SOCIAL-ECOLOGICAL IMPLICATIONS OF USING MARINE PROTECTED AREAS TO MANAGE AN ORNAMENTAL FISHERY IN HAWAII

By

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SOCIAL-ECOLOGICAL IMPLICATIONS OF USING MARINE PROTECTED AREAS

TO MANAGE AN ORNAMENTAL FISHERY IN HAWAII

Abstract

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Marine protected areas (MPAs) have been implemented across the globe to protect biodiversity and important habitats, enhance fisheries, and manage marine resource users. Several hundred thousand wild caught reef fish are captured and sold each year for the global aquarium trade in the state of Hawaii, U.S.A. The state's largest aquarium fishery is located on the west coast of the island of Hawaii (hereafter West Hawaii), where a network of MPAs were implemented in 1998 to enhance reef fish harvested for the trade and reduce conflict between aquarium fishers and other marine resource users.

My research focused on the following three questions: 1) How did aquarium fisher adaptations to the MPA network influence catch productivity and selectivity?; 2) How did the MPA network spatially displace aquarium fishing and what were the socioeconomic consequences from this displacement on the fishing community?; and 3) Are MPA networks effective for managing marine resource conflict?

My findings indicate fishers adopted new and effective fishing technologies and methods, and shifted from harvesting a diverse trophic composition to one focused mainly on noncorallivore fishes. Additionally, the MPA network displaced fishing effort on West Hawaii

farther from where fishing boats launch, but fisher socioeconomic well-being was unaffected despite the increase in fishing cost and travel time; exogenous trade factors likely buoyed these socioeconomic factors. Last, fishers and SCUBA dive operators perceived the MPA network moderately reduced conflict between them, but differences in value orientations toward the aquarium fish trade held by these groups are pervasive and likely contribute to recurring conflict in Hawaii. My findings illustrate that fishers adapt to MPAs, MPAs can spatially displace fishing effort and influence the socioeconomic well-being of fishers, and MPAs may not resolve human conflict when other social differences between groups exist. These findings underscore the importance of investigating human dimensions associated with using MPAs for fisheries and conflict management.

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CHAPTER ONE

INTRODUCTION

Marine protected areas (MPAs) are demarcated spatial areas designated to protect biodiversity, important habitats, enhance fisheries and manage resource users. Often biological attributes inform the process for designing and implementing MPAs without giving equal consideration to social attributes, such as how fishing and other coastal communities who depend on marine resources for their livelihoods will be affected by MPAs. The omission of social factors when establishing and monitoring MPAs has led to the biological failure of some well-intentioned conservation efforts. My dissertation focuses on examining how MPAs influence social-ecological dimensions in the State of Hawaii, U.S.A. The MPAs in Hawaii, which are locally termed Fish Replenishment Areas, were implemented to protect against perceived overharvesting of reef fish by residents on the west coast of the island of Hawaii and reduce conflict between opposing marine resource users, namely aquarium fishers and SCUBA operators.

My research objectives addressed the following three questions: 1) How did aquarium fisher adaptations to the MPA network influence their catch productivity and selectivity?; 2) How did the MPA network spatially displace aquarium fishing and what were the socioeconomic consequences from this displacement on the fishing community?; 3) Are MPA networks effective for managing marine resource conflict? Each question represents a separate chapter in my dissertation.

In chapter two, I examine how fishers adopted new fishing methods, approaches and technologies to increase their catch efficiency. I also investigate other attributes, such as fisher job satisfaction, to help explain why fishers continue to fish despite reported declines of target species in areas remaining open to fishing post-MPA network implementation. I also evaluate the catch composition of aquarium fishers, explore how it has changed over time and discuss the reasons and implications for why these changes occurred. In chapter three, I investigate whether the MPA network on Hawaii spatially displaced aquarium fishing effort and examine the socioeconomic consequences of fishing displacement on the aquarium fishers. I also explore the association between the locations of the MPAs and where fishers launch their boats, and how these dynamics may affect catch abundance and catch-per-unit-effort. In chapter four, I investigate how the MPA network influenced conflict dimensions between aquarium fishers and SCUBA dive operators on Hawaii and Maui. This required me to investigate perceived encounters, threats to the reefs and fishes, and value orientations toward the aquarium fish trade held by these stakeholder groups. The findings from my research underscore the importance of including human dimensions research when evaluating MPAs, particularly in cases where fishing communities are heavily dependent on the resource identified for protection.

Because the second, third and fourth chapters of my dissertation were published in scholarly journals, I used the alternative dissertation format approved by the Graduate School at Washington State University. This format requires me to describe where my work was published, formatting differences due to journal requirements, and co-author contributions to my published work. The second chapter was published in the ICES Journal of Marine Science; the third chapter was published in Biological Conservation; and the fourth chapter was published in Marine Policy. The writing (e.g., using first person pronouns) and formatting (e.g., reference formatting) styles differed by journal and are reflected in each chapter. As my academic advisor, Brian Tissot was included as a co-author on all three manuscripts because of his assistance with designing and executing the research. Jan Dierking was included as a co-author in chapter two for providing his fishing intensity and frequency survey data from 2002, assistance with applying the electivity index to my species data, and editing assistance. William Walsh was included as a co-author in chapter three for his significant data contributions and editing.

CHAPTER TWO

FISHER BEHAVIOUR INFLUENCES CATCH PRODUCTIVITY AND SELECTIVITY IN WEST HAWAII'S AQUARIUM FISHERY

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Abstract

In 1999, marine protected areas (MPAs) were implemented along the west coast of the Big Island of Hawaii, closing ~35% of the coastline to aquarium fishing. Catch per unit effort and total catch of the most commonly targeted fish, yellow tang (*Zebrasoma flavescens*), has increased since the implementation of the MPAs, yet its abundance has declined by 45% in areas open to aquarium fishing between 1999 and 2007. How effort allocation, harvesting efficiencies, and job satisfaction influence catch productivity and selectivity in West Hawaii's aquarium fishery are investigated, and how these dynamics explain the discrepancy between catch rates and relative abundance for yellow tang is discussed. Cross-sectional fisher questionnaires, semi-structured fisher interviews, and in situ and ex situ catch analyses were performed. The results indicate that fishers dive deeper when reef fish recruitment is perceived as weak, increase harvest efficiency with larger fishing teams, and intensively harvest "coral-friendly" reef fish to supply the global aquarium fish trade. Experienced fishers were less likely to exit the fishery, and job satisfaction was high despite declining fish stocks. These findings may help explain harvesting efficiencies and fleet investment, underscore the importance for evaluating fisher behaviours, and have potential management implications for other aquarium fisheries.

Key Words: coral reef fisheries, effort allocation, fisher job satisfaction, harvesting efficiencies, Hawaii, ornamental fish trade, yellow tang (*Zebrasoma flavescens*).

Introduction

It has been suggested that the collapse of a fishery can be attributed to misunderstanding fishing fleet dynamics rather than the resource (Hilborn, 1985), and that understanding fisher behaviour is a key component for effective fisheries management (Wilen *et al*., 2002). Fleet dynamics describe attributes that influence catch variability, including fleet investment and disinvestment, effort allocation, harvesting efficiencies, and discarding practices (Hilborn, 1985). The literature on fleet dynamics primarily focuses on large commercial fisheries (Branch *et al*., 2006), with a limited number of publications focusing on smaller, artisanal fisheries, and evidence suggests that factors other than economic profit may have greater influence on smaller fishing fleets than on larger commercial ones (Béné and Tewfik, 2001; Salas and Gaertner, 2004). One common thread between large- and small-scale fleet dynamics is that changes in the above-mentioned elements can contribute to variation in catch efficiency and hence influence catch productivity (Salas and Gaertner, 2004; Branch *et al*., 2006).

Understanding why people enter and exit a fishery is a key factor for elucidating fleet investment and disinvestment strategies, and social scientists are increasingly recognizing the importance of fisher job satisfaction as an underlying mechanism that influences these dynamics. Commercial fishing often fulfils the psychocultural needs of people who seek adventure and thrill, which sometimes supersede the needs of income generation (Pollnac and Poggie, 1988), as demonstrated by fishers subsidizing their fishing efforts with other income to maintain their lifestyle (Gatewood and McCay, 1990). Some economists argue that a target species will become economically extinct prior to becoming biologically extinct because of the low profitability of harvesting low-density populations (Dulvy *et al*., 2003); however, other studies have concluded that commercial fishing has considerable non-monetary benefits and suggest that not all fishers will quit fishing when economic models predict they should (Gatewood and McCay, 1990; Pollnac and Poggie, 2008). Understanding how job satisfaction and other job-related attributes influence fisher choice for entering or exiting a fishery has important implications for effective management, especially when fisher job satisfaction is strong in fisheries with declining stocks.

The global trade in ornamental fish is a major industry involving approximately 30 million fish annually with a retail value estimated between US$90 million and US$300 million (Wood, 2001a). Nearly all specimens harvested for the marine ornamental trade are from wild stocks in coral environments (Wood, 2001b). The State of Hawaii's aquarium fishery developed rapidly and expanded in the early 1970s, grossing $3.2 million in sales, with industry profits at $1.2 million in 2002, making it Hawaii's most lucrative nearshore fishery (Walsh *et al*., 2004). The majority of the State's aquarium fish catch value is now generated from the west coast of the Big

Island of Hawaii (hereinafter West Hawaii; Walsh *et al*., 2004), where approximately 37 aquarium fishers were considered active in 2007 (i.e. reporting an annual catch of more than 1000 yellow tang, *Zebrasoma flavescens*, the most commonly targeted species in the region) (Williams *et al*., 2009). In 1999, to improve management of the fishery, some 35% of West Hawaii's coastline was closed to aquarium fishing via a network of marine protected areas (MPAs; Tissot *et al*., 2009).

Walsh *et al*. (2004) and Williams *et al*. (2009) showed that catch per unit effort (cpue) and total catch for yellow tang, respectively, has increased since the establishment of the MPAs in West Hawaii, suggesting that they may have enhanced the aquarium fishery. In addition, Williams *et al*. (2009) detected evidence of spillover of adult yellow tang near the boundaries of several MPAs. Although these effects of MPAs may influence catch productivity positively outside the protected areas, the aquarium fishery targets juvenile yellow tang (Williams *et al*., 2009), which display high site fidelity and limited mobility (Claisse, 2009). Therefore, although MPAs may enhance recruitment by increasing the adult spawning stock, fishers targeting juvenile yellow tang are unlikely to benefit significantly from spillover dynamics, i.e. juvenile fish moving across MPA boundaries into fishable waters. Additionally, despite the presence of the MPAs, the abundance of yellow tang has declined by 45% in areas open to aquarium fishing between 1999 and 2007 (Williams *et al*., 2009), which is likely the result of increased fishing pressure from clustering fishers in permissible fishing areas after the MPAs were established. Fishery managers frequently assume fish abundance is proportional to cpue, which is often misleading (Maunder *et al*., 2006). Detecting an increase in cpue while stock abundance declines is a common pattern observed in commercial fisheries known as hyperstability, and it can manifest when the data used to calculate cpue are standardized by removing attributes associated with fleet efficiency (Hilborn and Walters, 1992; Maunder *et al*., 2006).

Several studies have provided a brief description of the methods used for capturing and processing reef fish and the catch composition of Hawaii's aquarium fishery (Randall, 1987; Miyasaka, 1994, 1997; Ogawa and Brown, 2001; Cesar *et al*., 2002), but these efforts have not examined the fleet factors that may contribute to catch variability within the fishery. Here, we attempt to explain catch trends for yellow tang in West Hawaii by describing the aquarium fishery and investigating how effort allocation, harvesting efficiencies, and job satisfaction influence catch productivity and selectivity. To our knowledge, this is the first study to investigate fishing fleet dynamics for a marine aquarium fishery anywhere in the world.

Methods

Interviews

In 2002, semi-structured in-person interviews were conducted with ten active aquarium fishers from West Hawaii to determine fisher age and fishing effort. The interview questions were determined *a priori*, and each participant was asked the same questions. In 2007, we obtained answers to the same questions using mailed surveys and in-person interviews to assess changes in these attributes over time. Additionally, in 2007 and 2008, we performed pre- and post-survey fisher interviews with 12 fishers who had a wide range of experience. The pre-survey interviews served to ascertain information about the social environment and perceptions surrounding the aquarium fishery, as well as to establish a rapport with the fishers for the planned surveys and *in situ* observations (see below). The post-survey interviews served to validate overall responses received from the surveys. Any detected incongruities in the responses were noted.

Surveys

The results from the pre-survey interviews were used to develop a cross-sectional survey to evaluate changes within the aquarium fishery subsequent to the establishment of the MPAs. We used income satisfaction, willingness to encourage new fishers to enter the fishery, and willingness to exit the fishery if training for another job with a similar income were used as surrogates for job satisfaction. Three aquarium fishers and the State fishery biologist responsible for West Hawaii pre-tested the survey before it was disseminated, to evaluate clarity and appropriateness.

Each fisher received a cover letter explaining the research objectives and a statement of confidentially, a survey, a self-addressed stamped envelope for returning the survey, and instructions on how to obtain a modest incentive for participating in the study. The State Division of Aquatic Resources (hereinafter DAR) sent the survey packets to all permit-holding aquarium fishers in West Hawaii (n = 67) on our behalf, and 23 surveys were returned. In addition to using the DAR's assistance, we also used fisher informants to help disseminate the survey to their peers who were less likely to respond to a survey sent from the state government. The returned surveys were coded and the responses were saved in a database. Kruskal–Wallis and Mann–Whitney U tests were used to analyse the survey and catch data, and results were considered significant at $p < 0.05$. Fisher perceptions were assessed both for fishers as an aggregate group and for fishers grouped by level of experience (0–5 years, 6–10 years, 11–15 years, 16–20 years, and 21+ years in the fishery).

Observations and catch analysis

Fisher observations and catch analyses were conducted between June and July 2007 and in November 2008, to document the methods used by aquarium fishers for capturing reef fish and to document and measure the target species and size of the fish caught, respectively. The number of fish caught per species (used here to calculate relative catch abundance), size (standard length in cm), depth and habitat of capture, capture mortality, and number of discarded fish per species were documented. Discarded fish were defined as those that were captured, brought to the surface, and released alive from the boat. Depth was measured using our scuba depth gauge at sites where nets were placed and fish collected. When possible, photographs at collection sites were used to classify preferred fisher habitats using methods developed by Ortiz and Tissot (2008). Overall fishing effort per fisher in 2002 and 2007 was calculated by multiplying the mean fishing intensity (i.e. the number of dives per fishing trip) by the mean fishing frequency (i.e. the number of trips per week) in those years. Finally, cpue was determined by counting the number of individuals of each species caught per dive duration.

Ivlev's electivity index (E_i; Ivlev, 1961) was used to determine the fisher's preference for fish caught:

$$E_i = (r_i - p_i) / (r_i + p_i),$$

where r_i is the numerical importance ($\%N$) of fish species i in the catch composition, and p_i is the $\%N$ of the same species in the reef environment.

E_i ranges between –1 and +1. Positive values indicate preference (a taxon overrepresented in the catch composition in relation to its availability in the environment), and negative values avoidance (a taxon underrepresented in the catch composition in relation to its availability; Lechowicz, 1982). The abundance data for reef fish were obtained from the West Hawaii Aquarium Project (WHAP) database, using methods described in Tissot *et al*. (2004). Although these data represent the best available estimates of reef-fish density, we acknowledge that abundance data from the WHAP may not correspond with actual reef-fish densities because cryptic or nocturnal species are generally undercounted during scuba surveys, monitoring data may not represent the same range and distribution of habitats where fish are harvested, and fish behaviour changes in the presence of divers (Williams *et al*., 2006).

When fishers sell their catch to an exporter, they are given an invoice stating the number of fish caught, the number of fish purchased by the exporter, the price per fish, and the names of the fishers who caught the fish. To assess the influence of team size on the number of yellow tang caught per dive, we analysed 247 sale invoices from one fisher who dived solo (102 invoices) and with one (127 invoices) or two (18 invoices) additional divers on different occasions. We assessed differences in the number of yellow tang caught by dive teams of different size using a Mann-Whitney *U* test, with probability values corrected for multiple comparisons (i.e. one vs. two divers, one vs. three divers, and two vs. three divers). Variables that may have confounded the results from these analyses (e.g. depth, location, season, team dynamics) were not available, and therefore could not be included. In all cases, however, the fish sold were caught using the same method.

Results

In 2007, 23 fishers completed the survey and 12 were interviewed. We only performed statistical analyses on the survey data, and we used the interviews to validate our findings and inquire about technology and gear use changes in the fishery pre- and post-MPA establishment. The mean age, number of years participating in the fishery, and number of fishing days per week for those who completed the 2007 survey was 47 years, 16 years, and 3 days per week, respectively, and 74% of fishers originally acquired their permits on the island of Hawaii (Supplementary material Figure S1).

Harvesting methods and efficiencies

In 2007, equipment and methods used for locating and capturing reef fish were observed and documented. In general, reef fish were corralled and pushed into monofilament barriernets set by the fishers; however, the specific process varied among fishers. Methods for locating fish varied from using dive masks or viewing scopes while on the boat to using underwater scooters (handheld motorized submersible devices that enable scuba divers to increase their mobility and speed with minimal exertion). Dive masks or viewing scopes were most commonly used for identifying yellow tang, both allowing a fisher to search the reef for fish while remaining on the boat. When yellow tang were located, fishers anchored their boat and commenced fishing using scuba. A less-common technique involved using underwater scooters to scout large areas of reef for yellow tang. Fishers would initially scout the reef using the scooter, identifying the locations of reef fish. They then corralled smaller clusters of fish into larger groups before capture. Both methods are highly effective for locating aggregating yellow tang.

During our investigation, we documented three primary approaches for capturing reef fish in West Hawaii. The two most common methods used two distinct monofilament barriernet designs: (i) crossnet and (ii) multiple-net designs (Figure 1). Barriernets have a float line at the top edge of the net and a lead line at the bottom to keep the net floating upright. The crossnet method involves using a single net that commonly measures approximately 9 m long by 2 m high, with a 1 cm mesh size. The method requires positioning the net in a V-shape, with the back lower end of the net forming a pocket, and the lead line placed flush with the substratum (Figure 1a). If available, fishers will set their nets near natural barriers (e.g. adjacent to sand patches, large boulders, or corals) to control fish movement. Using the crossnet design enables fishers to set and adjust their net in different locations on the reef multiple times per dive, based on where the fish are located. The fishers often use two 1.3-cm diameter fibreglass sticks that are sometimes referred to as “tickle sticks”, or probes that vary in length. Fishers use these devices to cluster small groups of reef fish into larger ones before corralling them into their nets. The number of times a fisher will set their crossnet and push fish into it can range from about 5 to 10 times per dive. Most fishers will set their net as few times as possible because it is strenuous and increases a diver’s demand for air, diminishing bottom time. Once the fish are in the net, fishers will extract them using their hands or a handnet and place them into an underwater live-well basket for the remainder of the dive. Whether a fisher uses their hand or a handnet to remove the fish from the barriernet is a matter of preference, but some claim that using their hands damages a fish and reduces its value. People who prefer the crossnet method usually dive solo or with one or occasionally two other fisher(s) and largely target surgeonfish such as yellow tang. Lastly, fishers decompressed their catch by slowly raising their live-well basket to the surface of the boat after they were on the vessel, and residual trauma was relieved by purging air from the fish’s swim bladder using a hypodermic needle.

The multiple-net method involves the use of much longer fence-, hook-, and crossnets, which are all barriernets, but differentiated based on their function (Figure 1b). Fishers who used this method sometimes operated individually, but more often in small teams of 2–4. The fishers divide an area of reef by placing a fencenet commonly measuring approximately 30 m long and 2 m high along the reef substratum. Next, they place the apex of a crossnet on one end of the fencenet, then adjoin a hooknet and “hook” it around the opposite end of the crossnet (Figure 1b). These crossnets are approximately 24 m long and 4 m high, and the hooknet approximately 30 m long and 2 m high. The fisher(s) will corral the fish and push them into the crossnet, then collect them as described above. Next, they will switch the hooknet and adjoin it to the opposite end of the crossnet and repeat the steps into the newly placed crossnet. Once both sides of the fencenet are fished, the fisher(s) will repeat the process by reversing the direction of the cross-, fence-, and hooknets. Depending on the number of people fishing this net design, it takes approximately 4–5 tanks of compressed air (or nitrox – oxygen-enriched air usually ranging between 32 and 36% oxygen, the higher percentage of oxygen increasing dive recovery time and bottom time, but reducing the operable depth through possible oxygen toxicity) to complete a set. Like crossnet fishers, people who use the multiple-net design primarily target surgeonfish.

Another method observed for capturing reef fish involved the use of handnets to target individual high-value fish that often take refuge in finger-coral habitat, e.g. juvenile *Ctenochaetus hawaiiensis*, *Centropyge potteri*, and *Centropyge loriculus*. Handnet size ranged from approximately 21to 30 cm in diameter, 21 cm being the most common. Fishers insert their tickle sticks into finger coral and coax hiding fish into the open, where they use a handnet to capture them. Handnets are also used to capture smaller fish like cleaner wrasses (*Labroides phthirophagus*) and docile deep-water reef fish that inhabit depths >60 m, e.g. *Chaetodon tinkeri* and *Apolemichthys arcuatus*. From our post-survey interviews, we estimated that ≤5 fishers within the fleet harvest deep-water reef fish with regularity. Lastly, handnets were also used to retrieve fish from cross- and multiple-net designs before placing them in the underwater baskets.

Post-survey interviews also revealed that gear and technology changed before and after the MPAs were implemented in 1999. The use of underwater scooters and nitrox were introduced to the fishery during the late 1990s. Approximately 5–8 people use scooters and nearly the entire fleet uses nitrox when targeting deep-water fish, with the exception of a few fishers who use compressed air. At least five fishers adopted global positioning system (GPS) devices between 2002 and 2005 and regularly used this technology in 2007. Finally, at least three fishers used artificial materials that mimic sand patches and are placed on top of the coral reefs to control fish movement and prevent them from taking refuge. We were unable to determine when this method of capture was first introduced.

Respondents in 2007 indicated that 18.2% fished solo, 45.5% fished with one additional diver, 22.7% fished with two additional divers, and 13.6% fished with more than 3 additional divers ($n = 22$). Sale invoices revealed a significant difference in the total number of yellow tang caught per team size ($H = 105.59$; $p < 0.001$; $n = 247$), with the mean numbers of fish caught equalling 111, 345, and 714 per one-, two-, and three-person team, respectively (1 vs. 2 divers: $U = 6981.5$; $p < 0.0001$; 1 vs. 3 divers: $U = 5394.5$; $p < 0.0001$; 2 vs. 3 divers: $U = 8683.0$; $p < 0.001$; Figure 2a). More importantly, the mean number of yellow tang caught per person per trip per team size was 111, 173, and 237 fish, increasing significantly with dive team size (1 vs. 2 divers: $U = 8857.5$, $p < 0.005$; 1 vs. 3 divers: $U = 5656.0$, $p < 0.005$; 2 vs. 3 divers: $U = 8996.5$, $p > 0.05$; Figure 2b).

Effort allocation

Most fishers collected fish at depths between 12.5 and 18 m, but preferred fishing depth differed significantly between periods with different levels of juvenile fish recruitment.

Specifically, preferred fishing depth was deeper when juvenile reef fish recruitment was perceived as weak as opposed to strong ($U = 422.0$; $p < 0.05$; $n = 45$; adjusted for ties; Table 1). Fishers also adjusted their fishing choices in response to weak juvenile fish recruitment (Table 2). Of the 21 fishers who indicated they were affected by weak juvenile fish recruitment, those with 11–15 years experience were most affected and most commonly stated they collected larger, older fish as a response. "Other" responses in Table 2 included: collected more variety (n = 1), collected in shallows (n = 1), caught less fish/made less money (n = 3), fewer trips that were farther distance (n = 1), too new to be affected (n = 1).

