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# 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.



## 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 (Mascia 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 (Forcada et al., 2009; Stelzenmüller et al., 2008; Kellner et al., 2007). 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 analytical 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

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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 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 and 17 fishers 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 (Mascia 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 Waldorf, 1981; Capitini et al., 2004; Maurin and Peck, 2008; Tissot et al., 2009). These 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 23 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 Anrup, 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 to 1999 (pre-MPA network) and 426 monthly reports were from 2000 to 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 10 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 and Castellan, 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 ($n = 15$).

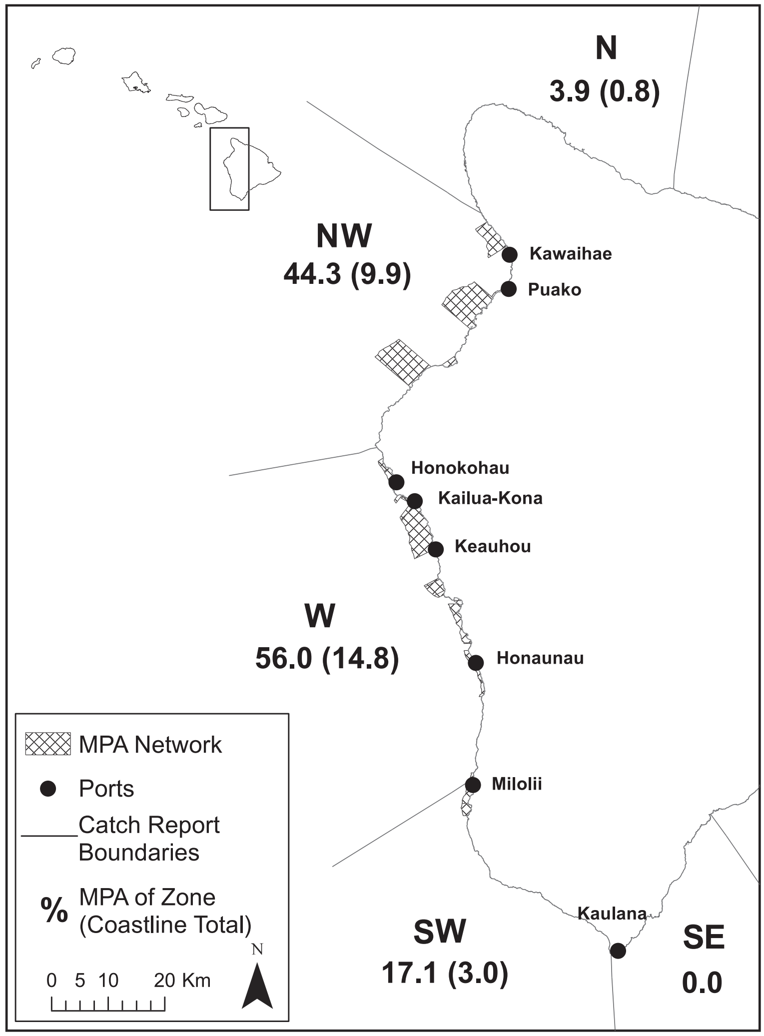


**Fig. 1.** West Hawaii MPA network, fishery catch reporting zones, port locations, and the percentage of each zone closed to aquarium fishing by MPAs. Percentages shown are the proportions of coastline designated as an MPA relative to zone length and, in parenthesis, the total length of the coastline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

*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 traveled 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

**Table 1**
Changes in perceived fishing and socioeconomic indicators in response to MPA network establishment. Bold values are significant at $p < 0.05$.

| | Number of responses | | | $P$ | Median |
|---|---|---|---|---|---|
| | Below median | Equal to median | Above 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 |

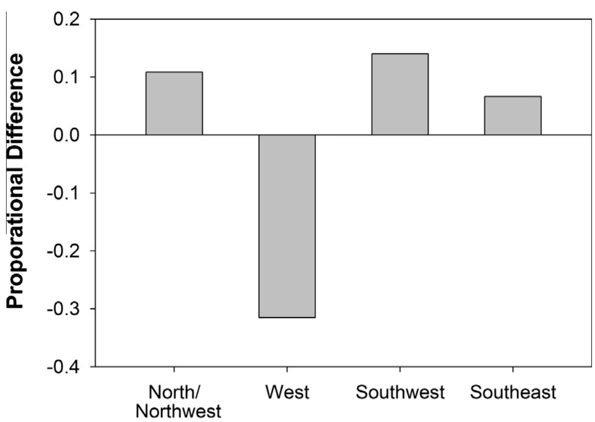


**Fig. 2.** Proportional difference between where fishers preferred launching their boats versus preferred fishing within a particular catch zone. A negative value indicated a preference towards launching in a particular zone, while a positive value indicated preference toward fishing a particular zone.

