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Pilot surveys to improve monitoring of marine recreational fisheries in Hawai‘i

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Highlights

- Fishing effort estimates from the roving survey were lower than the existing survey.
- Up to 27% of rod & reel gears were present in areas not covered by the roving survey.
- Night fishing accounted for more than 30% of total shore fishing trips.
- Catch rates from the pilot boat survey were comparable to the existing survey.

ABSTRACT

Marine recreational fishing from shore and from private boats in Hawaiʻi is monitored via the Hawaiʻi Marine Recreational Fishing Survey (HMRFS), using an access point intercept survey to collect catch rate information, and the Coastal Household Telephone Survey (CHTS) to collect fishing effort data. In response to a recent HMRFS review, roving surveys of shoreline fishing effort and catch rate, an aerial fishing effort survey, and a mail survey of fishing effort were tested simultaneously on one of the main Hawaiian Islands (Oʻahu) and compared with the current HMRFS approach for producing shoreline fishing estimates. The pilot roving surveys were stratified by region (rural vs urban), shift (three 4-hour periods during the day), and day type (weekday vs weekend). A pilot access point survey of private boat fishing was also conducted on Oʻahu, using an alternate sampling design created by NOAA Fisheries' Marine Recreational Information Program (MRIP). Three overlapping 6-hour time blocks and site clusters with unequal inclusion probabilities were used to cover daytime fishing. Group catch was recorded for an entire vessel rather than individual catch, which is the current standard for MRIP intercept surveys. Although catch estimates from the pilot private boat survey were comparable to the current HMRFS catch estimates, the catch estimates from the pilot roving survey were lower than the HMRFS estimates. HMRFS uses effort data from the CHTS, which

includes both day and night fishing in all areas, to estimate total catch, whereas effort data from the roving shoreline survey covered only daytime fishing from publicly accessible areas. We therefore suggest that a roving survey conducted during the day should have complementary surveys to include night fishing and fishing in remote and private/restricted areas. Results from these pilot studies will be used to improve the current surveys of marine recreational fishing activities in Hawai‘i.

1. Introduction

The design of the Hawai‘i Marine Recreational Fishing Survey (HMRFS) was originally modeled after the Marine Recreational Fisheries Statistics Survey (MRFSS) with two complementary surveys: an access point angler intercept survey (APAIS) to estimate catch rate and the coastal household telephone survey (CHTS) to estimate fishing effort. The National Research Council’s review of MRFSS provided recommendations for improving both intercept and telephone surveys (NRC, 2006). In response to the NRC recommendations for improving the fishing effort survey, NOAA Fisheries developed the National Saltwater Angler Registry (NSAR) to provide a more efficient sampling frame. Most U.S. coastal states (and U.S. territories, commonwealths, etc.) have applied for an exemption to the NSAR based on pre-existing angler registries, newly created licensing programs, or other alternative databases.

The State of Hawai‘i does not currently require a saltwater fishing license or registration for most recreational fishermen. Only commercial fishers, defined as those who sell any part of their catch, are required to obtain a commercial marine license and report their fishing trips and catch. Hawai‘i has a Federal permit requirement for non-commercial bottom fishing, but this only applies to a relatively small number of fishers. As a result, Hawai‘i is now the only state where recreational fishermen fishing in Federal waters (more than 3 miles from shore) are required to register with the NSAR. Although the federal registration requirement under NSAR applies to anglers catching ocean fish in Federal waters and those that move from Federal waters through state waters to breed in fresh water (anadromous fish), Hawai‘i shoreline and boat-based fishers who fish solely within 3 miles of shore (state waters) are not required to register with the NSAR since there are no anadromous fish in Hawai‘i. Therefore, the NSAR from Hawai‘i is an incomplete sampling frame that excludes a substantial number of fishers.