The depth at the collection sites included in our *in situ* catch analyses ranged from 13.7 to 27.4 m. Preferred habitat for collecting fish was located in deep coral-rich habitat with finger (*Porites compressa*), lobe (*P. lobata*), and mixed coral, as well as in uncolonized rubble, which is found at depths between 8 and 30 m (Ortiz and Tissot, 2008). Over a total of 45 fishing hours, the five divers observed in 2007 and two divers observed in 2008 collected 4611 fish, a cpue of ~100 fish per dive-hour. The most commonly targeted family of fish was the Acanthuridae, constituting 89% of the total catch. Yellow tang alone made up 69% ($n = 3200$) of the total catch. Acanthurids remained the most commonly targeted family of fish even with yellow tang excluded from the analysis, constituting 65% of the remaining catch. Some 75% of these acanthurids were *Ctenochaetus strigosus*, with *Naso lituratus* and *Acanthurus nigrofuscus* each yielding an additional 16%. The remaining catch consisted of Pomacentridae (12%), Chaetodontidae (8%), Labridae (7%), and other families (7%). Only three principally corallivorous fish were collected: speckled butterflyfish (*Chaetodon multicinctus*; $n = 32$), ornate butterflyfish (*C. ornatissimus*; $n = 1$), and fourspot butterflyfish (*C. quadrimaculatus*; $n = 1$). Fishers frequently released unwanted species underwater at the collection sites; such fish included ornate butterflyfish, saddle wrasses (*Thalassoma duperrey*), agile chromis (*Chromis agilis*), brown surgeonfish (*Acanthurus nigrofuscus*), and larger chevron tangs (*Ctenochaetus hawaiiensis*), longnose butterflyfish (*Forcipiger* sp.), yellow tang, and goldring surgeonfish. When the relative importance of the fish caught was compared with their abundance on the reef, psychedelic wrasse (*Anampses chrysocephalus*), goldrim surgeonfish (*Acanthurus nigricans*), Hawaiian domino damselfish (*Dascyllus albisella*), and yellow tang had the highest values of electivity (Table 3).

The mean standard length for the yellow tang caught was 6.1 cm (Table 3, Figure 3). Additionally, yellow tang caught during November 2008 were significantly smaller (mean = 5.92 cm; $n = 2382$) than those caught during June/July 2007 (mean = 7.78 cm; $n = 251$; $H = 296.1$; $p < 0.001$; $n = 2633$). Yellow tang harvested during November 2008 were bimodally distributed with the two modes at 5.0 cm and 8.5 cm. Mortality and discarded fish for observations made during November 2008 over 33 h of fishing effort was <1% ($n = 230$) of the total catch. The total number of discarded fish was 216, primarily *Chromis agilis* (53%), *Zebrasoma flavescens* (16%), and *Acanthurus nigrofuscus* (15%). All discarded fish were either commercially unimportant (e.g. *Chromis agilis*), blemished (e.g. natural discolouration and deformation, or laden with parasites), or injured (e.g. fin damage). Mortality was observed in *Dascyllus albisella* ($n = 7$), *Zebrasoma flavescens* ($n = 4$), *Centropyge loriculus* ($n = 1$), *Ostracion meleagris* ($n = 1$), and *Halichoeres ornatissimus* ($n = 1$) on the boat after the fish were decompressed.

Fishers with 0–5 and 21+ years of fishing experience were the two most common groups reporting they collected fish deeper in response to weak juvenile fish recruitment. Mean fishing effort per fisher remained constant between 2002 and 2007 at approximately 11 dives per week. In 2002 and 2007, the estimated mean time per dive was 45 and 52 min, respectively.

Job satisfaction

Fishers were extremely satisfied (*n* = 3), satisfied (*n* = 12), or held neutral opinions (*n* = 6) regarding their level of income earned from the fishery; none were dissatisfied or strongly dissatisfied. Of the fishers surveyed, 71% indicated they would not exit the aquarium fishery if training for another job that was equally profitable were provided. The difference between those fishers who would versus would not exit the fishery with job training was significant ($H = 12.27$; $p < 0.001$; $n = 21$). Fishers with 0–5 years of fishing experience were most willing to exit the fishery with training for another job that was equally profitable, whereas fishers with 21+ years of experience were least willing (Figure 4). The difference between respondents who would encourage versus not encourage younger fishers to enter the fishery was significant ($H = 15.75$; $p < 0.001$; $n = 23$), and regulations, conflict, competition, and initial start-up costs were reasons given for not encouraging newcomers. Fishers with 16–20 and 21+ years experience had a stronger proportional response for encouraging younger fishers to enter the fishery (Figure 4). Finally, the most consistent responses for what fishers liked most about their occupation included autonomy and exposure to nature, whereas bureaucracy, conflict, and poor industry reputation were the most consistent responses for what they liked least (Table 4).

Discussion

To our knowledge this is the first in-depth study investigating the fleet dynamics for any marine aquarium fishery. Our findings demonstrate that the decisions fishers make regarding the number of divers, operating depth, technology used, and fishing methods deployed may influence catch productivity in West Hawaii’s aquarium fishery. Additionally, fishers selectively target coral-friendly species such as yellow tang for the marine ornamental fish trade. Finally, fisher job satisfaction remained high despite declining yellow tang abundance, and fishers with more experience are less likely to exit the fishery. To that end, we now discuss the implications of our findings regarding catch productivity and selectivity for yellow tang in West Hawaii, and then explore the broader implications of our study for global aquarium fisheries.

Harvesting methods and efficiencies

The adoption of new technologies and equipment for catching fish can improve a fleet's catch efficiency (Branch *et al*., 2006; Marchal *et al*., 2007; Salas and Gaertner, 2004). The use of GPS by aquarium fishers in West Hawaii likely started during the past decade when the technology became more readily available and affordable, and GPS is used by some members in the fleet to chart areas and to mark desirable locations to fish the reef systematically. Robins *et al*. (1998) found that fishers increased their catch efficiency by 2 or 3% each year that they used GPS technology for the first three years, and increased fishing efficiency by 12% over five years, despite effort reductions of 39% in a prawn fishery in northern Australia. The increasing use of GPS among fishers in the West Hawaii fishery, revealed by our post-survey interviews, may therefore also result in increasing fishing efficiency. Similarly, studies have shown that using nitrox increases bottom time and extends scuba operating days by shortening diver recovery time (Mastro and Dinsmore, 1989). The increasing use of nitrox in West Hawaii increases the overall bottom time of fishers and likely contributes to increased catch.

Fishers are often exceptionally knowledgeable about the behavioural characteristics of their target species (Johannes *et al*., 2001; Moreno *et al*., 2007). In West Hawaii, juvenile yellow tang show strong habitat preferences for finger coral (Ortiz and Tissot, 2008), making them susceptible to capture in high densities even when overall abundance is low (Hilborn and Walters, 1992). Using a dive mask, underwater viewing scope, or scooter to locate yellow tang decreases search time and hence increases a fisher's catch efficiency. Some aquarium fishers have learned to capitalize on juvenile yellow tang that avoid swimming over sand patches by laying materials that mimic sand over the reef to prevent the fish from taking refuge in the coral. This improves a fisher’s ability to move fish underwater and into their nets. The extent to which fishers have learned to use these behavioural characteristics of yellow tang is therefore likely to have a strong potential to affect catch efficiency.

The sale-invoice analysis revealed that fishing team size has a significant effect on catch rates in West Hawaii’s aquarium fishery, because larger teams augment processes associated with searching, setting net (net management), and moving and corralling fish. Additionally, this is the first time that differences in the net designs applied in aquarium fish collections (cross- vs. multiple-net designs) have been documented for the West Hawaii fishery. It is uncertain if the multinet design is more efficient at catching fish because more fishers are generally needed to deploy it, or if having multiple nets decreases its efficiency. Future studies examining the differences in catching power between these methods may well be fruitful, because catching power may vary significantly.

The cumulative effects of adopting new technology and equipment, acquiring knowledge about target species behaviour as experience is gained, and variation in fishing team size have likely influenced catch efficiency and hence catch rates. These dynamics will likely change over time and influence overall catch productivity as fisher turnover rates fluctuate.

Effort allocation

Understanding fishing-effort allocation is important for effective fisheries management (Hilborn, 1985). In dive fisheries, effort is usually associated with physical limitations, such as ability and willingness to take risks (Béné and Tewfik, 2001). Nitrogen accumulation in fishers is a risk associated with fisheries requiring scuba, and these risks limit fishing effort. Therefore, it was not surprising that fishing effort, measured as the number of dives per week, remained stable between 2002 and 2007. Because of these limitations, it also appears unlikely that changes in fishing effort will influence future catch rates significantly in West Hawaii's aquarium fishery, unless new methods or technologies allow fishers to overcome the physical limitation associated with conventional scuba diving.

An interesting adaptation of fishers to the strength of recruitment of juvenile reef fish was the change of preferred dive depth, with a shift to deeper when juvenile fish recruitment was perceived as weak, particularly among fishers with 0–5 and 21+ years of experience. Recruiting and juvenile yellow tang commonly inhabit deep, coral-rich reefs, sandy rubble, mid-depth reefs, and boulder habitats. They then migrate to shallow turf-rich boulder habitat as they mature (Ortiz and Tissot, 2008; Claisse *et al*., 2009). Deeper water can act as a refuge for juvenile fish and other species commonly targeted in coral reef fisheries (Tyler *et al*., 2009). Shifting reef fish harvesting deeper when recruitment is weak may allow fishers to maintain high catch productivity by increasing their operating area and allowing them to target recruits (as opposed to shallower juveniles) and other species not typically caught. At the same time, this behaviour is likely to affect depth-refuge benefits negatively (Morato *et al.*, 2006). Additionally, fishers mentioned in interviews that newly recruited fish are more sensitive to chemicals used to control parasites and diseases in exporter holding facilities, making them more susceptible to mortality. In turn, post-collection mortality from handling, holding, and shipping in the aquarium fish trade presumably increases fishing pressure, because fishers will harvest more fish to offset losses (Wood, 2001b). As mentioned above, fishers who use scuba are physically limited by the number of dives they can complete safely, so greater post-collection mortality may not encourage fishers to dive more frequently, although it may encourage them to work harder to replace the lost catch the next time they dive, which may influence catch productivity.

A comparison of our results on catch composition with previous state-wide reports in Hawaii shows that catches from the aquarium fishery have become much more specialized on surgeonfish, particularly yellow tang, in the past ten years. Previously, aquarium fishers targeted a more diverse catch, including corallivorous reef fish (Miyasaka, 1994). For example, in the 1970s, surgeonfish and butterflyfish comprised ~40% and ~30%, respectively, of the total catch in Hawaii (W. Walsh, pers. comm.). This stands in stark contrast to the overwhelming importance of yellow tang and other surgeonfish in the catch recorded in this study, with butterflyfish contributing a mere 8% to the catch. This change in relative importance cannot be explained by changes in abundance in the wild, but rather reflects active choice by fishers, as indicated by high positive electivity (i.e. higher relative importance in the catches than the relative abundance on reefs would suggest) for species such as goldrim surgeonfish and yellow tang, and avoidance of species such as *Chaetodon multicinctus*. The electivity data also show that fishing pressure diverges between species. The underlying reason for the shift from butterflyfish to surgeonfish may lie in market dynamics. In particular, one interviewed aquarium fish exporter in Hawaii and one US-based wholesaler stated that home aquarium keepers have shifted away from buying corallivorous reef fish (e.g. ornate butterflyfish) because they are problematic when placed in live coral tanks, which have grown increasingly popular since the mid-1990s (Rhyne *et al.*, 2009). Additionally, fishers told us that soft-bodied fish, e.g.

butterflyfish and angelfish, are more prone to mortality, making the hardier surgeonfish more desirable for aquarium fishers and home aquarium-keepers. The hypothesis that catch composition is strongly influenced by active choice of fishers is further supported by the observation that fishers in our study frequently released certain species underwater immediately after capture, primarily multiband butterflyfish (*Chaetodon multicinctus*) and ornate butterflyfish. The choice for increasingly selecting coral-friendly surgeonfish may explain the amplified number of yellow tang caught in West Hawaii's aquarium fishery over the past decade.

In contrast, not all patterns in catch characteristics observed in this study were determined by fisher choice alone. In particular, a straightforward explanation for the differences in yellow tang size in catches in early summer 2007 and autumn 2008 lies in the recruitment patterns for this species. Fishers preferably target juvenile yellow tang that have grown for at least three months after recruiting to the reef, because this allows the fish to reach market size and increases survivorship in exporting holding facilities. Recruitment of yellow tang is strongly seasonal, with the main peak in late spring and summer (Bushnell *et al*., 2010). This means that fish would reach harvestable size for the first time in autumn, which explains the small mean harvested size in November. By the following spring, these fish would have grown, consistent with the higher mean harvested size of yellow tang then.

Generally, the bulk of catch for most regional aquarium fisheries focuses on a few key species (Wood, 2001a). These species-specific fisheries have greater potential to impact ecosystem functioning than fisheries with a more diverse exploitation strategy (Zhou *et al*., 2010), a concern for marine ornamental fisheries (Rhyne *et al*., 2009). The increasing trend towards selecting herbivorous reef fish to accommodate coral-friendly home aquarium tanks is potentially problematic on a global scale given the international nature of the industry, but particularly in

Hawaii where low abundance of herbivorous reef fish coupled with increased anthropogenic nutrient inputs can facilitate ecological phase shifts (Smith *et al*., 2001; Tissot and Hallacher, 2003). Considering that yellow tang in Hawaii are among the most abundant herbivores on the reefs, and that catches of juveniles for the aquarium fish trade result in declines in adult abundance (Claisse *et al*., 2009), the fishery for yellow tang could ultimately be reflected in declining levels of herbivory. In addition, several larger herbivorous species in Hawaii are overexploited by food fisheries (Williams *et al*., 2008), meaning that the synergistic effects of different fisheries may jointly affect herbivory level.

In this context, sustainability of the aquarium fishery is an important consideration. The significant decline in abundance of yellow tang over the past 12 years in areas open to fishing despite closing ~35% of the coastline to fish harvesting, and the +75% greater abundance of yellow tang inside the MPAs vs. outside underscores the fact that the fishery is having a strong effect on its resource (Williams *et al*., 2009). Unfortunately, despite the increase in fish abundance inside the MPAs, the MPAs may in part be responsible for the decline in the resource, because they concentrate fishers into fewer areas, while increasing (or at least maintaining) pre-MPA fishing pressure by allowing the numbers of fishers to increase over time. At the same time, the resilience of fish populations to continuous fishing appears to be relatively good, considering that reef fish have been harvested for the aquarium trade in West Hawaii for decades. This suggests that the aquarium fishery has the potential to be sustainable if catch levels could be controlled better; however, further biological and socio-economic research in this direction is necessary.

Despite their high value, our finding that few fishers target deep-water species such as *Chaetodon tinkeri* and *Apolemichthys arcuatus* with any regularity is likely explained by the necessity to dive to >60 m to capture these species. Diving at such depths necessitates more logistical planning, can only be performed for short intervals, and incurs greater physical risks that often outweigh the potential benefits. However, if new equipment, e.g. a closed-circuit breathing apparatus or blended gas mixtures, replaces conventional scuba, the accessibility to harvest deep-water species will increase. Population assessments for deep-water fish have not been performed, so it is uncertain if existing fishing pressure is impacting these species.

Job satisfaction

Although fisher income satisfaction was high, nearly all fishers indicated that non-monetary benefits generated from the fishery are what they liked most about their occupation (Table 4). This may explain the retention of older fishers despite the arduous labour associated with the fishery. However, the fact that fishers with 0–5 years of experience were more likely to exit the fishery if training for another job with equal income potential was available suggests that economic stimuli may be more important for newer operators. It is intriguing that despite a 45% decline in yellow tang abundance in areas open to fishing (Williams *et al*., 2009), most fishers are still satisfied with their occupation. This may support the hypothesis that non-monetary benefits and psychocultural needs influence job satisfaction (Anderson, 1980; Pollnac and Poggie, 1988, 2006; Smith, 1981). At the same time, considering that the total catch of yellow tang has not decreased despite their decline implies that the fishery remains profitable. In the end, both monetary and non-monetary benefits from the fishery could be operating synergistically to produce high levels of job satisfaction.

Conclusion

To our knowledge, this is the first study to have investigated fishing fleet dynamics for a marine aquarium fishery. Our results indicate that changes in fleet dynamics can significantly influence catch productivity (i.e. the number of fish caught) and selectivity (i.e. the targeted species). We have shown that aquarium fishers in West Hawaii use and adopted new technology and methods for capturing reef fish, and that dive team size significantly influences catch productivity for yellow tang. Additionally, job satisfaction is high and non-monetary incentives are important to aquarium fishers, which may encourage some fishers to maintain participation in the fishery despite declining fish stocks. Finally, the increased selection of coral-friendly fish by fishers is likely associated with consumer demand that has consequently put greater pressure on surgeonfish and contributed to the increased catch of yellow tang. Although reef fish abundance is significantly greater in the MPAs, it is unlikely that juvenile spillover dynamics have contributed significantly to the increased number of yellow tang caught since their implementation. We also acknowledge that Hawaii experienced exceptionally high juvenile yellow tang recruitment in 2009, which was potentially associated with the MPAs and may have influenced catch rates via replenishment (Christie et al., 2010). We argue that changes in fleet dynamics influenced by fisher behaviour and consumer demands for surgeonfish better explains the discrepancy between increasing catch rates and decreasing relative abundance of yellow tang in areas open to fishing in West Hawaii.

Although our study is regionally focused, the aquarium fish trade is a global industry. Our findings regarding effort allocation and harvesting efficiencies enhance our understanding of factors influencing the harvest of reef fish and therefore have the potential to contribute to the development of appropriate management strategies. In particular, in addition to developing management plans based on reef-fish abundance or fish import/export data for the aquarium trade, our results show that it will be essential to understand how and where fishers operate.

Supplementary material

Supplementary material on fisher response demographics for the 2007 survey effort is available at *ICESJMS* online, as Figure S1.

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References

Anderson, L. 1980. Necessary components of economic surplus in fisheries economics. Canadian Journal of Fisheries and Aquatic Sciences, 37: 858–870.

Béné, C., and Tewfik, A. 2001. Fishing effort allocation and fishermen's decision making process in a multi-species small-scale fishery: analysis of the conch and lobster fishery in Turks and Caicos Islands. Human Ecology, 29: 157–186.

Branch, T. A., Hilborn, R., Haynie, A. C., Fay, G., Flynn, L., Griffiths, J., Marshall, K. N., et al. 2006. Fleet dynamics and fishermen behavior: lessons for fisheries managers. Canadian Journal of Fisheries and Aquatic Sciences, 63: 1647–1668.

Bushnell, M. E., Claisse, J. T., and Laidley, C. W. 2010. Lunar and seasonal patterns in fecundity of an indeterminate, multiple-spawning surgeonfish, the yellow tang Zebrasoma flavescens. Journal of Fish Biology, 76: 1343–1361.

Cesar, H., van Beukering, P., Pintz, S., and Dierking, J. 2002. Economic valuation of the coral reefs of Hawai`i. Final Report. Hawai`i Coral Reef Initiative Research Program. 123 pp.

Christie M. R., Tissot, B. N., Albins, M. A., Beets, J. P., Jia, Y., Ortiz, D. M., Thompson, S. E., and Hixon, M. A. 2010. Larval connectivity in an effective network of marine protected areas. PLoS ONE 5(12): e15715.

Claisse, J. T. 2009. The life history and movements of yellow tang, Zebrasoma flavescens, with implication for fisheries management using protected areas. PhD thesis, University of Hawaii. 148 pp.

Claisse, J. T., Kienzle, M., Bushnell, M. E., Shafer, D. J., and Parrish, J. D. 2009. Habitat- and sex-specific life history patterns of yellow tang Zebrasoma flavescens in Hawaii, USA. Marine Ecology Progress Series, 389: 245–255.

Dulvy, N. K., Sadovy, Y., and Reynolds, J.D. 2003. Extinction vulnerability in marine populations. Fish and Fisheries, 4: 25–64.

Gatewood, J. B., and McCay, J. M. 1990. Comparison of job satisfaction in six New Jersey fisheries: implications for management. Human Organization, 49: 14–25.

Hilborn, R. 1985. Fleet dynamics and individual variation: why some people catch more fish than others. Canadian Journal of Fisheries and Aquatic Sciences, 42: 2–13.

Hilborn, R., and Walters, C. J. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York. 592 pp.

Ivlev, V. S. 1961. Experimental Ecology of the Feeding of Fishes. Yale University Press, New Haven. 302 pp.

Johannes, R. E., Freeman, M. M. R., and Hamilton, R. J. 2001. Ignore fishers' knowledge and miss the boat. Fish and Fisheries, 1: 257–271.

Lechowicz, M. J. 1982. The sampling characteristics of electivity indices. Oecologia, 52: 22–30.

Marchal, P., Andersen, B., Caillart, B., Eigaard, O., Guyader, O., Hovgaard, H., Iriondo, A., et al. 2007. Impact of technological creep on fishing effort and fishing mortality, for a selection of European fleets. ICES Journal of Marine Science, 64: 192–209.

Mastro, S. J., and Dinsmore, D. A. 1989. The operational advantages of enriched air nitrox versus air for research diving. Marine Technology Society Journal, 23: 42–46.

Maunder, M. N., Sibert, J. R., Fonteneau, A., Hampton, J., Kleiber, P., and Harley, S. J. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES Journal of Marine Science, 63: 1373–1385.

Miyasaka, A. 1994. Status report, aquarium fish, collections, fiscal year 1993–1994. Division of Aquatic Resources, Department of Land and Natural Resources, Honolulu. 8 pp.

Miyasaka, A. 1997. Status report, aquarium fish, collections, fiscal year 1994–1995. Division of Aquatic Resources, Department of Land and Natural Resources, Honolulu. 10 pp.

Morato, T., Watson, R., Pitcher, T. J., and Pauly, D. 2006. Fishing down the deep. Fish and Fisheries, 7: 24–34.

Moreno, G., Dagorn, L., Sancho, G., and Itano, D. 2007. Fish behavior from fishers' knowledge: the case study of tropical tuna around drifting fish aggregating devices (DFADs). Canadian Journal of Fisheries and Aquatic Sciences, 64: 1517–1528.

Ogawa, T., and Brown, C. L. 2001. Ornamental reef fish aquaculture and collection in Hawaii. Aquarium Sciences and Conservation, 3: 151–169.

Ortiz, D. M., and Tissot, B. N. 2008. Ontogenetic patterns of habitat use by a coral reef fish in a marine protected area network: a multi-scaled remote sensing and in-situ approach. Marine Ecological Progress Series, 365: 217–232.

Pollnac, R. B., and Poggie, J. J. 1988. The structure of job satisfaction among New England fishermen and its application to fisheries management policy. American Anthropologist, New Series, 90: 888–901.

Pollnac, R. B., and Poggie, J. J. 2006. Job satisfaction in the fishery in two southeast Alaskan towns. Human Organization, 65: 329–339.

Pollnac, R. B., and Poggie, J. J. 2008. Happiness, well-being and psychocultural adaptation to the stresses associated with marine fishing. Human Ecology Review, 15: 194–200.

Randall, J. E. 1987. Collecting reef fishes for aquaria. In Human Impacts on Coral Reefs: Facts and Recommendations, pp. 29–39. Ed. by B. Salvat. Antenne Museum E.P.H.E., French Polynesia. 253 pp.

Robins, C. M., Wang, Y. G., and Die, D. 1998. The impact of global positioning systems and plotters on fishing power in the northern prawn fishery, Australia. Canadian Journal of Fisheries and Aquatic Sciences, 55: 1645–1651.

Rhyne, A., Rotjan, R., Bruckner, A., and Tlusty, M. 2009. Crawling to collapse: ecologically unsound ornamental invertebrate fisheries. PLoS ONE, 4: e8413.

Salas, S., and Gaertner, D. 2004. The behavioral dynamics of fishers: management implications. Fish and Fisheries, 5: 153–167.

Smith, C. L. 1981. Satisfaction bonus from salmon fishing: implications for management. Land Economics, 57: 181–196.

Smith, J. E., Smith, C. M., and Hunter, C. L. 2001. An experimental analysis of the effects of herbivory and nutrient enrichment on benthic community dynamics on a Hawaiian reef. Coral Reefs, 19: 332–342.

Tissot, B. N., and Hallacher, L. E. 2003. Effects of aquarium collectors on coral reef fishes in Kona, Hawaii. Conservation Biology, 17: 1759–1768.

Tissot, B. N., Walsh, W., and Hallacher, L. E. 2004. Evaluating the effectiveness of a marine reserve network in Hawaii to increase the productivity of an aquarium fishery. Pacific Science, 58: 175–188.

Tissot, B. N., Walsh, W. J., and Hixon, M. A. 2009. Hawaiian Islands marine ecosystem case study: ecosystem and community-based management in West Hawaii. Coastal Management, 37: 255–273.

Tyler, E. H. M., Speight, M. R., Henderson, P., and Manica, A. 2009. Evidence for a depth refuge effect in artisanal coral reef fisheries. Biological Conservation, 142: 652–667.

Walsh, W. J., Cotton, S. P., Dierking, J., and Williams, I. D. 2004. The commercial marine aquarium fishery in Hawai‘i 1976–2003. In Status of Hawai`i’s Coastal Fisheries in the New Millennium, revised, pp.132–158. Ed. by A. M. Friedlander. American Fisheries Society, Hawaii Chapter, Honolulu. 230 pp.

Wilen, J. E., Smith, M. D., Lockwood, D., and Botsford, L. W. 2002. Avoiding surprises: incorporating fisherman behavior into management models. Bulletin of Marine Science, 70: 553–575.

