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Patterns in artisanal coral reef fisheries reveal best practices for monitoring and management

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Sustainable fisheries management is key to restoring and maintaining ecological function and benefits to people, but it requires accurate information about patterns in resource use, particularly fishing pressure. In most coral reef fisheries and other data-poor contexts, obtaining such information is challenging and remains an impediment to effective management. We developed the most comprehensive regional view of shore-based fishing effort and catch for the Hawaiian Islands to show detailed fishing patterns from across the main Hawaiian Islands (MHI). We reveal these regional patterns through fisher "creel" surveys conducted through collaborative efforts by local communities, state agencies, academics, and environmental organizations, at 18 sites and comprising >10,000 hr of monitoring across a range of habitats and human influences throughout the MHI. Here, we document spatial patterns in nearshore fisheries catch, effort, catch rates (i.e., catch-per-unit-effort [CPUE]), and catch disposition (i.e., use of fish after catch is landed). Line fishing was consistently the most commonly employed gear type (94%), followed by net fishing. The most efficient gear types (i.e., higher CPUE) were spear (0.64 kg hr^{-1}), followed closely by net (0.61 kg hr^{-1}), with CPUE for line (0.16 kg hr^{-1}) 3.9 times lower than spear and 3.7 times lower than net. Creel surveys also reveal rampant illegal fishing activity across the studied locations. Surprisingly, overall, most of the catch was not sold, but rather retained for home consumption or given away to extended family, which indicates that cultural and food security may be stronger drivers of fishing effort than commercial exploitation for nearshore coral reef fisheries in Hawai'i. Increased monitoring of spatial patterns in nearshore fisheries can inform targeted management, in order to maintain these fisheries for local communities' food security, cultural, and ecological value.

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Abstract:

Sustainable fisheries management is key to restoring and maintaining ecological function and benefits to people, but it requires accurate information about patterns in resource use, particularly fishing pressure. In most coral reef fisheries and other data-poor contexts, obtaining such information is challenging and remains an impediment to effective management. We developed the most comprehensive regional view of shore-based fishing effort and catch for the Hawaiian Islands to show detailed fishing patterns from across the main Hawaiian Islands (MHI). We reveal these regional patterns through fisher "creel" surveys conducted through collaborative efforts by local communities, state agencies, academics, and environmental organizations, at 18 sites and comprising >10,000 hr of monitoring across a range of habitats and human influences throughout the MHI. Here, we document spatial patterns in nearshore fisheries catch, effort, catch rates (i.e., catch-per-unit-effort [CPUE]), and catch disposition (i.e., use of fish after catch is landed). Line fishing was consistently the most commonly employed gear type (94%), followed by net fishing. The most efficient gear types (i.e., higher CPUE) were spear (0.64 kg hr^{-1}), followed closely by net (0.61 kg hr^{-1}), with CPUE for line (0.16 kg hr^{-1}) 3.9 times lower than spear and 3.7 times lower than net. Creel surveys also reveal rampant illegal fishing activity across the studied locations. Surprisingly, overall, most of the catch was not sold, but rather retained for home consumption or given away to extended family, which indicates that cultural and food security may be stronger drivers of fishing effort than commercial exploitation for nearshore coral reef fisheries in Hawai‘i. Increased monitoring of spatial patterns in nearshore fisheries can inform targeted management, in order to maintain these fisheries for local communities' food security, cultural, and ecological value.

Introduction:

Fisheries contribute 20% of the protein for more than 3 billion people and 17% of global protein consumed, representing a crucial contribution to global food security (UN FAO, 2014). In the tropics, coral reef fisheries support >6 million reef fishers in over 100 countries, providing critical and diverse values, including food, income, livelihoods, and cultural significance (Teh, Teh & Sumaila, 2013). Nowhere are coral reef fisheries more important than in the developing economies and communities in the Pacific (Dalzell, 1996; Gillett, 2016). In Hawai‘i, these fisheries are relied upon for economic, social, and cultural services, including important livelihood and food provisioning (Friedlander, Shackeroff & Kittinger, 2013). More than a third of Hawai‘i residents identify themselves as fishers (OmniTrak, 2011), and the diversity of cultures that live in Hawai‘i all place high importance on fishing.

Despite their importance, many small-scale reef fisheries, both commercial and non-commercial, in the Pacific have significant capacity gaps in management, threatening the food security and livelihoods that these fisheries provide to communities (Newton et al., 2007; Bell et al., 2009; Kronen et al., 2010a,b; Houk et al., 2012; Friedlander, Nowlis & Koike, 2014). Many of the challenges currently hindering sustainable management and fisheries sector development strategies are associated with a lack of information in the complex context of multi-species, multi-gear small-scale coral reef fisheries (Cinner et al., 2012).

There remain significant knowledge gaps for scientists and managers regarding the characteristics and magnitude of current fishing activities, including the total production of the fishery and its value to local communities and economies. Many of these fisheries are not effectively managed, largely due to a lack of assessments of fishing activities and fish stocks, yet un-assessed or otherwise data-poor fisheries account for more than 80% of the global fisheries catch (Dalzell, 1996; Sale, 2008; Costello, Wilson & Houlding, 2012; Ricard et al., 2012; Friedlander, 2015). The lack of investment in monitoring due to low technical and financial capacity in many coral reef geographies makes understanding their fisheries status more difficult, and as such, developing adequate, evidence-based regulations remains difficult (Pauly, 2006; Zeller et al., 2006; Pauly & Zeller, 2014). To ensure healthy ocean ecosystems will continue to support food, income, and livelihoods for people worldwide, fisheries managers and scientists need to address the challenge of developing sustainable fisheries management systems in data-poor situations by using innovative approaches for fisheries assessments (Johannes, 1998; Pauly & Zeller, 2014).

To develop better management strategies, scientists and managers need more accurate estimates of how much fish biomass is in the water, how much is being fished, what fishing gears are used, and whether the rate and amount of catch is ecologically sustainable. An empirical method for fisheries assessment that has worked very effectively at local community scales is the creel survey approach, which focuses on estimating total catch, dominant gear types used, selectivity of gear types (i.e., variety in targeted species), and other aspects of fishing behavior (Malvestuto, 1983). Creel surveys, involving observations of fishers paired with interviews, have been particularly useful in assessing the fishing pressure and total economic value to local communities in several locations in the Pacific (Albert et al., 2015a,b; Weijerman et al., 2016), and particularly in Hawaiʻi (Friedlander & Parrish, 1997; Everson & Friedlander, 2004; Kittinger et al., 2015). The name for a creel survey comes from the woven basket, or creel, that freshwater anglers use to hold their catch (Malvestuto, 1996). In Hawaiʻi, these surveys are referred to by the Hawaiian name for a tin basin used to hold nets called a pakini (Kittinger et al., 2015). Surveys are typically conducted at access points where fishers are asked about fishing activities. This participatory approach is generally more effective than studies that do not engage the local community, because the information gathered stems from the community, who have actively helped design monitoring and management efforts (Whyte, Greenwood & Lazes, 1989; Scholz et al., 2004; Kittinger, 2013). Creel surveys offer tremendous advantages in terms of accuracy in each location. However, they are resource-intensive to carry out, and are therefore often limited in their spatial and temporal scope, precluding researchers, managers, and communities from recognizing larger-scale trends necessary for managing targeted fish stocks in reef fisheries (Weijerman et al., 2016).