During a review of HMRFS in 2012, the fishing effort data collection by the CHTS was identified as insufficient due to the decreasing number of landline telephones in use and thus increasing undercoverage through time (Breidt et al., 2012; Ma et al., 2013). Undercoverage may result in serious bias if the uncovered part of the population differs systematically from the covered portion of the population. A pilot study was necessary to investigate alternative methods of surveying shore-based fishing effort. A roving survey was proposed to capture shoreline fishing catch and effort during daytime. Supplementary surveys, including a mail survey and an aerial survey, were recommended to estimate the proportion of fishing activity not covered by the roving survey such as night fishing and fishing in remote areas (Ma et al., 2014). Roving surveys are often used to estimate fishing effort, catch rate, and other parameters when access to a fishery occurs at too many points to accommodate in a traditional access point design (Pollock et al., 1994). Roving surveys are currently used, in addition to access point surveys at boat ramps, to monitor inshore fisheries in the U.S. territories in the Western Pacific (Lowe et al., 2013). Two types of surveys are conducted, one for fishing effort and the other for catch rate. While traversing the accessible coastline by road, surveyors count the fishermen and units of gear engaged in fishing during the roving effort survey on Guam (Amesbury et al., 1991). Similar roving effort surveys are conducted by counting fishermen and fishing gears on accessible coastal segments (entire shoreline not always accessible) in American Samoa and the Commonwealth of the Northern Mariana Islands. The counts are used to estimate fishing effort in terms of gear hours or fisher hours.

To address the National Research Council's concerns about catch data collection protocols and temporal sampling coverage in MRFSS, the MRIP Design and Analysis Workgroup (2012) developed a new sampling design for the intercept survey. The new design has been implemented in the U.S. mainland since 2013. Under the new design, surveyors are assigned to a survey site on a predetermined schedule (with fixed start time and duration). Surveyors are not allowed to conduct interviews solely at peak fishing times, which was practiced under MRFSS to increase the number of interviews. This change eliminates a potential bias when mean catch rates differ between peak and off-peak periods of fishing activity (MRIP Design and Analysis Workgroup, 2012). It was recommended to modify the new design, as used in the Atlantic and Gulf states, and to test it for a private boat fishing survey in Hawai‘i. The modifications include 1) different units used for the fishing effort survey, 2) different cluster methods for fishing access sites, and 3) different survey schedules. If the state vessel registry is used as a sampling frame for a private-boat fishing effort survey in Hawai‘i, fishing effort may be measured as vessel trips rather than angler trips and the corresponding catch rate would be evaluated as catch per vessel trip.

Two workshops were held in Honolulu to discuss survey designs for shoreline fishing and private-boat fishing (Ma et al., 2014, 2017b). The pilot surveys were tested in the field in 2015 and 2016. This contribution describes the Hawai‘i pilot survey designs, outlines results from the pilot surveys, compares these with current HMRFS surveys, and provides recommendations on future directions for the Hawai‘i Marine Recreational Fishing Survey.

2. Materials and methods

2.1. Roving survey for shore fishing

The roving survey was conducted on the island of O‘ahu during daylight hours from January–April 2015. Two surveys were conducted independently, one to collect fishing gear counts (effort survey), the other to collect interview data on catch rate (catch survey). Both surveys were stratified by region (rural vs urban, Fig. 1), day type (weekday vs weekend), and shift (morning 6:30–10:30, midday 10:30–14:30, and afternoon 14:30–18:30). For each survey type, 30 coastal segment and day combinations per month (primary sampling units, PSUs) were selected. Two survey assignments were allocated for weekend strata and three assignments for weekday strata (Table 1). Instantaneous counts of fishing gears were acquired during the effort survey. For the catch survey, fishers were intercepted and interviewed regardless of whether the fishing trip was in progress or completed. The catch, along with gear type, number of gear(s) used, and hours fished per gear were recorded during the interview. Effort survey and catch survey assignments were drawn separately and the direction for the survey route (clockwise or counterclockwise) was chosen at random.