Williams, I. D., Walsh, W. J., Claisse, J. T., Tissot, B. N., and Stamoulis, K. A. 2009. Impacts of a Hawaiian marine protected area network on the abundance and fishery sustainability of the yellow tang, Zebrasoma flavescens. Biological Conservation, 142: 1066–1073.

Williams, I. D., Walsh, W. J., Schroeder, R. E., Friedlander, A. M., Richards, B. L., and Stamoulis, K. A. 2008. Assessing the importance of fishing impacts on Hawaiian coral reef fish assemblages along regional-scale human population gradients. Environmental Conservation, 35: 1–12.

Williams, I. D., Walsh, W. J., Tissot, B. N., and Hallacher, L. E. 2006. Impact of observers' experience level on counts of fishes in underwater visual surveys. Marine Ecology Progress Series, 31: 185–191.

Wood, E. M. 2001a. Collection of coral reef fish for aquaria: global trade, conservation issues and management strategies. Marine Conservation Society, UK. 56 pp.

Wood, E. M. 2001b. Global advances in conservation and management of marine ornamental resources. Aquarium Sciences and Conservation, 3: 65–77.

Zhou, S., Smith, A. D. M., Punt, A. E., Richardson, A. J., Gibbs, M., Fulton, E. A., Pascoe, S., et al. 2010. Ecosystem-based fisheries management requires a change to the selective fishing philosophy. Proceedings of the National Academy of Sciences of the USA, 107: 9485–9489.

Tables and Figures

Table 1: Fisher dive and operating depth preference during perceived strong and weak recruitment years for reef fish in 2007.

Depth (m)	Optimal Recruitment (%)	Suboptimal Recruitment (%)
0 and 12	18.2	13.0
12.5 and 18	72.7	43.5
18.5 and 24	9.1	39.1
> 24.5	0	4.3
N	22	23

Table 2: Fisher responses as a percentage (%) for adjusting to perceived weak juvenile fish recruitment in 2007

Collected fish at deeper depths	26.5%
Collected larger, older fish	20.6%
Depended more on a preexisting, non-fishing job	17.6%
Increased fish collecting intensity	8.8%
Took a new job	5.9%
Sold my boat, property, equipment, or gear	2.9%
Relied on government assistance	2.9%
Relied more on other fisheries	2.9%
Other	11.8%
N	21

Table 3. Target species size and Ivlev's electivity index values (Ei) from 2007 and 2008 in situ catch analyses.

Species	Mean Standard Length (cm)	Standard Deviation	Range (cm)	n	E*i*
Zebrasoma flavescens	6.1	1.61	3.0 - 12.8	2633	**0.52**
Ctenochaetus strigosus	7.8	1.10	4.0 - 11.5	583	-0.38
Naso lituratus	13.0	3.00	7.5 - 20.0	73	0.18
Forcipiger flavissimus	9.7	1.40	7.5 - 12.5	46	0.36
Dascyllus albisella	9.6	1.20	7.2 - 11.5	35	**0.52**
Acanthurus achilles	8.2	2.0	3.0 - 12.0	34	0.40
Chaetodon multicinctus	7.0	0.90	5.6 - 8.9	20	-0.83
Halichoeres ornatissimus	9.9	1.40	6.8 - 11.5	20	-0.59
Myripristis berndti	13.2	0.80	12.0 - 14.0	17	-0.25
Acanthurus olivaceus	12.2	3.60	8.5 - 21.5	16	0.07
Ctenochaetus hawaiiensis	6.4	6.40	3.5 - 13.0	14	0.07
Anampses chrysocephalus	9.1	1.30	7.3 - 12.0	13	**0.90**
Acanthurus nigrofuscus	7.1	1.10	5.1 - 9.7	12	-0.94
Acanthurus nigricans	8.4	1.20	7.0 - 10.5	11	**0.53**
Sufflamen bursa	11.4	2.00	7.0 - 13.7	10	-0.48

Table 4. Fishers' stated preference for what they liked most and least about West Hawaii's aquarium fishery in 2007.

Most (%)		Least (%)	
Exposure to nature	25.8	Bureaucracy and conflict	20.7
Autonomy	25.8	Poor industry reputation	17.2
SCUBA diving	12.9	Bad weather	13.8
The challenge	9.7	Poor water conditions	13.8
N	23	N	23

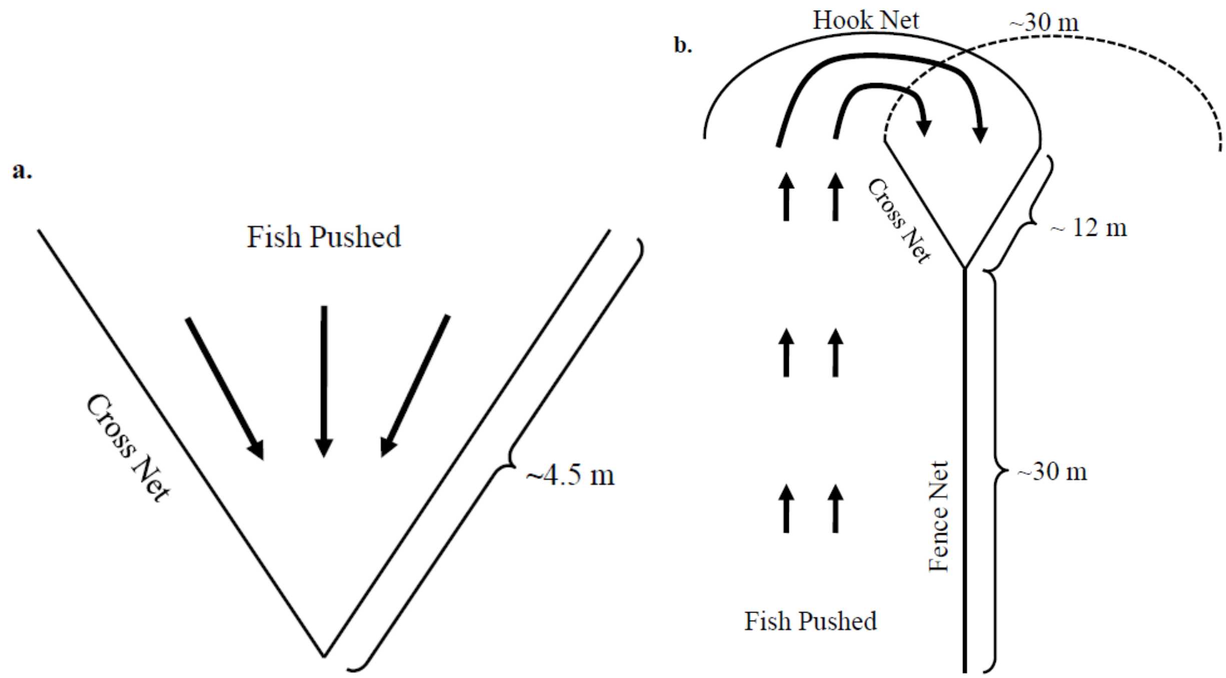

Figure 1. Aerial view of cross net (a) and multiple net (b) designs. The dashed hook net represents the re-set on the opposite cross net end.

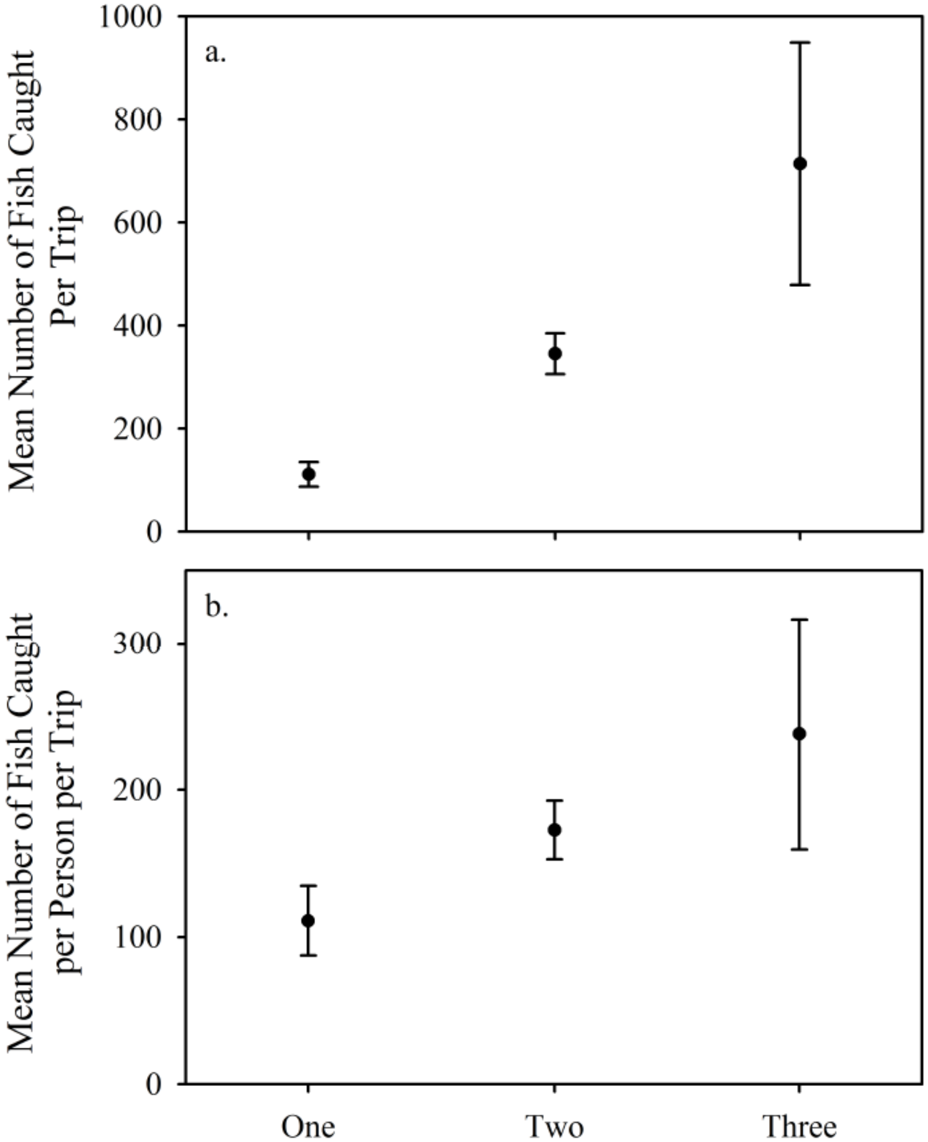

Figure 2. The mean number of yellow tang caught per trip (a) and per person per trip (b) were significantly influenced by the number of divers per fishing team.

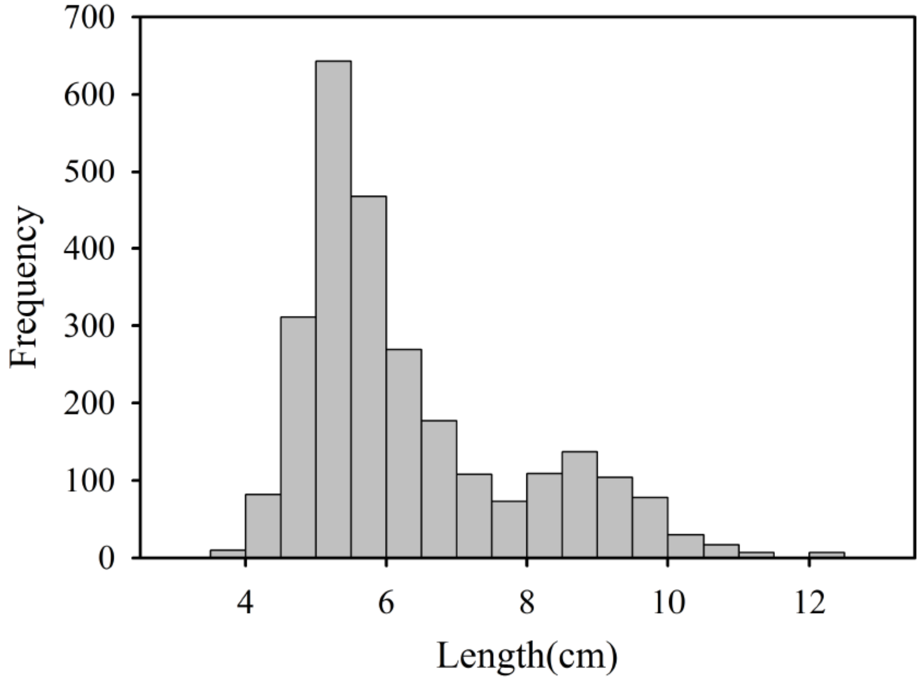

Figure 3. Pooled standard length (cm) and frequency histogram for yellow tang measured during June-July 2007 and November 2008 (n = 2633).

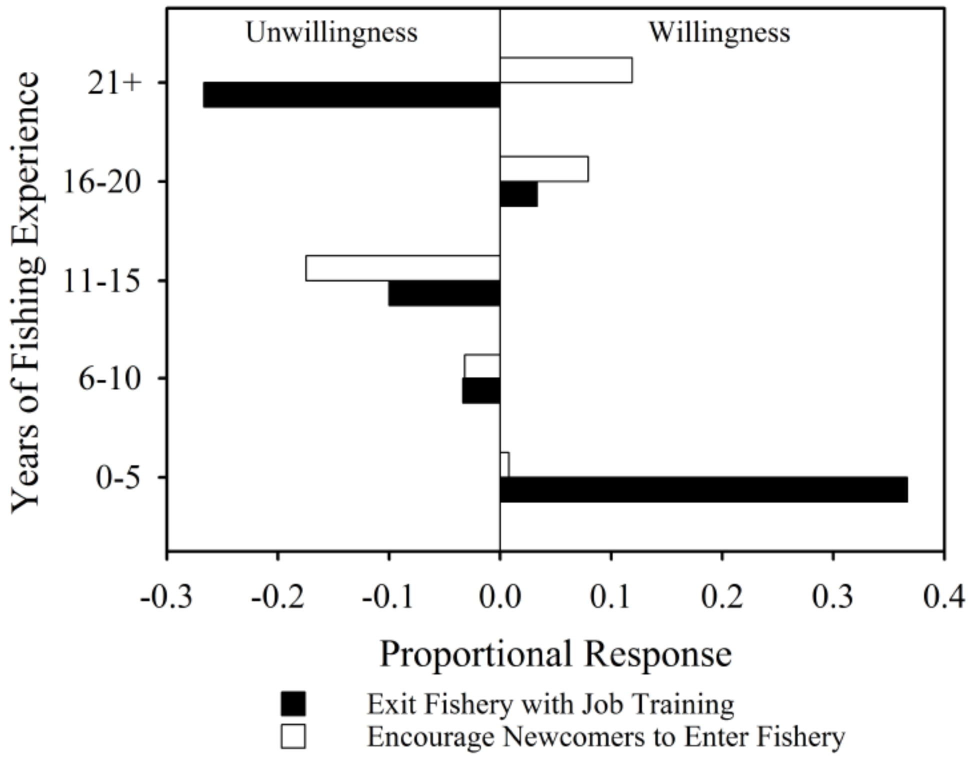

Figure 4. Proportional response of fishers who reported willingness to 1) exit the aquarium fishery in West Hawaii if training for another job with equal income earning potential was provided and 2) encourage new fishers into the fishery by years of fishing experience.

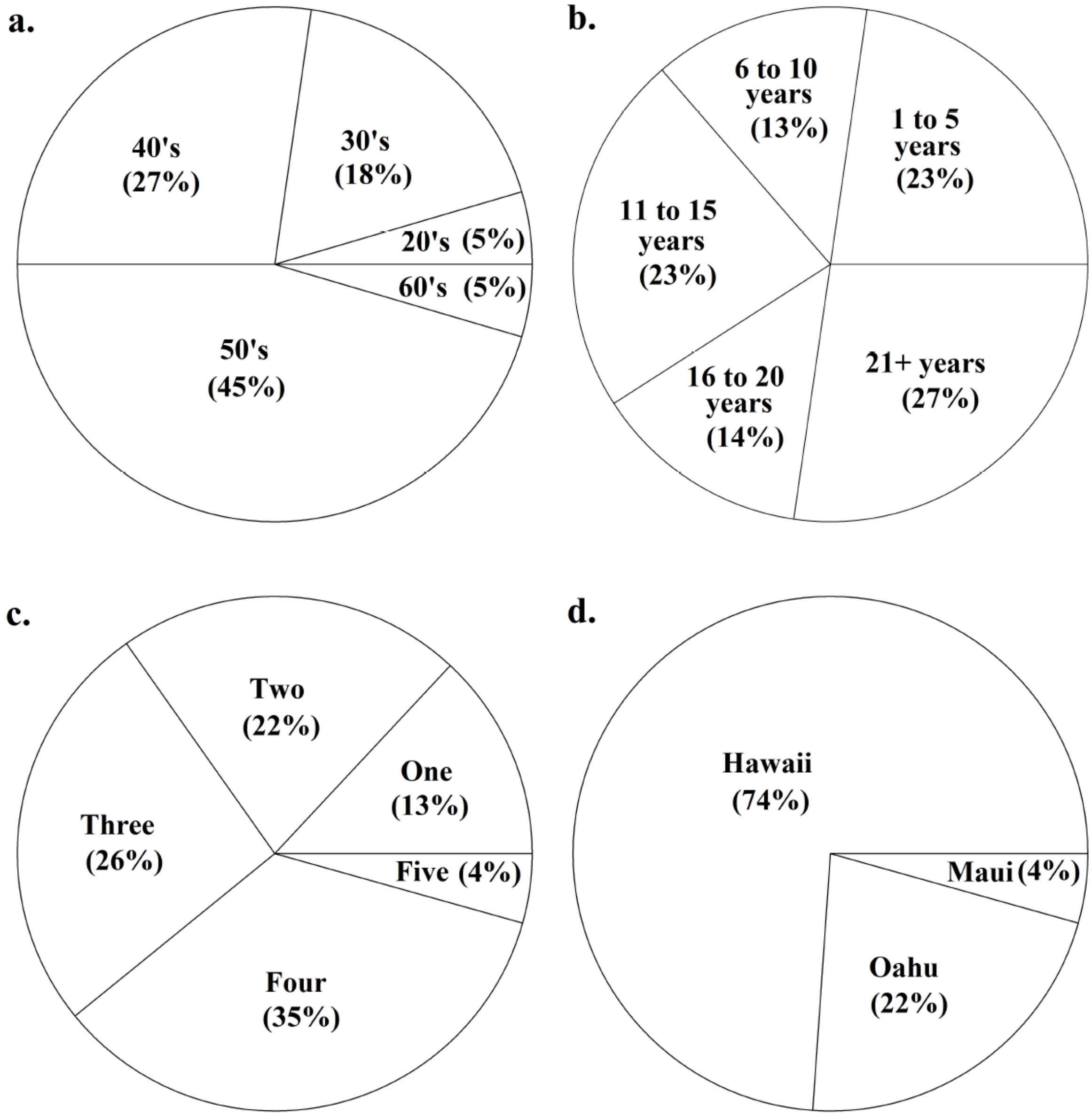

Figure S1: Response demographics for fishers surveyed in 2007 showing: (a) fisher age classes (n = 22); (b) years of fishing experience (n = 22); (c) number of fishing days per week (n = 23); and (d) location of fishing permit acquisition (n = 23).

CHAPTER THREE

SOCIOECONOMIC CONSEQUENCES OF FISHING DISPLACEMENT FROM MARINE PROTECTED AREAS IN HAWAII

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Abstract

Marine protected areas (MPAs) have been implemented across the globe to protect marine biodiversity, critical habitats, and to enhance commercially harvested fish stocks. Although ecological effects of MPAs are well documented, their impacts on fishing communities and the spatial distribution of fishing effort remains elusive and poorly understood. In 1999, a MPA network was implemented to protect against perceived declines of reef fish harvested for the aquarium trade on the island of Hawaii. We investigated how the MPA network altered the spatial distribution of fishing effort and impacted perceived fisher socioeconomic well-being and fishing operations, as well as if the economic and catch benefits offset costs in the newly established non-MPA fishing areas. Data were collected using social surveys, experimental fishing, and catch reports. The results suggest the MPA network significantly displaced fishing effort from the central to the northern and southern coastal regions of the island farther from ports of entry. Estimated catch revenues and experimental catch per unit effort were statistically greater as distance from port of entry increased. Perceived fisher socioeconomic well-being was unaffected, but perceived fishing cost and travel time increased significantly post-MPA network implementation. Although the MPA network displaced fishing effort, fisher socioeconomic well-being was not compromised likely because they expanded their operating range and favorable market factors helped offset potential economic losses. Our findings are relevant because they help clarify how MPA networks alter spatial fishing behavior and impact the well-being of small-scale fishers.

Keywords: Marine protected areas (MPAs); Fishing displacement; Socioeconomic impacts; Marine ornamental fisheries; Spatial fisheries management; Hawaii

1. Introduction

Marine protected areas (MPAs) have been implemented across the globe to protect marine biodiversity and critical habitats and enhance commercially harvested fish stocks (Roberts et al., 2005). The theory for using MPAs to enhance fisheries is that they provide refuge for adult spawning fish that replenish adjacent waters via larval dispersal or adult density dependent movement (Russ et al., 2004). Although the ecological benefits of MPAs are well documented, albeit their efficacy for protecting biodiversity remains controversial (Mora and Sale, 2011), their impacts on fishing communities and social dimensions remain elusive and poorly understood (Masica et al., 2010). Often the process for developing, implementing and managing MPAs is driven by scientists who focus on biological metrics and often put the interests of fishes over the well-being of fishing communities (Christie et al., 2003, Capitini et al, 2004; West et al., 2006; Mascia et al., 2010).

One anticipated outcome of MPAs on fisheries is the displacement of fishing effort post-implementation (Mascia and Claus, 2009; Rassweiler et al, 2012). Several studies have shown that MPAs can affect fishing behavior by reallocating fishing effort to less desirable areas and/or encourage fishers to aggregate near MPA boundaries (Kellner et al., 2007; Stelzenmüller et al., 2008; Forcada et al., 2009). Randomly placed MPAs that are introduced when a fishery is poorly understood can also reduce expected profits (Rassweiler et al, 2012). These responses can consequently influence individual fishers, fisher households, and fishing communities by modifying catch rates, and thus revenue, and encourage conflict as a result of crowding (Charles and Wilson, 2009; Mascia and Claus, 2009, Valcic, 2009). Despite the concern about how MPAs may displace fishing effort and impact the well-being of fishing communities, there have been few empirical studies that actually quantify displacement and the resultant effects (Agardy et al., 2011).

It is estimated that small-scale fisheries employ significantly more people and are more efficient at catching roughly the same amount of fish for human consumption compared to large-scale operations, so the social benefits and environmental impacts from small-scale fisheries are significant (Pauly, 2006). The impacts MPAs have on small-scale fishing communities are of particular concern because these fisheries generally operate within a narrow spatial range in nearshore marine environments and fisher mobility is usually more restricted compared to larger-scale fishers due to smaller vessel size (Garcia et al., 2008). Therefore, small-scale fishers can lose a significant percentage of their fishing grounds when MPAs are implemented (Mascia, 2004); however, if mobility is not a concern, the economic cost of foregone fishing opportunities within MPAs may not be incurred by small-scale fishers since they may offset the loss of access by continuing their activities in non-MPA areas (Mascia, 2004). The number of studies attempting to understand the impacts of management on small-scale fisheries are scant, and as a result understanding how best to manage these fisheries remains rudimentary and data deficient (Salas and Gaertner, 2004; Abernethy et al., 2006; Johnson et al., 2012).

Reef fish harvested for the aquarium fish trade is an example of a small-scale fishery where approximately 30 million wild fish are harvested from tropical coral reef ecosystems annually from 45 countries (Tissot et al., 2010). Many fish harvested for the aquarium trade originate from countries where employment opportunities are scarce and therefore the industry provides an important source of income and employment, particularly in the tropical Pacific (Reksodihardjo-Lilley and Lilley, 2007; Teitelbaum et al., 2010). Most aquarium fisheries are considered small-scale because fishers operate individually or in small groups using snorkel, SCUBA, or hookah equipment on modest boats and conduct day or short overnight fishing trips (Wilhelmsson et al., 2002; Ryan and Clarke, 2005; Stevenson et al., 2011). This study examines the effects an MPA network had on a small-scale live-caught aquarium fishery in Hawaii.

An MPA network was implemented in 1999 on the west coast of the island of Hawaii (hereinafter West Hawaii) to alleviate conflict between aquarium fishers and other marine resource users as well as encourage sustainable marine resource management (Capitini et al., 2004). The network comprised nine fish replenishment areas (FRAs), where take of any reef fish for the aquarium trade was illegal, and when combined with existing MPAs, these FRAs closed 35.2% of the total coastline to aquarium fishing (Tissot et al., 2009). Despite these closures the region's aquarium trade continues to export the largest quantity of reef fish from the state and the price for yellow tang (*Zebrasoma flavescens*), the primary species harvested, increased by an average of 33% since the MPA network was implemented (Tissot et al., 2009). Despite the dramatic increases in yellow tang abundance inside the MPAs, their numbers significantly declined by ~45% between 1999 and 2007 in areas that remained open to fishing (Williams et al. 2009).