The purpose of our study is to reveal with unparalleled geographical coverage and detail, a clearer picture of the reef-associated fishing effort, catch, catch-per-unit-effort, and fate of the reef catch in various locations in Hawai‘i. This work addresses long-standing interest in information about coastal fisheries in Hawai‘i which have remained poorly quantified particularly in terms of non-commercial fishing effort and catch. The patterns found here are determined through arguably the most accurate and high-resolution methodology: through fisher surveys conducted at 18 sites across the archipelago. This broad regional coverage provides unique insights into the current state of nearshore fishing effort and catch, and demonstrates the value of creel surveys as a community-level monitoring technique producing information critical to effective fisheries management by assessing distinct spatial patterns in: (1) gear usage; (2) annual catch; and (3) disposition of the catch.

Methods:

Study sites:

Current monitoring of nearshore fisheries by state and federal agencies in the MHI does not capture the full extent of fishing catch and effort due to the large non-commercial nature of these fisheries and the disparate landing sites across the state (McCoy et al., in review). To address this, we complied a large database of creel surveys conducted at 18 sites, across several islands, and over three decades. Details on the compiled information from creel surveys for fishing effort, catch, CPUE, fish flows, and illegal fishing (e.g., use of illegal gear, take of undersized regulated species, fishing in restricted areas) for the MHI and reported values are presented in the Supplemental Information (S1). All creel surveys included in this study were previously published in some form (peer-reviewed articles or gray literature reports) except the data for Kaloko-Honokōhau National Historical Park, Hawai‘i Island, which came from intercept interview data, and from which we produced estimates of effort, catch, and CPUE that are described in S1.

Sample sites included urban and major tourist destinations, such as Maunalua Bay, Pearl Harbor, and Waikīkī on O‘ahu, as well as Wailuku on Maui, which we expected to be characterized by high level of effort but low catch based on anecdotal evidence. Conversely, remote communities such as Kalaupapa National Historical Park on Moloka‘i, and Hā‘ena on Kaua‘i, were expected to have higher catch rates but lower overall effort (Fig. 1). Puakō on Hawai‘i Island was surveyed from May 1980 to September 1981 and again from December 2008 to December 2009 (Table 1). For patterns in fishing gear, we used data from all 18 locations. Examination of fishing effort and total catch had 14 available datasets, with 13 for CPUE, and 8 for fish flow (Table 1).

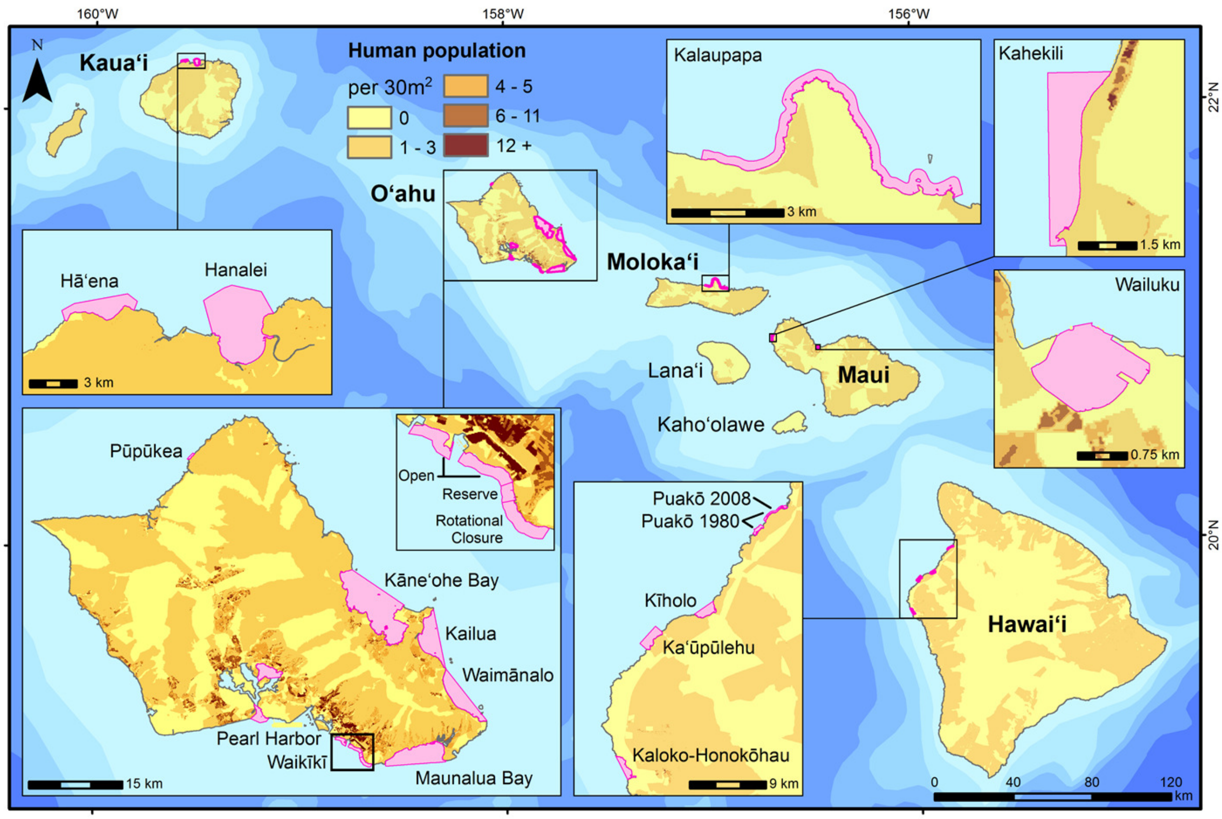

Figure 1. Survey sites where creel and/or fish flow surveys were conducted and included in this study are shown in pink. 2010 human population (State of Hawai'i, 2010) is distributed based on land cover types within census blocks.

Table 1. Location, availability of data, and its inclusion in analyses of gear most commonly used, effort, catch, CPUE estimates and/or fish flows and the source for this information. “0” indicates the information was not available and “1” indicates the information was available.

