowe, a doctoral student in the Ecology and Environmental Sciences Program at the University of Maine in Maine, USA. The faculty member overseeing this project is Dr. Heather Leslie, School of Marine Sciences, University of Maine. The purpose of this research is to understand how households in the Loreto Bay National Park region use and value chocolate clams. You must be at least 18 years of age to participate.

What Will You Be Asked to Do?

If you decide to participate, you will be asked to complete a survey that will take approximately 10-20 minutes. The survey will collect basic social and economic information about your household, and will ask about your household's use of chocolate clams. You will also be asked about the values chocolate clams provide to your household. If you prefer, the researcher can read the survey questions to you and record your responses.

Risks

Surveys will be confidential. Except for your time and inconvenience, there are no risks to you from participating in this study.

Benefits

There are no direct benefits to you for participating in the survey. However, this research may contribute to future management of chocolate clams that better accounts for and protects the values they provide to households in this region.

Confidentiality

Any information shared through this survey will be kept confidential. Paper copies of your responses will be destroyed in September 2019 after your answers are transferred to a password-protected computer, and these will be deleted in September 2020 after the study is complete.

Voluntary

Your participation is completely voluntary. If you choose to participate, you stop at any time, for any reason. You may skip any questions you do not wish to answer.

Contact Information

If you have any questions about this study, please contact Kara Pellowe at kara.pellowe@maine.edu or 613-118-38-27 (MEX). You may also reach the faculty advisor on this study, Dr. Heather Leslie at heather.leslie@maine.edu. For questions about your rights as a participant in this study, please contact the Office of Research Compliance, University of Maine, 207-581-1498 or 207-581-2657, umric@maine.edu.

Your verbal consent indicates you have read and understand this information and agree to participate in this study. If you agree to participate in this study, you will receive a copy of this consent document for you to keep.

Documento de consentimiento informado—Español

Le invito a participar en un estudio realizado por Kara Pellowe, una estudiante doctoral en el Programa de Ecología y Ciencias Ambientales a la Universidad de Maine en Maine, E.U. La profesora que supervisa este proyecto es Dra. Heather Leslie, Escuela de Ciencias Marinas, Universidad de Maine. El propósito de este estudio es entender como hogares en la región del Parque Nacional Bahía Loreto usan y valoran las almejas chocolatas. Debe tener 18 años o más para participar.

¿Qué se le pedirá que hagas?

Si decide participar, se le pedirá que complete una encuesta que duraría aproximadamente 10 a 20 minutos. La encuesta collectaría informacion social y económica sobre su hogar, y le preguntaría sobre su uso de las almejas chocolatas. La investigadora puede leerle las preguntas y escribir sus respuestas si prefiera.

Riesgos

Las encuestas son confidenciales. Salvo su tiempo e inconveniencia, no hay riesgos de participar en este estudio.

Beneficios

No hay beneficios directos a usted por participar en una encuesta. Sin embargo, este estudio podría contribuir al manejo futuro de las almejas y estadísticas para proteger los valores que proporcian ellas a la gente de esta region.

Confidencialidad

Cualquier información compartida será confidencial. Copias en papel de sus respuestas serán destruidas en septiembre 2019 (dos mil diecinueve) después de que sus respuestas sean transferidas a una computadora protegida con contraseña. Estas respuestas serán destruidas en septiembre 2020 (dos mil veinte) después del fin del estudio.

Voluntario

Su participación es totalmente voluntaria. Si decide a participar, puede parar en cualquier momento, por cualquier razón. También, puede omitir cualquier preguntas que no quiere contestar.

Información de contacto

Si tiene alguna pregunta sobre este estudio, por favor contacte a Kara Pellowe por email kara.pellowe@maine.edu o por teléfono 613-118-38-27 (MEX). También puede contactar a la profesora que supervisa el proyecto, Dra. Heather Leslie por heather.leslie@maine.edu. Para preguntas sobre sus derechos como participante en este estudio, contacte a la Oficina de Cumplimiento de Investigación, Universidad de Maine, 001-207-581-1498 o 001-207-581-2657, umric@maine.edu.

Su consentimiento verbal indica que usted ha leído y entendido esta información y está de acuerdo de participar en este estudio. Si está de acuerdo de participar, recibirá una copia de este documento de consentimiento para guardar.

APPENDIX D: HOUSEHOLD SURVEY QUESTIONNAIRE

Household Survey Questionnaire Bilingual

Do you have any questions about the study or the consent form before we begin?