The West Hawaii aquarium fishery is one of the State's most lucrative nearshore fisheries (Division of Aquatic Resources, 2010). Aquarium fishers in this region often perform day or short overnight trips, operate individually or in small groups of two or three people, and use SCUBA and barrier nets to capture fish (Stevenson et al. 2011). Most of them are between the ages of 40 and 60 years, have remained active in the fishery for more than 20 years, and fish approximately 3-4 days per week (Stevenson et al. 2011). Although the aquarium fisher population in West Hawaii remains relatively small, it has grown over the years. In 1999 there were 36 people holding aquarium fishing permits, while in 2007 there were ~67 people holding permits [the inconsistent number of people reported holding aquarium fishing permits stated in chapter two was a resulted of the DAR fishing permit database]. The number of issued permits can be misleading for determining the number of "active" aquarium fishers because many people hold unused permits. However, the number of permit holders harvesting ≥ 1000 yellow tang per year either individually or as part of a larger group reporting catch as a single group is much smaller (Williams et al. 2009). For example, in 1999 there were ~19 fishers who reported catching ≥ 1000 yellow tang per year, while in 2007 there were ~39 fishers who qualified under this criterion. Using the Williams et al. (2009) cutoff criterion, the Division of Aquatic Resources (DAR), the state agency responsible for managing the aquarium fishery in Hawaii, estimated there were between 14-17fishers who remained active in the fishery between 1999 (pre-MPAs) and 2007 (post-MPAs), while ~5 fishers left the fishery during this same period.

We investigated whether the MPA network in West Hawaii spatially displaced fishing effort and impacted perceived fisher socioeconomic well-being and fishing operations. Additionally, we investigated whether economic and catch benefits potentially offset costs in the newly established non-MPA fishing areas. The importance of these questions are underscored by recent studies examining similar relationships (Masica et al., 2010; Graham et al., 2011; Christie, 2011; Rassweiler et al, 2012). We believe our results contribute to understanding how MPAs affect small-scale fishing communities and the growing body of literature for managing the global marine aquarium fishery. Additionally, this study is one of few to concurrently examine fishery dynamics in conjunction with socioeconomic indicators to measure how MPAs impact small-scale fisheries.

2. Methods

2.1. Data Collection

Data were collected via social surveys, State fishing reports, and experimental fishing to evaluate how the MPA network influenced fisher socioeconomic well-being and fishing operations, fishing displacement, and estimated spatial-catch revenue relationships, respectively.

2.1.1. Social Surveys

In 2007, post-test surveys were mailed to aquarium fishing permit holders to examine how the MPA network influenced their socioeconomic well-being and fishing operations; however, we were only interested in capturing feedback from the ~39 active fishers reported in Williams et al. (2009), with particular interest on fishers who remained active pre- and post-MPA network implementation. Each permit holder received a questionnaire, letter of purpose, and a self-addressed stamped envelope for returning their completed responses. These surveys packets were mailed by the DAR on behalf of the authors to protect fisher confidentiality.

In addition to mailing the survey packets, non-probabilistic sampling was also employed, which may constrain data inferences but are appropriate for exploratory purposes (Cinner et al., 2012). Because the actual population of active fishers was unknown, but estimated at ~39 people, survey packets were also disseminated using a snowball approach (i.e., chain referral). This approach is ideal for researching sensitive issues involving groups of people who are dispersed and difficult to identify and was performed because there was concern fishers would not respond favorably to mailed questionnaires from the DAR given the historical tension associated with this fishery (Biernacki and Woldorf 1981; Capitini et al., 2004; Maurin and Peck, 2008; Tissot et al., 2009). The completed exploratory surveys complement the catch report analyses detailed below and we do not generalize the findings from these surveys beyond the sampled population.

Fishing activity level was assessed by asking permit holders how often they fished and any respondent indicating they fished at least once per month were classified as "active." The justification for this criterion is based on the assumption that fishers catch ≥ 100 yellow tang per month. This assumption is supported by the following: 1) the average fisher completes 3-4 dives per trip and can average ~100 fish per dive-hour (Stevenson et al., 2011); 2) yellow tang comprise approximately ~80% by number and ~70% by value of aquarium landings from West Hawaii (Williams et al. 2009); and 3) it is not uncommon for fishers to report catching ≥ 1000 yellow tang per month (Williams et al. 2009). This assumption implies fishers harvest ≥ 1200 yellow tang per year, which is similar to the value used by Williams et al. (2009) for defining an "active" fisher. All twenty-three surveys returned were from permit holders who met our "active" fisher criterion. This resulted in a response rate of approximately 59% when using the estimated number active fishers (n=39) identified by Williams et al. (2009).

Five point Likert scale questions were used to evaluate perceived changes in fisher socioeconomic well-being and fishing operations pre- and post-MPA implementation, where responses ranged from much worse to much better. The socioeconomic well-being attributes investigated included fisher health, economic status, occupation, bank savings, and family. These attributes were chosen because MPAs may impact fisher income (Valcic, 2009), which in turn may influence their overall health and well-being (Bloom and Canning, 2000; Pollnac and Crawford, 2000; McBride, 2001; Pomeroy et al., 2007; Graham et al., 2011). These attributes are proxies for socioeconomic well-being that could be influenced by other factors potentially unrelated to the MPA network. The fishing operation attributes investigated included fishing time, cost, success, and distance traveled to fishing sites. These attributes were selected because they can be influenced by MPAs post implementation (Smith and Wilen, 2003; Pomeroy et al., 2007; Charles and Wilson, 2009).

Fishers were also asked to state their fishing and boat launching location preferences along West Hawaii's coastline. We used the term "port" to describe any site where people launch their boats. Understanding these dynamics are important because fishers often operate in close proximity to where they launch (Prince and Hilborn, 1998; Oostenbrugge et al., 2001; Forcada et al., 2009) and MPAs may spatially alter fishing access and often impinge on travel time and operating costs (Mascia and Claus, 2009).

Fishers were also asked what alternative income generating activities they would pursue if they were not aquarium fishing to examine if the economic incentives associated with the fishery are greater than the preferred alternatives. This was assessed using open ended questions and responses were categorized as 1) a trade (e.g., construction, etc.), 2) another fishery, 3) service and retail (e.g., healthcare), or 4) unsure. Income potential plays a role in job retention and it would presumably be counterproductive to exit a fishery if it resulted in downward economic mobility (Carless and Arnup, 2011; Daw et al., 2012).

Lastly, fishers were asked to dichotomously indicate whether they perceived more fish available for harvest at or near the MPA boundaries. Several studies have documented fisher profiles concentrating effort around MPA boundaries to capitalize on adult fish spillover (McClanahan and Kaunda-Arara, 1996; Murawski et al., 2005; Kellner et al. 2007); however, these profiles likely correspond to how specific species respond to closures, which may not apply to a fishery that primarily targets juvenile reef fish like the aquarium fishery.

2.1.2. Fishing Reports

Aquarium fishers are required by State of Hawaii to submit monthly catch reports. When fishers submit their catch reports they indicate the catch reporting zone where they have invested their time fishing (Fig. 1). These reports were used to examine if the MPA network displaced fishing effort before versus after it was implemented. We analyzed the annual total number of fishers reporting per catch zone between 1990 and 2008. Additionally, the change in the mean number of reports by catch zone pre- and post-MPA network implementation was also investigated, where 418 monthly reports were from 1990-1999 (pre-MPA network) and 426 monthly reports were from 2000-2008 (post-MPA network). Fishers who harvest from multiple zones per month were instructed to complete a separate report for each zone. Like most self-reported fishery logbooks, it is speculated there are some discrepancies with the catch reports (Walsh et al., 2004); however, the social surveys examining preferred launching and fishing sites per zone was used to complement the effort allocation catch zone analyses.

2.1.3. Experimental Fishing and Economic Indicators

In 2008, cooperative experimental fishing with aquarium fishers was performed at ten sites along West Hawaii's coast over a ten day period in November. The objective was to determine if estimated catch revenues changed as a function of distance from ports of entry as well as MPA boundary versus non-MPA boundary sites. These sites included five MPA boundary sites and five non-MPA boundary sites spread between West Hawaii's north and south ends. All sites were selected based on the presence of contiguous deep coral-rich habitat with finger (*Porites compressa*), lobe (*Porites lobata*), and mixed coral, as well as in uncolonized rubble at depths between 8 and 30 m. These habitat and depth criteria are preferred by juvenile yellow tang (Walsh, 1984; Ortiz and Tissot, 2008), which is the primary focus of the fishery.

Fishing time was recorded at the beginning of each SCUBA dive and ended upon breaching the water surface. The fish were caught by aquarium fishers using crossnet methods described in Stevenson et al. (2011). We identified and counted the captured fish to the species level on the boat for each dive. Three dives, or fishing efforts, were performed at each of ten sites (n = 30). Experimental catch per unit effort (CPUE) was calculated using the fishing time and number of fish caught per dive. The same two fishers were used at each site to control for variation in catchability. Geographic coordinates were recorded using a GPS system at each moored fishing site and all dives were conducted within a 180 m radius from the boat. ArcGIS was used to measure the average distance between a given port of entry and fishing sites. Estimated catch revenues were calculated on a per dive basis by multiplying the average annual sale price per species in 2008 by the number of species caught in 2008. The average sale price per species was obtained from Hawaii's Division of Aquatic Resources. Fuel expenditures were calculated by multiplying the average fuel consumption rate for the boat used by the daily average retail fuel price for Hawaii County in 2008, and then multiplying that figure by the round trip distance from a port of entry to a fishing site divided by the number of dives per site. The average daily retail fuel price for Hawaii County was obtained from the Oil Price Information Service.

2.2. Data Analysis

Data were analyzed using MiniTab version 15 and results were considered significant at $p < 0.05$. All statistical assumptions were met for each respective test.

2.2.1. Socioeconomic Well-Being and Fishing Impacts

The survey data collected for evaluating how the MPAs impacted fisher socioeconomic well-being and fishing operations were analyzed using a non-parametric one-sample Sign test to determine if the median response by fishers was significantly different from the unchanged response option. This test is appropriate for ordinal data (Siegel, 1988). Because we were interested in understanding how the MPA network influenced these attributes, only responses from fishers who indicated they remained active in West Hawaii's aquarium fishery pre- and post-MPA network were analyzed (n=15).

2.2.2. Fishing Effort Displacement

A two-way ANOVA and two-sample t-tests were used for analyzing the catch report data to determine the interactions and changes in fishing effort allocation before and after the MPA network catch zones, respectively. The level of significance was adjusted for the two sample t-tests to correct for the number of tests performed. The data were transformed using square root transformation to obtain data normality and homoscedasticity.

All survey responses received were analyzed to assess preferred fishing (n=22) and boat launching locations (n=21). Responses were coded using the State's nearshore catch zones that we refer to as "north", "northwest", "west", "southwest", and "southeast" (Fig. 1). The north and northwest zones were grouped because launch sites do not exist in the north but people fish that region. The proportional difference between preferred launching and fishing zones was then calculated. A negative value indicated a preference for launching in a particular zone, while a positive value indicated a preference for fishing a particular zone. Lastly, completed responses from all surveys indicating alternative income generating activities if aquarium fishing was not pursued (n=20) and perceptions about potential fishing opportunities near the MPAs (n=19) were summarized as percentages.

2.2.3. Spatial-Catch Value Relationship and Spatial Analysis

The relationships between estimated catch revenue and experimental CPUE as a function of distance to port of entry were analyzed using linear regression. Experimental CPUE from MPA boundary and non-boundary sites were aggregated and compared using a two-sample t-test. The percentage of coastline designated within an MPA per catch zone and total coastline length were calculated using ArcGIS. The summed MPA portions were divided by respective zone lengths and the overall coastline length to give the proportion of protected area in each zone (Fig. 1).

3. Results

3.1.Socioeconomic Well-Being and Fishing Impacts

Fishing cost and distance travelled were perceived to have significantly worsened while economic status was perceived to have significantly improved post-MPA network establishment (Table 1). All other attributes remained statistically unchanged. Most respondents preferred launching their boats within the west catch zone but preferred fishing in the other three zones, particularly in the two southern regions (Fig. 2). Additionally, the fishers who responded (84%, n=16) did not believe there were more fish available for harvest at or near the MPA boundaries.

Therefore, although 56% of the west catch zone was designated within the MPA network (Fig. 1) and fishers held negative perceptions regarding harvesting opportunities near the MPAs, they continued launching from this zone knowing travel to fishing grounds was likely farther. Lastly, fishers who responded stated they would pursue work in the trades (30%, n=7), another fishery (26%, n=6), or in the service and retail industry (22%, n=5) if they were not aquarium fishing, while others remained uncertain about what they would pursue as alternative income generating activities (22%, n=5).

3.2.Fishing Effort Displacement

A two-way ANOVA showed a significant statistical interaction in fishing effort between catch zones before and after the MPA network was implemented (n = 94, $F = 9.50$, df = 4, 85, $p < 0.001$). Fishing allocation before versus after MPA network significantly increased in the southwest (n = 19, T = -3.13, df = 16, $p = 0.007$) and northwest (n = 19, T = 4.44, df = 15, $p < 0.001$) catch zones, and significantly decreased in the west catch zone (n = 19, T = 3.10, df = 15, $p = 0.007$) (Fig. 3). Therefore, establishing the MPA network redistributed fishing effort from the western catch zone, where the majority of MPAs were implemented to other catch zones in the north and south. These abrupt changes were clearly evident when examined longitudinally (Fig. 4).

3.3.Spatial-Catch Value Relationship

Estimated revenues ($r^2 = 36\%$, F = 15.9, df = 29, $p < 0.001$) (Fig. 5) and experimental CPUE ($r^2 = 26\%$, F= 9.93, df = 29, $p < 0.004$) significantly increased as distance from fishing sites increased from the port of entry. Experimental CPUE and estimated catch revenue were highest at the two most southern sites located within the south catch zone. Estimated revenue equaled fuel expenditures at approximately 60 km from a given port of entry (Fig. 5). Aggregated experimental CPUE was significantly higher (T = -2.57, df = 26, p = 0.016) at non-MPA boundary (~124 fish/hr) versus MPA boundary sites (~84 fish/hr).

4. Discussion

Scientists have recently been concerned with how management actions, such as the implementation of MPAs, influence fishing effort allocation and fisher well-being (Forcada et al., 2009; Kellner et al., 2007; Mascia et al., 2010; Graham et al. 2011; Rassweiler et al., 2012). The establishment of West Hawaii's MPA network was associated with the displacement of fishing effort away from the central fishing zone where the majority of MPAs were established – the same zone containing the largest and most heavily used ports of entry. It does not appear the redistribution of fishing effort negatively impact fishers' perceptions regarding their economic status, bank savings, family, health, or occupation, but fishers believed the MPA network was responsible for increasing fishing cost and distance traveled to fishing sites. The latter point is likely attributed to the fact that fishers prefer launching their boats in the western catch zone but also prefer fishing in other zones, which necessitates increased travel and thus increased cost. This could be explained from the results of our experimental fishing that showed estimated catch revenues and experimental CPUE increased with distance from ports of entry, which may serve as an incentive for traveling farther. However, it does not always make economic sense to travel farther from a given port of entry, as we found estimated revenues and fuel expenditures were equal at approximately 60 km round trip distance from ports of entry; after that point fuel expenditures exceeded estimated revenues.

We empirically showed that the MPA network in West Hawaii displaced fishing effort farther from the western catch zone, which is not surprising given 56% of the coastline within that zone was designated as an MPA (Fig. 1). Many buyers of reef fish caught for the aquarium trade in West Hawaii are located onshore within the western catch reporting zone near the main city of Kailua-Kona and the adjacent international airport. Launching from the western catch reporting zone allows fishers to keep their catch alive while traveling from fishing locations by flushing their live-wells with seawater. Launching from ports farther from Kailua-Kona would necessitate longer travel by land, making seawater replenishment difficult and thus increasing the likelihood of higher fish stress and mortality. This may partially explain why many fishers preferred launching their boats from the western catch reporting zone and why they perceived the MPA network increased travel time and fishing costs. This was validated by a longstanding fisher who claimed the MPA network forced him to travel farther, which increased gas consumption and wear and maintenance on his boat. Increasing travel time could unintentionally encourage careless fishing practices to recover the cost of longer trips and reduce the length of time at sea (McManus, 1997). For example, inadequately decompressing fish, overloading onboard live-wells with fish, poor anchor placements on reefs, and intentional reef destruction/manipulation are practices that may ensue as travel distance increases in live caught fisheries – we speculate these practices could lead to poorer quality of fish, higher rates of fish mortality, and reef damage.

Fishers will often adjust their harvesting strategies to increase their yield when faced with inclement weather, access limitations, and fish price fluctuations in open access fisheries (Wilen, 2004; Kellner et al., 2007; Monroy et al., 2010). In West Hawaii, fishers were displaced by the MPA network but adjusted to this spatial change by expanding their operating range, which allowed them to maintain reasonably high fishery yields (Williams et al., 2009). The idea that CPUE increases farther from port of entry is supported by optimum utilization theory and the "friction of distance" concept, which predicts resources will be exploited more aggressively closest to ports and fishery yields will increase farther from port where harvesting pressure is lower (Gordon, 1953; Caddy and Carocci, 1999).

A concern with displacing fishing post-MPA implementation is the reestablishment and concentration of fishers in new areas, which can encourage resource depletion as well as competition and conflict between fishers (Himes, 2003; Valcic, 2009). Although there is evidence of adult yellow tang spillover and larval dispersal from within West Hawaii's MPA network (Williams et al., 2009; Christie et al., 2010), the gradual decline in their abundance in waters remaining open to fishing implies fishing mortality is likely greater than the rates of replenishment from the network. One West Hawaii aquarium fisher explained how the MPAs did not influence their collection time or success, but fishers were catching fewer fish because they were aggregated into smaller areas and consequently those areas were experiencing intense harvesting pressure. This may have negative implications on the fishing community, fishery resource and ecosystem by inadvertently crowding fishers and encouraging overfishing in areas that remain open (Valcic, 2009).

Although we anticipated the MPA network would impose some negative perceived impacts on fisher socioeconomic well-being, we were unable to detect any support for this assumption. This may be explained by influences from exogenous economic factors and spatial fishing adaptations post-MPA implementation. For example, fishers indicated their economic status significantly improved since the MPA network was implemented. One longstanding fisher stated the rising price in fish elevated his economic status over the years, which he claimed was a result of "price wars" perpetuated by local fish buyers who export the fish off-island. These price wars were potentially influenced by the increased demand for keeping live coral aquarium tanks over the last couple of decades that have resulted in a concurrent increase in the demand for non-corallivorous fishes (Rhyne et al., 2009; Stevenson et al., 2011). The price for yellow tang, a herbivorous fish, increased on average approximately 33% since the MPA network was implemented (Tissot et al. 2009). An increase in fish price will raise the point of optimum fishing effort and consequently acts as an incentive for fishers to expand their operating range into largely unfished, higher-cost areas that could result in higher fish yields (Gordon, 1953; Hilborn and Kennedy, 1992; Prince and Hilborn, 1998). Also, the number of dives per fishing trip in the newly established fishing areas remained relatively constant between 2002 and 2007 and therefore increased fishing intensity unlikely explains the results from the measured socioeconomic well-being indicator (Stevenson et al., 2011). Therefore, the MPA network had a negative impact on distance traveled and cost, but these attributes were perhaps offset by exogenous factors (e.g., price increase for fish), such that the net change for economic status was perhaps constant to marginally positive and thus may have stabilized the other socioeconomic well-being attributes.

Our spatial catch value analysis indicated experimental CPUE and estimated revenues were highest in the southern catch zone, which is one of the zones fishers indicated they were more inclined to fish. An observed increase in the number of fish caught post-MPA implementation could emerge as a result of reallocation of fishing effort (Mascia et al., 2010), as fishers naturally spend more time in the most profitable fishing locations. When access restrictions are placed on these preferred locations, fishers will shift to the next most profitable area (Prince and Hilborn, 1998; Smith and Wilen, 2003). More remote areas with low human population densities, similar to the north and south shorelines of West Hawaii are associated with higher fish biomass on other Hawaiian islands (Williams et al. 2008). Therefore, in addition to changes in fishing tactics that occurred post-MPA network (Stevenson et al., 2011), we conjecture fishers were able to maintain, or potentially increase their fishing yield because the waters where they reallocated effort to were either underexploited or more biologically productive than the pre-MPA fishing sites. It is possible that the redistribution of fishing effort synergistically acted with favorable market forces to influence fisher socioeconomic well-being post-MPA network. This may have helped maintain the largely unchanged perception held by fishers regarding their socioeconomic well-being post-MPA network. The economic factors influencing this fishery are ambiguous due to the global nature of the trade and further investigations to clarify these dimensions are needed.

The ideal free distribution (IFD) concept has been used to predict fishing fleet distribution and assumes fishers have perfect spatial knowledge about the resources, there is no cost to choosing fishing locations, and movement into new neighboring grounds is profitable only when fish abundance on the best ground has dropped to an equal or lower level (Gillis, 2003). Violations in these assumptions could result from changes in fuel costs, difficult terrain, inclement weather, and other factors (Hilborn and Kennedy 1992; Prince and Hilborn 1998; Swain and Wade, 2003). We surmise fishers likely did not operate in the underexploited or more biologically productive areas prior to the MPA network as predicted by IFD fleet movement theory because it incurred a social (e.g., the imposition of being away from home, greater risk of boat damage and safety from unpredictable ocean conditions, etc.) and/or economic cost (e.g., farther travel increases fuel consumption and wear on boat) (Hilborn and Kennedy, 1992). This would imply the MPA network forced the fishers to change their preferred behavior and therefore could be considered an unmeasured social impact. Further investigation to understand these dynamics are warranted.

One goal of West Hawaii's MPA network was to alleviate user conflict between the aquarium fishers and other groups, primarily dive charter operators and the tourism industry. Therefore, the placement of the MPAs was based on both conflict "hotspots" and expert testimony (Capitini et al, 2004). This approach resulted in establishing many of the MPAs within West Hawaii's west catch zone, where high human population densities, tourist infrastructure, and major ports exist. Correspondingly, the other zones were more sparsely populated, less developed, frequented less by dive charter boats and had fewer ports, so conflict was less likely to occur between fishers and other reef user groups in those areas. Therefore, in addition to the abovementioned factors influencing spatial fishing allocation, the lack of conflict in certain zones could have motivated fishers to operate in those zones, which was one objective for establishing the MPA network.

The majority of fishers who responded to our social surveys did not believe fish were more abundant near the boundaries of the MPAs, and we detected significantly lower experimental CPUE near the MPA boundaries when compared to the non-MPA boundaries sites. Fishery managers and scientists often assume fishers will concentrate their effort on or near MPA boundaries, and there is some empirical evidence to support this assumption (McClanahan and Kaunda-Arara, 1996; Murawski et al., 2005; Kellner et al. 2007). In West Hawaii, 7 of the 8 ports are located inside or adjacent to MPAs and the major ports (i.e., Honokoau and Keauhou harbors) are located within the western catch zone - the same zone fishers prefer launching their boats. As mentioned earlier, fishery resources will likely be exploited more aggressively closest to ports and fishery yields will increase farther from port where harvesting pressure is lower. Therefore, it is possible the MPA boundaries were frequently fished given their close proximity to port, making the number of fish available for harvest significantly lower.

Although spillover from the MPAs was shown in adult yellow tang (Williams et al. 2009), juvenile yellow tang, the age class harvested by aquarium fishers in West Hawaii, exhibit high site fidelity and low mobility in habitat dominated primarily by finger coral (Ortiz and Tissot, 2008; Claisse et al., 2009; Stevenson et al., 2011). This suggests spillover near MPA boundaries for targeted fish is likely low, particularly for MPAs where appropriate juvenile habitat does not contiguously extend into fishable waters. Christie et al. (2010) showed that parent populations of adult yellow tang located inside the MPAs replenished areas open to aquarium fishing with larvae across West Hawaii's coast. Therefore, fishery benefits from the MPAs are likely more diffuse due to larval seeding. For these reasons it is unlikely fishers would gain significant benefits by concentrating their effort on or near the MPA boundaries for this particular fishery.