Location and	Most popular gear	Effort	Catch	CPUE	Fish flow	Source
Hāʻena, Kauaʻi	1	0	0	1	1	Vaughan & Vitousek, 2013; Kuaʻāina Ulu ʻAuamo (KUA), Hui Makaʻāinana o Makana and Limahuli Gardens staff, unpub. report; McCoy et al., in review
Hanalei, Kauaʻi	1	1	1	1	1	Friedlander & Parrish, 1997; Everson & Friedlander, 2004; Glazier & Kittinger, 2012
Kahekili, Maui	1	1	1	1	0	Friedlander et al., 2012
Kailua, Oʻahu	1	1	0	0	0	Friedlander et al., 2014
Kalaupapa, Molokaʻi	1	0	0	0	0	Tom, 2011
Kaloko-Honokōhau, Hawaiʻi	1	1	1	1	0	K. Tom and J. Beets unpub. data
Kāneʻohe Bay, Oʻahu	1	1	1	1	1	Everson & Friedlander, 2004
Kaʻūpūlehu, Hawaiʻi	1	1	1	1	0	Koike et al., 2015
Kīholo, Hawaiʻi	1	1	1	1	1	Kittinger et al., 2015
Maunalua Bay, Oʻahu	1	1	1	1	1	Kittinger, 2013, McCoy et al., in review
Pearl Harbor, Oʻahu	1	1	1	1	0	Wolfe et al., 2017
Puakō, Hawaiʻi (1980-1981)	1	1	1	1	0	Hayes et al., 1982
Puakō, Hawaiʻi (2008-2009)	1	1	1	1	1	Giddens, 2010; J. Giddens pers. comm.
Pūpūkea, Oʻahu	1	1	0	0	0	Stamoulis & Friedlander, 2013
Waikīkī reserve, Oʻahu	1	0	1	0	0	Meyer, 2003
Waikīkī open, Oʻahu	1	0	1	1*	0	Meyer, 2003
Waikīkī rotational closure area, Oʻahu	1	0	1	0	0	Meyer, 2003
Wailuku, Maui	1	1	1	1	1	Koike, Carpio & Friedlander, 2014
Waimānalo, Oʻahu	1	1	0	0	0	Friedlander et al., 2014; K. Stamoulis pers. comm.
Hawaiʻi Island, Hawaiʻi	0	0	0	0	1	Hardt, 2011

*The CPUE estimates for Waikīkī were not reported for the 3 individual sites separately.

Creel survey methodology:

Creel surveys in Hawai‘i have typically quantified fishing effort using elevated vantage points, where observers scanned the area on a systematic schedule using binoculars and/or high-power spotting telescopes (Friedlander & Parrish, 1997; Tom, 2011; Friedlander et al., 2014). Interview-based surveys are conducted using access point and roving survey methods. An access point survey targets a specific site that generally has a single pathway where fishers can be sampled upon completion of a fishing trip (e.g., piers, jetties, or a remote beach with one entry point (Robson & Jones, 1989). A roving survey targets a broader area where access is generally undefined and fishers are more dispersed (Malvestuto, Davies & Shelton, 1978; Malvestuto, 1996). It is conducted by walking and/or driving along a stretch of coastline and stopping when a fisher is located for a potential interview (Malvestuto, Davies & Shelton, 1978; Pollock et al., 1997). Interviews were usually conducted with participating fishers, preferably at the completion of their trip, to gather information such as catch and species composition. Estimates of total annual catch were obtained by multiplying effort for each gear type with the corresponding CPUE (references in Table 1 or S1).

Our assessment was focused on patterns in nearshore fishing by collating estimates from previously conducted creel surveys to produce regional maps of total annual catch, CPUE, and effort for three dominant gear types: shore-based line, net, and spear (McCoy et al., in review). These broad categories of gear are the most common and popular types of fishing methods in Hawai‘i (McCoy et al., in review). We created boundary polygons using ArcGIS 10.4 based on maps and description of surveyed areas in each creel study. These polygons represent the marine area surveyed and were delineated in reference to the National Oceanic and Atmospheric Administration (NOAA) Biogeography Branch shoreline data for the MHI (Battista, Costa &

Anderson, 2007). Total area in square kilometers for each creel survey area polygon was calculated in ArcGIS, as well as area of coral reef and hard bottom as delineated by Battista *et al.* (2007). Length of shoreline for each creel area was measured after first simplifying creel polygon features to standardize measurements using the ArcGIS Simplify Polygon tool with a maximum allowable offset of 100 m, which removed extraneous bends while preserving the essential shape (Table 2; ESRI, 2011).

Table 2. Location, start and end dates of surveys, coastline length, total area, and area of coral reef and hard bottom in creel survey sites as delineated by Battista *et al.* (2007). Surveys were executed from 1980 to 2016.

Location	**Start and end dates**	**Coastline (km)**	**Total Area (km^2)**	**Area of coral reef and hard bottom (km^2)**
Hāʻena, Kauaʻi	Aug 09-Dec 10	3.6	2.05	1.25
Hanalei, Kauaʻi	Jul 92-Dec 93	6.2	7.58	2.82
Kahekili, Maui	Jan 11-Dec 11	3.6	1.88	0.46
Kailua, Oʻahu	Jan 08-Aug 13	11.8	14.84	12.55
Kalaupapa, Molokaʻi	Aug 08-Nov 10	19.6	7.41	3.08
Kaloko-Honokōhau, Hawaiʻi	Jan 10-Jan 11	6.0	2.26	1.62
Kāneʻohe Bay, Oʻahu	Spring 91-Spring 92	33.7	48.46	23.97
Kaʻūpūlehu, Hawaiʻi	Aug 13-Aug 14	3.7	3.53	2.13
Kīholo, Hawaiʻi	May 12-Apr 13	4.5	2.65	1.77
Maunalua Bay, Oʻahu	Dec 07-Nov 08* and Jan 11-Jul 11#	15.1	19.12	16.11
Pearl Harbor, Oʻahu	Jun 15-May 16	14.9	8.06	1.96
Puakō, Hawaiʻi (1980-1981)	May 80-Sep 81	6.6	1.43	1.27
Puakō, Hawaiʻi (2008-2009)	Dec 08-Dec 09	4.9	0.85	0.75
Pūpūkea, Oʻahu	June 11-Sep 11	1.2	0.31	0.30
Waikīkī reserve, Oʻahu	Jun 98-Aug 01	0.7	0.31	0.28
Waikīkī open, Oʻahu	Jun 98-Aug 01	4.8	1.80	1.41
Waikīkī rotational closure area, Oʻahu	Jun 98-Aug 01	1.9	0.97	0.84
Wailuku, Maui	Mar 13-May 14	3.3	0.93	0.16
Waimānalo, Oʻahu	Jan 08-Aug 13	11.4	14.22	6.15

* start and end dates for the creel survey

#start and end dates for the fish flow survey

Fish flow surveys:

Improvements in fisheries management are most effective if they are informed by the main drivers of fishing (e.g., commerce, recreational, subsistence, culture). To accomplish this, we obtained information on fish flow (i.e., catch disposition) across the MHI. This information included the distribution of catch, and whether it was: 1) kept for home consumption; 2) given away; 3) sold (or bartered); 4) released; 5) used as bait and/or 6); used for other purposes (Hardt, 2011; Kittinger, 2013; Kittinger et al., 2015). Fish flow information estimates how catch from nearshore marine ecosystems is used by local fishers and the role it has in local economies and households (Glazier & Kittinger, 2012; Kittinger, 2013).