The roving effort survey had predetermined stops where surveyors were required to park and in some cases walk a short distance to observe and record effort data for up to five minutes per stop. All predetermined stops provided relatively quick and safe access and were also visited during the catch survey. In addition to the predetermined stops, a surveyor could pull over anywhere along each sub-segment to interview fishers or record effort data. A sub-segment was the coastline between two adjacent predetermined stops. There were six to ten sub-segments within each segment. The surveyors were allowed up to 30 minutes at each pullover area to conduct interviews. If a route could not be completed in a 4-hr time block, the surveyor would finish the sub-segment in progress, discontinue the survey, and record the finishing time on the field sheet. An assignment was considered complete if at least half of the route was sampled. For the roving effort survey in particular, when a route was completed early with at least one hour remaining in the shift, the surveyor would continue going in the reverse direction of the same route until the end of the assigned time block. In that case, the number of fishers and gears were again recorded, regardless of whether or not they had been recorded during the initial survey of that route. For the roving catch survey, the weight of an assignment was adjusted by the total number of sub-segments in a segment divided by the number of sub-segment visits during a catch survey. For the roving effort survey, total number of gears and fishers counted in a given sub-segment was divided by two if the sub-segment was visited twice during an effort survey. If gears and fishers were not counted for all sub-segments in a given segment, the weight of the effort assignment was adjusted by the ratio of the total number of sub-segments to the number of sub-segments visited.

The PSUs for the roving catch and effort surveys were segment days. The inclusion probability of a survey assignment is the number of assigned segment days divided by the total number of possible segment days in a stratum (cf. Table 1).The sampling weights are the inverses of the inclusion probabilities. Gear and fisher counts were observed on randomly selected segment days in the effort survey. The gear and fisher counts in a segment from a roving effort survey run represent the number of gears and fishermen present within the segment at any moment during the shift (4-hour period). Hoenig et al. (1993) used T to denote the duration of the interval under study and C for instantaneous counts. The estimated effort (gear hours or fisher hours) was expressed as $C \times T$, i.e. $C \times 4$ in a segment during a shift for this study. For the roving catch survey, catch interviews were observation units within PSUs (clusters). The base PSU weight was adjusted for interviews missed, refused, or barred due to a language barrier. Catch rate was estimated as the ratio of catch (for individual species by a particular gear type) to gear hours from the catch interviews.

2.2. Mail survey and aerial survey for shore fishing effort

In conjunction with the roving surveys, two other alternative/supplemental fishing effort surveys were conducted during the same period. An aerial survey was scheduled twice monthly (on one weekday and one weekend day) from January–April 2015. The aerial survey days were selected to coincide with at least one roving effort survey assignment. Continuous orthographic digital images of the shoreline area of Oʻahu were taken from a fixed-wing aircraft. Individual images were then stitched together to form mosaic tiles from which gear and fisher counts could be conducted. The aerial survey was used to get a more comprehensive snapshot of daytime fishing activity from shore over a broader spatial scale, including remote and restricted areas that may be inaccessible to ground-based surveyors. There are no paved roads leading to areas between segments A and B or between segments B and C. The gaps (between segments) not covered by the roving survey segments can be considered as remote areas (Fig. 1). Although access is not restricted, these gaps are not accessible to the surveyors by driving and would require a long walk/hike to conduct surveys. Access to the gaps between segments C and D, and between segments E and F, is restricted because of the presence of military bases and the Honolulu International Airport. Due to the ad-hoc nature of the aerial survey and other logistic constraints, the aerial survey data were mainly used to estimate the relative effort in areas not covered by the roving survey.

The second supplemental survey, an address-based mail survey, asked respondents about non-commercial fishing effort from all shorelines, including night fishing trips and in remote and private/restricted areas. The mail survey targeted fishing activity during the first two months of 2015. Fishermen were specifically asked about the number of days and nights fished from private and restricted areas (e.g. military base, private land, private marina, etc.). A simple random sample of 3,000 Oʻahu households was drawn from a total of 315,186 addresses in the sampling frame excluding drop boxes, traditional P.O. boxes, seasonal, and vacant addresses. The sample selection probability of each of the 3,000 households is 3,000/315,186. The survey followed the tailored design methods (Dillman, 2000), which consisted of a pre-letter (informing residents of the upcoming survey), two questionnaire mailings, and two postcard reminders. A total of 701 households responded to the survey. The sampling weight of each respondent was therefore calculated as 315,186/701.