¿Tiene algunas preguntas sobre el estudio o el documento de consentimiento antes de empezar?

Household socioeconomic characteristics / *Características socioeconómicas del hogar*

1. Location of household (town, neighborhood) / *Ubicación de hogar (pueblo o barrio)*

2. Size of household / *Cuántos habitantes hay en su hogar*

3. Ages of household members / *Edades de miembros de hogar*

1. Highest school grade level or degree achieved by household adults / *El grado de escuela o licenciatura más alta alcanzada de los adultos de hogar*

2. Employment status of household adults / *Estado de empleo de los adultos de hogar*

    Employed full-time / *Trabajo de tiempo completo*

    Employed part-time / *Trabajo temporal*

    Unemployed / *Desempleados*

3. Birthplaces of household adults / *Lugares de nacimiento de los adultos de hogar*

    a. How many years have you lived in this region? *Cuántos años ha vivido en esta región?*

4. Where did your household income come from in the past year? *¿De dónde vinieron sus ingresos de casa en el año pasado?*

    Primary income / *Empleo principal:*

    Amount per month and frequency / *Ingreso por mes y frequencia:*

    Additional sources / Ingresos adicional:

Current clam use / *Uso presente de almejas*

Answer for your entire household / *Conteste para toda su casa*

1. How frequently does a member of your household collect/harvest chocolate clams? *¿Con qué frecuencia colectan o sacan almejas chocolatas?*

    ____x per year / *por año*

    ____ x per month / *por mes*

    ____x per week / *por semana*

2. How frequently does your household buy chocolate clams? *¿Con qué frequencia compran almejas chocolatas?*

    ____x per year / *por año*

    ____ x per month / *por mes*

    ____x per week / *por semana*

3. How frequently does your household sell chocolate clams? *¿Con qué frecuencia venden almejas chocolatas?*

    ____x per year / *por año*

    ____ x per month / *por mes*

    ____x per week / *por semana*

4. How frequently does your household eat chocolate clams? *¿Con qué frecuencia comen almejas chocolatas?*

    ____x per year / *por año*

    ____ x per month / *por mes*

    ____x per week / *por semana*

Historic clam use / *Uso histórico de almejas*

1. Have you ever collected chocolate clams for any purpose? *¿Ha sacado almejas chocolatas por qualquier razón?*

2. If you collect or harvest chocolate clams, how long have you been collecting them? *Si ha sacado almejas chocolatas, ¿cuántos años las ha estado sacando o las ha sacado?*
3. If you buy chocolate clams, how long have you been buying them? *Si compra almejas chocolatas, ¿por cuántos años las ha comprado?*
4. Have you noticed any changes over time in the market or demand for clams? *¿Ha notado algún cambio en el mercado o la demanda para almejas chocolatas?*
    a. Have you noticed any changes over time in the quantity or quality of clams? *¿Ha notado algún cambio en la cantidad disponible o la calidad de almejas?*
    b. Have you noticed any changes over time in the size of clams? *¿Ha notado algún cambio en el tamaño de almejas?*
    c. Have you noticed any changes over time in the price of clams? *¿Ha notado algún cambio en el precio de almejas?*
    d. Have you noticed any changes in the availability of clams? *¿Ha notado algún cambio en la disponibilidad de almejas?*
5. Do have any thoughts on why these changes have occurred? *¿Tiene alguna idea en por qué han ocurrido estos cambios?*
6. Have these changes affected you and your household? *¿Han afectado estos cambios a su hogar?*

Chocolate Clam Values / *Valores de almejas chocolatas*

The following set of questions will ask about the values chocolate clams provide to your household. Please indicate whether you agree or disagree with each statement.

Se le preguntara sobre los valores que proporcionan almejas chocolatas a su hogar. Por favor indique si está de acuerdo o en desacuerdo con cada declaración.