Results:

Patterns in effort, catch and CPUE from creel surveys:

Line fishing was the most commonly employed gear type (94%), followed by net fishing (6%; Table 3). In all cases, line fishing had the highest estimate of effort (Table 3). However, the most efficient gear types (i.e., higher CPUE) were spear (0.64 kg hr^{-1}), followed closely by net (0.61 kg hr^{-1}), with CPUE for line (0.16 kg hr^{-1}) 3.9 times lower than spear and 3.7 times lower than net (Table 4).

Table 3. Location, estimates of effort for three shore-based fishing gear types (hr), and total annual catch (kg). Some values were not available ("-").

Location	Line	Net	Spear	Total catch
Hāʻena, Kauaʻi	-	-	-	-
Hanalei, Kauaʻi	15,850	5,370	397	15,801
Kahekili, Maui	3,925	108	2,857	1,214
Kailua, Oʻahu	3,867	106	2,184	-
Kalaupapa, Molokaʻi	-	-	-	-
Kaloko-Honokōhau, Hawaiʻi	4,538	208	2,331	3,277
Kāneʻohe Bay, Oʻahu	35,748	5,711	15,926	63,958
Kaʻūpūlehu, Hawaiʻi	5,089	1,319	4,587	4,599
Kīholo, Hawaiʻi	5,004	1,580	799	7,353
Maunalua Bay, Oʻahu	16,441	888	4,099	5,543
Pearl Harbor, Oʻahu	98,725	698	927	7,726
Puakō, Hawaiʻi (1980-1981)	5,017	NA	1,962	8,063
Puakō, Hawaiʻi (2008-2009)	2,917	1,239	1,958	2,323
Pūpūkea, Oʻahu	3,685	5	1,511	-
Waikīkī reserve, Oʻahu	-	-	-	28
Waikīkī open, Oʻahu	-	-	-	457
Waikīkī rotational closure, Oʻahu	-	-	-	581
Wailuku, Maui	15,701	2,192	719	2,161
Waimānalo, Oʻahu	7,140	11	317	-

Table 4. Catch-per-unit-effort (CPUE) estimates in kg hr^{-1} for three shore-based fishing gear types (line, net, and spear fishing). Some values were not available ("-").

Location	Line	Net	Spear
Hāʻena, Kauaʻi	0.09	0.43	0.56
Hanalei, Kauaʻi	0.07	0.96	0.87
Kahekili, Maui	0.09	0.03	0.30
Kailua, Oʻahu	-	-	-
Kalaupapa, Molokaʻi	-	-	-
Kaloko-Honokōhau, Hawaiʻi	0.01	0.07	0.67
Kāneʻohe Bay, Oʻahu	0.27	0.87	0.93
Kaʻūpūlehu, Hawaiʻi	0.23	0.39	0.51
Kīholo, Hawaiʻi	0.62	1.81	1.79
Maunalua Bay, Oʻahu	0.10	0.11	0.23
Pearl Harbor, Oʻahu	0.06	-	0.42
Puakō, Hawaiʻi (1980-1981)	0.28	-	0.48
Puakō, Hawaiʻi (2008-2009)	0.15	1.27	0.23
Pūpūkea, Oʻahu	-	-	-
Waikīkī, Oʻahu	0.04	-	1.13
Wailuku, Maui	0.12	0.14	0.22
Waimānalo, Oʻahu	-	-	-

Fishing effort estimates varied within and across the MHI. The highest estimates of effort were on Oʻahu, where approximately 70% of the state's population resides (Figs. 1 and 2). The highest estimate of fishing effort was recorded at Pearl Harbor, a densely-populated embayment in urban Honolulu, with >100,000 hr of non-vessel-based fishing effort, nearly all of which was line fishing (Fig. 2; Table 3). Kāneʻohe Bay is a large, sheltered bay on windward Oʻahu and had the second highest total effort among all locations (Fig. 2; Table 3). Effort estimates across Oʻahu were extremely variable, with the lowest overall fishing effort observed at Pūpūkea, on the relatively less populated north shore (Figs. 1 and 2). Fishing effort was generally lower at less populated parts of the MHI (Figs. 1 and 2).

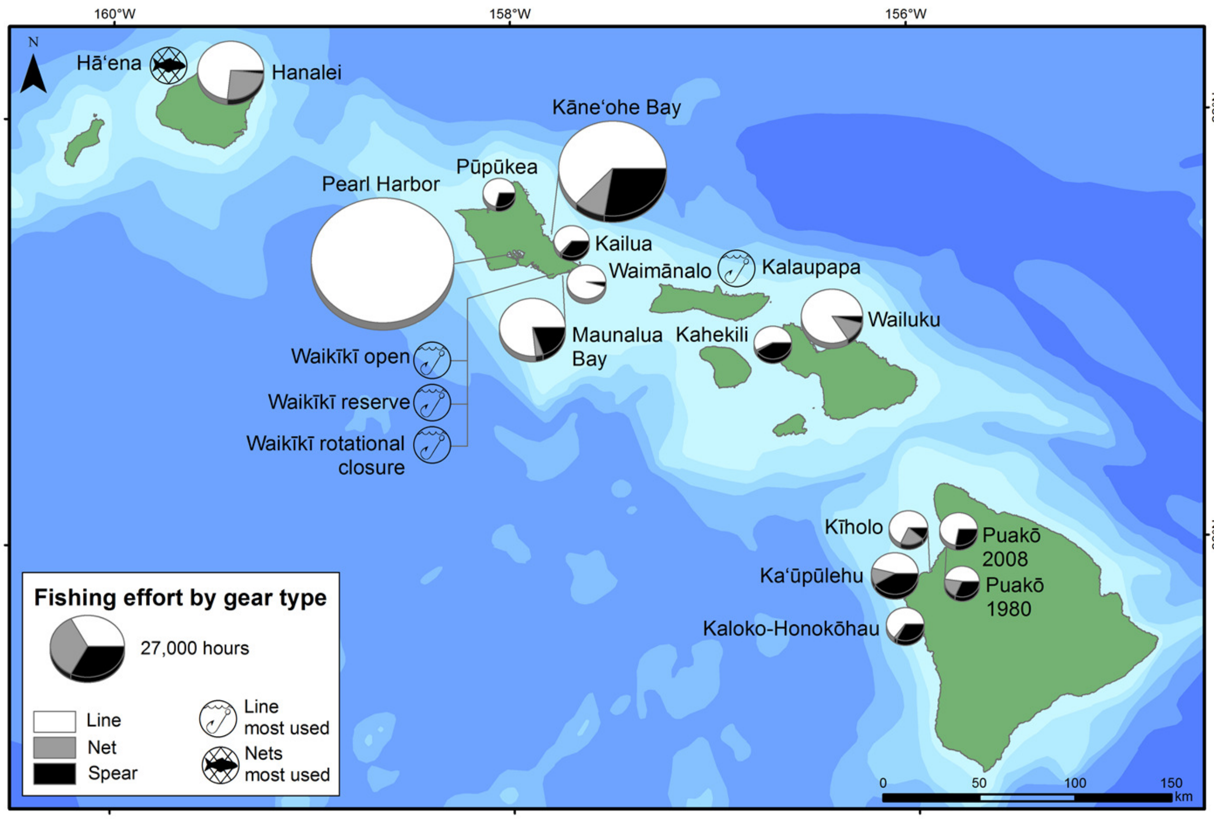

Figure 2. Shore-based fishing effort by gear type. Pie sizes are scaled to represent annualized estimates of total fishing effort by shore-based line, net, and spear fishing activities at each site. If annualized estimates of effort hours were not quantified for the gear types but the survey reported the most commonly used gear type (e.g., gear with highest frequency of occurrence, density of fishing activities by gear type), a symbol indicating the most commonly used gear was added to the map to document this gear preference.

