ESTIMATING NEARSHORE FISHERIES CATCH FOR THE MAIN HAWAIIAN ISLANDS

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Abstract

Nearshore fisheries in the main Hawaiian Islands (MHI) have great economic, recreational, and cultural value. Currently, information on these fisheries is disparate and incomplete, creating a challenge for effective management. This study combines and synthesizes several commercial and small-scale non-commercial datasets to estimate the total catch of nearshore fisheries in the MHI. Data used came from catch reports submitted by commercial fishers, a statewide recreational fisheries survey, and 12 small-scale, non-commercial creel surveys conducted at sites in Kauai, Oahu, Lanai, Maui, and Hawaii. Results include an estimated range for total nearshore catch between 1,441,407 and 7,739,548 kg/yr., with the non-commercial catch between 9 and 53 times the reported commercial reef fish catch. Additionally this study provides a comprehensive overview of the MHI nearshore fishery, including best-available estimates of fishery data such as catch-per-unit-effort (CPUE), gear-preference and participation rates, with data broken out at island-scale. This is likely more appropriate for management purposes than the statewide level at which nearshore catch data is currently reported in the MHI.

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List of abbreviations

ACL	annual catch limit
ANOSIM	analysis of similarities
ANOVA	analysis of variance
CBM	community-based management
CI	Conservation International
CML	commercial marine license
CNMI	Commonwealth of the Northern Mariana Islands
CPUE	catch-per-unit-effort
DOCARE	Division of Conservation and Resource Enforcement
EBFM	ecosystem-based fisheries management
FBSAB	fisheries biology and stock assessment branch
FAO	Food and Agriculture Organization
FERL	Fisheries Ecology Research Lab
HCFRU	Hawaii Cooperative Fisheries Research Unit
HCRI	Hawaii Coral Reef Initiative
HDAR	Hawaii's Division of Aquatic Resources
IUU	illegal, unreported, or unregulated
KBMCB	Kaneohe Bay Marine Corps Base
MHI	main Hawaiian Islands
MRIP	Marine Recreational Information Program
NGO	non-governmental organization
NMDS	non-metric multi-dimensional scaling
NOAA	National Oceanic and Atmospheric Administration
NWHI	Northwestern Hawaiian Islands
PMNM	Papahanaumokuakea Marine National Monument
PIFSC	Pacific Islands Fisheries Science Center
SSRI	Social Science Research Institute
TEK	traditional ecological knowledge
TNC	The Nature Conservancy
UN	United Nations

Introduction

Nearshore fisheries in the main Hawaiian Islands (MHI) are diverse, comprising commercial, recreational, and subsistence sectors, employing multiple gear types, and harvesting a wide variety of reef and estuarine finfishes, invertebrates, and schooling coastal pelagic species (Pooley 1993, Smith 1993, Friedlander & Parrish 1997, Schug 2001). Communities around the state rely substantially on these fisheries for economic, social, and cultural services, including important livelihood and food provisioning functions, as well as cultural practices, customs, and traditions (Pooley 1993, Friedlander et al. 2013).

It is important that these fisheries are managed sustainably to maximize the value of these resources. Challenges to achieving this goal arise from the data-poor nature of many of these sectors (Kittinger 2013). The current production – generation of biomass of fish per unit area (Anderson & Neumann 1996) – and catch from these fisheries remain largely unknown. The catch rate – catch-per-unit-effort (CPUE) – is often used as a proxy for abundance, or number of fish (Richer 1940), and several studies have shown that CPUE is proportional to abundance (Richards & Schnute 1986, Haggarty & King 2006). Small-scale, non-commercial fisheries often use numerous gear types over a wide geographic range by many fishers, making it difficult to accurately assess catch. Another complication is that much of that catch remains un- or under-reported in existing surveys, if it is available at all (Pauly et al. 2002, Zeller et al. 2008, 2014, Friedlander et al. 2014, Pauly & Zeller 2014).

Many catch statistics, including numbers from the Food and Agriculture Organization (FAO) of the United Nations (UN), do not include discarded catch, or illegal, unreported, or unregulated (IUU) catches (Pauly et al. 2002, Pauly 2009, Pauly & Froese 2012). Pauly et al. (2002) estimated global fish catch from 1950 - 1999 and included estimates of discards and IUU catches. These two categories accounted for ~ 38% of global catch in 1999, and fluctuated between 1/3 and 1/2 of total catch from 1950-1999. More recent data from 2000 to 2004 show a similar pattern (Pauly 2009), stressing the importance of estimating these types of catches to regulate and manage Hawaii's fisheries.

Small-scale, non-commercial fishing tends to be largely unreported (Zeller et al. 2008, Teh et al. 2013). It is imperative to incorporate these catch estimates in Hawaii because of the importance and relevance of small-scale fisheries to the residents and visitors of the state (Friedlander et al. 2013). Zeller et al. (2005) reconstructed fisheries landings from 1950 - 2002 in American Samoa, the Commonwealth of the Northern Mariana Islands (CNMI), and Hawaii (1950-2005) by incorporating small-scale, non-commercial and subsistence catch along with commercial fisheries data. They found that non-commercial catches were significant in all cases, and particularly in Hawaii, where they estimated that total non-commercial catch was ~1.8 times higher than reported commercial catches, with the total catch of non-pelagic species possibly underestimated by a factor of 3.7. This study expands on Zeller's study by using catch data from 2004-2013, and by focusing on reef fish species, whereas Zeller's work was focused on bottomfish.

Reconstructed total catch has been calculated for other coastal communities worldwide by including non-commercial catch, by-catch, and discards: Canada, Alaska, Siberia, Colombia, Mozambique, and Tanzania all calculated that reconstructed catch was anywhere from 1.3 – 6.2 times the catch reported by the FAO (Jacquet et al. 2010, Wielgus et al. 2010, Zeller et al. 2011). Several studies of other Pacific islands have incorporated small scale, non-commercial fishing data into total estimated landings and have found them to be substantial (Zeller et al. 2005, 2008, 2014, Lingard et al. 2012, Pauly & Froese 2012, Cuetos-Bueno & Houk 2014). Reconstructed catch from French Polynesia, Samoa, Tonga, and CNMI were estimated to be between 2 and 17 times the reported commercial catch, with non-commercial catch comprising between 43% and 79% of the total catch (Zeller et al. 2005, 2008, 2014, Lingard et al. 2012, Pauly & Froese 2012, Cuetos-Bueno & Houk 2014).

One way to gather catch data is through a fishing license program. With the exception of Hawaii and New Jersey, all other US mainland coastal states require a recreational fishing license (http://www.nmfs.noaa.gov/sfa/management/recreational/resources_for_fishermen.html). In the state of New Jersey, however, recreational fishers must register, but are not required to obtain a license (http://www.nj.gov/dep/fgw/marinelicenses.htm). These licenses help track resource use and most of these fees go towards management of the fisheries resources or employing enforcement officials. The state of Hawaii requires a permit for recreational freshwater fishing, collecting fish for the aquarium trade, and bottomfishing (http://dlnr.hawaii.gov/dar/licenses-permits/), but does not have a similar reporting requirement for non-commercial saltwater fishing (Zeller et al., 2008). In Hawaii, the only nearshore marine reporting requirements are for commercial fishers – those who "take marine life for profit or gain" (http://dlnr.hawaii.gov/dar/fishing/commercial-fishing/; Hawaii statutes section 189-3). Commercial marine license (CML) holders are required to submit monthly reports covering any marine life taken including discards, fishes retained but not sold, and fishes used as bait. However, the lack of any such requirement for the non-commercial fishing sector typically makes it is difficult to develop and implement catch-based management programs (Zeller et al. 2008, Houk et al. 2011, Friedlander 2015). Sustainable fisheries management strategies are greatly needed in the US Pacific region, given current challenges to management capacity and the importance of seafood production to local cultures and food security (Bell et al., 2009; Houk et al., 2011; Friedlander et al., 2013).

Non-commercial fishing data are, however, gathered by the National Oceanic and Atmospheric Administration (NOAA) and Hawaii's Division of Aquatic Resources (HDAR)'s Marine Recreational Information Program (MRIP). This is part of a national program that aims to provide small-scale (at the state level), non-commercial catch and effort estimates from a combination of intercept surveys (for catch information) and random telephone dialing surveys (for effort and participation data) (http://www.countmyfish.noaa.gov/aboutus/). Unfortunately, in many instances, the catch from these data are incomplete. Catch weight is considered unknown if there are less than two weight measurements for a specific mode of fishing in a 2 month survey 'wave'. Unfortunately, due to the diverse nature of the fishery, and the relatively limited amount of intercept-sampling effort, this is a common occurrence for targeted reef fish taxa in Hawaii, resulting in roughly two-thirds of the catch records having no weight estimation (Williams & Ma, 2013).

Annual state-wide non-commercial fisheries data summaries are served on the NOAA website (http://www.sefsc.noaa.gov/about/mrfss.htm), but data issues, as noted above, limit the value of these raw data. Walker et al., (2012) assessed the MRIP data for Hawaii from 2003-2010, using abundance instead of weight for catch (due to these data limitations), and showed that coral reef species made up the majority of Hawaii's non-commercial harvest. This can be improved by using weight instead of abundance, because abundance data have limited use in assessing and managing fisheries. Fish size gives important information about the life history of the fish, such as approximate age and length at spawning; in order to maximize the value of the resource, it is important to consider these characteristics (Haddon 2011).

In addition to the weaknesses of the state-wide non-commercial fisheries data, there is also a lack of finer resolution data, which is important for properly understanding the heterogeneous nature of

Hawaii's nearshore fisheries. Human population density has previously been used as an indication of fishing pressure in Hawaii due to this lack of suitable estimates of fishing effort (Williams et al. 2008). A number of high-resolution surveys of nearshore fisheries have been conducted in Hawaii by various government agencies, universities, non-governmental organizations (NGOs) and communities. These surveys are termed creel or pakini surveys (in Hawaiian). Creel refers to a woven basket that was traditionally used to hold a fisherman's catch, and because observers would ask to sample the fisherman's creel, this became known as a creel survey (Malvestuto 1996). Pakini is a Hawaiian noun for a tin pan or basin; many fishers would use this with a tire tied around it for floatation while harvesting seafood (Russell Amimoto, pers. com.). Methodologies for these surveys include: (1) "roving survey", in which the interviewer/observer travels through a prescribed route through a fishery (such as along a beach or length of coastline), or (2) an "access point survey", where an interviewer stays in one location to interview fishers as they leave a fishery area, or observe from a vantage point where the entire area can be seen, such as an aerial survey (Malvestuto 1996). Creel surveys are designed to capture effort and measure CPUE. Effort and CPUE are then combined to calculate total catch (National Research Council 2006). Although several creel surveys have been conducted across the MHI, they have not previously been combined in a systematic manner.

Nearshore fisheries in the MHI have declined dramatically over the past 100 years (Friedlander et al. 2014, Williams et al. 2015) and stocks are severely depleted relative to the remote, protected, and unfished Northwestern Hawaiian Islands (NWHI) (Friedlander & Demartini, 2002; Friedlander et al., 2008), and when compared to baseline estimates of the MHI in the absence of humans (Williams et al. 2015). The drivers of these declines are numerous, including the removal of reproductive stock through fishing below reproductive maturity, the use of unsustainable and/or highly efficient gear, policies that set minimum sizes below reproductive age, pollution and habitat alteration from coastal development, and several other fisheries independent factors (Birkeland, 2004; Friedlander et al., 2008; Kronen et al., 2010). While this situation has received some attention from the public and decision makers, policy makers have yet to adequately address the current fisheries policies and environmental management issues in Hawaii.

This study synthesizes commercial, non-commercial, and fine-scale creel surveys to develop a best-possible estimate of fishing yield across the MHI. These data have not been combined before due to limitations of the data, as well as inherent differences among the data sets, e.g., the immense differences in spatial scales. Weaknesses of the available large-scale datasets include that they rely on fishers' recall of effort and catch, that catch weights are frequently unavailable, and that the highly diverse non-commercial sector is relatively under-sampled. An additional complication is that issues of data confidentiality mean that it is frequently difficult or impossible to get complete fine scale (such as species level) commercial data. Specifically, data are withheld or are pooled into higher taxonomic, spatial or temporal level if the minimum reporting unit includes data from fewer than three CML holders (on a basis that in those cases, such data would allow particular fishers to determine catch by other CML holders). Different agencies conduct these surveys and gather fishery data using different methods and different gear type terminologies, which make it difficult to combine datasets. The fishery in Hawaii is substantial and diverse, making it inherently complex to quantify. This study overcomes these limitations to make available the best possible information on nearshore fisheries in Hawaii – including estimates of catch, as well as basic information about the fishery (participation, gear preference, CPUE) – and generates those at the scale of individual islands, likely a more appropriate management scale than the statewide level at which existing large scale programs currently report.

Methods

Study area

The MHI are comprised of the eight main inhabited islands of Niihau , Kauai, Oahu, Molokai, Maui, Lanai, Kahoolawe, and Hawaii, and 124 small islands, reefs, and shoals (Juvik & Juvik 1998). Located in the middle of the Pacific Ocean and spanning ca. 644 km, it is one of the most remote populated areas in the world (Juvik & Juvik, 1998), with the closest island group 1,800 km away (http://islands.unep.ch). The NWHI extend > 1,609 km to the northwest of the MHI and have a long history of exploitation (e.g., seabirds, lobster, deep-water bottomfishes), however, harvest of nearshore reef fishes was extremely limited due to the high cost and low economic value of these resources (Grigg & Tanoue 1984, Grigg et al. 2008). These islands are now included in the Papahanaumokuakea Marine National Monument (PMNM) where all fishing has been prohibited since 2005, and so the NWHI are therefore not considered in these analyses.

Taxa of Interest

The catch estimates generated from this study are for nearshore reef-associated species only. We therefore excluded pelagic species (e.g., tuna, billfish, wahoo) and bottomfish. For a complete list of species included, see Appendix A.

Data sources

Data for these analyses consisted of small-scale, non-commercial and commercial fishing data and came from four main different data sources (Fig. 1). Non-commercial fishing data were derived from the MRIP surveys (referred to as 'MRIP' data). Another source of non-commercial fishing effort came from a survey conducted by the Hawaii Coral Reef Initiative (HCRI) Research Program (referred to as 'HCRI' data) (QMARK 2005). In addition, numerous finer-scale creel surveys, conducted by the University of Hawaii's Fisheries Ecology Research Lab (FERL), The Nature Conservancy of Hawaii (TNC), NOAA, HDAR, Pono Pacific, Makai Watch, Conservation International (CI), Hawaii Cooperative Fisheries Research Unit (HCFRU), Alaka'i Consulting, Hui Aloha Kiholo, and the University of Hawaii (at Hilo and Manoa) provided data for small-scale, non-commercial fishing (referred to as 'creel' data). Commercial fishing data were provided by HDAR and were recorded by reporting blocks (42 blocks around the state, extending ~4 km from shore and varying in size from 56 to 248 km^2) (referred to as 'CML' data) (Fig. 2).

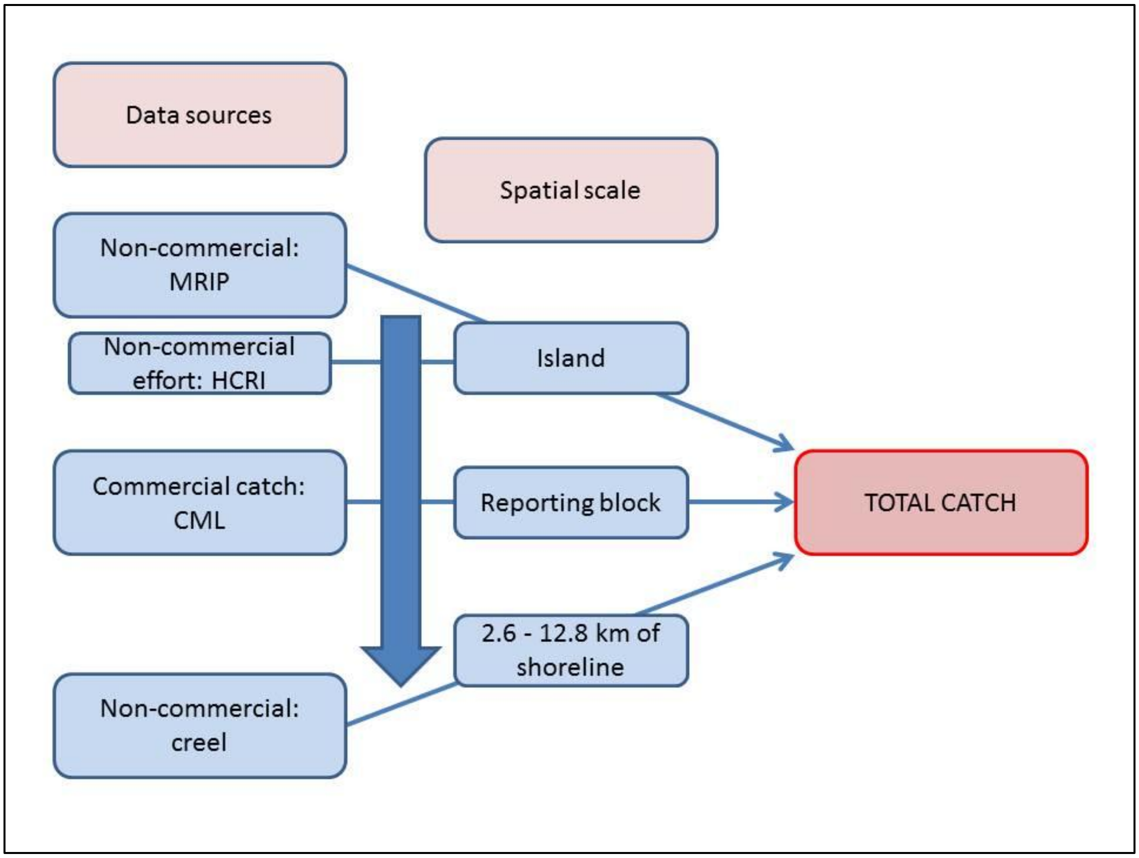

Figure 1. Data sources and spatial scales used to calculate total nearshore fisheries catch for the main Hawaiian Islands. The large arrow indicates decreasing spatial scale.