7. Chocolate clams are important to me and my family. *A mi y a mi familia nos importan las almejas chocolatas.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

8. Chocolate clams are important to my community. *A mi comunidad le importan las almejas chocolatas.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

9. Chocolate clams help sustain me and my family. *Las almejas chocolatas ayudan a sostener a mí y a mi familia.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

10. Chocolate clams help sustain other animals in Loreto Bay. *Las almejas chocolatas ayudan a sostener otros animales en la Bahía Loreto.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

11. Chocolate clams provide income to my household. *Las almejas chocolatas proporcionan ingresos a mi hogar.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

12. Chocolate clams are important to the local economy. *Las almejas chocolatas son importantes a la economía local.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

13. Tourists spend money on chocolate clams when they visit Loreto. *Los turistas gastan dinero en almejas chocolatas cuando visitan Loreto.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

14. Chocolate clams are a tourist attraction of Loreto. *Las almejas chocolatas son una atracción turística en Loreto.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

15. Chocolate clams provide some of my family's basic needs. *Las almejas chocolatas proporcionan algunas de las necesidades básicas de mi familia.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

16. Chocolate clams are important for scientists to study. *Las almejas chocolatas son importantes para que los científicos las estudien.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

17. Chocolate clams should be protected so that people can learn about them. *Las almejas chocolatas deben ser protegidas para que la gente puede aprender sobre ellas.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

18. Chocolate clams are important for recreation, including exercise and fun. *Las almejas chocolatas son importantes para la recreación en cuanto a ejercicio y diversión.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

19. It is fun or relaxing to look for or harvest chocolate clams. *Es divertido o relajante buscar o sacar las almejas chocolatas.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

20. Chocolate clams are beautiful. *Las almejas chocolatas son bellas.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

21. Chocolate clams contribute to the unique beauty of Loreto. *Las almejas chocolatas contribuyen a la belleza única de Loreto.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

22. Chocolate clams should be conserved for future generations. *Almejas chocolatas deben ser conservadas para futuras generaciones.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

23. Chocolate clams should be conserved because I or my family might want to harvest them in the future. *Almejas chocolatas deben ser conservadas porque yo o mi familia podría querer sacarlas en el futuro.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

24. Chocolate clams are important because of their history in this area. *Las almejas chocolatas son importantes para su historia en esta area.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

25. Chocolate clams are important to the culture of this area. *Las almejas chocolatas son importantes a la cultura de esta area.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

26. Chocolate clams are an important part of who I am as an individual. *Las almejas chocolatas son una parte importante de quien soy como individuo.*

__Agree / *De acuerdo*

__Disagree / *En desacuerdo*

__Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

__Prefer not to answer / *Prefiero no responder*

27. Chocolate clams are an important part of what it means to be a Loretano or to live in this area. *Las almejas chocolatas son una parte importante de lo que significa ser Loretano o vivir en esta area.*

  __Agree / *De acuerdo*

  __Disagree / *En desacuerdo*

  __Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

  __Prefer not to answer / *Prefiero no responder*

28. Even when I don't use chocolate clams, I like to know they are there. *Aún cuando no uso almejas chocolatas, me gusta saber que estan ahi.*

  __Agree / *De acuerdo*

  __Disagree / *En desacuerdo*

  __Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

  __Prefer not to answer / *Prefiero no responder*

29. Chocolate clams have value primarily because they provide benefits to people. *Las almejas chocolatas tiene valor principalmente porque proporcianan beneficios a la gente.*

  __Agree / *De acuerdo*

  __Disagree / *En desacuerdo*

  __Neither agree nor disagree / *Ni de acuerdo ni en desacuerdo*

  __Prefer not to answer / *Prefiero no responder*

30. Is there anything else you would like to add? *¿Hay algo más que le gustaría decir?*

31. Are there any questions I asked you that you'd like to discuss further? *¿Hay algunas preguntas que le pregunté que le gustaría discutir más?*

APPENDIX E: BLOG POST CHOCOLATE CLAM FESTIVAL 2016

June 4th, 2016 marked the date of the 4th Annual Chocolate Clam Festival in Loreto, Mexico, put on by the Restaurant and Bar Association of Loreto and attended by over 500 people from Mexico and abroad. This was the second year that I've worked with the festival organizers to set up a biology education tent near the entrance of the event.

This year's biology tent featured a touch tank where participants could "meet a chocolate clam", and learn basic clam anatomy using a microscope set-up with a dissected clam. Using these tools, I talked to participants about how clams go about their daily activities, such as feeding, breathing, and reproducing. On the dissected clam, participants were challenged to find the foot, gills, stomach, and siphons, and I used this opportunity to explain the function of each body part in the clams' daily lives. The touch tank also provided the opportunity to teach participants about the growth rings on a clam's shell, which can not only be used to tell the clam's approximate age, but also about the changing environmental conditions of the clam's habitat. For younger participants, there were coloring sheets of clamshells and a diagram of the clam life cycle.