The main objectives of the mail survey were to estimate: 1) the proportion of night fishing activities not covered by the roving and aerial surveys, and 2) the proportion of fishing activities from private and restricted areas which were not fully covered by the roving survey. Data from the mail survey were also used to estimate the mean gear hours (both day and night time) and gear days per Oʻahu household. Assuming there was no non-response bias, the mean gear hours per household and mean gear days were expanded to estimate total gear hours and gear days on Oʻahu for comparison with results from the roving survey.

2.3. Access point (intercept/interview) survey for private boat fishing

The pilot survey for private boat fishing was conducted from January to April 2016 on Oʻahu. The survey assignments were allocated 50:50 between each month in a wave (wave = two-month period) and 30:70 between weekdays and weekend days within a month. Holidays (except January 1st, which was not included in the survey) and Fridays were included in the sample frame as weekend days, an approach currently used in the MRIP intercept surveys in Atlantic and Gulf of Mexico states. A target of 30 survey assignments was set for each month. The survey was based on a stratified sampling design (stratified by weekday and weekend), with sample frame including site, time interval, and day (within a day type) combinations (PSUs). Major public boat ramps (harbors) on Oʻahu with active MRIP site registers included for the sample draw were Heʻeia Kea Small Boat Harbor, Maunalua Bay Launch Ramp, Ala Wai Harbor, Keʻehi Harbor, Waiʻanae Small Boat Harbor, and Haleʻiwa Harbor (Fig. 1). The vessel trips within a boat ramp/harbor (sampling unit) were observation units, sometimes called elements (Lohr, 1999).

Sampling intervals included three time blocks: 8:00–14:00, 11:00–17:00, and 14:00–20:00. A predetermined number of assignments were given to peak/non-peak and weekday/weekend combinations each month. Weekday and weekend were exclusive (strata), and peak (11:00–17:00) and non-peak (8:00–14:00, 14:00–20:00) intervals were designed to overlap. The inclusion probabilities (chances of being included in the sample) of a fishing site depended on fishing pressure at the site. The fishing pressure at a site (number of anglers present during a time interval) can differ depending on month, day type, and time of day. One interview was attempted per vessel trip, which recorded the total catch (group catch). Based on the original inclusion probabilities of assignments in peak and non-peak sampling intervals (six hours), the inclusion probabilities were calculated for two 3-hour periods within a sampling interval. For periods 8:00–11:00 and 17:00–20:00 (only occurring in non-peak intervals), there was no overlap, and no adjustment of inclusion probabilities was needed. The inclusion probabilities for periods 11:00–14:00 and 14:00–17:00 (occurring in both non-peak and peak intervals) are unions of inclusion probabilities during peak and non-peak intervals. The sampling weights are the inverses of adjusted inclusion probabilities.

To be consistent with HMRFS protocols for the private-boat fishing survey, interviews with full-time commercial fishermen were excluded because their catch rates tend to be higher. The sampling weights for each survey assignment (in a 6-hr sampling interval) were adjusted for fishing trips missed, refused interviews, or interviews with key items unanswered, with the latter treated as missed trips. The weight adjustment consisted of multiplying the base PSU weight by (completed + missed + refused + key-item refused) / completed. The sampling weights for each 3-hour period were also adjusted to account for situations when surveyors did not start on time or ended the assignment early (multiplied by (3 hours) / (actual survey hours)).

2.4. Data analysis

In HMRFS, available catch and unavailable catch are analyzed separately (Ma and Ogawa, 2016). Available catch is observed by the surveyors and can be measured for weight and length. Available catch records in HMRFS can include catch from individual fishers or a fishing group on a fishing vessel. Unavailable catch is reported by fishermen (not examined by the

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surveyors), and the catch record in HMRFS is for individual fishermen only. Available catch and unavailable catch from the pilot surveys were combined for data analysis in this study. For the pilot roving survey, catch records (available or unavailable catch) were always from individual shore fishermen. For the pilot access point survey of private boats tested in January–April 2016, group catch from a whole vessel, rather than catch from individual fishers, was recorded regardless of whether the catch was available or unavailable.