Spatial scales differ widely among datasets (Fig. 2). The broadest spatial scale used was island level, from the MRIP surveys for the islands of Kauai, Oahu, Molokai, Maui, Lanai, and Hawaii. The HCRI data were also available at the island level. The next smallest spatial scale came from the CML data, which were available by reporting blocks and differ in size and distance from shore. There are 82 reporting blocks for the MHI, 40 coastal (referring to offshore) and 42 inshore. Inshore blocks were used for this analysis because most reef fish species are caught closer to shore, and to make this dataset more comparable to the mostly shore-based creel surveys. These inshore blocks extend ~4 km from shore and vary in size from 56 to 248 km^2 (mean 131 ± 51 SD). Spatial scales of the creel surveys vary depending on location. For this analysis, we compiled creel data from 12 locations across Kauai, Oahu, Lanai, Maui, and Hawaii (Table 1). Data came from two locations on Kauai, four on Oahu, one on Lanai, two on Maui, and three in Hawaii. The duration of creel survey programs varied in length from two weeks to two years, and survey effort spanned 2.6-12.8 km of coastline.

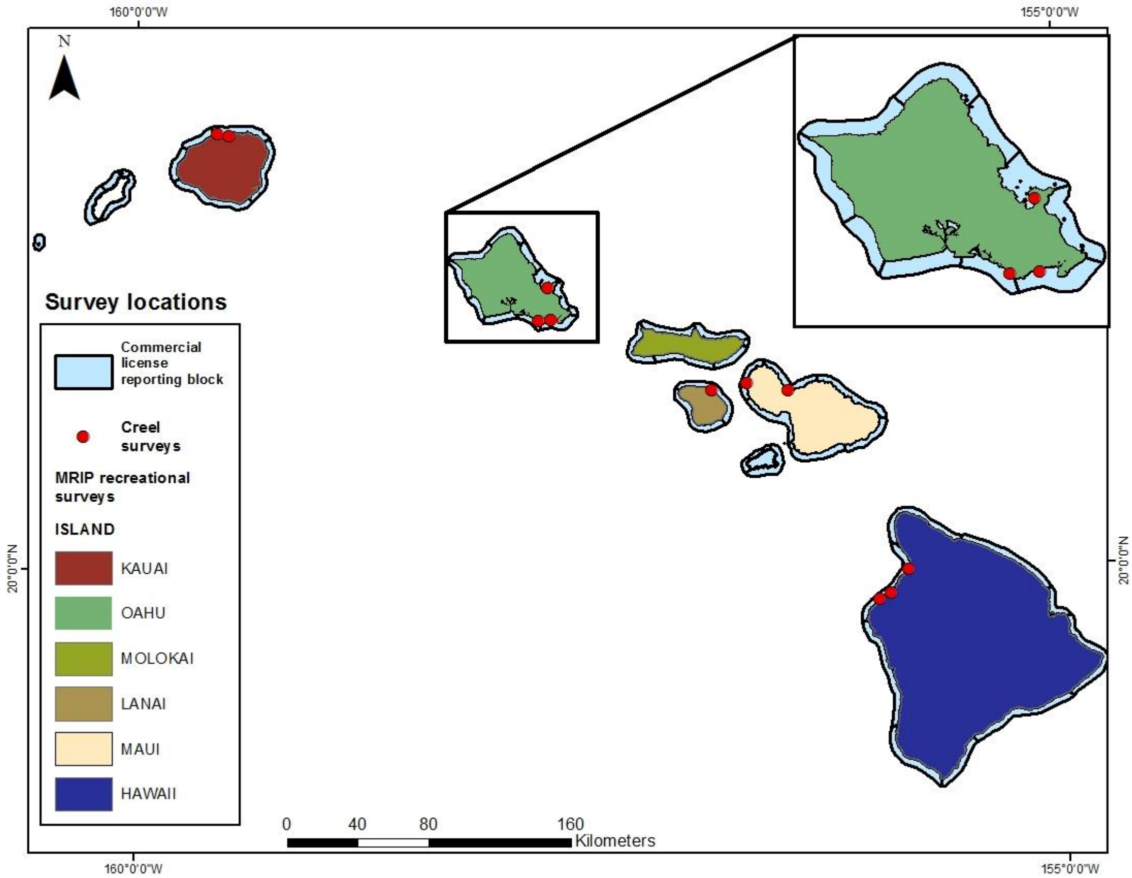

Figure 2. Spatial extent of fisheries data sets used in this analysis. MRIP and HCRI data were analyzed at the island level (indicated by different colors), CML data were analyzed at the reporting block level (indicated by blue surrounding the islands, only including the nearshore blocks, not the offshore ones), and creel data were analyzed for a small area of coastline (indicated by red dots). The island of Oahu is inset to show more detail on the scale of commercial reporting blocks.

Table 1. Creel survey site locations, time frame, duration, and length of coastline surveyed.

Location	Island	Month/Year	Duration	Coastline (km)
Maunalua	Oahu	12/2007-11/2008	1 year	11
Waikiki	Oahu	6/1998-8/2001	2 years, 2 mo.	7
Kaneohe Bay	Oahu	1991 - 1992	1 year	12.8
Kaneohe Marine Corps Base	Oahu	2/2011	1 month	7 sites across 12.5 km
Haena	Kauai	12/2009-12/2010	1 year	3.8
Hanalei	Kauai	7/1992-12/1993	~1 year	~ 4.8
Maunalei	Lanai	5-6/2013	2 weeks	~2.6
Kahekili	Maui	1/2011-12/2011	1 year	~ 3
Wailuku	Maui	3/2013 - 8/2013	5 months	~3.5
Kiholo	Hawaii	4/2012-5/2013	1 year	~4.7
Kaupulehu	Hawaii	8/2013-11/2013	3 months	3.5
Puako	Hawaii	12/2008-12/2009	1 year	3.6

Data compilation

The non-commercial data from the MRIP surveys, non-commercial data from the creel surveys, non-commercial effort data from the HCRI surveys, and commercial data from the CML program were combined to produce estimates of total catch at the island scale. Total catch was calculated by combining catch rate estimates (CPUE) from average hours fished per trip, gear type used, and amount of fish caught, and expanded fishing effort estimates using average number of trips per year. For each of the three summaries described below, non-commercial catch was combined with the commercial catch to estimate total catch. The non-commercial fisheries data collected by the MRIP surveys provide the largest spatial scale of available data, and constitute the base for the non-commercial estimates. Variations on non-commercial catch estimates included: (1) one total catch estimate was calculated by using only the MRIP data (referred to as MRIP); (2) a second estimate used effort estimates from the HCRI study with CPUE estimates from the MRIP data (HCRI-MRIP); and (3) a third estimate was calculated by using an average of the CPUE values from the creel surveys at each island, and combining that with the effort estimates from the MRIP surveys (MRIP-creel). All three estimates were averaged at each island to produce an estimate of total catch of nearshore reef fish. Yield for the average of the three estimates was calculated by dividing catch at each island by the area of hard bottom reef area to a depth of 30 m. Data were summarized as metric tons per km^2 per year. More detail on the data sets are provided below.

Commercial data – CML

Commercial fishers are required to have a commercial license and report their catch and effort on a monthly basis. These data are collected and summarized by HDAR. Species totals for each inshore reporting block was provided by HDAR; however, due to confidentiality agreements with fishers, raw data may not be reported if there are reports from fewer than 3 CML holders in a strata (e.g., reporting block, gear type, year). Due to this confidentiality agreement, 34% of the data were unavailable on a year by gear type by reporting block basis. To circumvent this issue, data totals were provided in 5-year blocks, from 2004-2008 and from 2009-2013. These data were still affected by the confidentiality agreement, with 17% of the data still missing from the analyses (see Appendix B). These CML data were summarized in one ten year time period, and a yearly average was calculated by reporting block, species, and gear type.

As this assessment focused on nearshore reef-associated fishes, deep-water bottomfishes and pelagic species were excluded from our analyses. In addition, fishing methods reported to HDAR that targeted offshore species, such as deep-sea handline, tuna handline, vertical line, and aku (skipjack tuna – *Katsuwonus pelamis*) boat methods were also excluded. A complete list of reef species that were included in our analyses is given in Appendix A.

Non-commercial data – MRIP

The MRIP program consists of two survey methods: a telephone survey to estimate fishing effort by household, and an intercept survey of fishers at access sites to estimate catch and CPUE. This program began on Oahu in 2001 and expanded to include neighbor islands in 2002-2004. Data were used from 2004-2013 so that comparisons could be made among the islands of Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii.

Telephone surveys – effort

Bimonthly telephone surveys are conducted using a random digit dialing system. Households are asked if they fish, and if so, how frequently in the past two months they have gone fishing. Details from each trip are recorded, including mode or platform (boat or shore), and gear type. The resulting information yields the number of trips per gear type per fisher for that two-month period, which is called a wave.

Fishing effort is categorized into three types of data, or three tiers. All types come from the household telephone survey.

- Type 1 data general household information, such as how many fishers are in each household (1 record per household).
- Type 2 data number of trips per fisher (1 record per fisher per household)
- Type 3 data trip information: platform (boat or shore) and gear type (1 record per trip).

Many records in the type 2 data did not have corresponding details in the type 3 data, whether due to memory lapse, time constraints, or unknown reasons. To account for these trips with no details, we used type 3 data to determine the percentage of each gear type from the total number of trips. This percentage was multiplied by the records in the type 2 data without associated type 3 details in order to obtain frequency of gear use for all type 2 records.

We estimated expanded effort by calculating average trips per household per year (by summing waves) and that was multiplied by census numbers of households per island (averaged from 2004-2008 or 2009-2013) (factfinder.census.gov).

$$\left(\sum \frac{t_{ijk}}{n_{ijk}}\right) H_{jk}$$

Where t = number of trips per wave (i) per year (j) per island (k), n = total number of households contacted per wave (i) per year (j) per island (k), and H =total number of households per year (j) per island (k).

NOAA's Office of Science and Technology prepares annual trip summaries at the county level, which are not as precise as island level estimates because Maui county consists of the islands of Maui, Molokai, and Lanai. The island level results produced in this study are similar to the county results from NOAA's office. For more information, see Appendix C.

Intercept surveys – catch

Intercept surveys are the second half of the MRIP program, and capture catch and CPUE information. Data were obtained from 25 sites on Kauai, 55 sites on Oahu, 11 on Molokai, 16 on Maui, and 41 on Hawaii. Interviewers approached fishers as they were leaving the shore or boat ramp and asked if they could interview them and measure their catch. These surveys are only conducted during the daytime and exclude nighttime catch. Two types of catch are recorded: available catch, and unavailable, or fisher-reported catch (released alive, or not available for identification – due to refusal, consumption, or bait use). MRIP catch estimates are provided for each fishing mode and fishing area (inland, ocean ≤3 miles from shore, ocean >3 miles from shore). For the state-wide summaries provided by NOAA, catch weight is calculated from the product of catch number and mean weight in the estimation domain (fishing mode and fishing area). If there are no weight measurements for a species in the estimation domain, the mean weight from the state for that wave, or 2 month period, is used as a substitution weight, and at least two weight measurements are needed. If there are not enough weight measurements to make the estimation, catch for this species is not calculated but substitute values are used instead. For reef fishes in Hawaii, about two-thirds of expanded catch records have missing weights. A study by Williams and Ma (2013) calculated substitute weights for reef fish species based on mode (boat vs. shore) using data from 2004-2011. These substitute weights were used for this analysis when weight and length were missing.

To calculate CPUE for this analysis, raw data from 2004-2013 were combined. Information used included gear type, hours fished, number of fishers, mode, and catch information, including species, weight, size and number of fish. There were many instances of incomplete records and missing information, and this was accounted for in several different ways.

To calculate catch weight, several substitutions were made. During the 10-year period, a total of ~6000 records of available catch provided ~32,000 fishes - only 4,429 fishes of which had weights (<14%). For 2,583 reef fishes, length (L) was recorded, and, in those cases, weight (w) was calculated from the following standard allometric equation:

$$w = a \times L^b$$

The parameter (a) is a scaling coefficient for the weight (w) at length (L) of the fish species. The parameter (b) is a shape parameter for the body form of the fish species (Keys 1928, Le Cren 1951). For more information on MRIP data processing, see Appendix D.5.

In order to combine information from the two survey methods, we consolidated gear types into three categories: net, line, and spear (Table 2). For the telephone data, gear types of rod and reel, dunking, spinning, whipping, handline, casting, kite, and line were combined into the line category. Jigging, trolling and bottomfishing methods were dropped as they targeted pelagic and bottomfish species. Some trip records had multiple gear types recorded. To account for this, each gear type was counted as a fraction of a trip. For example, a trip that listed both spear and handline as gear types was counted as 0.5 spear trips and 0.5 line trips.

Table 2. Gear types recorded in MRIP surveys for catch/intercept surveys, and for effort/telephone surveys, and how gear was grouped to be comparable.

Combined gear	Catch/intercept	Effort/phone	
boat and shore	boat and shore	boat gear	shore gear
line	handline, handpole, rod and reel	handline, rod and reel, casting, whipping	handline, kite, line, rod and reel, casting, spinning, dunking, whipping
net	scoop net, throw net, gill net, cross net, surround net	netting	netting
spear	spear	spear	spear
Excluded gear			
glean	trawl	bottomfishing	gleaning
crab net	crab net	trolling	crabbing
deep	hukilau	jigging	trap

Effort data were collected for the island of Lanai, but there are no intercept sites on Lanai that would enable us to apply CPUE estimates to the effort estimates. We estimated catch on Lanai by averaging CPUE values for each mode and method from Kauai, Oahu, Maui, Molokai, and Hawaii and multiplied this by the effort estimates from Lanai. Boat net methods had no catch estimates, but had effort data, so CPUE for shore net was used for catch calculations. For each island, each mode and each gear type, a 10-year average number of trips was calculated. This was multiplied by average hours per fishing mode/gear for that island, and that was multiplied by CPUE to get total catch. For a list of reef fish species, see Appendix A.

Non-commercial data – HCRI

In November and December of 2004, QMark Research & Polling, the Hawaii Coral Reef Initiative (HCRI) Research Program, and The Social Science Research Institute (SSRI) both at the University of Hawaii at Manoa conducted an ocean-use study by random telephone interviews of island residents. This survey was part of a larger project entitled Non-Economic Value of Coral Reef Study, which was conducted in the fall of 2004 and the winter of 2005 (QMARK 2005).

The survey was designed to obtain information on shore and nearshore activities and the frequency of these activities in the past year. The survey polled 1,600 randomly selected individuals across the MHI. The survey was designed to poll at least 300 people from the islands of Kauai, Maui and Hawaii, and at least 600 people from Oahu. Native-Hawaiians were oversampled to reach a quota of 400 overall. Respondents were asked if they had participated in fishing activities such as pole and line fishing, spear fishing, netting, and harvesting, either for subsistence or recreation, and if they had, how many times they had participated in that activity in the last year.

Fishing effort in the form of number of trips per year per gear type (line, net, or spear) was calculated from these data by island for Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii. Data were summarized by ethnic group for each island, and multiplied by a weighting factor in order to account for the over-sampling of native-Hawaiians. Estimates were multiplied by household numbers by island from census data, to calculate expanded effort. A portion of line trips were removed to account for trolling and bottomfishing trips, by using the percentage of those trips from the MRIP effort data. Values from the MRIP data were used to calculate total catch for each island; percent of trips by platform was calculated and applied to the HCRI total number of trips per island. This was then multiplied by average hours fished, and average CPUE value from the MRIP data. See Appendix D.1 for more information on data processing.