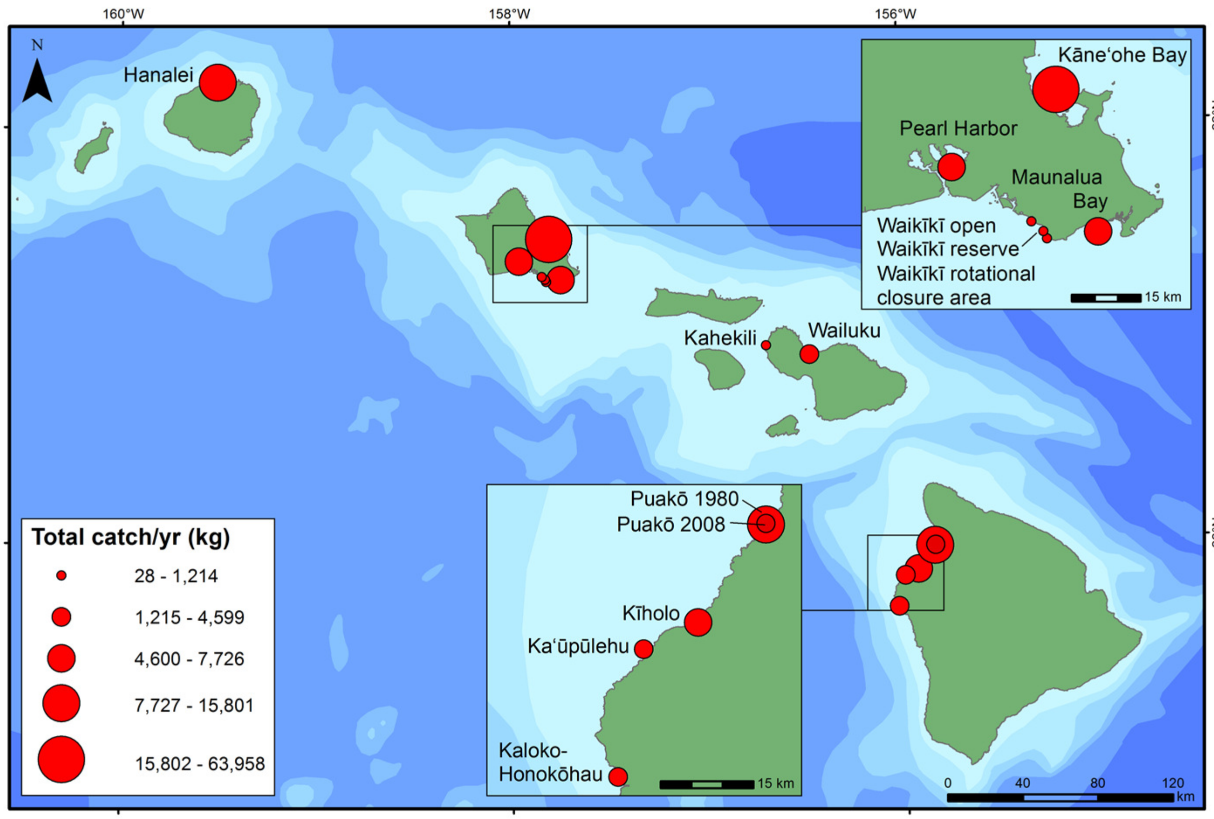

Figure 3. Total catch per year (kg) at each site. Circles scaled to represent total annual fisheries and invertebrate harvest at that site.

Total catch was highly variable among islands, with the highest observed in Kāne'ohe Bay, O'ahu were 52% of the catch caught by active gears consisted of octopus (*Octopus cyanea* and *Callistoctopus ornatus*) (Fig. 3; Table 3). Hanalei Bay on Kaua'i had the next largest annual catch, with a large portion (>70%) of the catch consisting of small coastal pelagic species (primarily *Selar crumenophthalmus* and *Decapterus* spp.) that were almost all (97%) caught by large nets. Catch was generally low in urban and/or tourist-dominated sites such as Waikīkī, Pearl Harbor, and Maunalua Bay on O'ahu, as well as Kahekili and Wailuku on Maui. Catches were similar for the four survey sites along the west coast of Hawai'i Island (Fig. 3). At Puakō, annual fisheries harvest decreased from 1980-1981 to 2008-2009 (Fig. 3). The size of the more recent creel survey at Puakō is 59% of the area of the older survey area, but the catch of the new survey was estimated to be only 29% of the total annual catch of the previous survey.

CPUE estimates were generally lower in more urban and/or touristic locations, as expected (e.g., Oʻahu, and Kahekili and Wailuku on Maui). Conversely, these estimates were generally higher at less densely population places, such as Hāʻena and Hanalei on Kauaʻi, and Kīholo on the island of Hawaiʻi, with the exception of high spear CPUE at Waikīkī (Fig. 4; Table 4). At Puakō, CPUE estimates decreased from 1980-1981 to 2008-2009 for both line and spear fishing by 46.4% and 52.1%, respectively (Table 3). Line fishing was almost always the least effective gear type (Fig. 4). Illegal fishing was reported at least nine of the survey locations. Violations at sites ranged from harvested undersized fish, use of illegal gears, take of prohibited species, and fishing in off-limit areas (Table 5).

253 Table 5. Location and examples of the reported illegal fishing activity reported at survey sites.

Location	Type of activity
Hanalei, Kauaʻi	More than 70% of all the juvenile jacks (Carangidae) caught were below the minimum legal size
Kahekili, Maui	At the Kahekili Herbivore Management Area there was illegal take of herbivorous fishes
Kailua, Oʻahu	Illegal gill net activities were detected in 2008 and 2012
Pearl Harbor, Oʻahu	Spearfishing and net fishing were documented in areas where these gear types were not allowed, as well as the catch of undersized species, primarily small jacks
Puakō, Hawaiʻi	Many of the convict tangs (*Acanthurus triostegus*), parrotfishes (Scaridae) and jacks (Carangidae) that were retained were smaller than the minimum legal size
Pūpūkea, Oʻahu	An average of 27 fishers per week illegally fishing in the Pūpūkea-Waimea marine reserve
Waikīkī reserve and boundary areas of the reserve	Dozens of illegal spear, and pole and line fishing events were observed in the Waikīkī reserve
Wailuku, Maui	33% of the fishing activity recorded was illegal