The event was a success. Many participants of all ages visited the biology education tent throughout the evening, asking questions about the clam life cycle and the clam fishery of Loreto Bay. Children flocked to see the live clams squirt water from their siphons, and many drew pictures of the clam body parts they had learned about through the dissected clam demonstration.

APPENDIX F: BLOG POST NATIONAL PARK 20TH ANNIVERSARY 2016

For the 20th Anniversary of Loreto Bay National Park in July 2016, Loreto held a week-long celebration of the park's accomplishments and contributions to the conservation of the species and ecosystems within its bounds. The waters and islands of Loreto Bay were designated a National Park in 1996, and in 2005, the area also became a World Heritage Site. The 20th Anniversary event kicked off with a presentation on the park's accomplishments and milestones over its 20-year history by the Park Director, Javier Alejandro Gonzalez Leija, and throughout the week several scientists gave public talks on topics related to the conservation of local species and habitats. A historical photo exhibition documented changes in the park and its islands over the years, and the celebration finished off with an all-day fiesta on the beach, featuring games and activities for children, a recycling challenge, and musical entertainment.

As part of the festivities, I was invited to give a public talk on chocolate clam biology and conservation. Government biologists and officials, NGO scientists, local political leaders, restaurant owners, fishermen, and community members showed up to attend the talk and learn about the importance of chocolate clams to Loreto Bay ecosystems and communities, learn how clams live and reproduce, and find out the results of my studies of chocolate clams in the bay. The talk sparked a community discussion about the importance of science to species and ecosystem management, and many questioned why it isn't easier to incorporate scientific knowledge into policy. The audience was very encouraging of the continuation of this work, and stressed the need for additional public talks and forums to disseminate knowledge and discuss as a community ways in which to conserve important local species.

APPENDIX G: BLOG POST CITIZEN SCIENCE 2016

For the past three years, I've studied social-ecological resilience in the fisheries of Baja California Sur, Mexico. The state of Baja California Sur makes up the bottom half of the Baja peninsula in northwestern Mexico, and has coasts on both the Pacific Ocean and the Gulf of California. With scant agriculture in this region due to the extreme temperatures and dryness of the Baja desert, communities in this region rely mainly on the ocean for food and income. One species of particular importance to BCS as a whole is the Mexican chocolate clam, *Megapitaria squalida*.

In the coastal community of Loreto, along the Gulf coast, the chocolate clam is not only a dietary staple, but also a source of local pride and identity. A rich cultural history surrounds the chocolate clam, dating back to pre-colonial times when indigenous communities roasted clams over bonfires of beach brush, a tradition known as *tatemada*. Today, chocolate clams can be found on the menu of every restaurant and at every family gathering in Loreto.

An expanding Loreto population, as well as growing tourist demand for the clams has led to the expansion of the commercial fishery in the past 10 years. Hookah compressors are now used by commercial divers to access clam banks at depths deeper than is possible via traditional free diving, and this equipment allows divers to stay on the ocean floor for several hours at a time, essentially "sweeping" a particular area of the seafloor and leaving few clams in their wake. There is widespread misunderstanding among fishers about the toll that this increased fishing effort has taken on clam populations over time. Government studies to establish fishing quotas have focused on small areas within Loreto Bay, and my own study of clam population density and size structure throughout the Bay, carried out in Summer 2015, was restricted to a two-month time period.

In collaboration with Loreto Bay National Park, local fishers in Loreto have decided to take the science into their own hands in order to understand what is really going on with the chocolate clam populations in their own backyard. During bi-monthly data collection days, five local clam-fishing cooperatives take to the water, each surveying a particular area of the Bay. Their goal is to create a public database to track clam populations in Loreto Bay over time. On a designated day twice a month, one boat from each of the five participating cooperatives heads out to count and measure clams within transects at 3 different depths in their assigned area. On the boat, one fisher takes GPS coordinates of the survey sites, one fisher dives to set up the transect and collect clams, and another records the measurements of the clams once the diver brings them to the surface.