Small-scale, non-commercial data – creel

Various sources (FERL, TNC, NOAA, UH, HDAR, CI, HCFRU, Pono Pacific, Makai watch, Alaka'i Consulting, and Hui Aloha Kiholo) have conducted surveys that provide high-resolution catch and effort data from 12 specific sites around the MHI representing a wide range of habitats and human use levels (Table 1). Several datasets were previously analyzed and available in the literature, while other datasets were analyzed for this study. In order to compare these datasets to the MRIP data, gear types were grouped into line, net, and spear. Total catch from these surveys can also be compared to the commercial reporting block that they fall into. See Appendix D.2-D.4 for more information on data processing.

Total catch calculation

Catch from the creel data and MRIP data were calculated by obtaining total fishing effort estimates over a specified time period, and CPUE estimates. Total catch from the commercial data was supplied in the summaries provided by HDAR.

To calculate total catch, the following equations were used:

Effort:

$$\bar{E} \times D$$

Where ($\bar{E}$) is the average effort times (D) the number of days.

CPUE:

$$\frac{\sum\sum\frac{c_{ij}}{E_{ij}}}{\sum n_i}$$

Where (c) is the catch from each interview (i) of each gear type (j), (E) is the effort from that interview of that gear type, and (n) is the number of interviews.

Total catch:

Effort x CPUE

When possible, CPUE was calculated for three categories of gear type: line, spear, and net, and in addition for the MRIP data, CPUE was differentiated by mode (shore or boat). This was found to be significantly different for the MRIP state-wide small-scale, non-commercial fishing estimates in Williams and Ma (2013). In order to compare the creel CPUE values to the MRIP values, CPUE was calculated for those gear groups.

Data comparisons

All data handling and analyses were performed using scripts written in R (R Development Core Team 2011). Types of gear used on fishing trips were compared using a Chi-squared test (R package stats). Differences in percentages of fishing households were compared using analysis of variance (ANOVA, R package stats). A least-squares linear regression model was used to compare CPUE values to population size per island, which was indicated by total number of households from the US census, and number of households that fish per island (R package stats). Population was log transformed to achieve a normal distribution of residuals.

Catch composition was compared between platform and gear types in ordination space using non-metric multi-dimensional scaling (NMDS) analysis coupled with analysis of similarities (ANOSIM) tests (R, package vegan). The data matrix consisted of mean fish biomass by family at each island and each platform and gear type combination. A Bray-Curtis similarity matrix was created from the ln(x+1) transformed mean fish biomass matrix prior to conducting the NMDS.

Results

Fishing Effort – MRIP

The majority of trips were shore line fishing trips on each island and ranged from 55% on Molokai to 80% on Hawaii. This was followed by spearfishing by shore for most islands (10-14%) except for Kauai (7%) and Molokai (13%), which had shore net trips as the second highest (10% and 16% respectively) (Fig. 3). Boat-based net fishing had the lowest number of trips per year for all islands except for Molokai (5%), only making up 1%. On Molokai, line fishing by boat had the lowest effort at 4.6%. The proportion of fishing trips of these different types were significantly different between islands (X^2 = 62350.43, df=25, p<0.01).

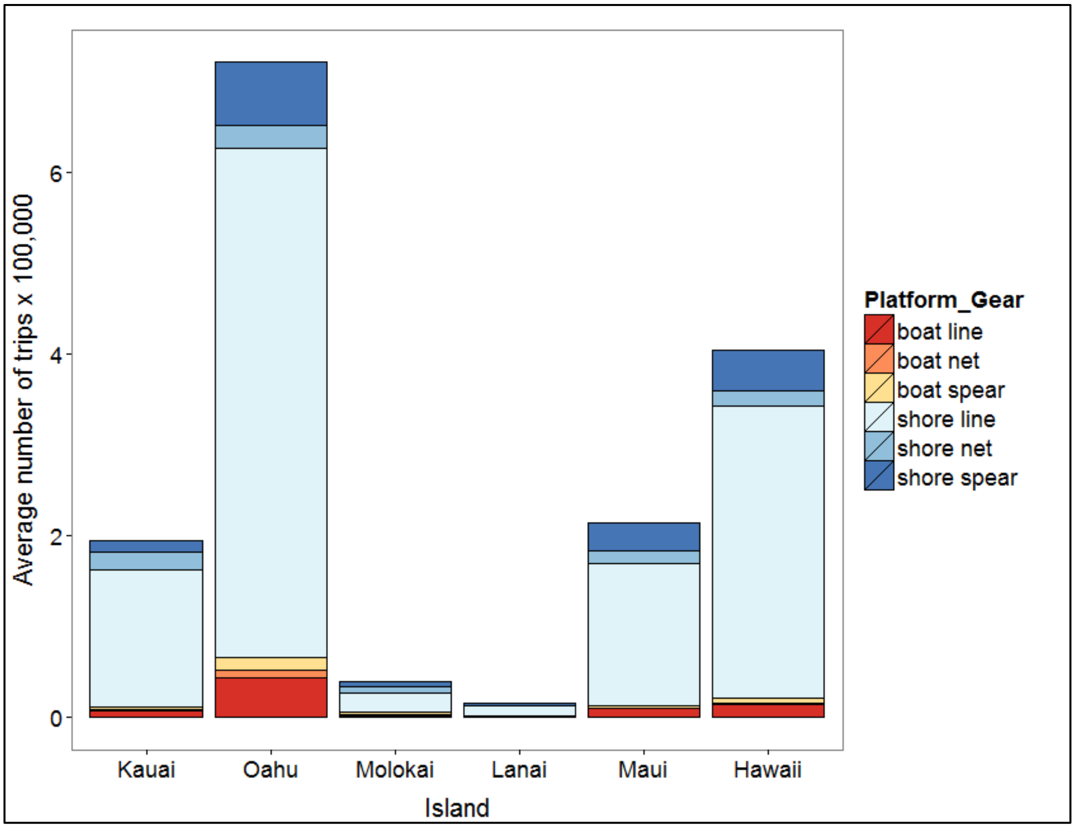

Figure 3. Mean number of fishing trips per year for Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii for each gear group and platform type from the MRIP data.

The percent of fishing households differs significantly among islands (ANOVA with year as factor; $F_{(1,5)}$=125.4, p<0.01) (Fig. 4). Molokai has the highest percent of fishing households (24.7% ± 1.8), while Oahu had the lowest percent (5.7% ± 1.1%). Lanai had the second highest (19.4% ± 3.8%), followed by Hawaii and Kauai (12.8% ± 1.8% and 12.8% ± 1.7%, respectively). While Oahu had the smallest percent of fishing households, it had the highest absolute number of fishing households (17,140 ± 2,782). This was followed by Hawaii (8,189 ± 1,129), Maui (4,412 ± 658), Kauai (2,843 ± 350), Molokai (614 ± 92), and Lanai (209 ± 41). The number of households that fished by island was strongly correlated with total human population among islands (linear regression, R^2 = 0.94, $F_{(10)}$=185.3, p<0.01), suggesting that population size is a good proxy for indicating fishing effort.

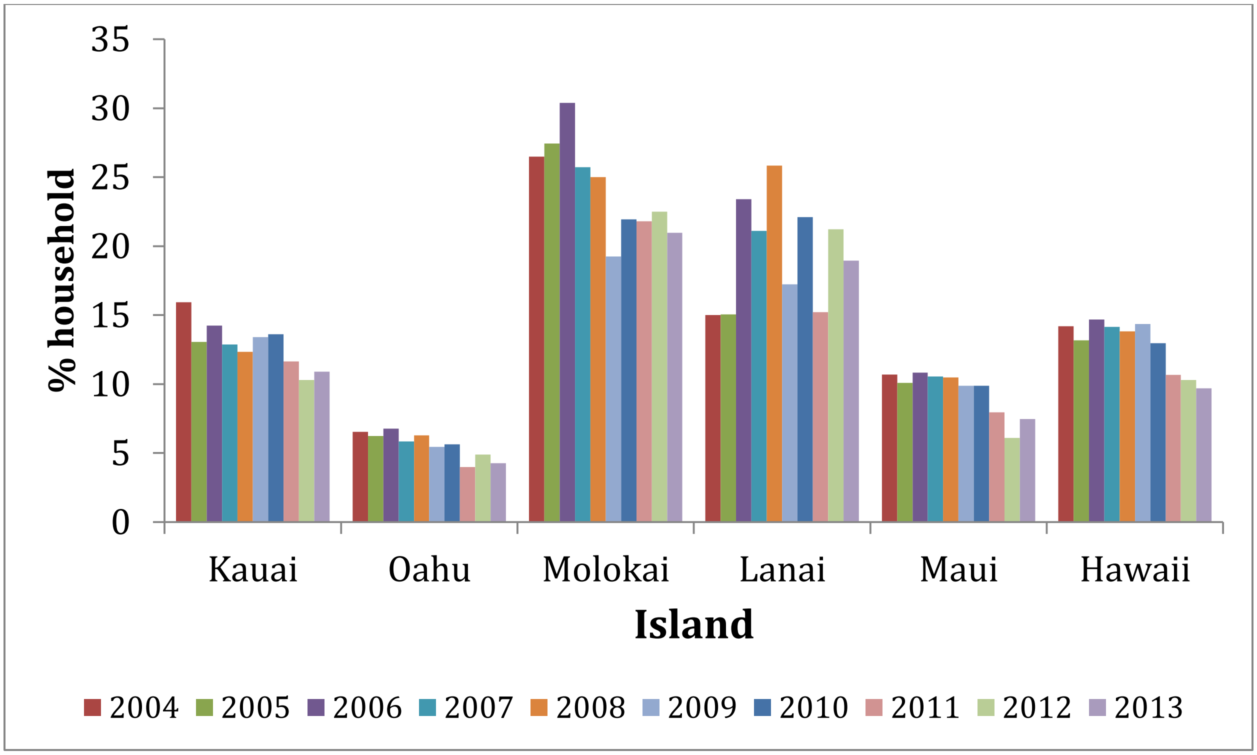

Figure 4. Percent of fishing households for Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii islands. Fishing households are defined as households with anglers who have fished in the past 2 months. Each color bar represents a different year from 2004-2013.

Another source of fishing effort data came from the HCRI survey. Survey respondents were asked if they fished in the last year, and how many trips of each gear type they took. Compared to the MRIP data, the HCRI data show a greater number of trips on Oahu, Maui, and Hawaii islands (Fig. 5). The greatest difference is on Oahu, where the HCRI estimate of fishing trips is 224% higher than the MRIP estimate. Trips on Hawaii island were estimated at 45% higher, and trips on Maui were 37% higher. However, trips on Kauai, Molokai, and Lanai had lower estimates than the MRIP estimates. Trips on Molokai from the MRIP data were 109% higher, Lanai was 43% higher, and Kauai had the closest agreement, with only 10% more trips reported than the HCRI data.

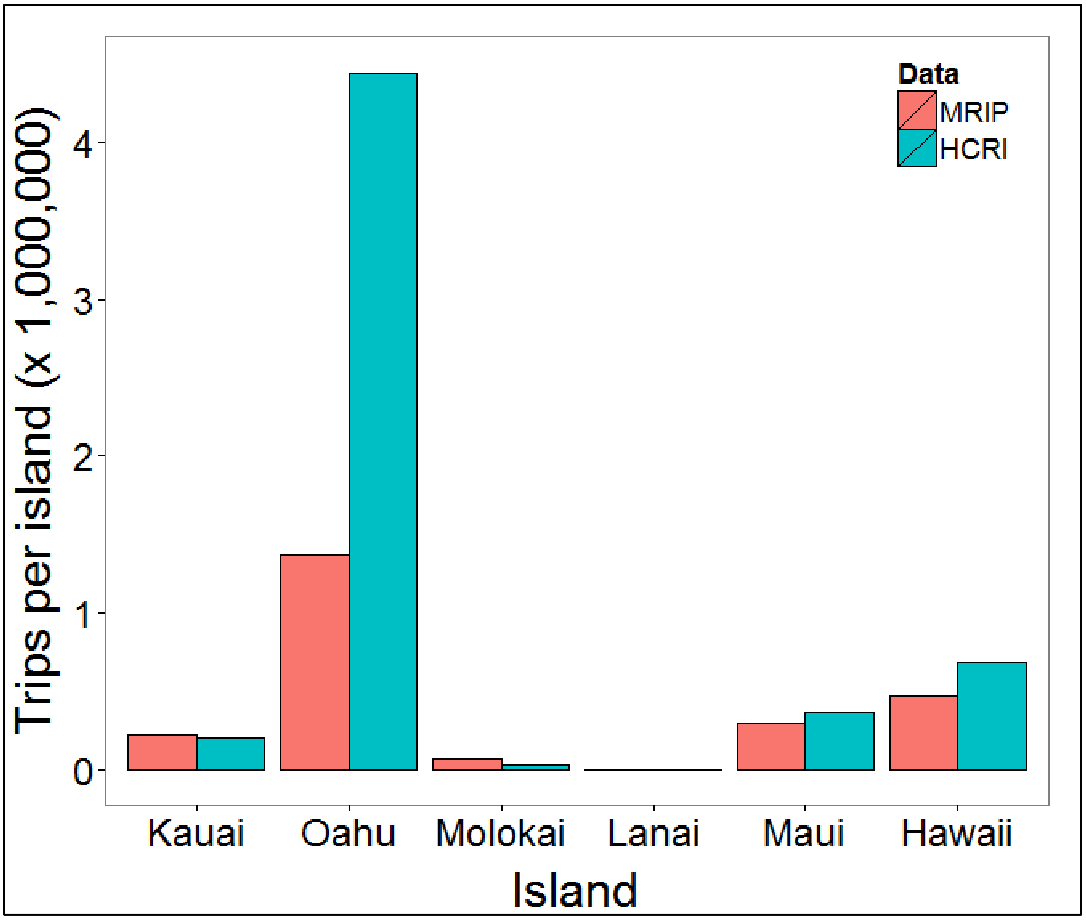

Figure 5. Expanded fishing effort based on the total number of fishing trips per island in 2004. MRIP estimates are in red and HCRI estimates are in blue.

Catch per unit effort (CPUE)

Compared to the other islands, Molokai had the highest CPUE for shore and boat line fishing, and shore net fishing, but the lowest catch rates for boat net fishing (Table 3). Oahu had the lowest catch rates for shore and boat line fishing, and shore and boat spear fishing. Kauai had the highest catch rates for boat net fishing, but was similar to Oahu for the lowest CPUE for shore spear fishing. Maui had the highest catch rates for boat spear fishing and Hawaii had the highest catch rate for shore spear fishing.

Table 3. Catch-per-unit-effort (CPUE) and coefficient of variation (COV = SE/mean) values from MRIP data for boat and shore platforms with gear types of line, net, and spear. No value indicates sample sizes < 5. No catch data were collected on Lanai.

Platform	Gear	Kauai CPUE (COV)	Oahu CPUE (COV)	Molokai CPUE (COV)	Maui CPUE (COV)	Hawaii CPUE (COV)
Boat	Line	0.34 (0.10)	0.13 (0.23)	0.52 (0.37)	0.34 (0.15)	0.46 (0.24)
	Net	2.65 (0.42)	2.10 (0.42)	1.17 (0.57)	-	-
	Spear	0.45 (0.53)	0.34 (0.31)	0.79 (0.52)	1.59 (0.50)	1.41 (0.34)
Shore	Line	0.21 (0.18)	0.09 (0.29)	0.42 (0.30)	0.19 (0.31)	0.22 (0.15)
	Net	0.49 (0.48)	1.04 (0.40)	2.10 (0.26)	0.93 (0.46)	0.50 (0.60)
	Spear	0.32 (0.34)	0.32 (0.57)	0.36 (0.48)	0.40 (0.44)	0.68 (0.68)

Catch rates for line fishing from boat and shore both showed significant negative relationships with human population by island (declined significantly as population increased) (Fig. 6). Catch rates for boat spear fishing (p=0.69) and shore net fishing (p=0.40) also showed negative relationships with increased human population, and although not significant, results were suggestive.