Pollnac et al. (2001) and Béné (2003) argue against the belief held by many researchers and policymakers that fishing is an industry reserved for people from impoverished communities. Their assertion appears true in the case in West Hawaii's aquarium fishery. The results from our ten day experimental fishing likely yielded significant estimated revenues despite unremarkable yellow tang recruitment that year. Based on Hawaii state wage statistics, it is unlikely the income generating alternatives listed by fishers would provide comparable revenue earned from the aquarium fishery (Hawaii Department of Labor and Industrial Relations, Research and Statistics Office, May 2011. <http://hawaii.gov/labor/rs>). Aside from the natural variability that influences harvest potential, aquarium fishers in West Hawaii may sometimes operate at an economic loss due to variable costs associated with fishing sites farther from port, particularly in the southern waters where ports are remote and limited. Fishing these sites may sound irrational, but when the lucrative nature of West Hawaii's aquarium fishery is compared to the alternative income generating options considered by fishers, it becomes clear the opportunity costs for leaving the fishery to pursue the alternative may be too high. Even if fishers occasionally operate at an economic loss, we posit that it still makes long term economic sense for them to maintain their involvement in the fishery as long as the demand for yellow tang remains high and/or the majority of the global yellow tang supply continues to originate from West Hawaii. Additionally, because non-monetary benefits derived from the aquarium fishery are valued by fishers in this region (Stevenson et al., 2011), they will likely be more inclined to take financial risks associated with catch variability to maintain these benefits (Gatewood and McCay, 1990).

There are several limitations with this study that are worth noting. First, it is difficult to preclude whether the stable or slightly improved socio-economic well-being indicators reported by fishers were influenced by other factors. For example, all perceived socio-economic indicators may have increased significantly and fishing operation indicators could have remained unchanged without the MPA network. Using a more robust observational design, similar to the before-after-control-impact design used for collecting the biological data in West Hawaii would have improved our study; however, this would have required collecting social data prior to implementing the MPA network on West Hawaii and on a comparable control sites without an MPA network. Second, we only surveyed active commercial aquarium fishers. Therefore, we did not examine potential impacts the MPA network imposed on fishers who may not have met our "active" fisher criterion or on people who harvest reef fish for recreational aquarium purposes. Third, although there were only five estimated fishers who left the fishery after the MPA network was implemented, they were not sampled and they comprised ~25% of the active fisher population prior to the MPA network implementation. We can only speculate why these people left the fishery, but if it was directly related to the MPA network (e.g., they did not have a large enough boat to accommodate farther travel), it would imply substantial impact on West Hawaii's aquarium fishing community. Lastly, shifts in fishing locations could have resulted from crowding by more people entering the fishery, but it is unlikely given the multiple lines of evidence indicating MPA network involvement.

5. Conclusions

The long term benefits of implementing MPAs are often diffuse and shared by society, while the short term costs are concentrated and often absorbed by fishing communities (Pomeroy et al., 2007). However, the MPA network in West Hawaii displaced fishing effort post implementation without detectable socioeconomic well-being consequences. This is likely because favorable market dynamics worked in conjunction with fishers who were able to shift their effort to lesser exploited or more productive areas to offset potential losses incurred by the MPA network. Although these spatial shifts have put additional pressure on yellow tang and other species in areas remaining open to fishing, additional management strategies such as limited entry, size and species restrictions are under consideration as of this writing. To manage widespread economic hardship on fishing communities and serial resource depletion when MPAs are implemented, it has been recommended that fishing effort be reduced proportionally to the areas considered for closure prior to implementation (Hilborn et al., 2004). This may not always be politically or socially feasible, but it may be appropriate and necessary in some cases.

The findings from our study clearly illustrate spatial impacts MPAs may impose on fishing communities. While there are many anecdotal examples of fishing displacement from MPAs in the literature, there are few empirical studies that document these dimensions. More studies that examine these patterns in conjunction with social impacts from spatial fishing displacement are needed, particularly for communities heavily dependent on commercial or subsistence fishing. Additionally, we believe there is a relevant need to further understand how MPAs influence fisher behavior and fishing practices, and how fisher responses to these management approaches could have direct impacts on target species and their respective habitats. MPAs remain an important tool for fishery management and conservation; however, better planning and forethought on how they affect fishers should be undertaken to avoid inadvertent deleterious consequences that could arise as a result (e.g., crowding fishers into areas post-MPA implementation), particularly for small-scale commercial fisheries operating around islands where intense harvesting occurs.

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References

Abernethy, K., Allison, E.H., Molloy, P.P., and Cote, I.M., 2006. Why do fishers fish where they fish? Using ideal free distribution to understand fisher behaviour of artisanal reef fishers. Canadian Journal of Fisheries and Aquatic Sciences 64, 1595-1604.

Agardy, T., Notarbartolo di Sciara, G., and Christie, P., 2011. Mind the gap: Addressing the short comings of marine protected areas through large scale marine spatial planning. Marine Policy 35, 226–232.

Béné, C., 2003. When fishery rhymes with poverty, a first step beyond the old paradigm on poverty in small-scale fisheries. World Development 36, 945–75.

Biernacki, P. and Waldorf, D., 1981. Snowball sampling: problem and of using nonrandom sampling methodologies. Sociological Methods & Research 10, 141–163.

Bloom, D.E. and Canning, D., 2000. The health and wealth of nations. Science 287, 1207–1209.

Caddy, J.F. and Carocci, F., 1999. The spatial allocation of fishing intensity by port-based inshore fleets: a GIS application. ICES Journal of Marine Science 53, 388–403.

Capitini, C.A., Tissot, B.N., Carroll, M.S., Walsh, W.J., Peck, S., 2004. Competing perspectives in resource protection: The case of marine protected areas in West Hawai‘i. Society and Natural Resources 17, 763–778.

Carless, S.A. and Anrup, J.L., 2011. A longitudinal study of the determinants and outcomes of career change. Journal of Vocational Behavior 78, 80–91.

Charles, A. and Wilson, L., 2009. Human dimensions of Marine Protected Areas. ICES Journal of Marine Science 66, 6–15.

Christie, M.R., Tissot, B.N., Albins, M.A., Beets, J.P., Jia, Y., Ortiz, D.M., Thompson, S.E., and Hixon, M.A., 2010. Larval connectivity in an effective network of marine protected areas. PLoS ONE 5, e15715.

Christie, P. 2011. Creating space for interdisciplinary marine and coastal research: five dilemmas and suggested resolutions. Environmental Conservation 38, 172–186.

Christie, P., McCay, B.J., Miller, M.L., Lowe, C., White, A.T., Stoffle, R., Fluharty, D.L., McManus, L.T., Chuenpagdee, R., Pomeroy, C., Suman, D.O., Blount, B.G., Huppert, D., Eisma, R.L.V., Oracion, E., Lowry, K., Pollnac, R.B., 2003. Toward developing a complete understanding: A social science research agenda for marine protected areas. Fisheries 28, 22–26.

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

Claisse, J.T., 2009. The life history and movements of yellow tang, Zebrasoma flavescens, with implication for fisheries management using protected areas. PhD thesis, University of Hawaii. 148 pp.

Daw, T.M., Cinner, J.E., McClanahan, T.R., Brown, K., Stead, S.M., Graham, N.A.J., and Maina, J., 2012. To Fish or ot to Fish: Factors at Multiple Scales Affecting Artisanal Fishers' Readiness to Exit a Declining Fishery. PLoS One 7, e31460–e31460.

Division of Aquatic Resources, 2010. A Report on the Findings and Recommendations of Effectiveness of the West Hawai`i Regional Fishery Management Area. Report to the Twenty-fifth Hawaii State Legislature, Department of Land and Natural Resources, pp. 1–53.

Forcada, A., Valle, C., Sanchez-Lizaso, J.L., Bayle-Sempere, J.T., and Corsi, F., 2009. Structure and spatio-temporal dynamics of artisanal fisheries around a Mediterranean marine protected area. ICES Journal of Marine Science 67, 191–203.

Garcia, S.M., Allison, E.H., Andrew, N.J., Béné, C., Bianchi, G., de Graaf, G.J., Kalikoski, D., Mahon. R., and Orensanz, J.M., 2008. Towards integrated assessment and advice in small-scale fisheries: principles and processes. FAO Fisheries and Aquaculture Technical Paper. No. 515. Rome, FAO. 84p.

Gatewood, J.B., and McCay, J.M., 1990. Comparison of job satisfaction in six New Jersey fisheries: implications for management. Human Organization 49, 14–25.

Gillis, D.M., 2003. Ideal free distributions in fleet dynamics: a behavioral perspective on vessel movement in fisheries analysis. Canadian Journal of Zoology 81, 177–187.

Gordon, H.S., 1953. An economic approach to the optimum utilization of fishery resources. Journal of the Fisheries Research Board of Canada 10, 442–457.

Graham, N.A.J., Ainsworth, T.D., Baird, A.H., Ban, .N.C., Bay, L.K., Cinner, J.E., De Freitas, D.M., Diaz-Pulido, G., Dornelas, M., Dunn, S.R., Fidelman, P.I.J., Foret, S., Good, T.C., Kool, J., Mallela, J., Penin, L., Pratchett, M.S., and Williamson, D.H., 2011. From microbes to people: tractable benefits of no-take areas for coral reefs. Oceanography and Marine Biology 49, 105–136.

Hawaii Department of Labor and Industrial Relations, Research and Statistics Office, May 2011. < http://hawaii.gov/labor/rs>

Hilborn, R. and Kennedy, R.B., 1992. Spatial pattern in catch rates: A test of economic theory. Bulletin of Mathematical Biology 54, 263–273.

Hilborn, R., Stokes, K., Maguire, J.J., Smith, T., Botsford, L.W., Mangel, M., Orensanz, J., Parma, A., Rice, J., Bell, J., Cochrane, K.L., Garcia, S., Hall, S.J., Kirkwood, G.P., Sainsbury, K., Stefansson, G., and Walters, C., 2004. When can marine reserves improve fisheries management? Ocean & Coastal Management 47, 197–205.

Himes, A.H., 2003. Small-scale Sicilian fisheries: Opinions of artisanal fishers and sociocultural effects in two MPA case studies. Coastal Management 31, 389–408.

Johnson, A.E., Cinner, J.E., Hardt, M.J., Jacquet, J., McClanahan, T.R., and Sanchirico, J.N., 2012. Trends, current understanding and future research priorities for artisanal coral reef fisheries research. Fish and Fisheries, doi: 10.1111/j.1467-2979.2012.00468.x.

Kellner, J.B., Tetreault, I., Gaines, S.D., Nisbet, R.M., 2007. Fishing the line near marine reserves in single and multispecies fisheries. Ecological Applications 17, 1039–1054.

McClanahan, T.R. and Kaunda-Arara, B., 1996. Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology 10, 1187–1199.

Mascia, M.B., 2004. Social Dimensions of Marine Reserves. In Marine Reserves: A Guide to Science, Design, and Use, eds. Sobel, J. and Dahlgren, C. Island Press, Washington, DC.

Mascia, M.B. and Claus, C.A., 2009. A property rights approach to understanding human displacement from protected areas: The case of marine protected areas. Conservation Biology 23, 16–23.

Mascia, M.B., Claus, C.A., and Naidoo, R., 2010. Impacts of marine protected areas on fishing communities. Conservation Biology 24, 1424–1429.

Maurin, P. and Peck, S., 2008. The West Hawai‘i fisheries council case study report. University of Hawai‘i Sea Grant College Program, Honolulu, HI. 32 p.

McBride, M., 2001. Relative-income effects on subjective well-being in the cross-section. Journal of Economic Behavior & Organization 45, 251–278.

McManus, J.W., 1997. Tropical Marine fisheries and the future of coral reefs: a brief review with emphasis on Southeast Asia. Coral Reefs 16, S121–S127.

Monroy, C., Salas, S., and Bello-Pineda, J., 2010. Dynamics of fishing gear and spatial allocation of fishing effort in a multispecies fleet. North American Journal of Fisheries Management 30, 1187–1202.

Mora, C. and Sale, P.F., 2011. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea. Marine Ecology Progress Series 434, 251–266.

Murawski, S.A., Wigley, S.E., Fogarty, M.J., Rago, P.J., and Mountain, D.G., 2005. Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science 62, 1150–1167.

Oostenbrugge, J.A.E., Densen, W.L.T., and Machiels, M.A.M., 2001. Risk aversion in allocating fishing effort in a highly uncertain coastal fishery for pelagic fish, Moluccas, Indonesia. Canadian Journal of Fish and Aquatic Sciences 58, 1683–1691.

Ortiz, D.M. and Tissot, B.N., 2008. Ontogenetic patterns of habitat use by a coral reef fish in a marine protected area network: a multiscaled remote sensing and in-situ approach. Marine Ecological Progress Series 365, 217–232.

Pauly, D., 2006. Towards consilience in small-scale fisheries research. Maritime Studies 4, 7–22.

Pollnac, R.B. and Crawford, B., 2000. Assessing behavioral aspects of coastal resource use. Coastal Resources Center, University of Rhode Island, Narragansett, Rhode Island.

Pollnac, R.B., Pomeroy, R.S., and Harkes, I.H.T., 2001. Fishery policy and job satisfaction in three Southeast Asian fisheries. Ocean and Coastal Management 44, 531–544.

Pomeroy, R.S., Mascia, M.B., and Pollnac, R.B., 2007. Marine protected areas, the social dimension. In FAO Expert Workshop on Marine Protected Areas and Fisheries Management: Review of Issues and Considerations, pp. 149–275. FAO, Rome. 330 pp.

Prince, J. and Hilborn, R., 1998. Concentration profiles and invertebrate fisheries management. In Proceedings of the North Pacific Symposium on Invertebrate Stock Asessment and

Management. Eds. Jamieson, G.S. and Campbell, A. Canadian Special Publication Fisheries and Aquatic Science 125, 187-196.

Rassweiler, A., Costello, C., and Siegel, D.A., 2012. Marine protected areas and the value of spatially optimized fishery management. PNAS 109, 11884–11889.

Reksodihardjo-Lilley, G., and Lilley, R., 2007. Towards a sustainable marine aquarium trade: An Indonesian perspective. SPC Live Reef Fish Information Bulletin 17, 11–19.

Rhyne, A., Rotjan, R., Bruckner, A., and Tlusty, M., 2009. Crawling to collapse: ecologically unsound ornamental invertebrate fisheries. PLoS ONE 4, e8413.

Roberts, C.M., Hawkins, J.P., Gell, F.R., 2005. The role of marine reserves in achieving sustainable fisheries. Philosophical Transactions of the Royal Society B: Biological Sciences 360, 123–132.

Russ, G.R., Alcala, A.C., Maypa, A.P., Calumpong, H.P., and White, A.T., 2004. Marine reserves benefit local fisheries. Ecological Applications 14, 597–606.

Ryan, S. and Clarke, K., 2005. Ecological assessment of the Queensland Marine Aquarium Fish Fishery. A report to the Australian Government Department of Environment and Heritage on the ecologically sustainable management of the Queensland marine aquarium harvest fishery, Department of Primary Industries and Fisheries, Brisbane, Australia, pp. 1–78.

Salas, S., and Gaertner, D., 2004. The behavioral dynamics of fishers: management implications. Fish and Fisheries 5, 153–167.

Siegel S, Castellan NJ. Nonparametric statistics for the behavioural sciences. 2nd edition. Singapore: McGraw-Hill; 1988.

Smith, M.D. and Wilen, J.E., 2003. Economic impacts of marine reserves: The importance of spatial behavior. Journal of Environmental Economics and Management 46, 183–206.

Stelzenmüller, V., Maynou, F., Bernard, G., Cadiou, G., Camilleri, M., Crec'hriou, R., Criquet, G., Dimech, M., Esparza, O., Higgins, R., Lenfant, P., and Pérez-Ruzafa, A., 2008. Spatial assessment of fishing effort around European marine reserves: Implications for successful fisheries management. Marine Pollution Bulletin 56, 2018-2026.

Stevenson, T.C., Tissot, B.N., and Dierking, J., 2011. Fisher Behaviour Influences Catch Productivity and Selectivity in West Hawaii's Aquarium Fishery. ICES Journal of Marine Science 68, 813–822.

Swain, D.P., and Wade, E.J., 2003. Spatial distribution of catch and effort in a fishery for snow crab (Chionoecetes opilio): tests of predictions of the ideal free distribution. Canadian Journal of Fisheries and Aquatic Sciences 60, 897–909.

Teitelbaum, A., Yeeting, B., Kinch, J., and Ponia, B., 2010. Aquarium trade in the Pacific. SPC Live Reef Fish Information Bulletin 19, 3–6.

Tissot, B.N., Best, B.A., Borneman, E.H., Bruckner, A.W., Cooper, C.H., D'Agnes, H., Fitzgerald, T.P., Leland, A., Lieberman, S., Amos, A.M., Sumaila, R., Telecky, T.M., McGilvray, F., Plankis, B.J., Rhyne, A.L., Roberts, G.G., Starkhouse, B., and Stevenson, T.C., 2010. How U.S. Ocean policy and market power can reform the coral reef wildlife trade. Marine Policy 34, 1385–1388.

Tissot, B.N., Walsh, W.J., and Hixon, M.A., 2009. Hawaiian Islands marine ecosystem case study: Ecosystem and community-based management in Hawaii. Coastal Management 37:255–273.

Valcic, B., 2009. Spatial policy and the behavior of fishermen. Marine Policy 33, 215–222.

Walsh, W.J., 1984. Aspects of nocturnal shelter, habitat space, and juvenile recruitment in Hawaiian coral reef fishes. Ph.D. Dissertation, University of Hawaii, p. 118.

Walsh, W.J., Cotton, S.P., Dierking, J., and Williams, I.D., 2004. The commercial marine aquarium fishery in Hawai'i 1976–2003. In Status of Hawaii's Coastal Fisheries in the New Millennium, rev. edn, pp.132–158. Ed. by A. M. Friedlander. American Fisheries Society, Hawaii Chapter, Honolulu. 230 pp.

West, P., Igoe, J., and Brockington, D., 2006. Parks and peoples: The social impact of protected areas. Annual Review of Anthropology 35, 251–77.

Wilen, J.E., 2004. Spatial management of fisheries. Marine Resource Economics 19, 7–19.

Wilhelmsson, D., Haputhantri, S.S.K., Rajasuriya, A., and Vidanage, S.P., 2002. Monitoring the trends of marine ornamental fish collection in Sri Lanka. In Linden, O., Souter, D., Wilhelmsson, D. and Obura, D. (eds.). Coral reef degradation in the Indian Ocean, Status report 2002. CORDIO & University of Kalmar, Sweden. pp. 158 –166.

Williams, I.D., Walsh, W.J., Claisse, J.T., Tissot, B.N., and Stamoulis, K.A., 2009. Impacts of a Hawaiian marine protected area network on the abundance and fishery sustainability of the yellow tang, Zebrasoma flavescens. Biological Conservation 142, 1066–1073.

Williams, I.D., Walsh, W.J., Schroeder, R.E., Friedlander, A.M., Richards, B.L., and Stamoulis, K.A., 2008. Assessing the importance of fishing impacts on Hawaiian coral reef fish assemblages along regional-scale human population gradients. Environmental Conservation 35, 261–272.

Tables and Figures

Table 1: Changes in perceived fishing and socioeconomic indicators in response to MPA network establishment. Bold figures indicates significance at $p < 0.05$.

	Number of Responses				
	Below Median	Equal to Median	Above Median	*p*	Median
Fishing Indicators					
Fishing Time	5	9	1	0.22	3
Distance Traveled	13	2	0	**<0.001**	1
Fishing Success	5	9	1	0.22	3
Fishing Cost	13	2	0	**<0.001**	2
Socioeconomic Indicators					
Economic Status	1	6	8	**0.04**	4
Family	0	10	5	0.06	3
Health	2	10	3	1.00	3
Occupation	1	9	5	0.22	3
Bank Savings	3	6	6	0.51	3

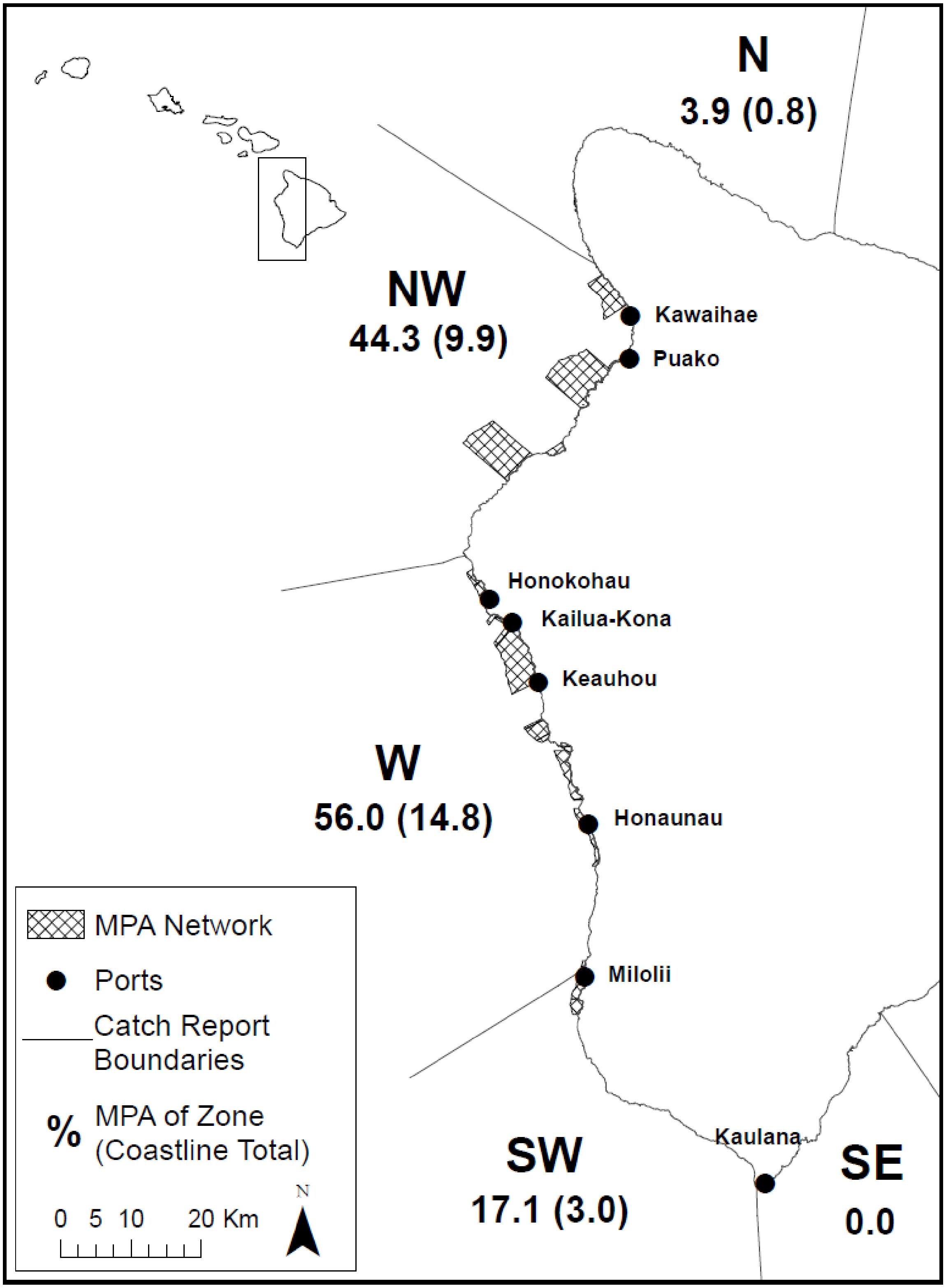

Fig. 1. West Hawaii MPA network, fishery catch reporting zones, port locations, and the percentage of each zone closed to aquarium fishing by MPAs. Percentages shown are the proportions of coastline designated as an MPA relative to zone length and, in parenthesis, the total length of the coastline for all five reporting zones.