On the first few outings, each boat was also assigned a biologist to observe and document the process, and to offer suggestions. On the first day, I sat on the boat of a cooperative I have worked with closely for the past few years. As part of my own studies of fishery resilience, I have measured hundreds of clams from this cooperative's daily catch. The cooperative president, today driving the boat and diligently marking the GPS coordinates of our stops, has watched me measure these clams, using a grey plastic vernier caliper to take measurements of clam after clam in the shade of an orange tree in his garden. Today, bags of clams from several different transects are sitting at his feet, and he holds the grey plastic caliper up to clam after clam. "This is considered the width, right?" he asks me, showing me a clam clenched in the caliper's opening. "Sí," I say. He mutters measurements to a young fisher sitting opposite him, who scribbles on a clipboard. A bunch of clams that have already been measured sit in a small pool of water at my feet, resting at the bottom of the small fiberglass boat. Once all the clams have been measured, the diver will return them to the sea floor. While awaiting their release, however, a few clams stick out their siphons to begin filter feeding in the sun-warmed water. One clam sticks out its bright orange foot to adjust its position among the pile. I point to it, "Look it's moving its foot". The young fisher with the clipboard looks up at me, then to the clam. "Wait—I thought that was its tongue," he responds, sounding puzzled. "It does look like a tongue," I say, "but it's actually a foot. That's what clams use to move and rebury themselves in the sand." The young fisher seems intrigued, but a serious look comes across his face when he realizes he missed the last measurement. He asks the cooperative president to repeat the last measurement, then quickly goes back to scribbling on the clipboard.

No one cares more about the future of chocolate clams than the communities that rely on them, and being present as these fishers take ownership of science to conserve one of their most valued species has been one of the most rewarding experiences of my work in Baja.

APPENDIX H: BLOG POST ECO-ALIANZA PUBLIC TALK 2019

I have been studying the chocolate clam fishery in Loreto Bay National Park since 2013, as part of my dissertation research in University of Maine's Graduate Program in Ecology and Environmental Sciences (EES). As a marine conservation scientist, I also work closely with faculty in UMaine's School of Marine Sciences, and am based at the Darling Marine Center, in Maine's midcoast region.

My interdisciplinary research looks at how ecological and social factors interact to affect the sustainability of the clam fishery. The communities where I work, including Loreto, are tucked into a strip of Baja desert between the calm, glittering blue waters of the Sea of Cortes, and the jagged peaks of the *Sierra de la Giganta* mountain range. Tourism and commercial fishing drive Loreto's economy, and one of the top fished species in Loreto is the Mexican chocolate clam, *Megapitaria squalida*. Chocolate clams are found from the Baja peninsula south along the Pacific coast to Peru, but they have particular importance in Loreto, where they not only contribute to the local economy, but also enjoy a rich cultural and culinary tradition. Chocolate clams also provide an important source of supplementary food and income for many families in the region. Chocolate clams are found buried in sandy-muddy sediment on the ocean floor, at depths of 1-120m. They are harvested via free-diving, where the diver holds their breath and dives to the ocean floor, and via hookah diving, where a gasoline-powered compressor pumps air from a boat down to a diver on the ocean floor.

During my recent fieldwork in Loreto, I investigate the importance of chocolate clams to Loreto households, in terms of food, employment, and cultural and recreational values. I surveyed local residents and used other established anthropological methods, e.g., interviews and participant observation, to document the connections between the clam fishery, local marine ecosystem and people of Loreto. The trip also gave me an opportunity to share results of my last five years of work with the local community. I gave two public talks in both English and Spanish, which were well attended by a mix of scientists, tourists, fishermen and other community members.

My dissertation draws on both natural and social science approaches to advance understanding of how this fishery can be sustained into the future. With this ‘sustainability science’ approach, I undertook a series of complementary studies on both clam biology and fishing activities. These included studies of clam growth, clam abundance and sizes in Loreto Bay National Park, the sizes of clams harvested by fishermen, and the effect of different minimum and maximum legal sizes on clam populations. I also studied the fishery, including the various types of people involved in the chocolate clam fishery, and current processes for creating chocolate clam management. I have found that conservation of the species is hindered by the loss of traditional fishing rights. This loss of rights has excluded a diversity of voices from management conversations, reduced community confidence in fisheries management, and made chocolate clam management a divisive local issue. My research has shown that fishers’ ecological knowledge, together with the broader community's desire to conserve and protect these clams for future generations, could be crucial components of sustaining this fishery and the ecosystem of which it’s a part.

Based on my studies, I developed the following recommendations to improve the sustainability of the chocolate clam fishery and the values it provides to the local community:

1) Cultivate meaningful involvement in management by diverse members of the community;

2) Consider establishing a maximum legal size, in addition to the current minimum legal size to maximize the reproductive potential of chocolate clam populations; and

3) Protect and legalize the equitable distribution of traditional fishing rights.