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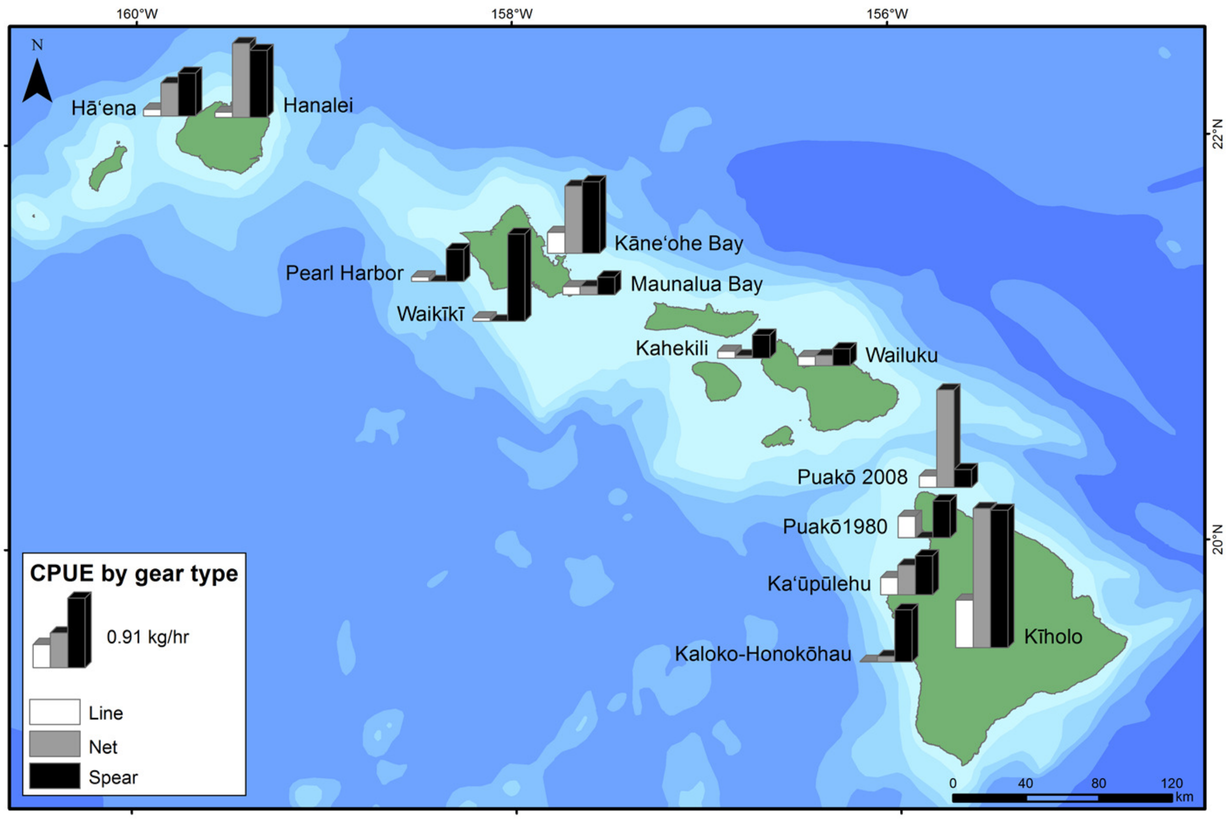

254

255 Figure 4. Catch-per-unit-effort (CPUE - kg hr^{-1}) for the three dominant shore-based fishing gears

256 (line, net, and spear) by survey location.

257

Patterns in Fish Flows:

Surprisingly, the majority of fish caught was either kept or given away for home consumption (Fig. 5). Negligible proportions of the catch were reported as sold (Fig. 5). Only at Wailuku, Maui, more than 40% of the catch was released, reportedly due to fish being undersized. While all the fish flow surveys quantified the proportion of fish and invertebrate biomass kept, not all surveys (e.g., Wailuku) quantified the proportion of catch that was sold. Additionally, some of the fish flow categories varied among survey locations. For example, the survey of Wailuku only reported the categories of catch that were kept and released and surveys conducted at Hāʻena and Puakō, catch used as bait was quantified separately.

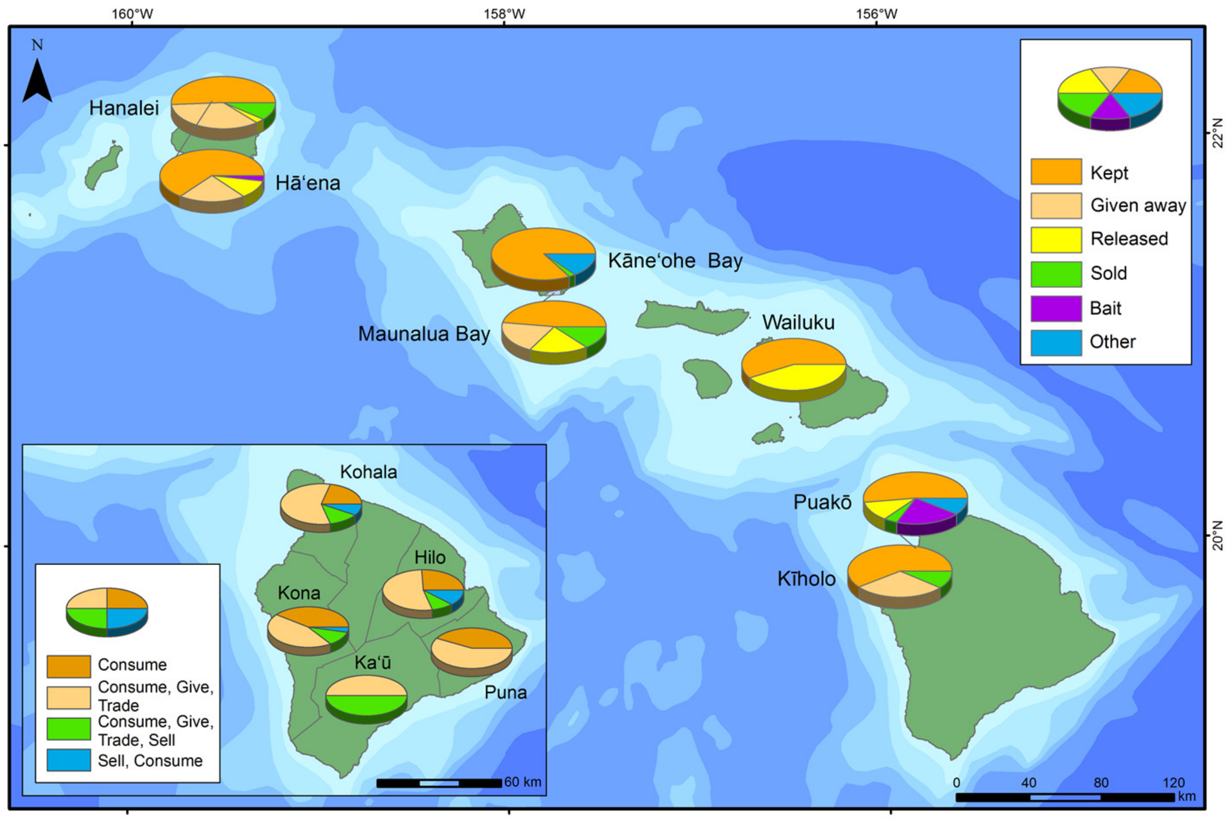

Figure 5. Fish flow for each survey location. Disposition of catch: kept, given away, used as bait, other, released and/or sold. In the lower left inset, data from Hardt (2011) on fish flows were included.