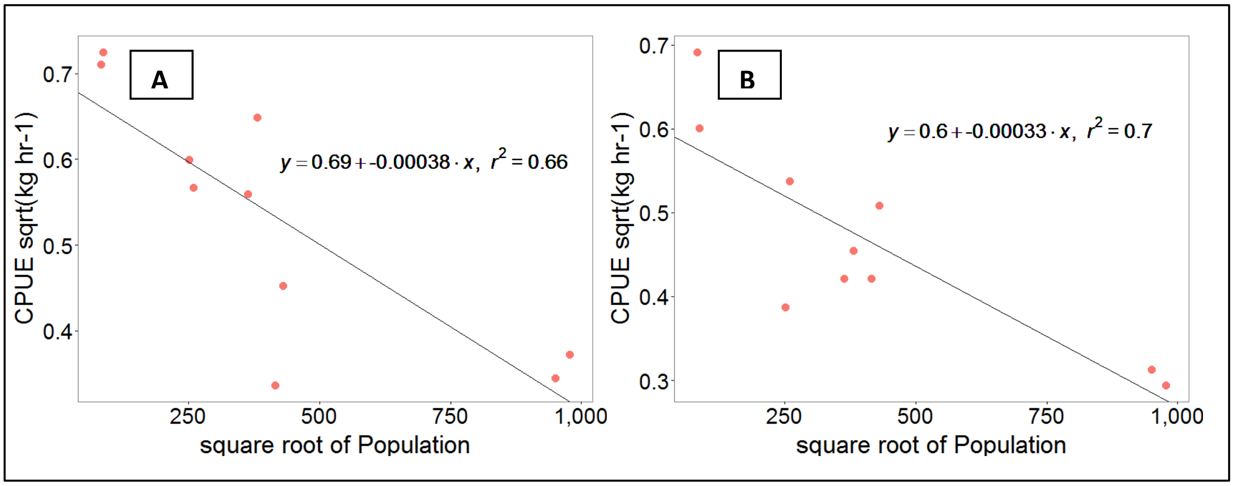

Figure 6. Square root transformed values of line CPUE by (A) boat (p<0.01) and (B) shore (p<0.01) and population size. As population size increases, CPUE decreases. Each point represents CPUE from an island of 2 different time periods: (2004-2008, and 2009-2013), i.e., there are 2 points for each island.

CPUE values were compiled from most available creel surveys to generate a range of CPUE values per island and gear type (Fig. 7). Comparisons were made for different gear types from shore for Kauai, Oahu, Maui, and Hawaii.

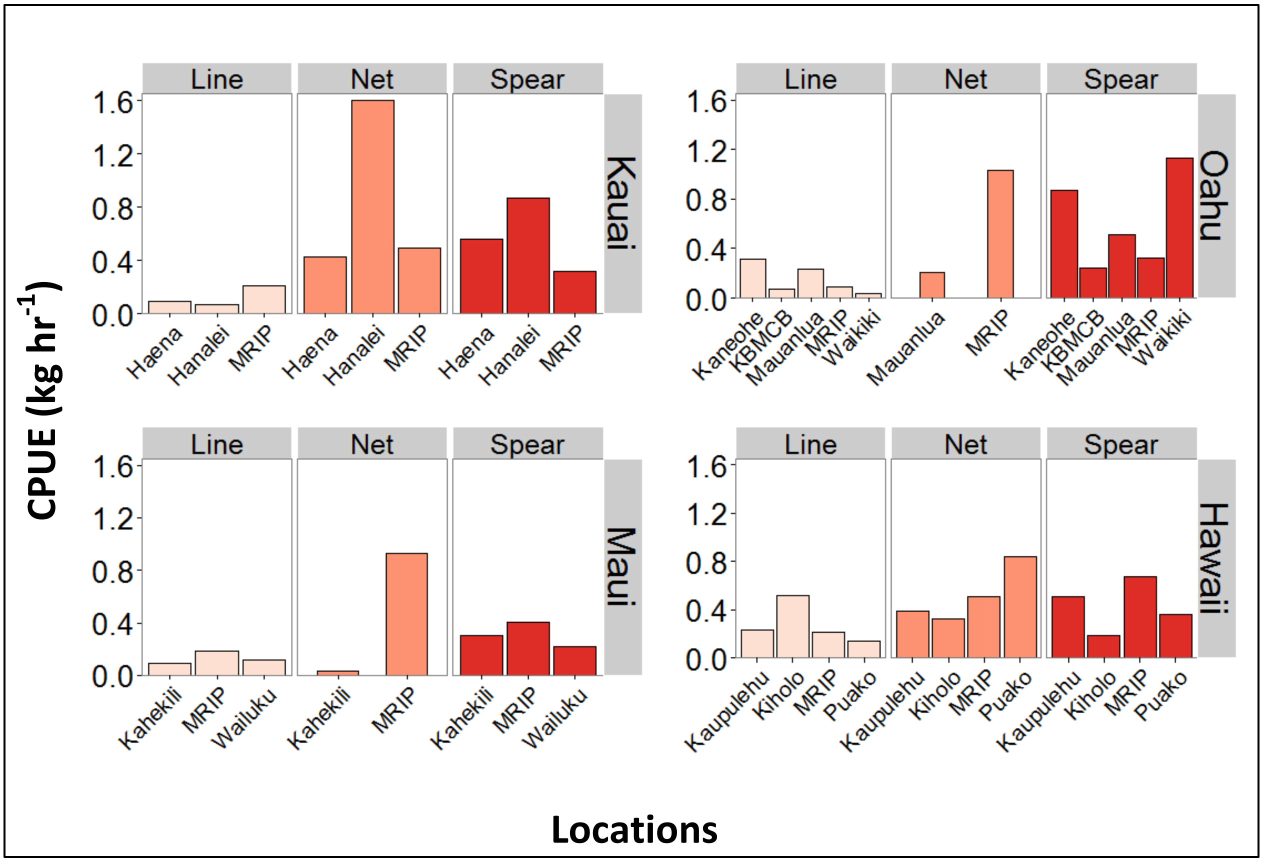

Figure 7. CPUE values for different locations across Kauai, Oahu, Maui, and Hawaii islands, including the island-wide MRIP estimate for line, net and spear fishing from shore. NOTE: Hanalei shore net = cast net, Haena shore net = thrownet. KBMCB = Kaneohe Bay Marine Corps Base.

On Kauai, the MRIP estimate of CPUE for shore line fishing was higher than the creel surveys. Hanalei had the highest estimates for shore net fishing and shore spear fishing. The MRIP CPUE estimate for shore spear fishing was lower than both Hanalei and Haena (Fig. 7).

On Oahu, the MRIP CPUE estimates fell in between most of the ranges of estimates from the creel surveys (Fig. 7). CPUE for shore net was highest according to the MRIP estimate, but there was only one other value for comparison. Shore spear fishing CPUE was highest in Waikiki, followed by Kaneohe bay and Maunalua bay. CPUE was relatively low for Kaneohe Bay Marine Corps Base (KBMCB), which is part of Kaneohe bay; the discrepancy in numbers shows how variable these data can be.

On Maui, the MRIP CPUE estimates were higher than the creel survey estimates in both Kahekili and Wailuku (Fig. 7). Shore net fishing had the lowest CPUE value of all three gear types for Kahekili and

Wailuku, but shore line fishing had the lowest CPUE value for the MRIP data. Shore net fishing had the highest CPUE of the Maui data sets.

On Hawaii, the MRIP values for CPUE was highest for spear fishing, but fell in the middle range for net and line fishing when compared with the smaller scale creel surveys (Fig. 7). Kiholo had the lowest CPUE for spear fishing, but the highest CPUE for line fishing. Puako had the highest CPUE for net fishing, and the lowest CPUE for line fishing. MRIP had the highest CPUE value for spear fishing, and Kiholo had the lowest, but not by a wide margin.

Catch

Non-commercial– MRIP

The MRIP catch differed in species composition for each island (Table 4). Jacks (Carangidae) were one of the top contributors to total catch across all islands. For most islands, top catch is a mixture of reef fish species, like parrotfishes, wrasses (Maui) and aquarium fishes (Hawaii), and reef-associated species, such as amberjack (*Seriola dumerili*), green jobfish (*Aprion virescens*), and sharks.

Table 4. The top species or groups caught from the non-commercial MRIP data for Kauai, Oahu, Molokai, Maui, and Hawaii islands, catch (kg) and the percent of the total MRIP catch.

	Kauai		Oahu		Molokai		Maui		Hawaii	
Species/group	catch (kg)	% of catch	catch (kg)	% of catch	catch (kg)	% of catch	catch (kg)	% of catch	catch (kg)	% of catch
Acanthurus dussumieri	12,940	0.3%	55,257	1.2%	89,377	3.1%	169,524	2.6%	59,913	1.8%
Acanthurus triostegus	10,450	0.3%	109,452	2.4%	76,322	2.6%	80,931	1.3%	44,580	1.3%
Albula glossodonta	56,572	1.4%	258,526	5.7%	141,698	4.8%	93,383	1.5%	39,050	1.1%
Aprion virescens	92,521	2.3%	209,034	4.6%	59,927	2.0%	787,686	12.3%	252,284	7.4%
Carangoides orthogrammus	3,227	0.1%	67,663	1.5%	33,999	1.2%	344,199	5.4%	15,538	0.5%
Caranx ignobilis	1,056,433	25.9%	548,249	12.1%	602,109	20.6%	889,298	13.9%	204,005	6.0%
Caranx melampygus	392,426	9.6%	1,431,990	31.6%	520,175	17.8%	638,908	10.0%	187,781	5.5%
Carcharhinus amblyrhynchos	79,734	2.0%	-	0.0%	-	0.0%	119,601	1.9%	-	0.0%

Table 4. (Continued) The top species or groups caught from the non-commercial MRIP data for Kauai, Oahu, Molokai, Maui, and Hawaii islands, catch (kg) and the percent of the total MRIP catch.

	Kauai		Oahu		Molokai		Maui		Hawaii	
Species/group	**catch (kg)**	**% of catch**	**catch (kg)**	**% of catch**	**catch (kg)**	**% of catch**	**catch (kg)**	**% of catch**	**catch (kg)**	**% of catch**
Carcharhinus galapagensis	39,867	1.0%	-	0.0%	-	0.0%	478,405	7.5%	-	0.0%
Chanos chanos	-	0.0%	76,894	1.7%	92,969	3.2%	-	0.0%	14,451	0.4%
Ctenochaetus strigosus	-	0.0%	8,623	0.2%	384,527	13.1%	36,602	0.6%	112,664	3.3%
Iniistius pavo	-	0.0%	23,707	0.5%	1,433	0.0%	800,225	12.5%	11,829	0.3%
Kuhlia sandwicensis	19,553	0.5%	36,009	0.8%	5,916	0.2%	77,474	1.2%	113,334	3.3%
Kyphosus bigibbus	69,480	1.7%	6,776	0.1%	3,963	0.1%	96,162	1.5%	26,865	0.8%
Lutjanus kasmira	128,022	3.1%	77,773	1.7%	8,825	0.3%	156,419	2.4%	73,070	2.1%
Mugil cephalus	23,977	0.6%	98,774	2.2%	11,205	0.4%	7,934	0.1%	219,968	6.5%
Mulloidichthys flavolineatus	178,662	4.4%	58,788	1.3%	34,609	1.2%	148,005	2.3%	65,721	1.9%
Mulloidichthys pfluegeri	15,939	0.4%	129,654	2.9%	1,622	0.1%	27,521	0.4%	11,034	0.3%
Mulloidichthys vanicolensis	9,506	0.2%	74,752	1.7%	6,156	0.2%	120,933	1.9%	110,919	3.3%
Naso unicornis	7,191	0.2%	18,917	0.4%	64,252	2.2%	10,069	0.2%	21,804	0.6%
Scaridae	41,547	1.0%	250,455	5.5%	65,709	2.2%	7,984	0.1%	101,080	3.0%
Seriola dumerili	1,487,906	36.4%	94,844	2.1%	17,244	0.6%	12,022	0.2%	258,807	7.6%
Sphyraena barracuda	43,749	1.1%	166,883	3.7%	33,271	1.1%	90,125	1.4%	26,265	0.8%
Triaenodon obesus	16,140	0.4%	-	0.0%	80,701	2.8%	-	0.0%	16,140	0.5%
Zebrasoma flavescens	-	0.0%	231	0.0%	-	0.0%	-	0.0%	406,033	11.9%
Total	**3,785,842**	**92.7%**	**3,803,252**	**84.0%**	**2,336,007**	**79.8%**	**5,193,411**	**81.2%**	**2,393,134**	**70.2%**

Family composition of the non-commercial catch also differed between islands (Fig. 8). Oahu had the highest catch of jacks, goatfishes, parrotfishes, barracudas, and bonefishes. Hawaii had the highest catch of snappers, surgeonfishes, mullets, chubs, and flagtails. Maui had the highest catch of sharks and wrasses.

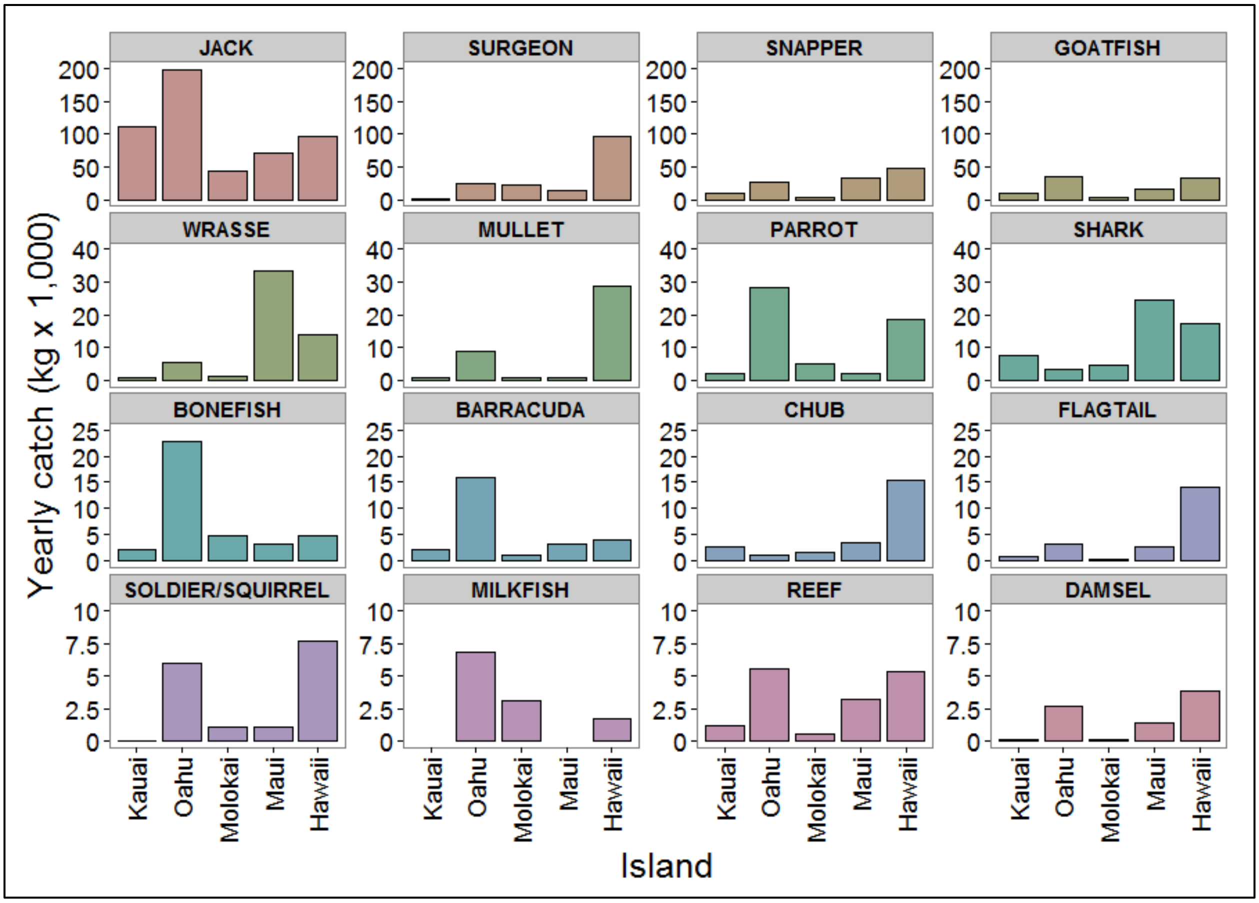

Figure 8. Yearly expanded catch in kg for Kauai, Oahu, Molokai, Maui, and Hawaii islands from the MRIP data for goatfishes, jacks, snapper, surgeonfishes, mullets, parrotfishes, sharks, wrasses, barracudas, bonefishes, chubs, and flagtails. Note different y-axis scale for each row.

Catch quantity differed significantly by island and gear type as well (X^2=197066.6, df=25, p<0.01). Shore line catch had the highest yield on all islands except Molokai, where shore net catch dominated (Fig. 9). The smallest proportion of catch for Hawaii came from boat line fishing. For Kauai and Oahu, it was boat spear fishing and for Lanai and Maui, it was boat net fishing.