I have shared these recommendations with local residents and fisheries managers, and look forward to continuing to work in the Loreto area in the future. My graduate education at UMaine has led me to new questions and ways of thinking about how marine species and ecosystems are interwoven into the lives of people in coastal communities. I have discovered that communities near and far often face similar challenges, and that lessons learned in one context can contribute to better understanding in another. My education at UMaine has taught me the importance of forging connections between scientists and coastal communities, and has prepared me for a future in applied marine conservation.

APPENDIX I: RESEARCH INTRODUCTION HANDOUT 2014

Figure I.1. Research introduction handout 2014

Investigando cambios en las pesquerías de almejas en el Golfo de California, México

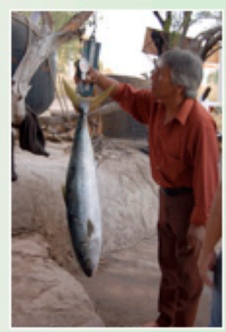
Kara Pellowe, estudiante de doctorado de la universidad de Brown en los Estados Unidos, junto con sus colaboradores en E.U. y México, están realizando un estudio para entender los posibles cambios en las pesquerías de almejas, especialmente de la almeja chocolata, en la zona de Loreto. En particular, Kara y sus colaboradores quieren entender cómo la biología de esta especie afecta la productividad y la dinámica de la pesquería local.

Como los pescadores tienen amplio conocimiento sobre estos temas queremos aprender de su conocimiento. Su participación es importante para el éxito de este estudio. La información proporcionada es confidencial y utilizada con fines académicos y de investigación científica. Su participación es voluntaria. Retirando su participación en cualquier momento u optar por no contestar preguntas que no quiera responder. Si usted tiene preguntas sobre este estudio puede contactarnos en cualquier momento.

¡Muchas gracias!

Preguntas principales del nuestro estudio:

- ¿Cómo han cambiado las pesquerías almejas en la zona de Loreto – año por año y a largo plazo?
- ¿Cómo responden los pescadores a estos cambios?
- ¿Cómo usan los pescadores su conocimiento sobre la biología de la almeja para pescarla?



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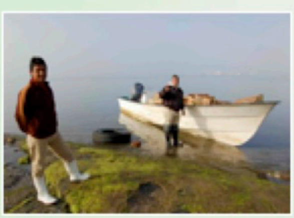


Este estudio es apoyado por la Universidad de Brown, en colaboracion con las organizaciones siguentes:

BROWN

UABCS

Duke UNIVERSITY

CENTRO PARA LA BIODIVERSIDAD MARINA Y LA CONSERVACIÓN A.C.

APPENDIX J: PRELIMINARY RESULTS HANDOUT 2014

<u>Resultados Preliminarios</u>

Estos son resultados preliminarios. Con más datos, tendré resultados mas seguros y específicos. Puede contactarme en qualquier momento a discutir su participacion en este estudio. Muchas gracias!

Información de la contacta: Kara Pellowe, 613.111.2569, kara_pellowe@brown.edu.

Table J.1. Datos preliminarios de las almejas sacadas

Lugar	**Número de muestras**	**Promedio del ancho (mm)**	**Ancho mínimo (mm)**	**Ancho máximo (mm)**
Ensenada Blanca	181	71.2	57	80
La Ballenita	289	73.3	52	110
La Dárcena	198	72.6	52	105
La Negrita	400	72.7	56	106
La Salinita	176	69.1	55	95
Ligüí	100	74.5	65	87
Mil Palmas	50	72.1	62	97
Playa Ligüí	60	71.3	59	86
Playa Mulegina	200	68.7	58	89