Discussion:

Localized small-scale creel surveys monitoring non-commercial fishing for reef-associated species offer a unique opportunity for scientists and resource managers to interact with fishing communities on a personal basis, thus strengthening the potential for collaborative management on a local level (Malvestuto, 1996). Our first-of-its-kind regional analysis of spatial trends in nearshore fisheries based on creel surveys in Hawaiʻi revealed important insights into the characteristics of the fishery in unprecedented detail. The compiled surveys comprised >10,000 hr of monitoring across a diverse set of locations, with participation from local communities, state agencies, academics, and environmental organizations. Our results showed that fishing effort, catch, and CPUE estimates varied across space (between and within islands) and among fishing gears. The findings can directly improve the design of more cost-effective and standardized creel survey approaches that can be instituted to facilitate more informed fisheries management in Hawaiʻi and beyond.

Nearshore fisheries sustainability and rebuilding fisheries

There are several ways to assess the health of reef fisheries. While a range of yield estimates for sustainable harvesting have been proposed for coral reefs (Newton et al., 2007), by most measures the nearshore fisheries in Hawaiʻi are in poor health (Friedlander & DeMartini, 2002; Friedlander et al., 2008; Williams et al., 2008; Nadon et al., 2015; Friedlander et al., in press). By pairing creel surveys with fish flow surveys, one can start to understand human use patterns in nearshore fisheries, along with mapping the extent of the fisheries benefits to the community, as well as the drivers of fisher behavior. Such information helps a community develop a more informed understanding of the drivers of marine resource harvest and the state of the resources. This, in turn, helps inform effective, sustainable community-based fisheries management. While creel surveys are arguably the best way to monitor nearshore environments, there are numerous ways to assess the health of reef fisheries.

Managers need to address the challenge of overfishing in Hawaiʻi since fishing is a popular activity for both tourists and locals, and a third of the local population identify as recreational fishers (OmniTrak, 2011). Fisheries managers have at their disposal a range of tools that can be tailored to the specific context and challenges of a fishery to sustain, and in some cases, rebuild fisheries (Friedlander, 2015). In general, these tools include input controls (which restrict effort), output controls (which restrict catch), and spatial measures (time/area closures), which are further supported by a range of technical measures (such as monitoring, assessment, and enforcement) (Walters & Martell, 2004). In coral reef fisheries, a range of approaches have been implemented, with a rich literature assessing the efficacy of these approaches (Friedlander, 2015). Inputs, fishing technology, and effective gear types, are often seen as the 'accelerators', whereas outputs and output controls are seen as the 'brakes' in small-scale fisheries (Purcell & Pomeroy, 2015).

Despite their effectiveness, in Hawai'i, nets and spears are used far less often than line, which means further regulation on nets and spears could possibly reduce overall catch while not affect the majority of fishers. Gill nets are regulated in some areas in Hawai'i (e.g., Kailua, a large portion of the south shore of O'ahu, number of locations in West Hawai'i, and the entire island of Maui). Justification for these bans was the indiscriminate catch, including juvenile fishes, and a high bycatch of threatened and endangered species (e.g., sea turtles, marine mammals) (Donovan et al., 2016; Division of Aquatic Resources, 2017). Certain methods of spear fishing such as nighttime and/or on scuba are highly efficient, particularly for parrotfishes, which sleep on the reef at night and are easily harvested at this time (Richmond et al., 2002; Sabetian & Foale, 2006). Scuba-based spear fishing is now banned in West Hawai'i, along with many Pacific Island nations and territories (Gillett & Moy, 2006; Lindfield, McIlwain & Harvey, 2014; Division of Aquatic Resources, 2017). Restriction on or banning of gill nets, nighttime and/or scuba-based spear fishing could potentially be quite effective and should be considered for other locations as well (McClanahan, Maina & Davies, 2005; McClanahan & Cinner, 2008; Cinner et al., 2009).

Time/area spatial closures (i.e., marine protected areas [MPAs]), have been proven to be highly successful in conserving biodiversity (Lubchenco et al., 2003; Lester et al., 2009) but are strongly opposed by many fishers (Agardy et al., 2003; Fernandes et al., 2005). Fishers are often less resistant to gear restrictions than they are to MPAs (McClanahan, Maina & Davies, 2005). In Papua New Guinea and Indonesia, traditional forms of periodic area closures were found to be effective for maintaining targeted fish biomass (McClanahan et al., 2006). However, in areas of Fiji with high-intensity fishing effort, rotational or periodic closures are not always effective because fishers are very successful at drastically reducing fish biomass when closures are opened (Cohen & Foale, 2013; Goetze et al., 2016). Traditional periodic closures can be effective for short-lived taxa that reproduce quickly, but evidence across the Pacific, including Hawai‘i, shows that taxa that are long-lived and reproduce later in life do not benefit from rotational closures (Williams et al., 2006). However, protected areas can provide benefits to local fisheries through juvenile and adult spillover (Russ et al., 2004; Abesamis & Russ, 2005). The Pūpūkea-Waimea MPA on the north shore of O‘ahu has resulted in significant benefit for fishers through this spillover effect (Stamoulis & Friedlander, 2013).

Output controls include annual catch limits, catch size restrictions, bag limits, and other limitations on catch. Annual catch limits have not yet been developed for most species in Hawai‘i due to the difficulty of assessing multi-species coral reef fish stocks, and are most effective for a limited number of high value species such as lobsters and limpets. Hawai‘i DAR has developed and implemented numerous output controls including size, season, and bag limit rules. However, these controls should be adapted as new knowledge emerges of the geographical variability in spawning cycles and growth characteristics of various reef fish among locations (Schemmel & Friedlander, 2017).

Local fisheries management that is driven and informed by traditional knowledge has been shown as effective in certain locations in Hawai'i, as well as other locations in the Pacific (Poepoe, Bartram & Friedlander, 2005; Friedlander, Shackeroff & Kittinger, 2013; Severance et al., 2013; Levine & Richmond, 2014; Birkeland, 2017). To determine the exact portfolio of output controls, input controls, and area closure measures that will be most successful in rebuilding reef fisheries will require careful local monitoring, including creel surveys, and they will need to be combined with efforts to manage other threats such as land-based sources of pollution and invasive species.

Effective management of fishing and the commercial and non-commercial needs of fishers in Hawai'i would include limits to overly efficient, but less popular fishing gears such as nets that usually have higher CPUEs and are responsible for harvesting a disproportionate amount of the catch, including prohibited and protected species. Net fishing was less common and less selective in the species caught, but this gear type along with spear fishing, have much higher catch rates than line fishing. Certain types of nets (e.g., gill and surround nets) are far more effective than other types of nets. Spear fishing is also effective and targets finfish, as well as octopus (*O. cyanea* and *C. ornatus*), which comprised a large proportion of the total catch at some sites (Everson & Friedlander, 2004). The large take of herbivorous reef fishes by nets and spear is a concern for healthy coral reef function because herbivores help control algae populations and prevent phase shifts from coral-dominated to algae-dominated reefs (Weijerman et al., 2008).