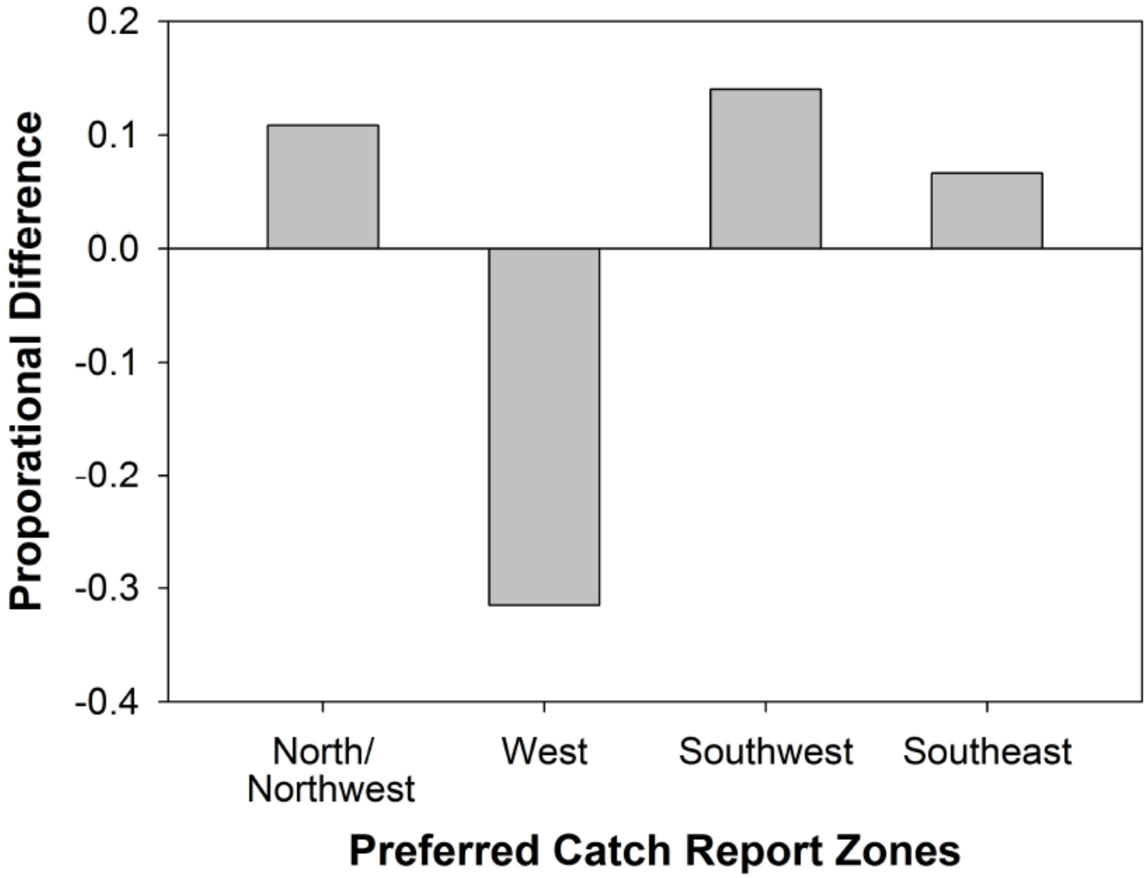

Fig. 2. Proportional difference between where fishers preferred launching their boats versus preferred fishing within a particular catch zone. A negative value indicated a preference towards launching in a particular zone, while a positive value indicated preference toward fishing a particular zone.

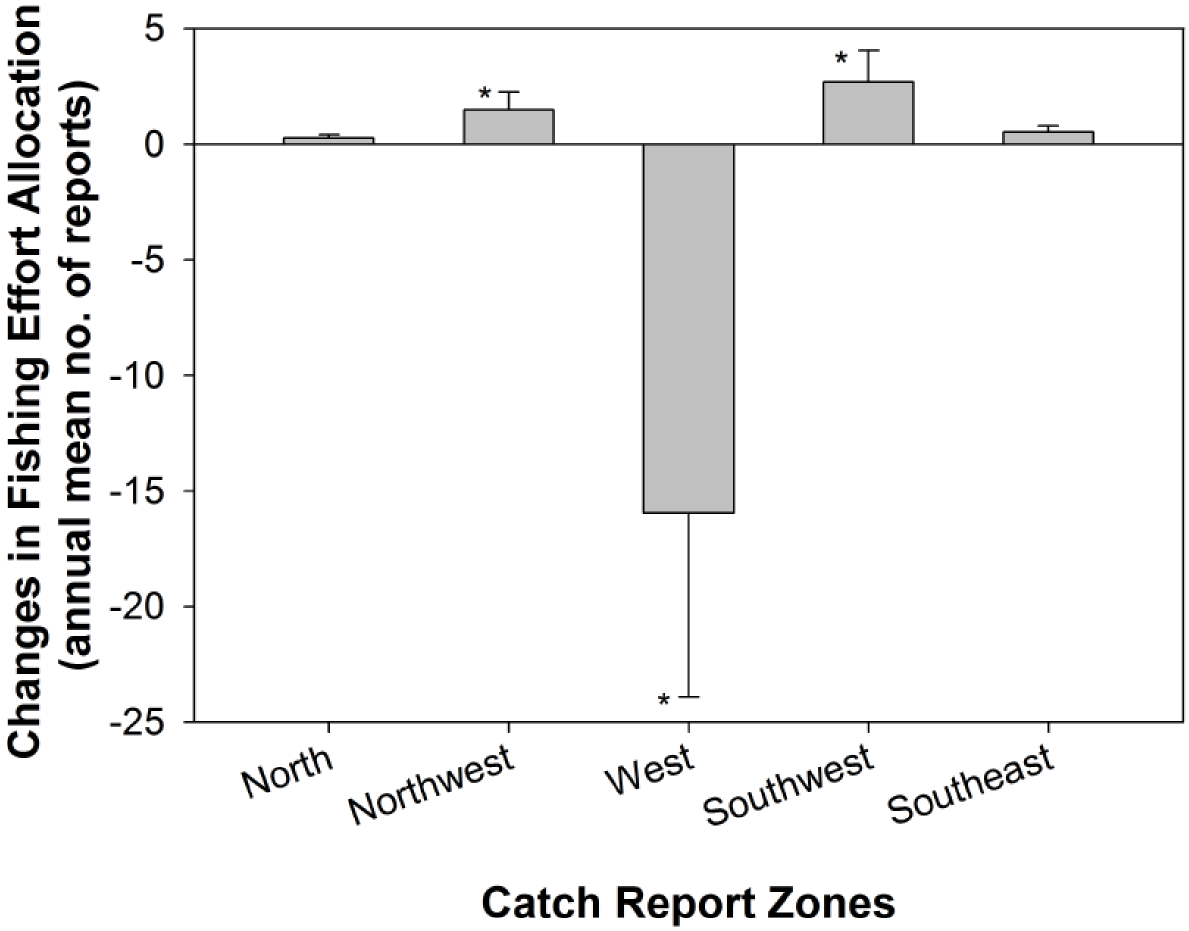

Fig. 3. Change in the annual mean number of reports submitted by fishers before (1990-1999) versus after (2000-2008) the MPA network by catch reporting zone. The asterisk (*****) indicates a statistical significance.

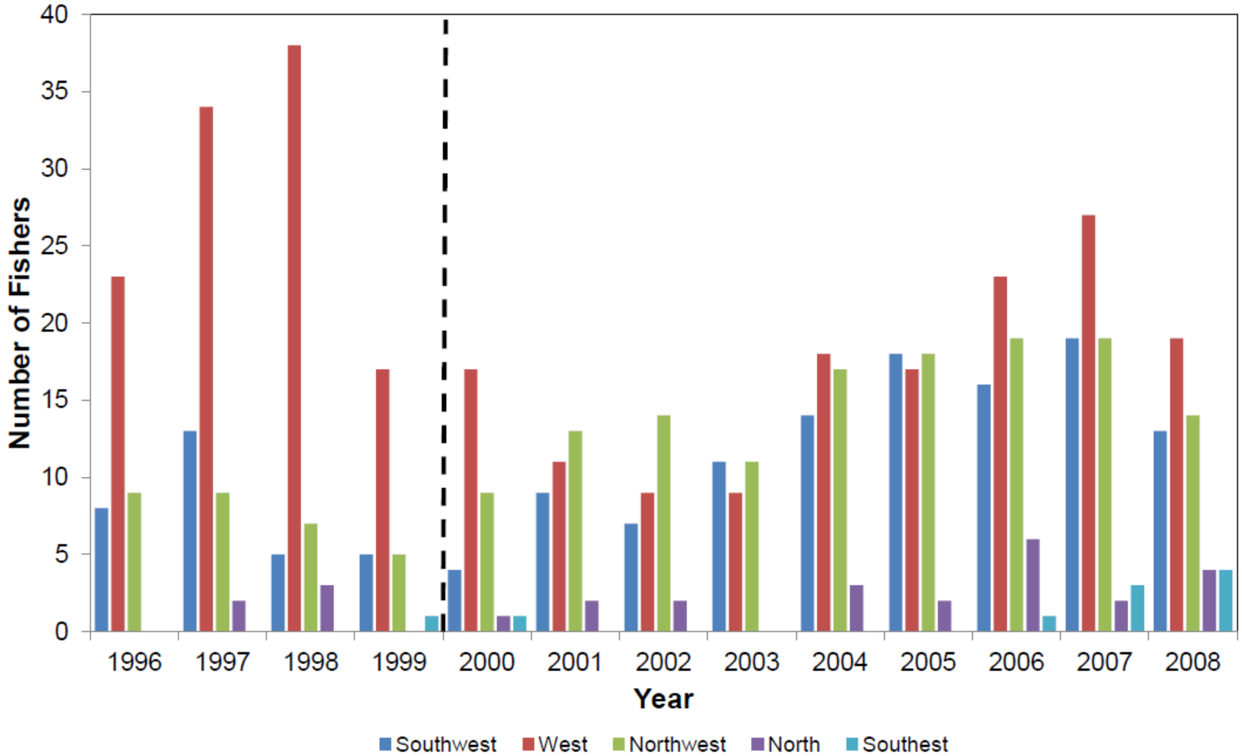

Fig. 4. Longitudinal changes in the number of fishers reporting by catch zone per year in West Hawaii. The dashed line marks the year when the MPA network was implemented and colors correspond to particular catch zones.

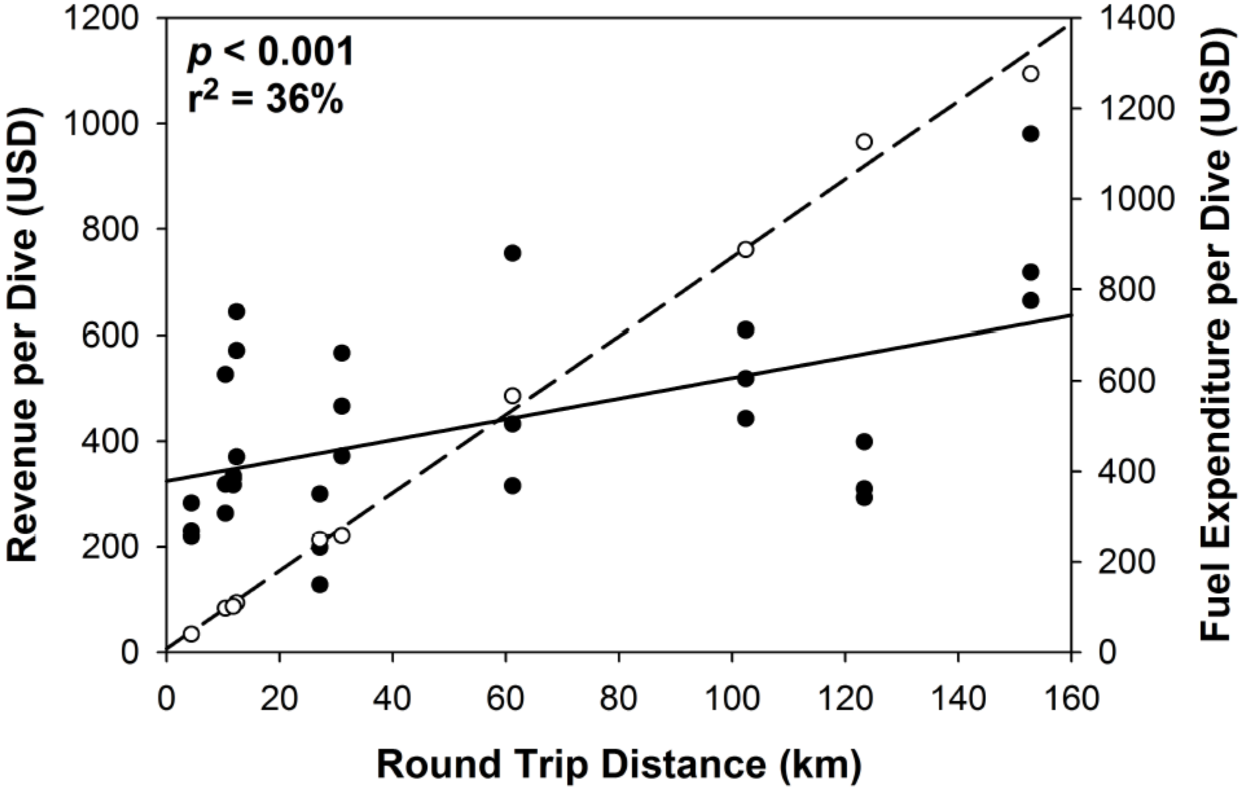

Fig. 5. Estimated catch revenue per dive (**solid line, ●**) increased significantly farther from ports of entry. The sites yielding the highest and lowest revenues were located in the west and southwest catch zones, respectively. Estimated catch revenues and fuel expenditures (**dashed line,** ○) intersected at ~ 60 km round trip from ports of entry. The linear regression values indicate a positive correlation between catch revenues and distance from ports of entry to fishing sites.

CHAPTER FOUR

EVALUATING MARINE PROTECTED AREAS FOR MANAGING MARINE RESOURCE CONFLICT IN HAWAII

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Abstract

Conflict surrounding commercial fisheries is a common phenomenon when diverse stakeholders are involved. Harvesting reef fish for the global ornamental fish trade has provoked conflict since the late 1970s in the State of Hawaii. Two decades later the state of Hawaii established a network of marine protected areas (MPAs) on the west coast of the island of Hawaii ("West Hawaii") to protect and enhance the fish resources and alleviate conflict between stakeholders, principally between commercial dive tour operators and aquarium fishers. The perceptions held by these stakeholders on West Hawaii and Maui were evaluated to understand how MPAs influenced conflict dimensions, as the former location had a well-established MPA network designed to alleviate conflict, while the latter did not. This was accomplished by analyzing the following questions: 1) perceptions about the effectiveness of MPAs to alleviate conflict and enhance reef fish; 2) perceived group encounters and threats to coral reefs; 3) willingness to encourage fishing; and 4) value orientations toward the aquarium fish trade. The results indicate the MPAs in West Hawaii were moderately effective for alleviating conflict, encounters between stakeholders occurred on both islands, dive operators strongly opposed commercial fishing and perceived aquarium fishing as a serious threat to the coral reef ecosystem, and polarized value orientations toward the aquarium fish trade confirms pervasive social values conflict. The conflict between these groups was also asymmetrical. MPAs are inadequate for resolving long term conflict between groups who hold highly dissimilar value orientations toward the use of marine resources. Future marine spatial planning and MPA setting processes should include stakeholder value and conflict assessments to avoid and manage tensions between competing user groups.

Key words: Marine resource conflict, aquarium fisheries, dive tour industry, ornamental fish trade, marine protected areas, Hawaii

1. Introduction

The commercial capture of marine resources has been fraught with conflict since the early part of the 20th century when the participation in commercial fisheries proliferated [1]. Fisheries conflict typologies have focused on describing: who controls fisheries; how fisheries are controlled; relations between fishery users; relations between fishers and other users of the aquatic environment; and relations between fishers and non-fishery issues [2, 3]. Although these typologies are useful for identifying incompatibilities between groups, they do not explain why the incompatibilities occur, which is paramount for understanding when conflict for common pool resources develops at a deeper, more cognitive level [4].

Another approach for examining conflict requires an investigation of social values and interpersonal conflict dimensions. Social values conflict may occur when individuals or groups of people do not share similar norms and values about an activity [5, 6], and it can occur even when there is no physical contact between conflicting individuals or groups [7]. Values serve as the foundation for attitudes and beliefs, where the pattern, direction and intensity of basic beliefs form value orientations toward things such as fish and coral reefs [8, 9]. Vaske et al. [5] empirically described a classic case of social values conflict between wildlife viewers and hunters in Colorado, United States. Despite spatial separation via topography and management regulations, the wildlife viewers simply oppose hunting the animals they enjoyed viewing. This value difference engendered a social values conflict between hunters and wildlife viewers.

Interpersonal conflict may occur when the presence or behavior of an individual or group interferes with the goal of another individual or group [10]. For example, interpersonal conflict may arise when a novice fisher encroaches and disturbs the space of a more experienced one. In this example, interpersonal conflict may occur when two fishers vie for the same resource; one fisher seeks solitude while another seeks company with other fishers; when a more experienced fisher believes the less experienced one may diminish the chance of catching fish. To examine social values and interpersonal conflict more systematically, Vaske et al. [6] suggested researchers evaluate whether opposing groups observe each other while undertaking their respective activity and if they perceive each other as a problem [Fig. 1]. These conflict dimensions have never been quantitatively described between commercial fishers and other stakeholders in Hawaii's nearshore marine environment.

The direction in which conflict occurs is also important. Symmetrical conflict, or two-way conflict, occurs when both groups observe and perceive each other as a problem, while asymmetrical conflict, or one-way conflict, may occur when one group observes the other and perceives them as a problem [11]. Asymmetrical conflict is widely documented between recreational groups, such as between canoeist and motorboaters, hikers and trailbikers, oar-powered and motor-powered whitewater rafters, cross-country skiers and snowmobilers, backpackers and horsepackers, water skiers and anglers, and hunters and wildlife viewers [11].

Many coastal regions in the tropics have experienced a shift away from fishing and trade economies toward tourism-dependent ones. This often pits burgeoning tourism against fisheries in the competition for ocean space and resources [3, 12, 13, 14, 15]. Conflicts between tourism and fishing industries were documented in Jamaica [16], the Philippines [13, 14, 15], Tanzania [17], the Caribbean [12, 18], the Galapagos Islands [19], Australia [20], and the United States [21, 22]. Marine protected areas (MPAs) are an effective tool for protecting biodiversity and important habitats, and enhancing fisheries [23]. More recently, however, MPAs have also been employed as a spatial tactic for separating incompatible user groups [18, 22, 24, 25, 26]. Using MPAs in this context can leave some stakeholders feeling marginalized when they are excluded from areas they commonly use while others maintain access and use benefits [13, 22, 27]. This perceived marginalization can hinder conflict resolution and sometimes inflame tensions, particularly when conflicting party values are unclear or ignored [13, 22, 27]. For example, Oracion et al. [13] describe a situation in which conflict developed between the dive tourism industry and fishers over the perceived economic advantages the former party enjoyed from the implementation of MPAs in the Philippines. Broad and Sanchirico [28] found that groups reliant on tourism are more likely to support spatial management, such as MPAs, because they are seldom excluded from these areas. Although using MPAs may work to alleviate conflict, especially interpersonal conflict, between opposing marine stakeholders, its efficacy has rarely been empirically examined in a marine system.

Harvesting reef fishes for the global aquarium trade involves 45 countries and removes approximately 30 million fish per year from tropical coral reef ecosystems [25, 29]. Conflict between aquarium trade fishers and the tourism sector was reported in Australia [30], Fiji [30], Maldives [25] and Hawaii [22], with overharvesting reef fish populations as the most common complaint [30]. Bruckner [31] suggested using spatial zoning and closures for managing multiple stakeholder conflicts when associated with marine aquarium fisheries, which was done in Hawaii.

The aquarium fish trade in Hawaii started on Oahu in the 1950s and rapidly expanded to other islands in the 1970s, with the largest share of the annual catch originating from the west coast of the island of Hawaii (hereinafter "West Hawaii") [32]. Conflict between aquarium fishers and other stakeholders in Hawaii as a result of perceived overharvesting of reef fishes was first documented in 1978 [33]. The conflict nearly erupted into violence in the late 1990s before the public pressured the state to intervene [34]. In July 1998, the State of Hawaii passed House Bill 3457, which upon approval became known as Act 306, and called for management to ensure resource sustainability, enhance nearshore fish resources, and minimize conflicts [34]. Act 306 resulted in the designation of the entire 235 km of West Hawaii's coastline as a Fishery Management Area, and later allowed for the creation of nine MPAs (regionally termed Fish Replenishment Areas). These MPAs prohibited the harvest of reef fish for the aquarium trade along ~35% of the coastline, which included ~7.4% of coastline previously protected. In 1997, Tissot and Hallacher [35] observed significant depletions in West Hawaii reef fish in areas where aquarium fishing occurred, suggesting that MPAs might assist in recovery of fish populations. Act 306 also authorized the creation of the West Hawaii Fisheries Council, a volunteer community advisory group established to receive community input on co-managing nearshore fisheries with state fishery managers [22, 36]. These accomplishments were the result of a collaborative effort between the State's Division of Aquatic Resources (DAR), the dive tourism sector, nonprofit organizations, aquarium fishers, academics, residents, and other stakeholders.

More recently, hard-line animal rights activists from Maui attempted to ban, or severely restrict the aquarium fishery using multiple state legislative bills that were subsequently rejected [37, 38]. However, unlike on West Hawaii, where there are approximately 40 active aquarium fishers [39], state records report ≤ 5 active aquarium fishers on Maui [40] and the coastal MPA spatial coverage around Maui is < 2% [41]. Animal rights activists vehemently oppose the trade despite the small size of the fishery and the lack of any direct evidence suggesting it is a serious threat to the island's marine ecosystem [42].

Here, the effect of MPAs on the dimensions of conflicts between aquarium fishers (hereinafter "fishers") and dive operators on West Hawaii and Maui are examined by investigating the following questions: 1) Do fisher and dive operator perceptions on West Hawaii differ regarding the effectiveness for MPAs to alleviate conflict and enhance reef fish populations?; 2) Do fisher and dive operator perceptions differ on West Hawaii and Maui regarding encounters with the opposing group and threats to coral reefs?; 3) Are fishers and dive operators on Maui and West Hawaii equally willing to encourage recreational, subsistence, and/or commercial fishing?; and 4) Do dive operators and fishers on West Hawaii and Maui hold similar value orientations toward the aquarium fish trade? These stakeholders were selected as research subjects not only because there is a history of conflict between fishers and dive operators on West Hawaii [22, 34, 43], but also because they both exploit reef fish for commercial purposes: fishers generate revenue from harvesting the resource, while dive operators generate revenue from clients who come to observe the resource. Focusing on these stakeholders does not negate the importance of others in Hawaii's coastal marine ecosystem. To our knowledge, this is the first attempt to empirically evaluate whether MPAs are an effective tool for improving values conflict between two commercial entities, such as commercial fishers and dive operators. This research contributes significantly to the understanding of conflict dimensions related to MPAs, coastal resource management, and the global aquarium fish trade.

2. Methods

2.1. Data Collection

Data were collected through two distinct survey instruments disseminated to fishers and dive operators on West Hawaii and Maui. The lack of a sampling frame required the employment of several purposive sampling methods. This approach may constrain data inferences but is appropriate for exploratory purposes [44]. The findings from these exploratory endeavors are not generalized beyond the sampled population. Dive operators were classified as boat captains and crew who worked at a commercial outfitter providing recreational SCUBA and snorkel experiences to clients.

The objective of the first survey instrument was to evaluate stakeholder perceptions regarding the effectiveness of the MPAs on West Hawaii for alleviating conflict and enhancing reef fish abundance. The DAR mailed the first survey to fishers on West Hawaii during the summer of 2007. The objective was to obtain responses from the ~39 active fishers previously reported [39]. Each permit holder received a questionnaire, letter of purpose, and a self-addressed stamped return envelope. Snowball sampling (or chain referral sampling) was also used to augment the mailed questionnaires because the actual active fisher population was only an estimate and there was concern fishers might not respond favorably to receiving inquiries from the DAR, given the history of conflict surrounding this fishery [22, 34, 43]. Snowball sampling uses existing subjects to recruit new ones from among their peers; it is ideal for researching sensitive issues involving groups of people who are dispersed and difficult to identify [45].

To evaluate the MPA goals, five point Likert scale questions were used, in which possible responses ranged from 1 (extremely ineffective), 2 (ineffective), 3 (neutral), 4 (effective), and 5 (extremely effective). Respondents were also asked how often they fished, so as to gauge activity, and the study classified respondents as "active" if they fished at least once per month. The justification for this criterion is based on the assumption that fishers catch ≥ 100 yellow tang per month. This assumption is supported by the following: 1) the average fisher completes 3-4 dives per trip and can average ~100 fish per dive-hour [46]; 2) yellow tang comprise approximately ~80% by number and ~70% by value of aquarium landings from West Hawaii [39]; and 3) it is not uncommon for fishers to report catching ≥ 1000 yellow tang per month [39]. This assumption implies that fishers harvest ≥ 1200 yellow tang per year, which is similar to the value used previously [39] for defining an "active" fisher. All 23 surveys returned were from permit holders who met the "active" fisher criterion. This resulted in a response rate of approximately 59% when using the estimated number designating the active fishers population size (n=39).

The first survey instrument was sent to dive operators on West Hawaii during the summer of 2008. A database of existing dive operators was initially created using industry experts, internet searches, and local phone books. This database contained company and personnel names, websites, email addresses, physical locations, and phone numbers, and it was used as a reference to ensure industry representation and to avoid duplicating survey dissemination. Thirty dive operators, or outfitters, were identified on West Hawaii using this approach. Next, dive operators were intercepted and sampled purposively at major boat launch sites in West Hawaii (i.e., Puako, Honokohau, Kailua Pier, and Keauhou). All intercepted recipients received a questionnaire, letter of purpose, and a self addressed stamped return envelope. In addition, questionnaires were delivered to the remaining dive operators in the database who were not intercepted at boat launch sites. Approximately 103 questionnaires were disseminated of which 36 were returned, resulting in a 34% response rate.