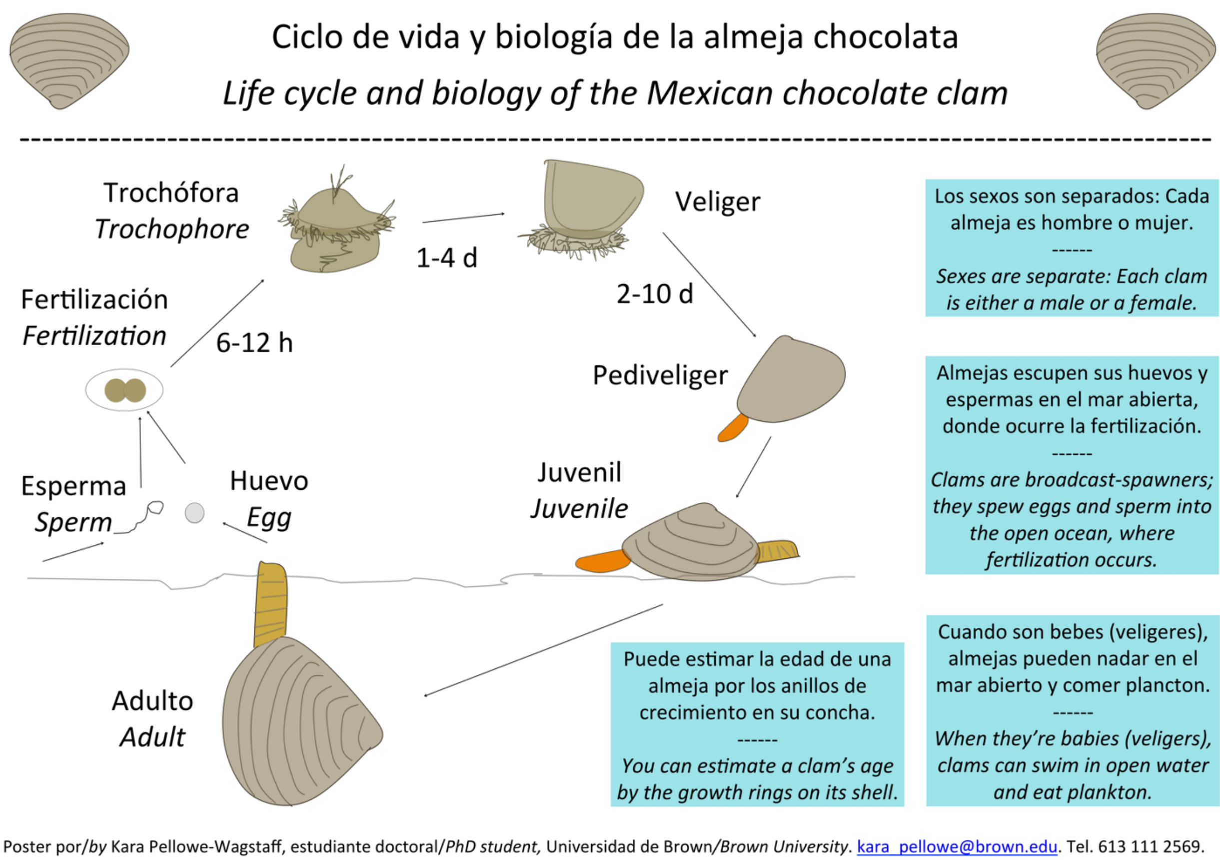
Los lugares con la major variación en tamaños son: La Ballenita, la Dárcena, y La Negrita. En general, con más años de experiencia pescando almejas, Pescadores sacan almejas con menos variabilidad de tamaño.

Table J.2. Cooperativas y zonas de pesca

Cooperativa	**Zonas de pesca observadas en este estudio**
Buzos de Cortes de Ensenada Blanca	Ensenada Blanca
Buzos Libres Loretanos	Playa Mulegina, La Ballenita
Carnadores y Pescadores de Loreto	La Dárcena
Los Melcenares	La Ballenita, La Salinita
Monserrat	Playa Ligüí, Ligüí, Mil Palmas, La Salinita
Pescadores de Colonia Zaragoza	La Negrita

APPENDIX K: CHOCOLATE CLAM FESTIVAL POSTER 2015

Figure K.1. Chocolate clam festival educational poster 2015

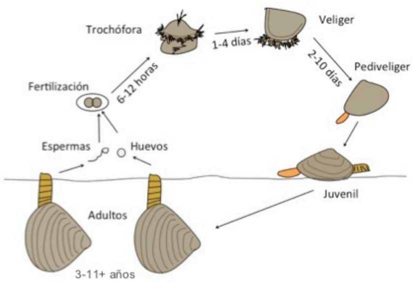


APPENDIX L: CHOCOLATE CLAM EDUCATIONAL BROCHURE 2019

Figure L.1. Front of chocolate clam educational brochure 2019

Figure L.2. Back of chocolate clam educational brochure 2019

Ciclo de vida de la almeja chocolata
Life cycle of the chocolate clam



Distribución

Desde la peninsula de Baja California y Baja California Sur, y al sur a la costa del océano Pacífico hasta Perú.

Distribution

From the Baja peninsula, south along the Pacific coast to Peru.

Hábitat

Estas almejas se encuentran enterradas en sedimentos al fondo del océano, a profundidades desde 1 a 120 metros.