A diverse range of management options needs to be developed through a collaborative approach. There is a strong movement in Hawai'i toward decentralized fisheries management, with a revitalization of community-based fishery management based on customary practices and knowledge (Vaughan & Vitousek, 2013), including a recent legal mandate for collaborative management between the state and local communities to establish Community-Based Subsistence Fishing Areas (Kittinger et al., 2012; Ayers & Kittinger, 2014). There are over 20 community initiatives currently active in Hawai‘i (Ayers & Kittinger, 2014), which is among the most promising developments in nearshore fishery management. In Hawai‘i, the cultural diversity and isolation of the islands lead to many expressions of self-determination; one of those expressions is the desire for “local production for local consumption, under local control” (Loke & Leung, 2013). At all sites where fish flow surveys were conducted, the majority of fish caught was either kept or given away for local consumption, demonstrating the high food security and cultural value of these non-commercial subsistence/recreational fisheries for the people of Hawai‘i, particularly in rural areas.

Direct translation of traditional practices into a modern management context is often not possible for political and historical reasons. Current management strategies are often an adaptation and melding of traditional with the contemporary (Cinner & Aswani, 2007; Shackeroff, Campbell & others, 2007; Ayers & Kittinger, 2014). Movement towards the establishment of more co-management arrangements is also driven by recent findings that locations under community-based management have similar amounts or greater fish biomass compared to no-take protected areas (Friedlander, Shackeroff & Kittinger, 2013). Both of these management regimes harbor higher biomass than partially protected or completely open-access areas, clearly indicating that community-managed areas can be effective in providing positive ecological outcomes by sustaining both ecosystems and ecosystem benefits (Friedlander, Shackeroff & Kittinger, 2013).

Local monitoring as a tool for reducing illegal fishing and supporting community-based management

Illegal, unreported, and unregulated (IUU) fishing is a global problem that likely impacts the nearshore environment of Hawai'i, and elsewhere in the region, due to limited monitoring, compliance, and enforcement (UN FAO, 2001; Young, 2016; Pauly & Zeller, 2016). On many coral reefs across the Pacific, including Hawai'i, there is limited capacity for fisheries monitoring (Pauly & Zeller, 2014), thus making fishing effort and total annual catch poorly understood and difficult to quantify (Zeller et al., 2006; McCoy, 2015; Gillett, 2016). These realities behoove us to identify cost-effective and accurate monitoring tools and survey instruments to appropriately track ecological and social aspects of small-scale tropical fisheries, the results of which can successfully inform adaptive state and community-level fisheries management.

Our results highlight numerous illegal fishing activities occurring across the MHI for decades. Illegal fishing activities were reported at least half of the locations surveyed, frequent violations at some locations. Violations at sites ranged from harvested undersized fish, take of prohibited species, use of illegal gears, and fishing in off-limit areas. Instances of illegal fishing and the spatial and temporal patterns of fishing catch and effort have important management implications, and such trends help guide strategies to optimally monitor fisheries given logistical limitations (e.g., limited time, equipment, and personnel to monitor vast amount of area). For this reason, managers and scientists cannot monitor the entire geographic areas of most coral reef fisheries as intensely as needed. In these situations, local monitoring efforts are critical to inform place-based management (McClanahan & Mangi, 2004; McClanahan et al., 2006). However, these local monitoring efforts also need to be aggregated into broader analyses of temporal and spatial scales for managers to gain insights about fishery trends and appropriate management approaches.

Fishing effort varied not only across space but also across time, reflecting seasonal and weekly cycles. In many of the locations, fishing effort was typically higher on the weekends and holidays than on weekdays (Hayes et al., 1982; Friedlander & Parrish, 1997; Koike et al., 2015). Fishing patterns were constrained by regular weekday working hours (i.e., higher fishing effort observed on weekend days and holidays) and by weather patterns. Along north facing shores, fishing effort was constrained in winter due to large surf (Everson & Friedlander, 2004; Koike, Carpio & Friedlander, 2014). For example, Pūpūkea is a *de facto* seasonal refuge from fishing for nearly half of the year due to large surf causing inaccessible fishing conditions (Stamoulis & Friedlander, 2013). However, when the site is accessible, it is heavily fished, therefore negating any benefits accrued during the high surf season.

Many locations in Hawaiʻi, particularly sandy shores and embayments, experience higher fishing effort during summer (June-August) when juvenile goatfishes aggregate in mass very close to shore (Kamikawa, 2016). Summer months also experienced higher fishing pressure because school is not in session and weather conditions are typically more favorable, allowing more people to spend more time fishing with their families. In an era where the threats to reefs and their associated fisheries are escalating due to overfishing, pollution, and climate change (Bell, Johnson & Hobday, 2011), local efforts must be embedded into broader regional management efforts if reefs and the benefits they provide to people are to survive.

To best monitor legal and IUU fishing, we need to determine the most effective survey approach for a given set of personnel, geographies, and available resources. For example, many coastal areas in Hawaiʻi are expansive and relatively undeveloped. Access points to these areas are generally indistinct and parking haphazardly on the side of a road is common. Local fishers often prefer to utilize these areas where resources are generally not as depleted. In addition to many line fishers, spear, and net fishers tend to favor remote areas where capture success is likely greater due to higher resource availability. Based upon the general characteristics of the coastal areas and the diversity of shore-based fisheries in Hawai‘i, the roving survey is often considered the more suitable survey method to collect shoreline fishing information. Also, given that fishing effort is generally higher on weekends and holidays during non-winter months, optimally allocating limited effort for monitoring to those times and locations with higher fishing pressure, could possibly lead to better coverage of fishing activities as well as better enforcement of current regulations. We recommend that creel surveys are conducted more regularly at sites as fishing effort and catch can change over time. For example, estimates were quite different at Puakō between surveys of the area in 1980-1981 and 2008-2009. Current estimates of catch and effort could also be quite different for Hanalei Bay and Kāne‘ohe Bay, which were conducted in 1992-1993 and 1991-1992, respectively. Therefore, repeat sampling of the same areas through time is needed.

We advocate for further systematic design and implementation of community-level citizen science participatory creel surveys as a method for state agencies to collaboratively monitor and manage nearshore shore-based seafood harvesting. Hawaii's local coastal communities, like many similar communities across the Pacific, have a significant dependence on coastal resources. Continued monitoring through creel surveys and other means will provide a wealth of information on catch, fisher behavior, IUU fishing, and effectiveness of different management regimes: where they work and where they fail. Therefore, the use of creel surveys should be increased through space and time for better monitoring of nearshore fisheries and

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determining the best way to manage fisheries for diverse purposes (subsistence, culture, sustainability, recreation, seafood security, and commerce).

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