A second questionnaire was disseminated on Maui and West Hawaii during the summer of 2009 and winter of 2010, respectively. This allowed an examination of: 1) perceptions held by fishers and dive operators regarding threats to the reef; 2) perceived encounter rates between surveyed groups held by dive operators and fishers; 3) value orientations toward the aquarium fish trade among by fishers and dive operators; 4) dive operator and fisher willingness to encourage recreational, subsistence, and commercial fishing; and 5) dive operator awareness about the aquarium fishery. This questionnaire was disseminated in a manner similar to the first one, with slight modifications made to improve its accessibility for respondents on West Hawaii. For example, the survey was made available online using SurveyMonkey™ for fishers and dive operators on West Hawaii. The online and paper versions were identical, and online access instructions were included in the letter. A postcard was also sent to fishers on West Hawaii, one month after the questionnaire was mailed to them, encouraging participation; it also included online access instructions. Maui dive operators were intercepted and sampled purposely at major boat harbors (i.e., Lahaina, Maalaea, Kihei, and Mala), and surveys were disseminated using the same approach employed on West Hawaii.

The DAR on West Hawaii removed inactive fishing permits from their database around the time the second questionnaire was mailed. Consequently, fewer questionnaires were mailed (n = 47) to fishers on West Hawaii. Twenty eight completed questionnaires were received, resulting in a 53% response rate. One hundred eleven questionnaires were disseminated to dive operators on West Hawaii and 38 were returned, resulting in a 34% response rate. On Maui, 105 questionnaires were disseminated to dive operators and 46 were returned, resulting in a 44% response rate. Ten questionnaires were mailed to people who held aquarium fishing permits on Maui; however, it was estimated that there were ≤ 5 people on Maui who actively fished with any regularity. Four questionnaires were returned from Maui fishers, resulting in an 80% response rate from active fishers, assuming there were five active fishers.

To investigate perceived reef threats, respondents were asked on a five point Likert scale about the factors they felt threatened the quality of coral reefs and their associated fish populations. Threats were reported as “no threat,” “minor threat,” “moderate threat,” “threat” and “serious threat.” The threat factors included: poor management, invasive species, throw-net fishing, hook and line fishing, aquarium fishing, bottom fishing, surround net fishing, troll fishing, spearfishing, recreational overuse, global warming/climate change, land-based development/pollution, natural oceanic processes, and other. The “poor management” attribute was purposely undefined and thus left open to interpretation. Respondents who indicated “other” as a threat were instructed to specify this factor. Next, respondents were asked how often they perceived encountering each other while undertaking their respective activity using “never,” “occasional,” and “frequent” response variables. “Encounter” referred to any and all engagement experienced by these groups. Dive operator awareness about aquarium fishing was also evaluated using a five point Likert-scale question, in which responses ranged from 1 (unaware) to 5 (very aware).

Finally, willingness to encourage fishing and value orientations toward the aquarium fish trade were investigated. Respondents were asked if they would encourage commercial fishing, recreational fishing, subsistence fishing, all three fishing categories, or none of the three fishing categories. Separately, three measurable items were used to formulate a latent values construct (i.e., a theoretical concept), which in this case was the value orientation toward the aquarium fish trade. Respondents were asked about their level of agreement with three value statements (or items) on a 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree), and 5 (strongly agree) point Likert scale. The three value statements included: V_1) harvesting reef fish for commercial trade is wrong; V_2) reef fish belong on the reef, not in tanks; and V_3) the trade in reef fishes is inhumane. Other value statements were also evaluated: V_4) Reef fish are acceptable as pets; V_5) Reef fish are a renewable resource for human use; and V_6) Home aquarium keeping is a wonderful educational hobby.

2.2.Data Analysis

Likert scale responses were analyzed using Mann-Whitney *U* tests in Minitab version 15 and Wilcoxon matched-pairs signed-rank tests in StataIC version 12. The former test was used to compare differences between two independent samples, while the latter test was used to compare differences between two related samples. The results were considered significant at $p < 0.05$. These tests are appropriate for the level of measurement and small sample sizes that exhibit non-normal distributions [47, 48, 49]. Statistical interisland within-group equivalencies for all perceived threats and willingness to encourage commercial, recreational, or subsistence fishing were detected. Therefore, these responses were combined by group (i.e., fishers versus dive operators) and analyzed further. The medians and means were calculated for all threat factor responses for both groups; the top three factors with the highest median and mean values were selected and categorized in terms of percentages for further analysis. The fishing category responses were calculated as percentages and analyzed using chi-square analysis. Maui fisher responses were identical in terms of their perceived level of encounters with dive operators (i.e., they never encountered them while fishing). Therefore, their median response value was used and compared to West Hawaii fisher response values using 1-sample sign test.

Construct reliability for the value orientation statements was tested using Cronbach's alpha in Minitab version 15 software. This test is a measure of internal consistency to ensure that statements are estimating the same general construct. An alpha coefficient ≥ 0.65 and item adjusted total correlations of ≥ 0.40 imply that the variables are reliably measuring their respective orientation [50, 51]. Construct reliability analysis validated combining corresponding variables for further analysis. Item adjusted total correlations are coefficients for the score on an individual item and the sum of the scores on the remaining items, and generally should be > 0.40 [51]. The "alpha if deleted" variables assess whether removing an item from the analysis improves the internal consistency [51].

Exploratory factor analysis (EFA) employing the principle factor and orthogonal varimax rotation was used to extract and confirm that the value orientation statements were measuring a single factor. Construct validity for the value orientations toward the aquarium fishery was determined using confirmatory factor analysis (CFA). Multivariate normality is an assumption of CFA and was tested using the Doornik-Hansen [52] and Mardia's [53] tests for multivariate kurtosis and skewness; however, Satorra-Bentler robust estimator was used to correct for these assumptions because they were violated [54]. Factor loadings were considered acceptable at ≥ 0.55 [55]. The comparative fit index (CFI) with a value ≥ 0.95 as a post-estimation measure for assessing overall CFA model fit was used, as it is robust and stable when dealing with smaller sample sizes ($50 < n < 250$) [56, 57]. StataIC version 12 software was used for performing the factor analysis functions. After construct validity and reliability were confirmed, the value orientations toward the aquarium fish trade held by both groups were compared using Mann-Whitney *U* tests.

3. Results

The perceived ability for the MPAs to enhance reef fish abundance differed between fishers and dive operators on West Hawaii ($U = 1237.0$, $p < 0.0001$, Table 1). There was no difference between these groups regarding their perceptions for the MPAs to alleviate conflict ($U= 620.0$, $p = 0.449$, Table 1). Dive operators perceived the MPAs were more effective for enhancing fish abundance than for alleviating conflict ($z = -4.379$, $p < 0.0001$, Table 1), while fishers perceived the MPAs were more effective for alleviating conflict than for enhancing fish abundance ($z = 3.436$, $p = 0.0006$, Table 1).

The three perceived threat factors with the highest means and medians as reported by fishers were land-based development and pollution, invasive species and poor management, whereas aquarium fishing, land-based development and pollution, and poor management were the highest for dive operators (Table 2). Although both groups perceived poor management as a concern, dive operators more often perceived it as a greater threat (Table 3). Dive operators on West Hawaii ($n = 38$) were more aware about aquarium fishing than their counterparts on Maui ($n = 45$) ($U = 1629.5$, $p = 0.0175$).

Dive operators on both islands indicated they both occasionally encountered fishers ($U = 1909.5$; $p = 0.6990$). In contrast, of the 23 West Hawaii fishers, 15 were above and 8 were equal to the median Maui fisher response value, which reflects reports of having no encounters with dive operators ($p = 0.0001$). Fishers were more inclined to encourage all three fishing categories, while dive operators were more willing to encourage subsistence and recreational fishing but not commercial fishing (Table 4). Neither group indicated they would solely encourage commercial fishing. The alpha values exceeded the minimum reliability criteria (≥ 0.65) and therefore the value statements (e.g., V_1, V_2, and V_3) were reliably measuring the latent aquarium fish trade value orientation construct (Table 5). The other value statements (V4, V5, and V6) did not meet the reliability criteria and were therefore omitted from further analyses.

The EFA extracted one factor that explained 69% of variation (eigenvalue = 2.32; loadings: $V_1 = 0.78$, $V_2 = 0.95$, $V_3 = 0.91$), further confirming that the value statements measured the same construct. The CFA model revealed factor loadings ≥ 0.55 for all three statements with a CFI model fit value of 1.0, implying that the measured value statements were valid for describing the latent aquarium fish trade value orientation construct (Fig. 2). The value orientation held by Maui dive operators and fishers ($U = 325.0$, $p = 0.0001$) and West Hawaii dive operators and fishers ($U = 14070.0$, $p < 0.0001$) were both significantly different (Table 6).

4. Discussion

Previous research on West Hawaii's MPA network has focused on examining its efficacy for enhancing reef fish abundance [58, 39]. This study is the first to empirically examine the other goal for establishing West Hawaii's MPA network: conflict alleviation. Although multiple stakeholders frequently interact on West Hawaii's coast, this research focused on the interactions and conflict between commercial dive operators and aquarium fishers because of the historical tensions between these groups [22, 34, 43]. Our findings indicate that fishers and dive operators on West Hawaii were uncertain regarding the ability for the MPA network to alleviate conflict. The interisland within-group differences observed among fishers and dive operators was negligible. Dive operators on both islands held similar perceptions regarding the frequency they encountered fishers, believed aquarium fishing was a serious threat to the reef, would encourage recreational and subsistence fishing far more than commercial fishing, and shared similar value orientations toward the aquarium fish trade. In contrast, fishers on both islands believed land-based pollution and development were serious threats to the reef, strongly encouraged all three fishing categories, and shared similar value orientations toward the aquarium fish trade; however, fishers on Maui perceived encountering dive operators less frequently than their West Hawaii counterparts. These within-group similarities and between-group differences likely explain the underlying and recurring conflict surrounding the aquarium fishery that is pervasive in Hawaii. The results are discussed below in the context of social values and interpersonal conflict, and the policy implications for managing conflict in nearshore marine environments are also described.

The difference between dive operators' perceptions regarding MPA effectiveness in enhancing reef fish populations and those of fishers was significant, with the former perceiving MPAs as markedly more effective. Williams et al. [39] showed significant increases in reef fish abundance inside West Hawaii MPAs and declines were noted in areas that remained open to the aquarium fishery. Anecdotal evidence suggests most commercial dive operators use state-employed moorings located inside many of West Hawaii's MPAs. Conversely, harvesting reef fish for the aquarium fishery is prohibited in all the MPAs and therefore fishers operate in the remaining coastal areas; the same areas where declines in reef fish were detected. Therefore, it was not surprising that dive operators perceived the MPAs as more successful for enhancing reef fish populations than do fishers in West Hawaii.

Although dive operators perceived that the MPA network enhanced reef fish populations in West Hawaii, this study revealed more uncertainty from dive operators and fishers regarding the ability of the MPA network to alleviate conflict. This was unexpected given that the MPA network partitioned the coastline and forced fishers to move farther north and south to areas less frequented by commercial dive operators [59]. Thus, it appears that spatially separating opposing user groups may reduce interpersonal conflict, but its efficacy for managing conflict remains questionable when social values differences between groups prevail [5].

Dive operators' perceptions regarding encounters with fishers were similar on both islands despite the prevalence of more fishers on West Hawaii relative to Maui. West Hawaii fishers occasionally encountered dive operators while fishing; Maui fishers indicated they never encountered them. These findings were unexpected because there are significantly more dive operators on both islands than fishers and therefore it was expected fishers would have reported higher encounters with divers. It is possible that Maui dive operators have a heightened awareness to the presence of fishers due to the anti-aquarium trade campaign and therefore may identify them more regularly. Alternatively, fisher misidentification may occur more frequently on Maui because aquarium fishing boats are not marked with "AQ" stickers and flags as required in West Hawaii.

It is difficult to definitively conclude whether the MPA network on West Hawaii reduced encounters between these stakeholders, as it appears they still occur, which implies that sustained or recurring conflict between these groups is possible. The locations of encounters were not evaluated, but given that many fishers in West Hawaii use harbors that are often within or adjacent to MPAs [59], which is where many dive operators take their clients, it is likely these groups frequently encounter each other in transit to or from dive/fishing sites or at the harbors. These types of encounters will unlikely change and are difficult to avoid, but even if they could be avoided conflict could still persist.

The coral reefs surrounding the state of Hawaii have sustained significant deleterious impacts from fishing (including aquarium fishing), invasive species, climate change, coral diseases, recreational overuse, coastal development and runoff, and coastal pollution [36, 42, 60]. Therefore, neither group mistakenly identified threats to the coral reefs and fish for West Hawaii and Maui, but surprisingly dive operators on both islands perceived aquarium fishing as one of the three principal threats. This is certainly not the case on Maui where threats to the coral reef ecosystem from anthropogenic eutrophication are more significant concerns [61].

Environmental activism may explain why dive operators on Maui perceived aquarium fishing as a primary threat. Hard-line animal rights activists on Maui, who vehemently oppose the aquarium fish trade, implemented an aggressive anti-aquarium fishing campaign in an attempt to garner support for their legislative agenda aimed at banning the fishery state-wide. Although it is plausible that this campaign influenced Maui dive operator awareness about this fishery, the level of awareness held by their counterparts on West Hawaii was significantly higher, so it is unlikely the anti-aquarium fishing campaign solely influenced respondents' perceptions. It appears that the hard line opposition to the aquarium trade, originating in Maui, actually galvanized West Hawaii residents. This may have occurred because residents on West Hawaii, particularly those involved in the West Hawaii Fishery Council, worked tirelessly to develop a co-operative approach to managing their nearshore marine resources. These efforts included dive operators and fishers. The attempts, by people from Maui, to dismantle this co-management system may have engendered resentment from people on West Hawaii. Investigating how community cohesiveness strengthens co-management regimes in a U.S. context is warranted, particularly in West Hawaii.

Dive operators and fishers on both islands identified poor management as a threat to Hawaii's reefs. As part of Act 306, West Hawaii residents cultivated a co-management environment for its nearshore marine resources [34]. Conversely, a similar approach for managing the nearshore marine resources on Maui remains absent [42]. Co-management approaches for managing marine resources are an effective strategy for long-term success [62, 63]. Therefore, it was surprising that both groups on West Hawaii indicated poor management as a threat. This could be explained by two factors. First, Jentoft et al. [64] argued that fisheries co-management requires communal values that are rare in industrialized and increasingly globalized fisheries. Perhaps social value and worldview contradictions held by these user groups influenced their perception about the effectiveness of the co-management approach. Second, Tissot [33] identified fisheries law enforcement as a limitation for managing nearshore marine resources in Hawaii. It is therefore possible that respondents conflated inadequate fisheries law enforcement with poor management, an understandable confusion because these responsibilities are performed by two distinct divisions who operate within the same department in Hawaii's state government.

It was expected that fishers would encourage all fishing categories, but having dive operators show such strong reluctance to encourage commercial fishing was unanticipated. Dive operators were more willing to encourage recreational and subsistence fishing than commercial, yet evidence suggests that global fish stocks are threatened by recreational and commercial fishing [65, 66]. This implies some level of bias against commercial fishing by dive operators. Commercial fishers are often viewed by opponents as predatory profit maximizers who act in self-interest [2]. Similar assertions about aquarium fishers were expressed by dive operators and may have contributed to their unwillingness to encourage commercial fishing. Unexpectedly, fishers were also slightly more inclined than dive operators to not encourage all three fishing categories. Although it is unclear why this was the case, it seems sensible for fishers to believe that encouraging other people to fish would result in greater competition and diminish economic incentives, particularly in an open access fishery [67].

There are myriad regional similarities and differences between West Hawaii and Maui that could influence the results of this research. One difference between these islands was the existence, on West Hawaii, of an MPA network that aimed to minimize conflict between aquarium fishers and dive operators. In the absence of any well-documented baseline prior to implementing the MPA network, it is difficult to conclusively argue whether it was effective for achieving its conflict mitigation goal. The MPA network spatially separated dive operators and fishers in West Hawaii [59], which may have diminished interpersonal conflict between these groups; however, the polarized value orientations toward the aquarium fish trade held by these groups on both islands implies some fundamental level of incompatibility. Spatially separating these groups will likely not resolve the recurring conflict that has occurred in West Hawaii since the late 1970s [43].

The perceptions of conflict between dive operators and aquarium fishers on Maui and West Hawaii also appears asymmetrical. Fishers on Maui reported never encountering dive operators and did not perceive them as a threat to the coral reef ecosystem. Although fishers on West Hawaii occasionally encountered dive operators, they also did not perceive them as a threat to the coral reef ecosystem. These responses by fishers on both islands suggest that they did not experience interpersonal or social values conflict with dive operators (Table 1). Conversely, dive operators on both islands claimed to occasionally encounter fishers and perceived them as a serious threat to Hawaii's coral reef ecosystem. It is possible that dive operators experienced both interpersonal and social values conflict with fishers on Maui and West Hawaii; however, dive operators have strong opposition to the aquarium fish trade as expressed in their value orientation toward it, implying that social values conflict with fishers is likely the principal driving force behind their opposition to the trade.

It is unclear where the strong value orientation against the aquarium trade held by dive operators originates. It is possible that some underlying values observed in traditional Hawaiian culture, that prohibited the harvest of marine resources for personal gain, influences state residents today [33]. For example, *mālama kai,* or serving and caring for the sea, is a value that traditional Hawaiian society upheld, and that is still widely invoked and embraced by state residents today.

Another reasonable explanation is the self-selecting nature of each group which attracts people who hold a shared worldview toward the environment. Needham [9] found that many people participating in Hawaii's dive tour industry held a similar "biocentric" worldview toward the environment. This worldview is likely at odds with the more utilitarian one held by many commercial fishers, such as aquarium fishers in Hawaii. The cultural cognition hypothesis argues that worldviews held by specific groups reflect and reinforce their commitments to particular visions of the ideal society, which persist even when education, income, personality type, and ideology are controlled [68]. Different worldviews likely explain the contrasting value orientations toward the aquarium trade held by fishers and dive operators in Hawaii.

There are a number of social factors in the state of Hawaii that may contribute to the aquarium fish trade conflict. The state experienced rapid human population growth and major coastal development that grew the tourism industry between the 1950s and 1970s [69, 70]. Presumably these changes led to a growing level of affluence, education, and urbanization that could have resulted in communities demanding stronger environmental protection [71, 72]. This hypothesis is supported by the expanding number of MPAs implemented in Hawaii since the 1970s and the strong mutualistic worldview toward wildlife and the environment held by the state's residents [71, 73]. These changes occurred while the state became increasingly dependent on the tourism industry, and specialized economies can cause entrenched conflict over resource allocation, particularly when the goal of one group conflicts with that of another [74].

These findings are relevant from a policy perspective because of the bourgeoning interest in deploying co-management strategies that use MPAs for managing common pool marine resources conflict. Adams et al. [4] believes policy debates around managing common pool resources, such as many marine fisheries, are often flawed because people involved frequently assume that others share their perspective regarding the particular problem discussed. Implementing co-management strategies that use MPAs remains a viable and effective approach when differing worldviews and values held by stakeholders are identified and understood [75]. Understanding and acknowledging these differences may help prevent more influential stakeholders from monopolizing the dialogue or process associated with co-management efforts. Co-management institutions that are ineffective at managing conflict may result in perceptions of inequality or injustice among the stakeholders that can then derail even the most well-intentioned effort [3, 76]. Having equitably-delineated rights, community management systems with clear leadership, and fair law enforcement will help strengthen co-management regimes [3, 63]. Therefore, marine resource managers should perform some baseline conflict assessment, prior to implementing MPAs, to examine the impacts from these interventions, presumably using a before-after-control-impact observational design whenever possible.

5. Conclusions

Although there were many interisland within-group similarities between fishers and dive operators on Maui and West Hawaii, it does not appear that the observed differences detected among these groups resulted from the MPA network in West Hawaii. The significant difference in value orientations toward the aquarium fish trade held by these groups appears as the primary factor contributing to the recurring conflict between them. Thus, spatially separating aquarium fishers and dive operators via MPAs is unlikely to be an effective long-term strategy for managing social values conflict in Hawaii. The MPAs may intermittently quell tensions between stakeholders, as they did after Act 306 was implemented on West Hawaii, but as both industries, particularly the dive tour industry, cycle through employees, tensions may periodically return as they have in recent past when high profile fishing violations were publicized.

More research is needed to understand whether social values conflict is prevalent in other fisheries, or if it is unique to the tropical aquarium fish trade. Opposition toward the aquarium fish trade in Hawaii might reflect a western value that may not exist in other societies, particularly in places like the Philippines and Indonesia where most reef fish for the aquarium trade originate and where values toward marine wildlife may differ from western values. Additionally, although education and outreach campaigns were identified as best practice for resolving social values conflict [6], longitudinal research in this arena is needed to determine the effectiveness of these approaches. Last, additional research is needed to understand how differing values and worldviews between stakeholders influence conflict dimensions surrounding marine spatial management and co-management efforts.

It is essential to recognize that conflict should not always be perceived as something negative. Conflict may result in reconciliation that reflects society's resilience for coping with change [3]; however, achieving this result requires institutional capacity for preemptively dealing with conflict before, during and after tension arises. Performing stakeholder conflict evaluations before marine spatial management strategies are enacted is a valid first step for potentially predicting and resolving future marine resource conflict.

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References

[1] Caddy JF, Cochrane KL. A review of fisheries management past and present and some future perspectives for the third millennium. Ocean and Coastal Management 2001; 44: 653–82.

[2] Charles AT. Fishery conflicts; a unified framework. Marine Policy 1992; 16: 379–93.

[3] Bennett E, Neiland A, Anang E, Bannerman P, Rahman AA, Huq S, Bhuiya S, Day M, Fulford-Gardiner M, Clerveaux W. Towards a better understanding of conflict management in tropical fisheries: evidence from Ghana, Bangladesh and the Caribbean. Marine Policy 2001; 25: 365–76.

[4] Adams WM, Brockington D, Dyson J, Vira B. Managing tragedies: understanding conflict over common pool resources. Science 2003; 302: 1915–16.

[5] Vaske JJ, Donnelly MP, Wittmann K, Laidlaw S. Interpersonal versus social-values conflict. Leisure Science 1995; 17: 205–22.

[6] Vaske JJ, Needham MD, Cline, RC. Clarifying interpersonal and social values conflict among recreationists. Journal of Leisure Research 2007; 39: 182–95.\

[7] Carothers P, Vaske JJ, Donnelly MP. Social values versus interpersonal conflict among hikers and mountain bikers. Leisure Sciences 2001; 23: 47–61.

[8] Fulton DC, Manfredo MJ, Lipscomb J. Wildlife value orientations: a conceptual and measurement approach. Human Dimensions of Wildlife 1996; 1: 24–47.

[9] Needham MD. Value orientations toward coral reefs in recreation and tourism settings: a conceptual and measurement approach. Journal of Sustainable Tourism 2010; 18: 757–72.

[10] Jacob GR, Schreyer R. Conflict in outdoor recreation: a theoretical perspective. Journal of Leisure Research 1980; 12: 368–80.

[11] Donnelly MP, Vaske JJ, Whittaker D, Shelby B. Toward an understanding of norm prevalence: a comparative analysis of 20 years of research. Environmental Management 2000; 25: 403–14.

[12] Trist C. Recreating ocean space: recreational consumption and representation of the Caribbean marine environment. Professional Geographer 1999; 51: 376–87.

[13] Oracion EG, Miller ML, Christie P. Marine protected areas for whom? fisheries, tourism, and solidarity in a Philippine community. Ocean and Coastal Management 2005; 48: 393–410.

[14] Majanen T. Resource use conflicts in Mabini and Tingloy, the Philippines. Marine Policy 2007; 31: 480–87.

[15] Fabinyi M. The intensification of fishing and the rise of tourism: competing coastal livelihoods in the Calamianes islands, Philippines. Human Ecology 2010; 38: 415–27.

[16] Bunce L, Gustavson K. Coral reef valuation: a rapid socioeconomic assessment of fishing, watersports, and hotel operations in the Montego Bay Marine Park, Jamaica and an analysis of reef management implications. World Bank Research Committee Project #RPO; 1998: 681–605.

[17] Masalu D. Coastal and marine resource use conflicts and sustainable development in Tanzania. Ocean and Coastal Management 2000; 43:457–494.

[18] Sandersen HT, Koester S. Co–management of tropical coastal zones: the case of the Soufriere Marine Management Area, St. Lucia, WI. Coastal Management 2000; 28: 87–97.