Habitat

These clams are found buried in sediment on the ocean floor, at depths of 1 to 120 meters.

Reproducción

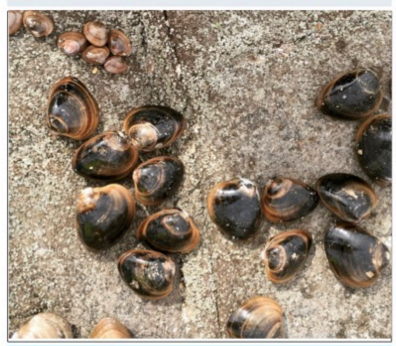
Las almejas se distinguen por dos sexos: macho o hembra.

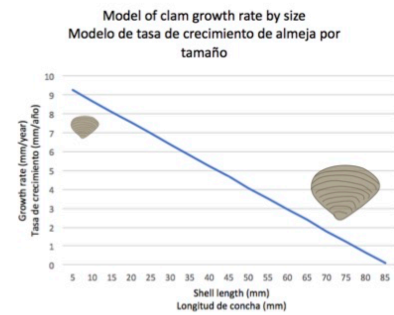
Estas escupen sus huevos y espermas en el mar abierto, donde ocurre la fecundación.

Reproduction

Sexes are separate: Each clam is either a male or a female.

Clams are broadcast-spawners; they spew eggs and sperm into the open ocean, where fertilization occurs.





Reclutamiento y crecimiento

Cuando las almejas chocolatas son bebés (veligeres), ellas pueden nadar en el mar abierto y comer plancton. Cuando ellas se asientan al fondo, usan un "pie" muscular para enterrarse en la arena. El crecimiento de una almeja depende de su tamaño: almejas chicas crecen más rápido que almejas grandes.

Recruitment and growth

When clams are babies (veligers), they can swim in open water and eat plankton. Once they settle, they use a muscular "foot" to bury themselves in the sand. The growth rate of clams depends on their size: small clams grow more quickly than large clams.

BIOGRAPHY OF THE AUTHOR

Kara Pellowe was born in Albany, New York on October 16, 1989, and grew up in Parker, Colorado. She developed a love of marine science at a young age, and dreamt of becoming a marine scientist so she could help protect the species and ecosystems she loved so much. She graduated from Chaparral High School in 2008, and attended Cornell University for her undergraduate degree. From 2010 to 2011, Kara participated in the International Honors Program Rethinking Globalization study abroad program, spending her junior year traveling throughout the United States, India, Tanzania, New Zealand, and Mexico, and studying how globalization has shaped ecological processes, governance systems, and the social landscape in five diverse countries. In 2012, she graduated from Cornell University *Cum Laude* with Distinction in Research as part of the Biology Honors Program, and earned a Bachelor of Science in the Science of Environmental Systems, with a concentration in Environmental Biology. Her honors thesis was based on two years of field and lab research at Shoals Marine Laboratory, Appledore Island, Maine, and was entitled, “Dispersal by overflow in a rock-pool metacommunity is trophic-level specific”. After completing her degree at Cornell University, Kara worked as Island Coordinator and Lab Preparator at Shoals Marine Laboratory for two summer field seasons before beginning graduate school in 2013 at Brown University under the advisement of Dr. Heather Leslie. In 2016, Kara graduated from Brown University with a Master of Science in Ecology and Evolutionary Biology and a Master of Arts in Sociology. Her master’s thesis was entitled, “Temporal variability and resilience in small-scale fisheries in Baja California Sur, Mexico”. Kara is committed to studying the links between people and marine ecosystems, and plans to continue conducting research that contributes to the resilience of coastal ecosystems and the human communities that depend on them. Kara is committed to communicating her science with the public through education and outreach, with the goal of encouraging stewardship of the oceans. Kara has authored two published papers: Pellowe-Wagstaff & Simonis, 2014, in Freshwater Biology; and Pellowe & Leslie, 2017, in PLOS ONE. Kara is a member of the

Ecological Society of America, the Society for Conservation Biology, Sigma Xi Scientific Research Society, and the American Academy of Underwater Sciences. After receiving her degree, Kara looks forward to continuing research on resilience as a post-doctoral researcher at the Stockholm Resilience Centre, in a collaboration with the University of Maine. Kara is a candidate for the Doctor of Philosophy degree in Ecology and Environmental Sciences from the University of Maine in August 2019.