The Statistical Analysis System (SAS) "SURVEYMEANS" procedure was used to produce point and variance estimates for both roving and access point surveys. For the roving effort survey, segment days were the primary sampling units. For the roving catch survey, segment days were clusters, and angler catch interviews were observation units within a cluster. For the access point catch survey (for private boats), site days (within different sampling intervals) were clusters and vessel catch interviews were observation units. Catch rate was estimated as a ratio of catch to fishing effort for both roving and access point surveys. The variance of catch was estimated by $C_r^2 \times$ variance (effort) + effort$^2 \times$ variance (C_r) - variance (C_r) $\times$ variance (effort) (Goodman, 1960). Catch rate (C_r) and effort estimates were derived from two separate surveys and were considered independent. Key estimates from each pilot survey and the linkages among different surveys are summarized in Table 2. The estimators for the key point estimates and their variances are provided in Appendix A. The variance was estimated using the Taylor series method (the default in the SAS SURVEYMEANS procedure). The finite population correction was not included for the variance estimation because the sampling rates were low (< 1% for the mail survey and < 10% for the roving survey).

3. Results

3.1. Roving Survey

The fisher and gear counts per segment from the roving effort survey in each stratum are shown in Fig. 2. Rod & reel was the main gear type for shore fishing (Table 3). Mean counts of fishers and rod & reel gears per segment were generally higher during the weekend. During weekend days, the mean gear counts appeared higher in the rural region.

The sum of gear and fisher hours from 12 strata each month is presented in Table 3. The monthly estimates for rod & reel gear hours and fisher hours have reasonable precisions with percentage standard error (PSE, relative standard error (= standard error / point estimate) expressed as a percentage) ranging from 6–15%.

Table 4 includes the total catch estimates of bluefin trevally (*Caranx melampygus*), bigeye scad (*Selar crumenophthalmus*), and bluespine unicornfish (*Naso unicornis*) by different gears. Bluefin trevally were caught by rod & reel only in the roving catch survey. Bigeye scad were caught by both rod & reel and hand pole. Bluespine unicornfish were caught by rod & reel and spear. Even though the gear hours from rod & reel were an order of magnitude greater than the gear hours from hand pole or spear (Table 3), the catch estimates of bigeye scad by hand pole and bluespine unicornfish by spear were comparable to their corresponding catch by rod & reel due to the higher catch rates from hand pole (for bigeye scad) or spear (for bluespine unicornfish) (Table 4).

3.2. Mail survey

Of the 3,000 questionnaires mailed out to O‘ahu households, 132 were undeliverable, and 701 households responded. The overall response rate was 24.4%. Based on the responses, 16.0 % (112 out of 701) of households had anglers who fished in the past year, and 10.3 % (72 out of 701) had anglers who fished in the past two months. A total of 55 fishing nights and 65 fishing days were from private and restricted areas (Table 5). For fishing nights and days in all areas (public, private, and restricted), fishers were asked for number of fishing nights and days by gear type, the typical trip length, and the typical number of each gear used. We defined the gear with the highest number of fishing days or nights for a fisher as his/her main gear type. The sum of gear nights from all gears was defined as total gear nights. The number of fishing nights would fall between the number of main gear nights and total gear nights, given that more than one gear type may be used during a fishing trip. The total number of main gear nights was 192.5 and the total number of gear nights was 238.5 during the first two months of 2015 for all fishers who responded to the survey (Table 5). For the same group, the total number of main gear days was 379.5, and the total number of gear days was 447.

For individual gear types, the total numbers of nights and days fished by the 701 households are shown in Table 6. For rod & reel and hand pole, night fishing accounted for more than one third of the total fishing days and nights. For spear fishing and throw netting, night fishing accounted for about 10–20% of the total fishing activity. For the “other nets” category, one fisher reported 20 days and 20 nights for crab/lobster. If this non-finfish record was excluded, there would have been only 2 gear nights, 3 gear days, and 6 nighttime and 8 daytime gear hours registered for other types of nets.

Assuming no non-response bias, the gear hours in Table 6 can be expanded to the total gear hours from all O‘ahu households (Fig. 3). Total gear days and main gear days for O‘ahu in

January–February 2015 were estimated to be 200,982 (SE = 35,577) and 170,632 (SE = 29,525), respectively.