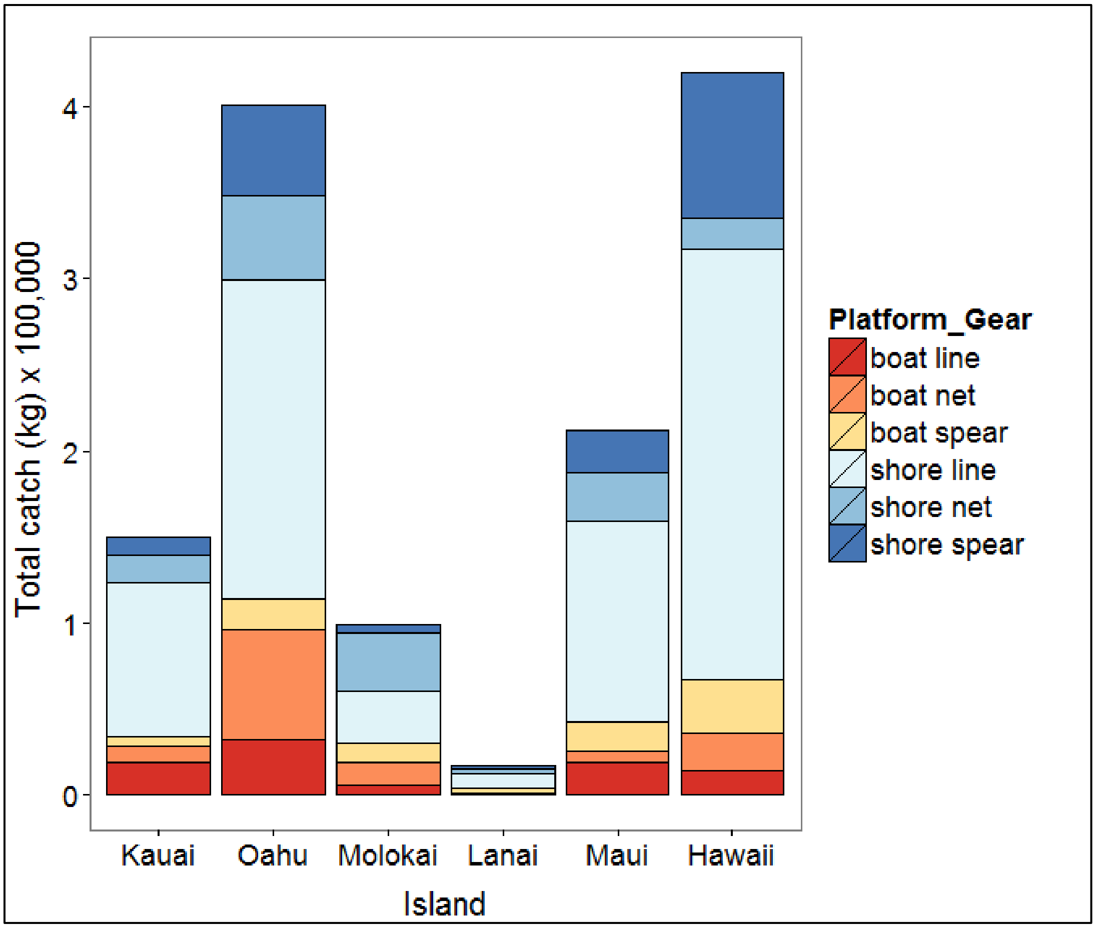

Figure 9. Total catch for one year by gear type (line, net, or spear) and platform (boat or shore) for Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii.

Catch composition differed significantly by gear type (analysis of similarity, R=0.67, p<0.01, Figs. 10 & 11). Shore and boat based spear fishing are similar to one another in ordination space based on fish species composition, as are shore and boat based net fishing. In contrast, line fishing from shore is different from line fishing from a boat in ordination space. All three gear types are well separated, indicated by the low stress value (stress=0.09). Line fishing catch composition was dominated by sharks, eels, hawkfishes, milkfish, wrasses, barracudas, bonefishes, and other reef fishes. Spear fishing catch was dominated by goatfish, jacks, soldiers/squirrels, parrotfish, snappers, emperors, and big eyes, and net catch was dominated by flagtails, mullet, surgeonfish, butterflyfish, and chubs (Fig. 11).

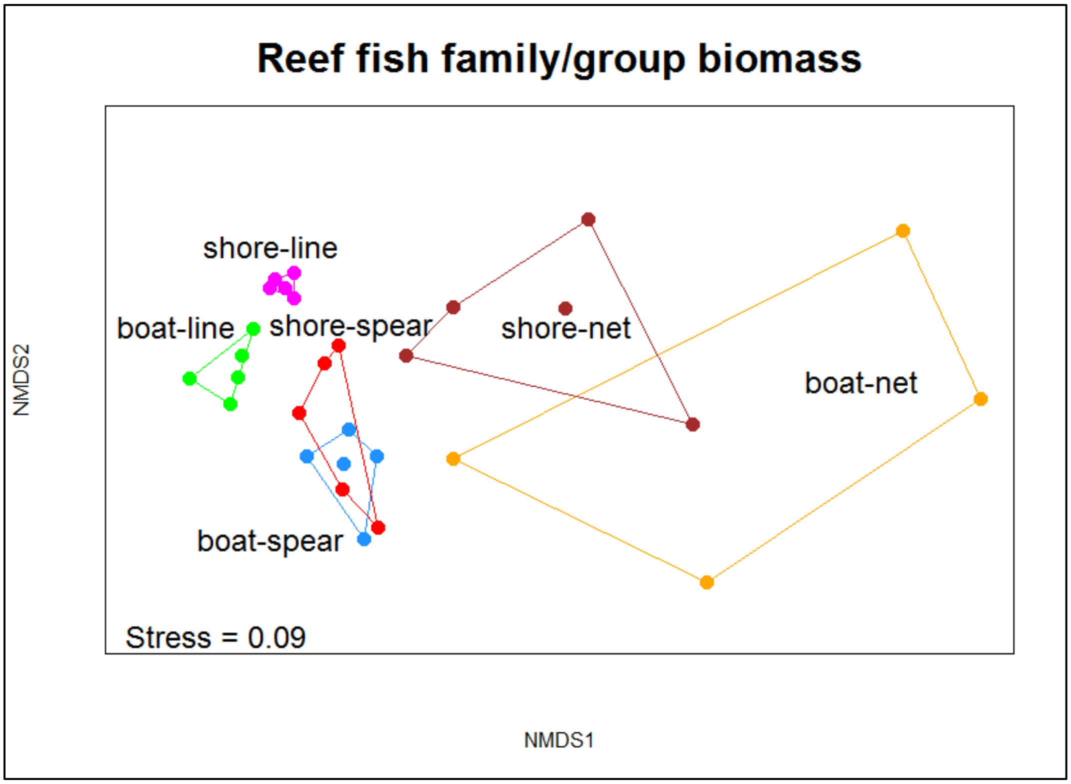

Figure 10. Comparison of reef fish family/group biomass (g/m^2) by island, platform, and gear type, shown in a nonmetric multi-dimensional scaling plot. Each point represents an island, platform (boat or shore), and gear type (line, spear, or net). Minimum convex polygons are drawn around each platform-gear type combination for visual purposes.

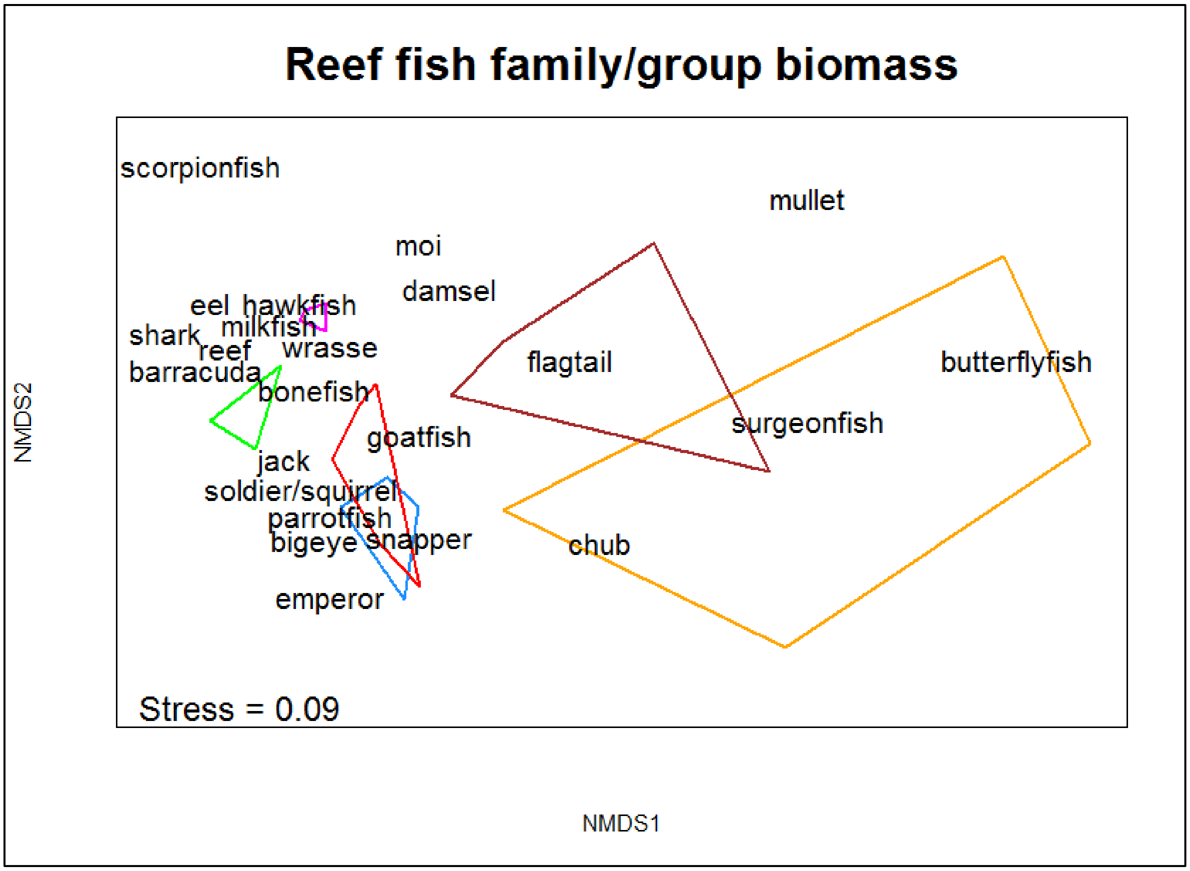

Figure 11. Comparison of reef fish family/group biomass (g/m^2) by island, platform, and gear type, shown in a nonmetric multi-dimensional scaling plot. Common family names/groups are clustered in ordination space by platform and gear type. Minimum convex polygons are drawn around each platform-gear type combination for visual purposes.

Non-commercial–MRIP vs commercial –CML

Non-commercial total catch was much higher than the commercial catch for each island (Fig. 12). Differences ranged from 4 times the catch on Oahu to ~190 times the catch on Molokai.

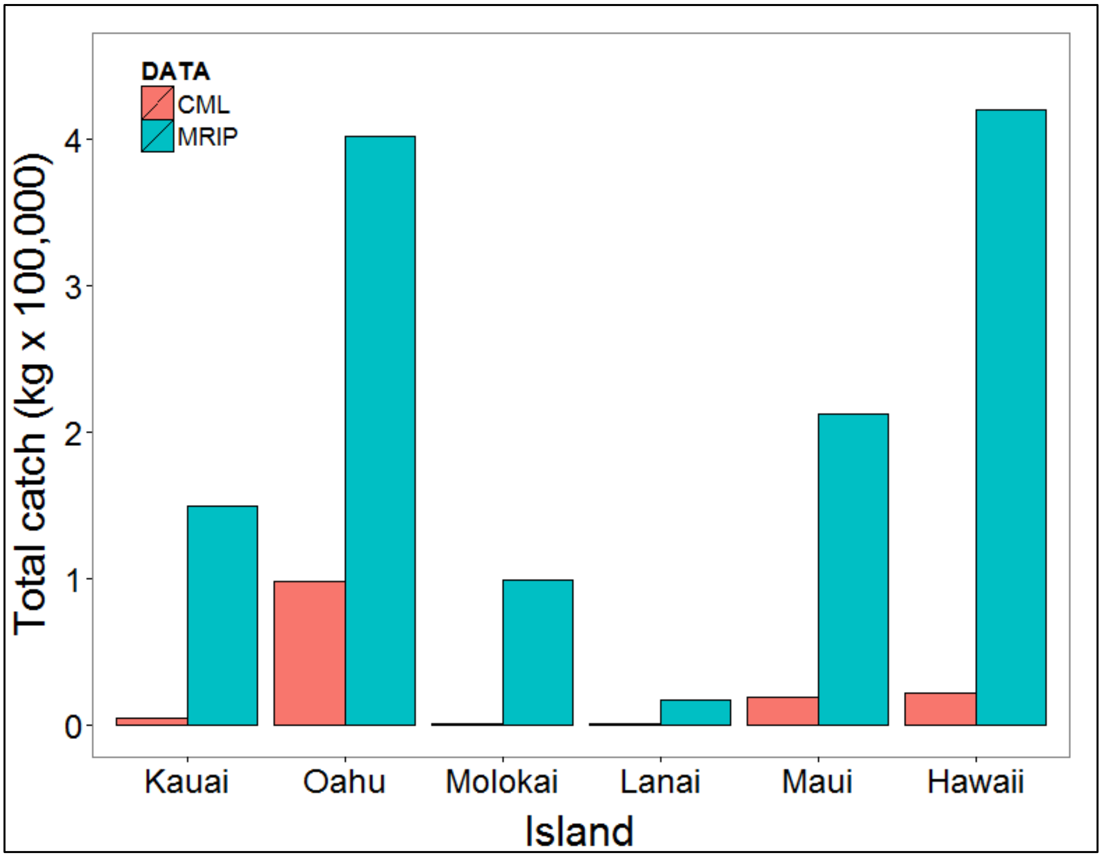

Figure 12. Yearly expanded catch in kg for Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii islands from the MRIP and the CML data.

Catch for many families were 2-27 times the reported CML catch in the same time period (Table 5). Annual catch limits (ACLs) for each family are set each year by the Western Pacific Regional Fishery Management Council (http://www.wpcouncil.org/managed-fishery-ecosystems/annual-catch-limits/2013-acl-specification/), based on the CML data. These limits and the CML data are supposedly representative of the entire fishery. In 2013, the CML catch alone was over the limit for 3 of the 7 families with limits specified. After adding in the non-commercial catch from the MRIP estimates, catch from all 7 families exceeded the catch limits, indicating that this is not the best management strategy.

Table 5. Common reef fish families, yearly estimate of catch (kg) from the MRIP and CML data, ratio of MRIP to CML catch, 2013 annual catch limits (ACLs), and percent over the limit.

Family	MRIP catch	CML catch	Ratio MRIP/CML	2013 ACL s	% over ACLs
Surgeonfishes	157,731	40,811	3.9	36,535	443%
Jacks	518,786	157,140	3.3	87,735	67,042%
Soldier/squirrelfishes	15,986	18,443	0.9	20,013	7,203%
Flagtails	20,645	756	27.3	-	-
Chubs	23,931	10,740	2.2	-	-
Wrasses	54,581	2,053	26.6	-	-
Emperor	681	1,420	0.5	-	-
Snappers	118,282	14,350	8.2	29,530	34,915%
Mullet	40,115	2,796	14.3	18,648	13,012%
Goatfishes	96,427	20,013	4.8	57,068	10,404%
Parrotfishes	55,862	23,051	2.4	15,116	42,205%

Small-scale non-commercial–creel vs commercial –CML

Catch from Maunalua Bay on Oahu from creel survey data was compared to the CML reporting block that it falls into (Fig. 13). The area of the Maunalua Bay creel survey area is 18 km^2, and the area of the CML reporting block is 98 km^2. Even though the CML block is more than 5 times (18%) the area of the creel survey, the total catch from Maunalua Bay is ~3% more than the entire CML block. The creel surveys shows a higher catch of spear and line, but a smaller catch from nets.