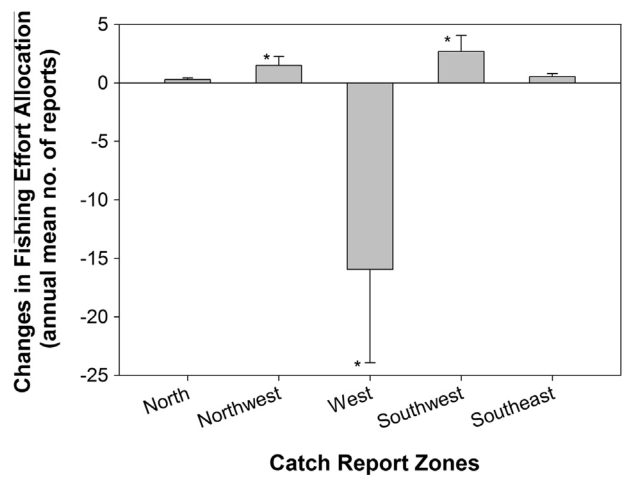


**Fig. 3.** Change in the annual mean number of reports submitted by fishers before (1990–1999) versus after (2000–2008) the MPA network by catch reporting zone. The asterisk (*) indicates a statistical significance.

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/h) versus MPA boundary sites (~84 fish/h).

## 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

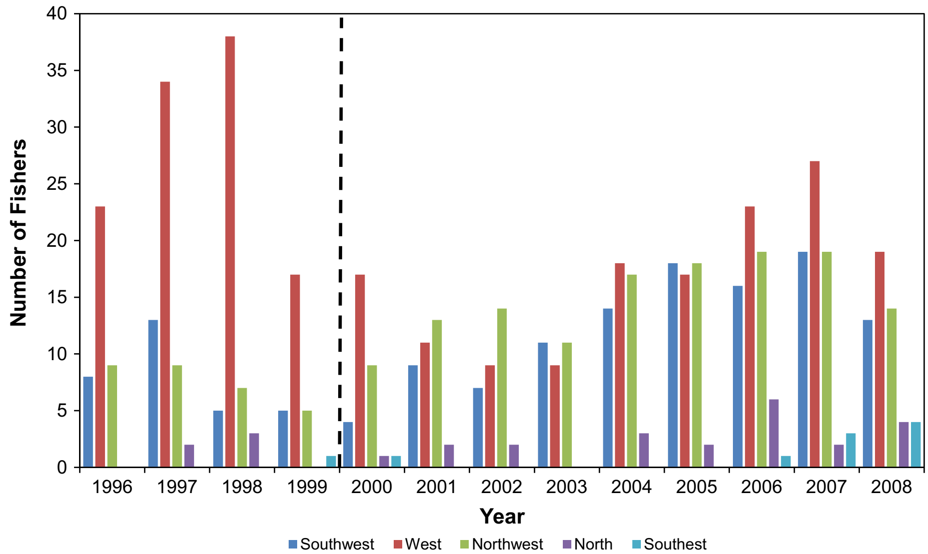


**Fig. 4.** Longitudinal changes in the number of fishers reporting by catch zone per year in West Hawaii. The dashed line marks the year when the MPA network was implemented and colors correspond to particular catch zones.

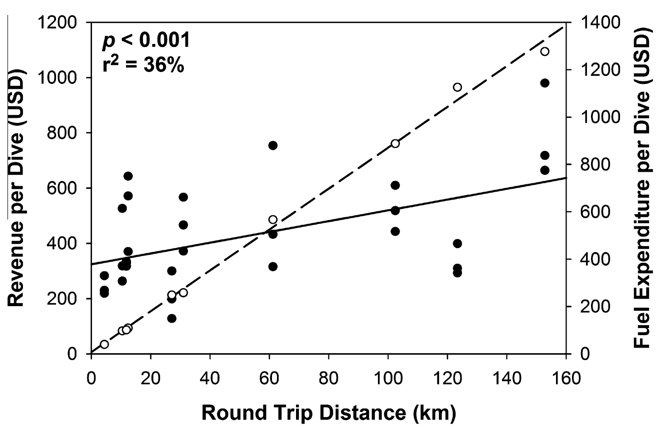


**Fig. 5.** Estimated catch revenue per dive (**solid line,** ●) increased significantly farther from ports of entry. The sites yielding the highest and lowest revenues were located in the west and southwest catch zones, respectively. Estimated catch revenues and fuel expenditures (**dashed line,** ○) 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.

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 (Stevenson and Tissot, 2013). 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 above-mentioned 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, 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) argued against the belief held by many researchers and policymakers that fishing is an industry reserved for people from impoverished communities. Their position is supported the case in West Hawaii's aquarium fishery. The results from our 10 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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