[19] Baine M, Howard M, Kerr S, Edgar G, Toral V. Coastal and marine resource management in the Galapagos Islands and the Archipelago of San Andres: issues, problems and opportunities. Ocean and Coastal Management 2007; 50: 148–73.

[20] Lynch TP, Wilkinson E, Melling L. Hamilton R, Macready A, Feary, S. Conflict and impacts of divers and anglers in a marine park. Environmental Management 2004; 33: 196–211.

[21] Dobrzynski TJ, Nicholson EE. User group perceptions of the short-term impacts of marine reserves in Key West. Proceedings of the Ninth International Coral Reef Symposium, Bali, 23-27 October 2000, Volume 2. pp. 759–63. 2002.

[22] Capitini CA, Tissot BN, Carroll MS, Walsh WJ, Peck S.. Competing Perspectives in Resource Protection: The Case of Marine Protected Areas in West Hawai`i. Society and Natural Resources 2004; 17: 763–78.

[23] Harrison HB, Williamson DH, Evans RD, Almany GR, Thorrold SR, Russ GR, Feldheim KA, van Herwerden L, Planes S, Srinivasan M, Berumen ML, Jones GP. Larval export from marine reserves and the recruitment benefit for fish and fisheries. Current Biology 2012; 22, 1023–28.

[24] Bohnsack J. Marine reserves: they enhance fisheries, reduce conflicts, and protect resources. Oceanus 1993; 36: 63–71.

[25] Wood E. Global advances in conservation and management of marine ornamental resources. Aquarium Sciences and Conservation 2001; 3: 65–77.

[26] Day JC. Zoning—lessons from the Great Barrier Reef Marine Park. Ocean and Coastal Management 2002; 45: 139–56.

[27] Suman D, Shivlani M, Milon JW. Perceptions and attitudes regarding marine reserves: a comparison of stakeholder groups in the Florida Keys National Marine Sanctuary. Ocean & Coastal Management 1999; 42: 1019–40.

[28] Broad K, Sanchirico JN. Local perspectives on marine reserve creation in the Bahamas. Ocean and Coastal Management 2008; 51: 763–71.

[29] Tissot BN, Best BA, Borneman EH, Bruckner AW, Cooper CH, D'Agnes H, Fitzgerald TP, Leland A, Lieberman S, Amos AM, Sumaila R, Telecky TM, McGilvray F, Plankis BJ, Rhyne AL, Roberts GG, Starkhouse B, Stevenson TC. How U.S. ocean policy and market power can reform the coral reef wildlife trade. Marine Policy 2010; 34:1385–88.

[30] Wabnitz C, Taylor M, Green E, Razak T. From ocean to aquarium. UNEP World Conservation Monitoring Centre, Cambridge, UK: UNEP-WCMC; 2003 <http://www.unep.org/pdf/from_ocean_to_aquarium_report.pdf >.

[31] Bruckner AW. The importance on the marine ornamental reef fish trade in the wider Caribbean. Revista de Biologia Tropical 2005; 53: 127–38.

[32] Walsh WJ, Cotton SP, Dierking J, Williams ID. The commercial marine aquarium fishery in Hawai‘i 1976–2003. In Status of Hawaii's Coastal Fisheries in the New Millennium, rev. edn, pp.132–158. Ed. by A. M. Friedlander. American Fisheries Society, Hawaii Chapter, Honolulu. 230 pp. 2004.

[33] Tissot BN. Integral marine ecology: community-based fishery management in Hawaii. World Futures 2005; 61: 79–96.

[34] Tissot BN, Walsh WJ, Hixon MA. Hawaiian Islands marine ecosystem case study: ecosystem and community-based management in West Hawaii. Coastal Management 2009; 37: 255–73.

[35] Tissot BN, Hallacher LE. Effect of aquarium collectors on coral reef fishes in Kona, Hawaii. Conservation Biology 2002; 1759–68.

[36] Walsh, WJ. Community-based management of a Hawai`i aquarium fishery marine ornamentals ’99. 1999. Waikoloa, Hawaii, 83–7.

[37] Talbot R. Senate Bills Call for Complete Ban on Sale of Hawaiian Aquatic Life. CORAL Magazine 2012 < http://www.coralmagazine-us.com/content/senate-bills-call-complete-ban-sale-hawaiian-aquatic-life>, Retrieved April 18, 2012.

[38] Tablot R. Extremists Call for Ban on All Aquarium Livestock Collection in Hawaii. CORAL Magazine 2011 <http://www.coralmagazine-us.com/content/extremists-call-ban-all-aquarium-livestock-collection-hawaii>, Retrieved April 18, 2012.

[39] Williams ID, Walsh WJ, Claisse JT, Tissot BN, Stamoulis KA. Impacts of a Hawaiian marine protected area network on the abundance and fishery sustainability of the yellow tang, Zebrasoma flavescens. Biological Conservation 2009; 142: 1066–73.

[40] Talbot R. Hawaiian Politicians Seek to Ban or Curtail Aquarium Collection. CORAL Magazine 2011 < http://www.coralmagazine-us.com/content/hawaiian-politicians-seek-ban-or-curtail-aquarium-collection>, Retrieved April 18, 2012.

[41] Williams ID, Walsh WJ, Schroeder RE, Friedlander AM, Richards BL, Stamoulis KA. Assessing the importance of fishing impacts on Hawaiian coral reef fish assemblages along regional-scale human population gradients. Environmental Conservation 2008; 35: 261–72.

[42] Maui Coral Reef Recovery Team. 2012. Ola Nā Papa i Mālama ‘Ia: A Practical Plan for the Technical and Cultural Restoration of Maui’s Coral Reefs. Maui Nui Marine Resource Council, Kahului, Maui. 587 pp.

[43] Maurin P, Peck S. The West Hawai‘i fisheries council case study report. University of Hawai‘i Sea Grant College Program; 2008.

[44] Cinner JE, McClanahan TR, Graham NAJ, Daw TM, Maina J, Stead, SM, Wamukota A, Brown K, Bodin O. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Global Environmental Change 2012; 22: 12–20.

[45] Biernacki P, Waldorf D. Snowball sampling: problem and of using nonrandom sampling methodologies. Sociological Methods & Research 1981; 10: 141–63.

[46] Stevenson TC, Tissot BN, Dierking J. Fisher behaviour influences catch productivity and selectivity in West Hawaii's aquarium fishery. ICES Journal of Marine Science 2011; 68: 813–22.

[47] Siegel S, Castellan NJ. Nonparametric Statistics for the Behavioural Sciences. New York: McGraw-Hill; 1988.

[48] Nachar N. The Mann-Whitney *U*: a test for assessing whether two independent samples come from the same distribution. Tutorials in Quantitative Methods for Psychology 2008; 4: 13–20.

[49] de Winter JCF, Dodou D. Five-point Likert items: t test versus Mann-Whitney-Wilcoxon. Practical Assessment, Research & Evaluation 2010; 15: 1–12.

[50] Cortina JM. What is coefficient alpha? An examination of theory and applications. Journal of Applied Psychology 1993; 78: 98–104.

[51] Vaske JJ. 2008. Survey research and analysis: Applications in parks, recreation and human dimensations. State College, PA: Venture Publishing.

[52] Doornik JA, Hansen H. An omnibus test for univariate and multivariate normality. Oxford Bulletin of Economics and Statistics 2008; 70: 927-39.

[53] Mardia KV. Measures of multivariate skewness and kurtosis with applications. Biometrika 1970; 57: 519-30.

[54] Satorra A, Bentler PM. Corrections to test statistics and standard errors in covariance structure analysis. In Latent Variables Analysis, eds. von Eye A, Clogg CC., 399–419. Thousand Oaks, CA: Sage; 1994.

[55] DiStefano C, Hess B. Using confirmatory factor analysis for construct validation: an empirical review. Journal of Psychoeducational Assessment 2005; 23: 225–41.

[56] Tanguma J. Effects of sample size on the distribution of selected fit indices: a graphical approach. Educational and Psychological Measurement 2001; 61: 759–76.

[57] Schreiber JB, Nora A, Stage FK, Barlow EA, King J. Reporting structural equation modeling and confirmatory factor analysis results: a review. The Journal of Educational Research 2006; 99: 323–38.

[58] Tissot BN, Walsh WJ, Hallacher LE. Evaluating effectiveness of a marine protected area network in West Hawai‘i to increase productivity of an aquarium fishery. Pacific Science 2004; 58: 175–88.

[59] Stevenson TC, Tissot BN, Walsh WJ. Socioeconomic consequences of fishing displacement from a network of marine protected areas in Hawaii. Biological Conservation In press.

[60] Friedlander, AM, Aeby G, Brown E, Clark A, Coles S, Dollar S, Hunter C, Jokiel P, Smith J, Walsh B, Williams I, and Wiltse W. The state of coral reef ecosystems of the Main Hawaiian Islands. In The state of coral reef ecosystems of the United States and Pacific freely associated States: 2005, ed. J. Waddell, 222–269. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring.

[61] Dailer ML, Knox RS, Smith JE, Napier M, Smith CM. Using δ15N values in algal tissue to map locations and potential sources of anthropogenic nutrient inputs on the island of Maui, Hawaiʻi, USA. Marine Pollution 2010; 60: 655–71.

[62] Cinner JE, McClanahan TR, MacNeil, MA, Graham NAJ, Daw TM, Mukminin A, Feary DA, Rabearisoa AL, Wamukota A, Jiddaw N, Campbell SJ, Baird AH, Januchowski-Hartley FA, Hamed S, Lahari R, Morove T, Kuange J. Comanagement of coral reef social-ecological systems. PNAS 2012; 109: 5219–22.

[63] Gutierrez NL, Hilborn R, Defeo O. Leadership, social capital and incentives promote successful fisheries. Nature 2011; 470: 386–389.

[64] Jentoft S, McCay BJ, Wilson DC. Social theory and fisheries co-management. Marine Policy 1998; 2: 423–36.

[65] Coleman FC, Figueira WF, Ueland JS, Crowder LB. The impact of United States recreational fisheries on marine fish populations. Science 2004; 305:1958–60.

[66] Cooke SJ, Cowx IG. Contrasting recreational and commercial fishing: searching for common issues to promote unified conservation of fisheries resources and aquatic environments. Biological Conservation 2006; 128: 93–108.

[67] Beddington JR, Agnew DJ, Clark CW. Current problems in the management of marine fisheries. Science 2007; 316: 1713–16.

[68] Kahan DM. Cultural cognition as a conception of the cultural theory of risk. In Handbook of risk theory: epistemology, decision theory, ethics, and social implications of risk, eds. Roeser S, Hillerbrand R, Sandin P, Peterson M., 725–60. New York, NY: Springer, 2012.

[69] Bardolet E, Sheldon PJ. Tourism in archipelagos: Hawai'i and the Balearics. Annals of Tourism Research 2008; 35: 900–23.

[70] Kittinger JN, Pandolf JM, Blodgett JH, Hunt TL, Jiang H, Maly K, McClenachan LE, Schultz JK, Wilcox BA. Historical reconstruction reveals recovery in Hawaiian coral reefs. PLoS One 2011; 6: e25460.

[71] Teel TL, Dayer AA, Manfredo MJ, Bright AD. Regional results from the research project entitled "Wildlife Values in the West." (Project Rep. No. 58). Project Report for the Western Association of Fish and Wildlife Agencies. 2005. Fort Collins, CO: Colorado State University, Human Dimensions in Natural Resources Unit.

[72] Cinner JE, McClanahan TR, Daw TM, Graham NAJ, Maina J, Wilson SK, Hughes TP. Linking social and ecological systems to sustain coral reef fisheries. Current Biology 2009; 19: 206–12.

[73] US National Ocean Service. National Marine Protected Areas Center. www.mpa.gov, accessed 27 April 2012.

[74] Cinner J, Bodin O. Livelihood diversification in tropical coastal communities: A network-based approach to analyzing 'livelihood landscapes'. PLoS ONE 2010; 5: e11999.

[75] Gelcich S, Edwards-Jones G, Kaiser MJ. Importance of attitudinal differences among artisanal fishers toward co-management and conservation of marine resources. Conservation Biology 2005; 19: 865–75.

[76] Christie, P. Marine protected areas as biological successes and social failures in Southeast Asia. In Aquatic protected areas as fisheries management tools: design, use, and evaluation of these fully protected areas, J.B. Shipley, ed. (Bethesda, M.D.: American Fisheries Society), 2004; pp. 155–64.

Tables and Figures

Table 1: Perceived MPA effectiveness for achieving conflict alleviation and fish abundance enhancement goals in West Hawaii

	Fishers (n=24)		Diver Operator (n=34)	
	Conflict Alleviation	Fish Enhancement	Conflict Alleviation	Fish Enhancement
Extremely Ineffective	13.04%	**39.13%**	0.00%	2.94%
Ineffective	17.39%	8.70%	20.59%	2.94%
Neutral	**34.78%**	30.43%	**38.24%**	14.71%
Effective	26.09%	17.39%	35.29%	**61.76%**
Extremely Effective	8.70%	4.35%	5.88%	17.65%

Table 2: Means and medians for perceived threats to coral reefs and fishes held by fishers and dive operators

	Fishers			Dive Operators		
Threat	Mean	Median	n	Mean	Median	n
Poor management	**3.30**	**3.00**	27	**4.33**	**5.00**	82
Invasive species	**4.07**	**4.50**	28	3.89	4.00	82
Thrownet fishing	2.39	2.00	26	3.03	3.00	80
Hook and line fishing	2.37	2.00	27	2.84	3.00	82
Aquarium fishing	2.29	2.00	28	**4.43**	**5.00**	83
Bottom fishing	2.62	2.50	26	3.11	3.00	81
Surround net fishing	2.78	2.00	27	3.48	3.00	79
Troll fishing	2.44	2.00	27	2.68	3.00	77
Spearfishing	3.00	3.00	27	2.74	2.00	80
Recreational overuse	3.22	3.00	27	3.00	3.00	82
Global warming/climate change	3.04	3.00	27	3.18	3.00	79
Land-based development/pollution	**4.25**	**4.00**	28	**4.35**	**5.00**	82
Natural oceanic processes	2.82	3.00	27	2.32	2.00	79

Table 3: Top three perceived threats to Hawaii's coral reefs and fishes held by dive operators and fishers

Threat Factor	Divers (%)	Fishers (%)	U	p-value
Poor management	n = 82	n = 27	5093.0	< 0.001
No Threat	2.4	3.7		
Minor Threat	1.2	18.5		
Moderate Threat	12.2	**40.7**		
Threat	29.3	18.5		
Serious Threat	**54.9**	18.5		
Aquarium fishing	n = 83	n = 28	5588.0	< 0.001
No Threat	0	14.3		
Minor Threat	3.6	**64.3**		
Moderate Threat	10.8	10.7		
Threat	24.1	0		
Serious Threat	**61.5**	10.7		
Land-based development/pollution	n = 81	n = 28	1467.5	0.56
No Threat	0	0		
Minor Threat	1.2	3.6		
Moderate Threat	18.3	14.3		
Threat	24.4	35.7		
Serious Threat	**56.1**	**46.4**		
Invasive species	n = 82	n = 28	4406.0	0.32
No Threat	0	0		
Minor Threat	13.4	14.3		
Moderate Threat	17.1	14.3		
Threat	**36.6**	21.4		
Serious Threat	32.9	**50.0**		

Table 4: Fisher and dive operator willingness to encourage three fishing categories

	Fishers (n=27)	Divers (n=69)	$\chi2$	p
Commercial	0.0%	0.0%	36.20	< 0.001
Recreation	7.4%	34.8%		
Subsistence	7.4%	**43.5%**		
All of the above	**63.0%**	7.3%		
None of the above	22.2%	14.5%		

Table 5: Cronbach's alpha results for value orientations toward the aquarium fish trade

Value orientation statements	$\bar{x}$	Item Adj Total Correlation	Alpha (α) if deleted	Cronbach's alpha
Harvesting reef fish for commercial trade is wrong (V_1)	3.22	0.75	0.94	0.91
Reef fish belong on the reef, not in tanks (V_2)	3.39	0.90	0.82	
The trade in reef fishes is inhumane (V_3)	3.24	0.84	0.86	

Table 6: Median, range and sample size (n) for value orientation statement responses from fishers and dive operators on West Hawaii and Maui

Value orientation statements	West Hawaii Fishers (n=23)		West Hawaii Dive Operators (n=38)		Maui Fishers (n=4)		Maui Dive Operators (n=45)	
	Median	Range	Median	Range	Median	Range	Median	Range
Harvesting reef fish for commercial trade is wrong (V_1)	1.0	1.0	5.0	4.0	1.5	3.0	4.0	4.0
Reef fish belong on the reef, not in tanks (V_2)	1.0	2.0	5.0	3.0	2.0	1.0	4.0	4.0
The trade of reef fishes is inhumane (V_3)	1.0	1.0	4.0	3.0	2.0	2.0	4.0	4.0

		Perceived Problem	
		No	**Yes**
Observed	**No**	No Conflict	Social Values Conflict
	Yes	No Conflict	Interpersonal and Social Values Conflict
			Interpersonal Conflict

Figure 1: Theoretical matrix for evaluating social values and interpersonal conflict (adapted from Vaske et al. [6]).

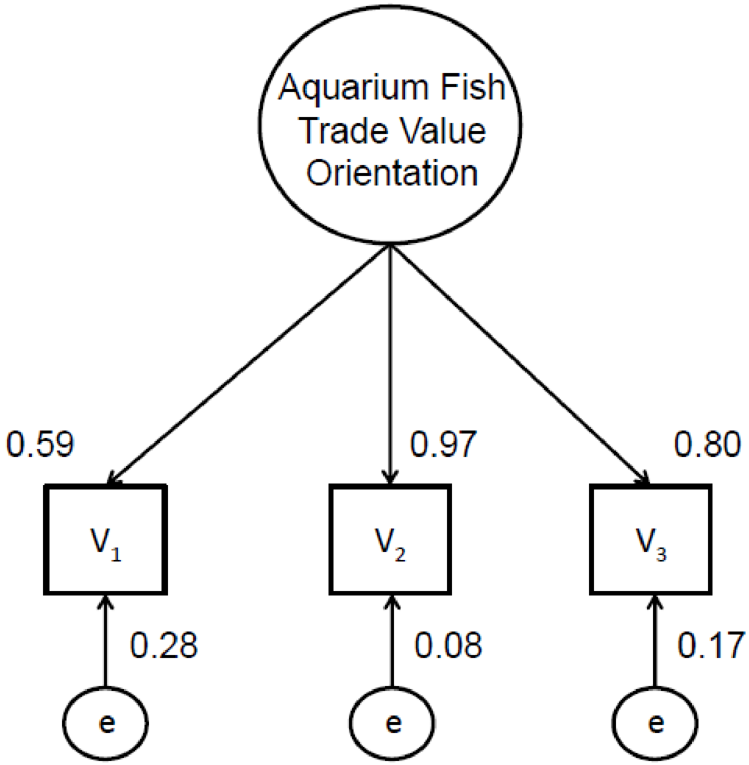

Figure 2: Confirmatory factor analysis indicates single factor model validates value orientations toward the aquarium fish trade in Hawaii (CFI = 1, e = error). The larger circle at the top represents the latent construct, while the smaller circles at the bottom are the error values for the measured value (V) variable. The error values differ from the latent factor because their effect is associated with only one measured variable. The straight line pointing from a latent construct to the measured value (V) variables indicates the correlation between the latent variable and the measured value (V) variables [56].

CHAPTER FIVE

CONCLUSION

With past research endeavors largely examining the effects MPAs have on biological attributes, the need to include more human dimension aspects into MPA research remains clear, especially in the state of Hawaii where many residents rely on nearshore marine ecosystems for their livelihood. This need strongly influenced my doctoral dissertation and led me to pursue the following research questions: 1) How did aquarium fisher adaptations to the MPA network influence their catch productivity and selectivity?; 2) How did the MPA network spatially displace aquarium fishing and what were the socioeconomic consequences from this displacement on the fishing community?; 3) Are MPA networks effective for managing marine resource conflict?

I investigated the first question in chapter two by exploring how aquarium fishers on West Hawaii changed their behavior in ways that have improved their catch productivity and efficiency post-MPA implementation. My findings show fishers: shifted their harvesting preference away from a mixed catch composition to one dominated by surgeonfishes since the 1970s; adopted new fishing methods, gear and technology, such as the use of GPS and nitrox gas, which can significantly increase catch efficiency and productivity; and experienced high job satisfaction and found job autonomy, exposure to nature and the “challenge” as the most enjoyable aspects of their occupation, suggesting non-monetary benefits are important and may serve as an incentive to continue fishing despite declining densities of yellow tang in areas remaining open post-MPA network establishment. My findings largely agree with past research in other marine fisheries and illustrate how fishers adapt to fishery management policies to maintain their involvement and catch efficiency in a fishery.

I explored the second question in the third chapter that focused on how MPAs displace fishing effort and its socioeconomic consequences on a fishing community. The scholarly literature often assumes MPAs displace fishing effort without providing empirical evidence. Additionally, the socioeconomic costs for implementing MPAs and displacing fishing are often assumed to be absorbed by fishing communities, yet investigations into how displacement from MPAs influences fishers' socioeconomic well-being remain scant. My findings show the MPAs displaced fishers from West Hawaii's central coast to the northern and southern regions. Fishers perceived this displacement negatively affected distance travelled to fishing sites and fishing operating costs. These factors were likely impacted because many MPAs were placed adjacent to boat ramps, forcing fishers to travel farther if wanting to fishing in the direction of the MPA. Additionally, many fishers preferred launching their boats in the same area where the majority of MPAs were established (i.e., the west catch reporting zone). This was the same region where half the boat ramps were located, the largest and most populated town centers were located, and where many fishers sell their catch post-harvest. These factors most likely influenced the perceived increases in distance travelled to fishing sites and fishing costs expressed by fishers post-MPA network establishment. Surprisingly, most fishers perceived their overall socioeconomic well-being was unaffected by the MPAs; in fact, many believed their economic status improved. This may be explained by the fact that many fishers now operate in the northern and southern regions along West Hawaii coast, where catch per unit effort for yellow tang was noticeably higher. My findings are one of the first to examine fisher movement pre-post MPA network establishment and how this movement influences the well-being of a fishing community. Further studies are needed in other MPA locations to understand broader implication of fishing displacement form spatial management approaches.

My fourth chapter investigated my last question that focused on examining the effectiveness of the MPA network on West Hawaii to alleviate conflict between aquarium fishers and dive operators. My results show dive operators and fishers on West Hawaii perceived the MPA network had minimal influence on conflict dimensions. This was surprising given the results in chapter three that clearly showed the fishers were displaced from areas where dive operators frequent. When I investigated interpersonal and social values conflict between these stakeholders on West Hawaii and Maui, dive operators on both islands believed aquarium fishing was one of the more serious threats to the nearshore marine ecosystem and perceived to occasionally encounter aquarium fishers while working. In contrast, while fishers did not believe recreational overuse was a major threat impacting the marine ecosystem, the fishers on West Hawaii occasionally encountered dive operators while working but their counterparts on Maui perceived to never encounter them. According to theory on interpersonal-social values conflict, my findings imply asymmetrical conflict between dive operators and fishers were present on both islands, with the former likely experiencing greater conflict with that latter group. I also found contrasting value orientation toward the aquarium fish trade held by these groups on both islands. These value differences may explain the recurring conflict in the region surrounding Hawaii's aquarium fishery, and suggest spatial management, such as the use of MPAs, will unlikely resolve conflict when value differences about how the marine resource should be used differs between parties. My findings are important because there are few MPA networks explicitly implemented to resolve resource conflict, such as in case of West Hawaii. As competition for marine space and resources increases with human population growth in coastal areas, understanding approaches for dealing with conflict will be needed.

My research underscored the importance for investigating fisher behavior and how choices made by fishers can dramatically influence their harvest efficiency. My research also underscores the importance for understanding how spatial management can displace fishing effort and fisher well-being. Understanding things such as where fishers operate, where they sell their catch, or where they launch their boats are critical attributes that could influence a MPA network's efficacy to manage a particular species or ecosystem. Last, as trade economies continues to shift to more tourism dependent ones, conflict between people belonging to these groups will continue to develop. Understanding social dimensions related to conflict is essential for resolution, particularly conflict driven by disparate values held by opposing parties.

From my perspective, the inclusion of human dimensions in coastal resource management research in the United States is lagging behind other parts of the world, such as Melanesia and Southeast Asia. This means there is ample opportunity to increase involvement and funding in these areas, particularly in the state of Hawaii, but also in places along the U.S. west and east coast. Fisheries management is people management, and if humans want to manage the world's fishery resources in a socially, economically and biologically sustainable manner, scientists and coastal resource managers need to integrate more human dimensions research into their scientific and management objectives.