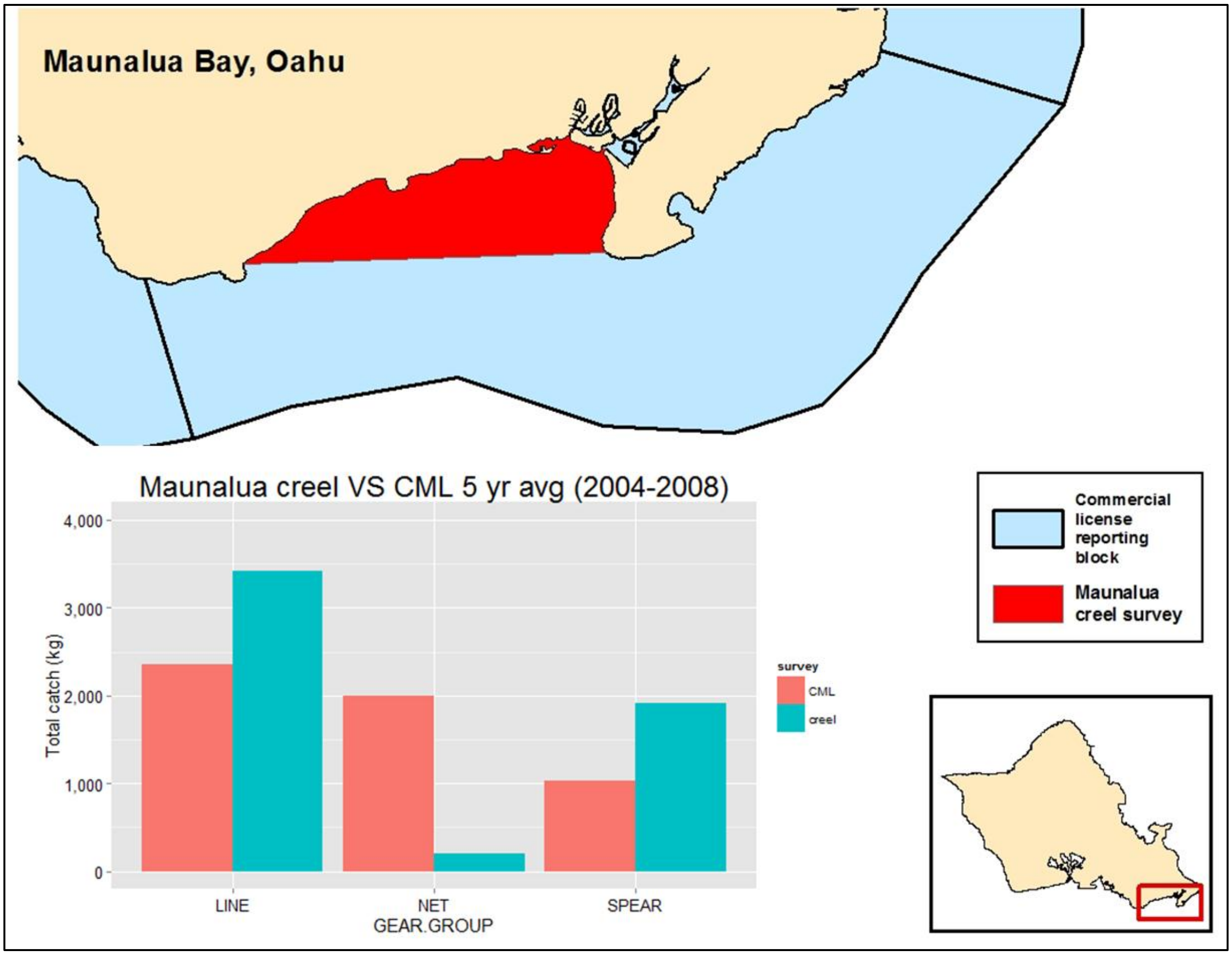

Figure 13. Creel survey catch (kg) for Maunalua Bay on south Oahu by gear type compared to CML catch for a larger area encompassing the creel survey area.

Creel surveys were conducted in Kahekili, Maui in 2011. The area for the creel survey is 1.8 km^2, and the area of the CML block is 96 km^2. The catch from the CML block is about 2 times the catch of the creel survey, even though the area is about 53 times larger (creel survey 2%) (Fig. 14).

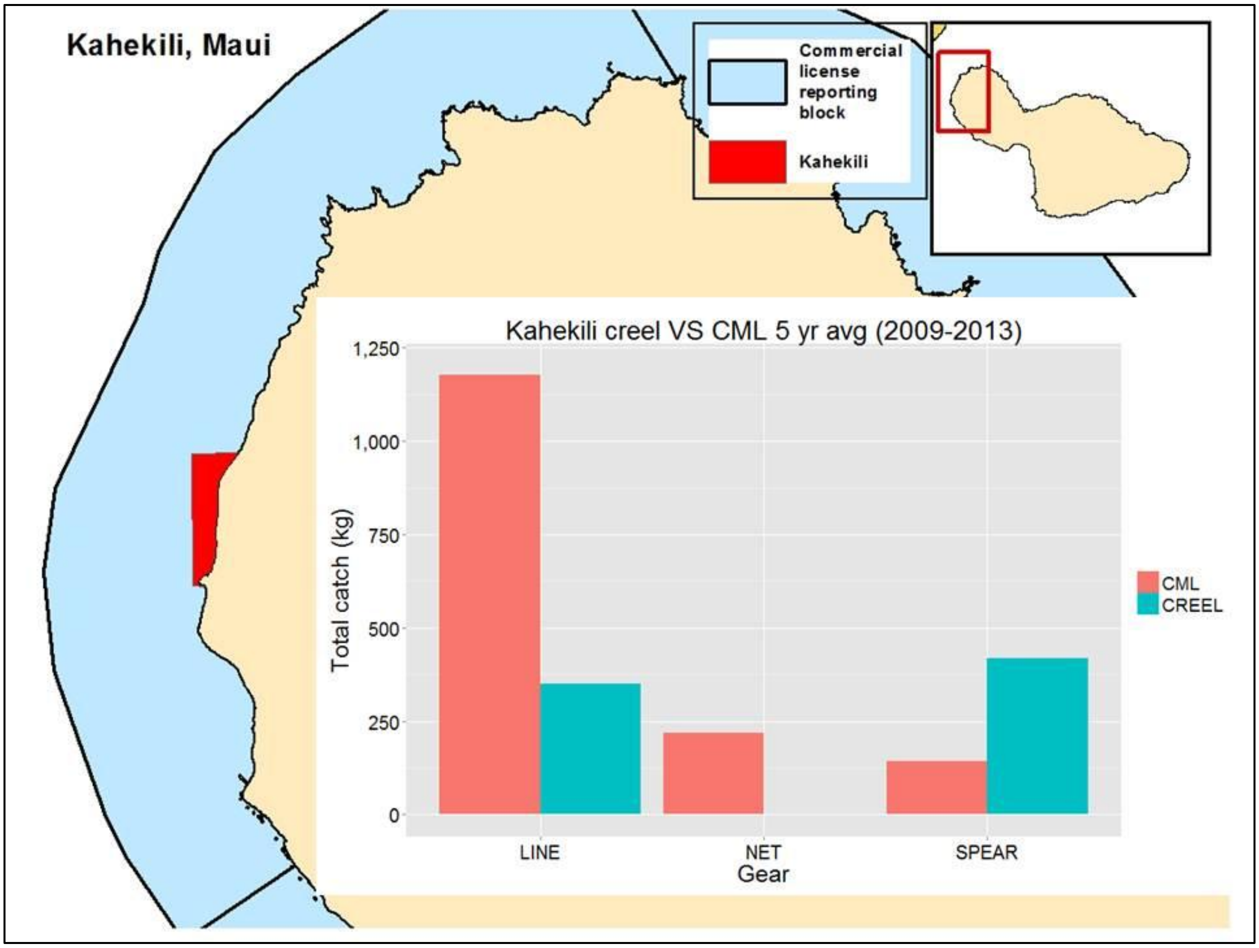

Figure 14. Creel survey catch in kg for Kahekili on west Maui by gear type compared to CML catch for a larger area encompassing the creel survey area. Creel net catch = 2.2 kg.

Combined catch values

Expanded catch estimates were generated at the island scale by combining non-commercial catch from several different sources, and commercial catch supplied by HDAR (Table 6). The non-commercial catch from the MRIP estimates were combined with the CML catch estimates to generate a yearly average from 2004-2013 (Fig. 15). Total catch was highest on Oahu, followed by Hawaii and Maui, and was lowest on Lanai.

Total catch estimates were also generated using the HCRI effort data (Fig. 5, see Appendix D.1 for numbers) by using average trips per year by gear type, and combining that with the MRIP estimates for average hours fished and average CPUE values. Lanai catch estimates decreases by half (0.51), but the HCRI Hawaii catch estimate is 1.8 times the MRIP estimate, Kauai is 1.4 times greater, Maui catch is 1.4 times greater and Oahu catch is 15.5 times greater than the MRIP catch estimates. HCRI catch on Oahu greatly exceeds the catch estimates from the other data sources, but the estimates for the other islands are in closer agreement with the other estimates (Fig. 15). Expanded total catch can also be estimated by using the average CPUE values from the creel surveys at each island (Fig. 15). This was mainly for shore CPUE values, as most creel surveys capture shore fishing.

Table 6. Range of catch estimates for one year (kg) from each island with each data source. The MRIP/HCRI effort estimates came from MRIP CPUE and HCRI effort estimates. The MRIP/creel CPUE estimates came from an island-average creel CPUE and MRIP effort estimates. There were no creel surveys from Molokai used in this study.

Island	Data Source					Total catch (non-commercial average+ commercial)
	Commercial	Non-commercial				
	CML	MRIP/HCRI effort	MRIP	MRIP /creel CPUE	Average	
Kauai	4,270	213,758	149,612	177,196	180,189	184,459
Oahu	97,519	6,202,799	401,246	693,807	2,432,617	2,530,136
Molokai	523	102,719	98,601	-	99,973	100,497
Lanai	510	8,462	16,740	36,403	20,535	21,045
Maui	18,331	303,889	212,118	124,663	213,557	231,888
Hawaii	22,008	764,761	419,928	468,826	551,172	573,180
Total	143,162	7,596,387	1,298,246	1,599,496	3,498,043	3,641,204

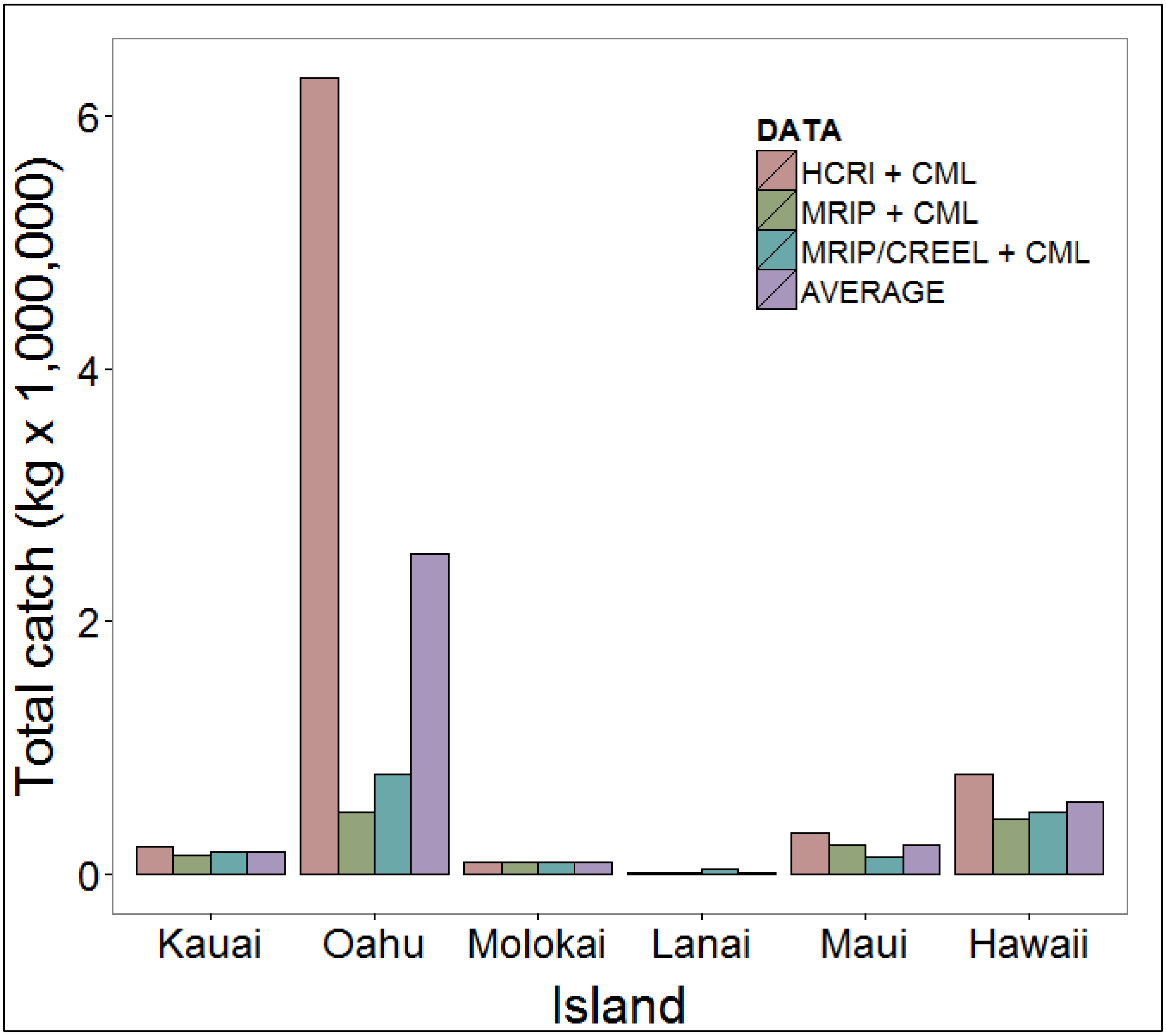

Figure 15. Three estimates of total yearly catch (kg) for the islands of Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii, from multiple sources of non-commercial data plus the CML data, and the average estimate of all three sources (in purple).

Reef catch was summarized as metric tons of catch per km^2 of reef. Catch for the MHI falls in between several other estimates for reef fish yield in the Pacific, indicating that the total catch estimate is somewhere in the ballpark of where it should be (Fig. 16). Yield for Oahu is at the higher end of the spectrum, indicating higher fishing effort per area of reef. Maui, Molokai, Kauai and Lanai fall at the lower end of the yield spectrum in the Pacific, indicating lower fishing effort.

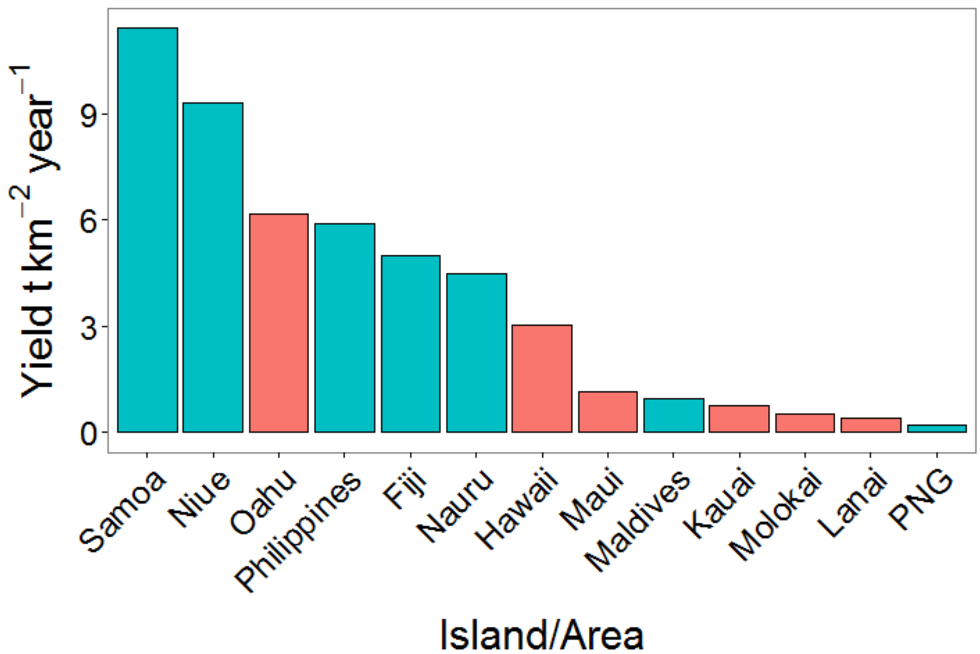

Figure 16. Yield, in metric tons per km^2 per year, for the MHI (in red) compared to other islands/areas in the Pacific (blue).

Discussion

Catch estimates

This study provides the best available estimates of nearshore reef fish catch in the MHI at the island level, which is more relevant to management than the currently available state level summaries. Total catch estimates range between 1,441,407 and 7,739,548 kg/year, with an average of 3,641,204 kg/year. This wide range in difference indicates the poor quality of the available data. The most conservative estimate comes from the MRIP data, followed by the MRIP-creel data, and the highest is from the HCRI-MRIP data. The largest difference is due to the variable effort estimates on Oahu, indicating that effort estimates need to be improved.

Catch composition is comprised of some of the same fish families for all islands, plus a few specific to each island. The non-commercial catch on all islands is dominated by jacks, surgeonfishes, snappers, goatfishes, mullets, parrotfishes, and reef sharks (most sharks were bycatch and were released), as well as barracudas and bonefishes on Oahu, chubs and flagtails on Hawaii, and wrasses on Maui. The wrasses on Maui - the peacock razorfish (*Iniistius pavo*) - make up 13% of the catch, which is second to the giant trevally (*Caranx ignobilis*) at 14%.

The total non-commercial catch derived from the MRIP data was 1,281,506 kg/year. This is roughly 2 times the estimated total from nearshore reef fish catch (excluding pelagics) that was reported to the Western Pacific Fishery Council from the MRIP data (yearly average from 2004-2010: 657,629 kg)(Ma 2012); this is most likely due to the fact that roughly two-thirds of the catch records had no weight estimation due to missing values, which were discarded when reported (Williams & Ma, 2013). Williams & Ma estimated that total catch with these substitutions was 1,014,380 kg/year (2013), which is still lower than this estimate. Several reasons for that difference could be that this study included several families/species that Williams & Ma did not (e.g., Mugilidae and *Albula glossodonta*, or bonefish), and fishing effort could have been calculated slightly differently i.e., with different population estimates.

The overall average of total catch values for most islands seem reasonable. We expect these values to be higher than existing estimates, as this is the most complete analysis that has been synthesized. Estimates for Lanai and Oahu could be greatly improved -the catch estimates for Lanai are based off of average CPUE values from the other islands, because there is no catch data from Lanai from the MRIP data; the only catch information comes from a 2-week frame creel survey that was conducted.

Oahu effort estimates can be greatly improved, and other studies should be incorporated to determine a better estimate.

Yield was calculated as a method to compare catch per reef area in the MHI to other areas that are fished in the Pacific. Yield for Oahu is similar to the more populated island areas of Samoa and the Philippines, indicating high fishing pressure. Maui, Molokai, Kauai and Lanai fall at the lower end of the yield spectrum in the Pacific, indicating lower fishing effort.

CPUE

Overall, the CPUE values generated from the MRIP data are close to the creel estimates from across the islands (Fig. 7). This evidence suggests that the MRIP intercept/catch surveys provide valid information. The highest discrepancy is in the net values, which vary due to the diversity of net gear types included in the net category. For example, a scoop net will have a very different catch than a gill net.

Although similar across islands, the island of Molokai has the highest CPUE values for most methods of fishing. If CPUE is a proxy for abundance, it would indicate that there are more reef fishes around Molokai (for the most common families captured by the most efficient gear types). Of the islands evaluated (except Lanai), Molokai has the least number of fishing trips, indicating that CPUE may be high due to low fishing pressure and healthier fish stocks. This is also supported by the results that show a decline in CPUE for line fishing with human population size by island. This could be due to factors other than fishing pressure (i.e., runoff, pollution), although increased fishing effort in more populated areas is likely a strong contributor to this pattern.

Spear CPUE from other areas around the Pacific ocean ranged from 0.4 kg gear hr^{-1} in Guam to 8.5 kg gear hr^{-1} in Palau, with a mean of 2.23 ± 2.28 kg gear hr^{-1} (Dalzell 1996). Spear CPUE from this study had a mean of 0.57 ± 0.38, indicating the MHI has a lower spear CPUE than other areas of the Pacific. However, the Pacific mean came from data compiled between 1989-1994, while this study used data from 2004-2013, so there would be some inherent difference. Handline CPUE from around the Pacific ranged from 0.55 kg gear hr^{-1} in Guam to 13.6 kg gear hr^{-1} in Norfolk Island (northwest of New Zealand), with a mean of 3.09 ± 3.28 kg gear hr^{-1} (Dalzell 1996). Line CPUE from this study had a mean value of 0.22 ± 0.17 kg gear hr^{-1}, again suggesting that CPUE for the MHI is on the low end of the spectrum. However it would be more meaningful to compare these to more recent Pacific averages.

Non-commercial vs CML catch

The current commercial catch reports underestimate total catch (commercial + non-commercial). Total catch for non-commercial nearshore reef fish species in the MHI is anywhere from 9 – 46 times the reported commercial catch, showing that non-commercial catch is a critical consideration in fisheries management. When non-commercial and commercial catch are combined, commercial catch makes up 0.5% - 20% of the total catch, depending on the island and effort data source for the non-commercial data. Commercial catch on Oahu makes up 20% of the total catch when using the MRIP estimates, but when using the HCRI estimates for Oahu, it only makes up 2%. This is extremely low if this is the only information that HDAR is basing fisheries management off of for nearshore reef fish. The estimate produced by this study is significantly more than Zeller's earlier study, which estimated that non-commercial catch was about 2 times the commercial catch in Hawaii from 1950-2005 (Zeller et al. 2005). This indicates that non-commercial catch has become more significant over the last 10 years.

Non-commercial catch estimates of certain reef fish families are 2 -27 times what is reported from the commercial data. This indicates that non-commercial fisheries target more fish than the commercial data are reporting. Regulating Hawaii's fisheries based on commercial data is misleading as it is missing important data on several groups, including flagtails, wrasses, snappers, mullets, and goatfish.

When catch from creel surveys are compared to the surrounding and much larger commercial reporting blocks, catch from the creel surveys can show a disproportionally large catch for the area, and occasionally higher annual catch than the entire commercial reporting block, such as from Maunalua Bay. A study of Kaupulehu on the west side of Hawaii Island showed that the catch from a creel survey conducted in 2013 was similar to the reported commercial catch for the entire reporting block, even though the area was only 5% of the commercial reporting area (Koike et al. 2015). A recent study calculated that expanded catch from Kiholo Bay on the island of Hawaii is 17 times higher than the average of the surrounding CML block, which is 78 times larger (2.6 km vs 204 km) (Kittinger et al. 2015). These findings stress the importance of non-commercial catch when considering fisheries management.

Effort

This study also provides basic information on the non-commercial nearshore fishery, such as how it differs between islands in gear selection and effort. The least populated islands tend to have a higher percentage of the population that fishes, and use net fishing more often than the more populated islands. This makes sense as nets are more specialized gear, and more frequent fishers would use gear types that require more skill and practiced technique to use.

The expanded catch from the non-commercial MRIP data indicate that the catch on Hawaii is greater than the catch on Oahu. However, when considering alternative sources for effort, such as the data from the HCRI study, catch on Oahu far exceeds other islands. This makes sense as Oahu is the most populated island, and has the highest number of fishing households. The HCRI effort may be more accurate, as it captures more occasional fishers than the MRIP study, where respondents are asked if they have fished in the last two months, as opposed to in the last year. The HCRI survey estimates that Oahu residents take 3 times more line trips than the MRIP effort data captures, 20 times the amount of net trips, and 12 times the amount of spear fishing trips. However, it is also plausible that catch on Oahu can be lower than Hawaii, because there may be fewer fish due to the larger population and higher fishing effort (Williams et al. 2008). Although the HCRI survey captured more of the occasional fishers, it also introduced more variability by asking respondents to recall all fishing events from the previous year instead of just the last 2 months.

Each year, NOAA Fisheries releases a national annual report from the MRIP data summarized by state and region. They estimated that the number of recreational trips in Hawaii in 2013 was 1,513,000 (Fisheries Economics of the United States 2013, 2015), compared to this estimate of 2,454,860 trips, and this is the lowest effort estimate of the sources we used. This could be due to the fact that trips with no corresponding details are dropped. The large discrepancy in these numbers highlights the need to reform these surveys.

Management implications

Currently, Hawaii's nearshore reef fishery is managed in part by creating ACLs for the commercial fishers. These ACLs are created with the aim of preventing overfishing while maintaining high productivity (Haddon 2011, Friedlander 2015). However, often these limits are ineffective in data-poor fisheries (Friedlander 2015). These limits are based off of previous year's commercial catch, in addition to in-situ population surveys to estimate abundance (Marc Nadon, pers. com.). In Hawaii, this is only a small fraction of the stock that is actually being fished. For example, non-commercial average annual parrotfish catch (from 2004-2013) was 55,862 kg, compared to the commercial catch of 23,051 kg for the same time period. This is a low estimate, as it does not include night/illegal fishing. The annual catch limit for parrotfishes in 2013 was set at 15,116 kg (http://www.wpcouncil.org/managed-fishery-ecosystems/annual-catch-limits/2013-acl-specification/), which means that the catch of parrotfishes exceeded the ACL by 63,797 kg (commercial catch + non-commercial catch – 2013 ACL), or 422% in 2013. This limit needs to be adjusted by including catch data from non-commercial fisheries, or other forms of management should be considered.

Other suggested methods for management include bag limits, which create individual quotas for non-commercial fishers, but are difficult to enforce (Friedlander 2015). State-wide there are several existing bag limits, and this has recently been expanded to include parrotfish and goatfish on Maui (http://dlnr.hawaii.gov/dar/fishing/fishing-regulations/, Hawaii Administrative Rules, Title 13.4, Ch. 95.1). Gear restrictions can also be implemented to control harvest for certain species that are vulnerable to highly efficient gear (McClanahan et al. 2004). Other control methods include marine protected areas, closures, and size limits (Friedlander 2015). Currently in Hawaii, these methods have been established using only commercial catch.

Other methods of management that are recommended and gaining momentum are an ecosystem-based fisheries management (EBFM) approach, and community based management (CBM) based on traditional ecological knowledge (TEK). Both of these methods involve using knowledge of ecosystem functions that affect fisheries management, and TEK from the communities surrounding the fisheries (Friedlander 2015). These methods are implemented at a small scale and involve knowledge of an ecosystem in a small area, which stresses the need for smaller scale fisheries catch data – much smaller than the state-wide level.

A study by McClenachan and Kittinger reconstructed catch for Hawaii from the beginning of human settlement, or 1250 AD. They found that Hawaii sustained high levels of catch pre-European contact, indicating that management at that time was effective (Mcclenachan & Kittinger 2012). The CBM approach utilizing TEK would echo those practices and help the MHI move towards more sustainable fisheries management.

Suggested improvements

There are many limitations associated with estimating total catch from disparate data sources. There are many approximated values, such as using average size for missing species and average hours fished for missing information. In addition, the commercial catch data are limited by confidentiality agreements. Many values can be adjusted or improved, such as household estimates. This study used 5-year averages, but these estimates could be made more accurate by using yearly household estimates.

One challenge in incorporating all of these disparate datasets is the spatial scale of inference. For example, catch estimates from creel surveys could be extrapolated for similar habitats by calculating reef area. However there are many other factors in addition to reef area that contribute to catch and these need to be explored in greater detail. The best case scenario would be to have creel surveys that encompass every km of accessible shoreline; however creel surveys are time consuming and costly. It is imperative that we come up with a best estimate from the data that we have, and work to obtain more robust data in the future.

These data could be improved by estimating nighttime catch and illegal catch. It is difficult to obtain illegal catch data because most of the data are self-reported from fishermen and these surveys are voluntary. Reports from Hawaii's Division of Conservation and Resource Enforcement (DOCARE) could be compiled, and there are several creel surveys that have identified illegal fishing activities.

One of the issues with some monitoring/data collection programs is that they continue collecting data, and are not sure what needs to be recorded or how until someone tries to use it. It is best to set up a survey, do a trial run and try to analyze the data; this is called a frame survey (National Research Council 2006). After conducting a frame survey, an organization can improve methods and implement the survey. Programs must take the time to set up the survey correctly and carry it out according to plan, making sure that surveyors are properly trained. Common issues with effort surveys that could be addressed include: recording time fished, conducting the survey in an orderly fashion - i.e., making rounds every hour, approach fishermen as they are leaving, or note if they are interviewed in the middle of their trip, and record zeros if no fishermen are observed. If local fish species names are recorded, keep a list of common/scientific names on hand. When entered into a database, scientific names are needed so that weight can be calculated from length. If someone is fishing from a boat, note what gear type is used ("boat" is often recorded as the gear type, which is incorrect).

The existing surveys could be greatly improved and the MRIP surveys are currently undergoing a reorganization, which is much needed. Relying on human memory for the phone surveys is not very robust, and using landlines limits the population that is surveyed. Effort surveys must record hours fished and specific gear types used. Hours fished was calculated from the intercept data, but that is less accurate due to the smaller sample size. CPUE differs among gear types, and when they are combined, precision is lost (i.e., combining scoop net, throw net and gill net). It is imperative that the gear types match from the effort and catch surveys. The MRIP surveys only capture effort from consistent fishers, excluding the occasional fishers. Most importantly, it is difficult to apply a nation-wide survey method to Hawaii. Hawaii is a unique state, with the high cultural significance of fishing, and the subsistence culture (Pooley 1993, Friedlander et al. 2013). Hawaii consumes almost twice the amount of live seafood per capita than the mainland US (Loke et al. 2012). The MRIP surveys for Hawaii need to be specifically tailored to the state, and the data need to be collected and analyzed by people who understand the fishery.

Future directions

This study can be used to increase understanding of the quantity and composition of Hawaii's fisheries at the island level. For example, total catch can be assessed at the trophic level, as herbivore biomass can be an indicator of coral reef resilience (Edwards et al. 2013, Mumby et al. 2015); it would be helpful to know what proportion of the catch is composed of herbivores.

Stock assessments can be improved with these non-commercial catch estimates. The current models can be updated to include the non-commercial catch as well as the commercial catch. The Fisheries Biology and Stock Assessment Branch (FBSAB) of the Pacific Islands Fisheries Science Center (PIFSC) is currently working to improve stock assessments of reef fish, and have recently published work on assessments of several nearshore species using length measurements from diver-recorded visual data as well as the CML data (Nadon et al. 2015). They intend to improve these estimates by incorporating catch from the MRIP surveys.

This information on catch can also be used in managing ecosystem tipping points (Selkoe et al. 2015). Ecosystems have different stable states, and can shift between them, for example, from a coral-dominated ecosystem to an algal-dominated ecosystem (Hollings 1973). In order to prevent unwanted phase shifts, it is important for managers to be able to manage resources in order to avoid these tipping points (Selkoe et al. 2015).

Conclusion

Under-reporting catch is a worldwide problem in fisheries, due to the diverse nature of fisheries, and the difficulties associated with gathering data, which makes sustainable management difficult (Pauly et al. 2002, Zeller et al. 2008, 2014, Kittinger 2013, Friedlander et al. 2014, Pauly & Zeller 2014). In order to sustainably manage nearshore fisheries in the MHI, we need the best available estimates of current fishing activity, which means including non-commercial catch estimates. Non-commercial nearshore reef fish catch is anywhere from 9 - 53 times the commercial catch in the MHI. If HDAR continues to manage fisheries based solely on commercial catch data, they are ignoring the activities that are taking the majority of the nearshore reef fish. In order to continue fishing for subsistence, cultural importance, recreation, and livelihoods, it is imperative that non-commercial fishing activity is properly recorded and estimated. Improved survey methods and more frequent and extensive surveys would greatly improve data quality, and inform management so that the residents of the MHI can continue to fish sustainably for years to come.

Appendix A: Species and family names included from small-scale, non-commercial (MRIP) data, and commercial data.

Table A1. Species and Family names of reef fish that are used in this analysis. An 'X' in MRIP indicates that they were found in the MRIP data, 'X' in commercial indicates they were in the CML data.

Family	Species	MRIP	Commercial
Acanthuridae	*Acanthurus achilles*	X	X
Acanthuridae	*Acanthurus blochii*	X	X
Acanthuridae	*Acanthurus dussumieri*	X	X
Acanthuridae	*Acanthurus leucopareius*	X	
Acanthuridae	*Acanthurus nigrofuscus*	X	
Acanthuridae	*Acanthurus nigroris*	X	X
Acanthuridae	*Acanthurus olivaceous*	X	
Acanthuridae	*Acanthurus triostegus*	X	X
Acanthuridae	*Acanthurus xanthopterus*	X	
Acanthuridae	*Ctenochaetus hawaiiensis*	X	X
Acanthuridae	*Ctenochaetus strigosus*	X	X
Acanthuridae	*Naso annulatus*	X	
Acanthuridae	*Naso brevirostris*	X	
Acanthuridae	*Naso hexacanthus*	X	X
Acanthuridae	*Naso lituratus*	X	X
Acanthuridae	*Naso unicornis*	X	
Acanthuridae	*Zebrasoma flavescens*	X	
Albulidae	*Albula glossodonta*	X	X
Apogonidae	*Apogon kallopterus*	X	
Aulostomidae	*Aulostomus chinensis*	X	X
Balistidae	*Melichthys niger*	X	
Balistidae	*Melichthys vidua*	X	
Balistidae	*Rhinecanthus aculeatus*	X	
Balistidae	*Rhinecanthus rectangulus*	X	
Balistidae	*Sufflamen bursa*	X	
Bothidae	*Bothus mancus*	X	
Carangidae	*Alectis ciliaris*	X	X
Carangidae	*Carangoides ferdau*	X	
Carangidae	*Carangoides orthogrammus*	X	X
Carangidae	*Caranx ignobilis*	X	X
Carangidae	*Caranx lugubris*	X	
Carangidae	*Caranx melampygus*	X	X
Carangidae	*Caranx sexfasciatus*	X	X
Carangidae	*Decapterus macarellus*	X	

Table A1. (Continued) Species and Family names of reef fish that are used in this analysis. An 'X' in MRIP indicates that they were found in the MRIP data, 'X' in commercial indicates they were in the CML data.

Family	Species	MRIP	Commercial
Carangidae	*Elagatis bipinnulata*	X	X
Carangidae	*Gnathanodon speciosus*	X	X
Carangidae	*Pseudocaranx cheilio*	X	X
Carangidae	*Scomberoides lysan*	X	X
Carangidae	*Selar crumenophthalmus*	X	X
Carangidae	*Seriola dumerili*	X	X
Carangidae	*Uraspis helvola*	X	X
Carcharhinidae	*Carcharhinus amblyrhynchos*	X	
Carcharhinidae	*Carcharhinus galapagensis*	X	
Carcharhinidae	*Carcharhinus melanopterus*	X	
Carcharhinidae	*Carcharhinus plumbeus*	X	
Carcharhinidae	*Triaenodon obesus*	X	
Chaetodontidae	*Chaetodon lunula*	X	
Chaetodontidae	*Chaetodon unimaculatus*	X	
Chanidae	*Chanos chanos*	X	X
Cirrhitidae	*Cirrhitus pinnulatus*	X	X
Cirrhitidae	*Paracirrhites forsteri*	X	
Congridae	*Conger cinereus*	X	
Diodontidae	*Diodon holocanthus*	X	
Diodontidae	*Diodon hystrix*	X	
Fistulariidae	*Fistularia commersonii*	X	
Holocentridae	*Myripristis amaena*	X	
Holocentridae	*Myripristis berndti*	X	
Holocentridae	*Myripristis chryseres*	X	
Holocentridae	*Myripristis vittata*	X	
Holocentridae	*Plectrypops lima*	X	
Holocentridae	*Sargocentron spiniferum*	X	X
Holocentridae	*Sargocentron tiere*	X	X
Holocentridae	*Sargocentron xantherythrum*	X	
Kuhlidae	*Kuhlia sandwicensis*	X	
Kyphosidae	*Kyphosus bigibbus*	X	
Kyphosidae	*Kyphosus cinerascens*	X	
Kyphosidae	*Kyphosus vaigiensis*	X	
Labridae	*Anampses chrysocephalus*	X	
Labridae	*Anampses cuvier*	X	

Table A1. (Continued) Species and Family names of reef fish that are used in this analysis. An 'X' in MRIP indicates that they were found in the MRIP data, 'X' in commercial indicates they were in the CML data.

Family	Species	MRIP	Commercial
Labridae	*Bodianus bilunulatus*	X	
Labridae	*Cheilio inermis*	X	
Labridae	*Coris flavovittata*	X	
Labridae	*Coris gaimard*	X	
Labridae	*Gomphosus varius*	X	
Labridae	*Halichoeres ornatissimus*	X	
Labridae	*Iniistius baldwini*	X	
Labridae	*Iniistius pavo*	X	
Labridae	*Iniistius umbrilatus*	X	
Labridae	*Novaculichthys taeniourus*	X	
Labridae	*Oxycheilinus unifasciatus*	X	X
Labridae	*Thalassoma ballieui*	X	
Labridae	*Thalassoma duperrey*	X	
Labridae	*Thalassoma trilobatum*	X	
Lethrinidae	*Monotaxis grandoculis*	X	X
Lutjanidae	*Aphareus furca*	X	X
Lutjanidae	*Aprion virescens*	X	
Lutjanidae	*Lutjanus fulvus*	X	X
Lutjanidae	*Lutjanus kasmira*	X	X
Monacanthidae	*Aluterus scriptus*	X	
Mugilidae	*Mugil cephalus*	X	X
Mugilidae	*Neomyxus leuciscus*	X	X
Mugilidae	*Valamugil engeli*	X	
Mullidae	*Mulloidichthys flavolineatus*	X	X
Mullidae	*Mulloidichthys pfluegeri*	X	
Mullidae	*Mulloidichthys vanicolensis*	X	X
Mullidae	*Parupeneus cyclostomus*	X	X
Mullidae	*Parupeneus insularis*	X	X
Mullidae	*Parupeneus multifasciatus*	X	X
Mullidae	*Parupeneus pleurostigma*	X	X
Mullidae	*Parupeneus porphyreus*	X	X
Mullidae	*Upeneus arge*	X	X
Muraenidae	*Enchelycore pardalis*	X	
Muraenidae	*Gymnomuraena zebra*	X	
Muraenidae	*Gymnothorax eurostus*	X	

Table A1. (Continued) Species and Family names of reef fish that are used in this analysis. An 'X' in MRIP indicates that they were found in the MRIP data, 'X' in commercial indicates they were in the CML data.

Family	Species	MRIP	Commercial
Muraenidae	*Gymnothorax flavimarginatus*	X	
Muraenidae	*Gymnothorax rueppelliae*	X	
Muraenidae	*Uropterygius macrocephalus*	X	
Polynemidae	*Polydactylus sexfilis*	X	X
Pomacentridae	*Abudefduf abdominalis*	X	
Pomacentridae	*Abudefduf sordidus*	X	X
Pomacentridae	*Chromis verater*	X	
Pomacentridae	*Stegastes fasciolatus*	X	
Priacanthidae	*Heteropriacanthus cruentatus*	X	
Priacanthidae	*Priacanthus meeki*	X	
Scaridae	*Calotomus carolinus*	X	X
Scaridae	*Chlorurus perspicillatus*	X	
Scaridae	*Chlorurus sordidus*	X	
Scaridae	*Scarus dubius*	X	
Scaridae	*Scarus psittacus*	X	
Scaridae	*Scarus rubroviolaceus*	X	
Scorpaenidae	*Dendrochirus barberi*	X	
Scorpaenidae	*Scorpaenopsis cacopsis*	X	
Serranidae	*Cephalopholis argus*	X	
Sphyraenidae	*Sphyraena barracuda*	X	X
Sphyraenidae	*Sphyraena helleri*	X	X
Sphyrnidae	*Sphyrna lewini*	X	
Synodontidae	*Saurida elongata*	X	
Tetraodontidae	*Arothron hispidus*	X	
Tetraodontidae	*Arothron meleagris*	X	
Tetraodontidae	*Canthigaster amboinesis*	X	

Appendix B: Commercial marine license data

The following table summarizes data that we requested from the state by species and reporting block compared to the family/group totals that are available online. Due to the confidentiality agreement, we are missing 17% of the data. Raw data are the data that we received pooled up to the family level. State level data publicly available come from HDAR's website (http://dlnr.hawaii.gov/dar/fishing/commercial-fishing/).

Table B1. Family, common group name, weight in lbs. from our data set vs. the state level data that is publicly available, and the percent missing.

Family	Group	Raw data(Lbs.)	State level data publicly available (Lbs.)	Lbs. missing	% missing
Acanthuridae	surgeon	899,733	977,074	77,341	8%
Albulidae	bonefish	78,798	92,324	13,526	15%
Aulostomidae	reef	359	1,077	718	67%
Balistidae	reef	1,053	7,159	6,106	85%
Bothidae	reef	48	184	136	74%
Carangidae	jack	3,464,346	4,778,857	1,314,511	28%
Chanidae	milkfish	9,855	16,317	6,462	40%
Cirrhitidae	hawkfish	4,581	6,313	1,732	27%
Congridae	eel	119	1,587	1,468	93%
Holocentridae	soldier/squirrel	406,598	15,135	-	-
Kuhliidae	flagtail	16,660	24,045	7,385	31%
Kyphosidae	chub	236,785	255,583	18,798	7%
Labridae	wrasse	45,253	54,882	9,629	18%
Lethrinidae	emperor	31,309	39,563	8,254	21%
Lutjanidae	snapper	316,366	398,010	81,644	21%
Mugilidae	mullet	61,650	91,100	29,450	32%
Mullidae	goatfish	441,216	467,025	25,809	6%
Muraenidae	eel	1,751	4,332	2,581	60%

Table B1. (Continued) Family, common group name, weight in lbs. from our data set vs. the state level data that is publicly available, and the percent missing.

Family	**Group**	**Raw data(lbs)**	**State level data publicly available (lbs)**	**lbs missing**	**% missing**
Polynemidae	moi	3,363	6,113	2,750	45%
Pomacentridae	damsel	311	617	306	50%
Priacanthidae	bigeye	34,036	46,371	12,335	27%
Scaridae	parrotfish	508,196	529,867	21,671	4%
Scorpaenidae	scorpionfish	11,458	12,722	1,264	10%
Sphyraenidae	barracuda	17,746	127,155	109,409	86%
TOTAL	**all reef fish**	**6,591,590**	**7,953,412**	**1,361,822**	**17%**

Appendix C: MRIP effort from NOAA's Office of Science and Technology

Summary numbers of expanded trips per year by county were produced by NOAA's office of Science and Technology. These numbers were summarized by methods used by NOAA's national MRIP program. In order to calculate the island estimates for Maui county (Maui, Molokai and Lanai islands), we used a percent of trips from our island estimates. These trip numbers were used to calculate total catch and compared to the catch numbers from this study. The estimates using the methods described in this study were in close agreement.

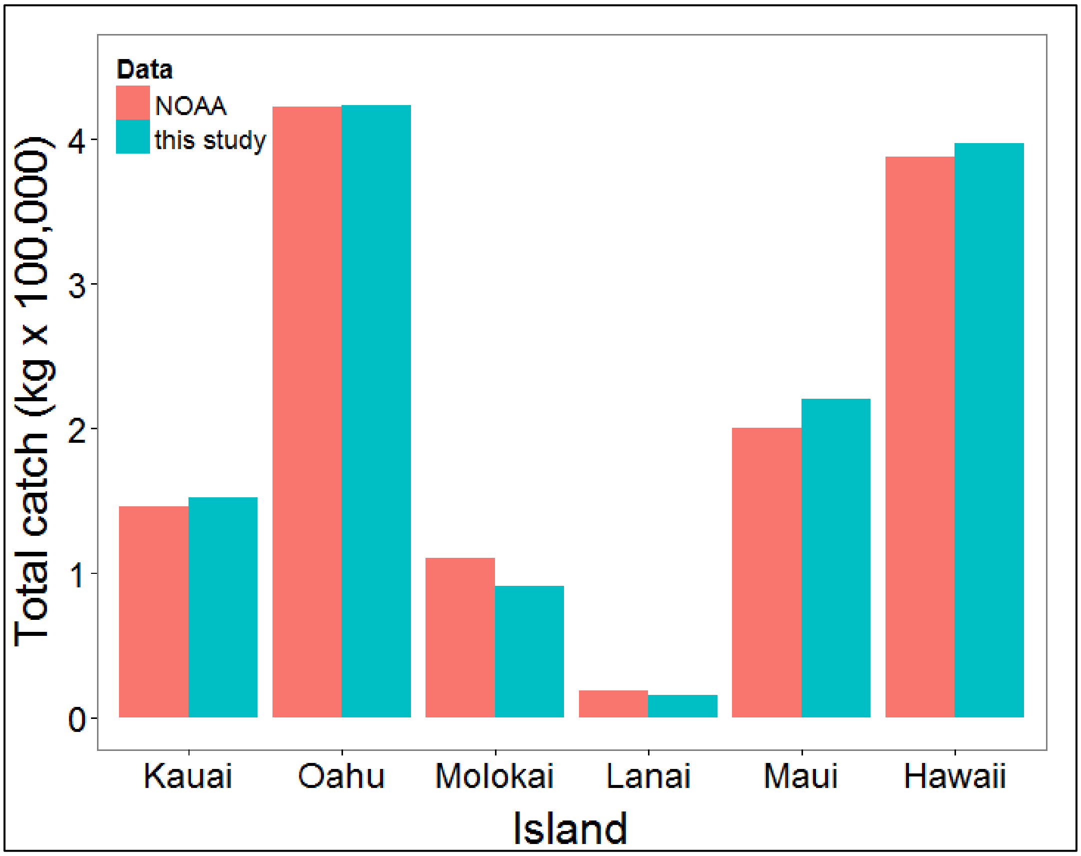

Figure C1. Yearly average of total catch for the islands of Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii from 2004-2013 MRIP data. Blue is summarized from the raw data for this study, red indicates effort data that were summarized by NOAA's office of Science and Technology.

Appendix D: Data processing details

Appendix D.1. Non-commercial data –HCRI

Changes that were made to the raw data:

- Blank entries for number of trips: substituted average for each island - 28 records: 9 line, 14 other, 3 hand, 2 spear.– did not use Lanai or Molokai 'other' category because of small sample size (<5)
- Number of fishing trips/year: 8 records had numbers over 365. Changed to 365.

The MRIP data showed higher effort on Molokai and Lanai than the HCRI data, but for all other islands, the HCRI data showed a higher number of trips (Table D.1.1).

Table D.1.1. Average number of trips per island in 2004, according to 2 data sources (MRIP and HCRI).

Island	MRIP	HCRI
Kauai	233,455	225,688
Oahu	1,367,740	4,666,544
Molokai	77,246	36,514
Lanai	7,385	5,366
Maui	297,398	407,421
Hawaii	471,635	732,470

Appendix D.2. Non-commercial data– Maunalua Bay, Oahu creel survey

Changes:

- Blank time entries: filled based on the time and location of observations in the same event
- Blanks or NA in number of fishers and number of gears: changed to 1 if gear/method type was listed, unless it was obviously more (2 units of spears = 2 fishermen, 2 fishermen= 2 units of gear)
- Deleted records with missing number of fishers, number of gear, and method
- GEAR GROUP: LINE = Bamboo, cast, dunk, fly, handline, pole, slide, whip; Troll: left on its own
- Observations: 55 records have no gear type recorded of 1308 records
- Deleted 76 duplicates out of 1253 records
- Interview entries with ID but no information were deleted
- Several blank entries for start and stop time (144 entries). Substituted average hours fished for that gear type (line, spear, glean, thrownet, scoopnet, crab)

- Entries with NA for hours fished was filled with an average hours fished for that gear type. Net was filled with throw, because there was only 1 entry for net. Interviews that had more than 1 gear type and NA for hours fished: average was calculated, (e.g. 1 spear and 2 line = (avg. spear time+2*avg. line time)/3)
- Time entries: used end interview time for end fishing time
- 191/967 records were NA values (fishing started after interview or blank values). These were filled with average hours fished from each gear group
- 15 interviews had no gear type specified and were deleted
- Number of fish: filled blank with 1 if there was a fish. BUNCH papio changed to 3
- Records with missing length and weight (114): used Williams and Ma (2013) weights for shore for 20 records. Averages of other species in the dataset were used if sample size >2 (27 records). For blacktip and hammerhead, used average of reef shark from dataset
- 10 catch records of unidentified fish were dropped
- 48 catch records with no length/weight information were dropped (26 of these were thrown back, 3 used for bait)

Appendix D.3. Non-commercial data– Puako Bay, Hawaii creel survey

Changes:

- Gear combinations: LINE = pole and line, rod & reel dunk, rod & reel whip, hand line, bamboo

  NET= throw net, scoop net, hand net, lay/gill

  SPEAR = scuba spear, spear

  TROLL = troll

- Dropped 12 records with no gear type = 250 records
- LENGTH VALUES: 1 entry had 25-35 cm, changed to 30
- Changed 25-30 cm to 27 cm
- SAEN = Holocentridae species, best guess squirrel fish
- UNKNOWN= ACTR. 3 @ 15 (*Acanthurus triostegus* most common fish caught on spear)

Appendix D.4. Non-commercial data– Haena, Kauai creel survey

Changes:

- 37 fish had no length: substituted shore weights for aholehole (Kuhlia species), nenue (Kyphosus species) from Williams and Ma (2013). For oama, used average from Haena catch data set

- TIME: 12 of 27 blank entries, 9 had catch. Filled with averages (average(sample size)) for line 2.2 hrs. (3), net 1.7 hrs. (9), and spear 1.3 hrs. (2). Compared to hrs. fished/gear type for MRIP for Kauai: line: 3.3 (442), net: 1.8 (10), spear: 2.6 (34). Used MRIP numbers for Kauai shore

Appendix D.5. Non-commercial data– MRIP

Changes/stats:

- Of ~6000 records of unavailable catch, weight was estimated for ~42,000 fishes. About 30,000 of these fishes are pelagic or bottomfish species, and were excluded. The total number of reef fishes that had available or substituted weights for this analysis totaled 43,554 fishes
- If hours fished was not recorded, an average was used for that mode and gear type for that island. For example, if a fisher on Kauai fished from shore using a rod and reel but the time was not listed, a mean value of 3.3 hours (±2.0 SD) was substituted
- In some instances, gear type was not specified. The percentage of each gear type was calculated from known records, and the proportion was applied to the number of unknown gear type records
- If number of fishers was missing, 1 was substituted as the most conservative estimate

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