3.3. Aerial survey

Air traffic, scheduled activities at military bases, and adverse weather conditions sometimes limited or restricted flight patterns for an aerial survey. Aerial surveys planned for January were delayed by logistics. Therefore, two survey assignments for January were added to February. The gaps between roving survey segments were not covered by the roving surveys and were defined as remote areas in Table 7. The proportion of fisher counts from the remote areas ranged from 1–20%. The proportion of gear counts from the remote areas was 1–27% for rod & reel and 2–23% for all gears combined (Table 7). The gear and fisher counts at individual segments from the aerial survey were also compared with the counts from ground-based roving survey (see discussion).

3.4. Access point survey

Catch rate and total catch were estimated for four major pelagic species occurring frequently in the survey catch records. Catch rates (catch per vessel trip) for skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) from the pilot survey in 2016 were higher in wave 2 than in wave 1, whereas the catch rate of mahimahi (*Coryphaena hippurus*) appeared higher in wave 1 than in wave 2 (Fig. 4). The catch rate (catch per angler trip) was also calculated during the same period using data collected on O‘ahu by regular HMRFS staff. The estimated number of fishers per vessel trip was 2.25 in waves 1 and 2 on

O‘ahu. For comparison, catch rates from HMRFS were converted to catch per vessel trip by a factor of 2.25. The error bars (SE) for catch rate estimates from the pilot survey and regular HMRFS survey overlap for seven out of eight pairs (Fig. 4).

The estimated number of angler trips for private boat fishing on O‘ahu were 14,391 in wave 1 (SE = 7,641) and 20,386 in wave 2 (SE = 16,157) based on the CHTS data. The more than 50% PSE of these estimates indicates that the effort estimates at island and wave levels were imprecise. The angler trip estimates (SE) were converted into vessel trips for catch estimates using catch rate from the pilot survey. Effort was also estimated using data from the pilot survey (Fig. 5). However, the effort estimates from the pilot survey did not cover night fishing trips and fishing at other sites (i.e. other than the public boat ramps included in the sampling frame) on O‘ahu. Similar to the catch rate comparisons, catch estimates from the two surveys were not significantly different for each of the four pelagic species in a wave (Fig. 6). The catch estimates from both surveys were imprecise due to the low precision of the effort estimates from the telephone survey.

4. Discussion

4.1. Shore fishing effort estimates from different surveys

The pilot roving survey produced total effort estimates (gear hours) for rod & reel and spear fishing with reasonable precision. Percent standard error (PSE) was 6–14% for monthly rod & reel effort estimates (Table 3) and was less than 10% for gear-hour estimates at the wave level (over a 2-month period). The PSE was 21–25% for monthly spearing effort estimates and was less than 20% for estimates by wave. For other gear types, the precision was low with PSE sometimes greater than 50%.

One of the main objectives of the mail survey was to estimate the proportion of fishing not covered by the onsite roving surveys. Data from the mail survey were also used to estimate fishing effort (gear hours) during the day and at night. The estimated daytime gear hours for wave 1 (January–February) in 2015 were 1,079,883 (SE = 231,146) for rod & reel and 126,794 (SE = 42,085) for spear, based on the mail survey. Effort estimates from the mail survey were expected to be greater than estimates from the roving survey (Table 3) due to the undercoverage of remote and private/restricted areas in the roving survey. The total fishing days during wave 1 from all mail survey respondents were between 379.5 and 447, of which 65 days were in private and restricted areas (Table 5). Thus, the proportion of fishing days in private and restricted areas was between 14.5% and 17.1%. The aerial survey showed that the percentage of rod & reel gear counts from the areas not covered by the roving survey segments (including remote areas and areas restricted by military bases) could reach up to 27% of the total (Table 7). Thus, fisher and gear counts from private/restricted and remote areas combined may account for a significant proportion of the total on Oʻahu.

The fishing effort estimates from the mail survey appeared greater than those from the current CHTS. The percentage of households with anglers who fished during the past two months in wave 1 of 2015 was 10.3% (SE = 1.15%) from the pilot mail survey on Oʻahu versus 2.9% of households (SE = 0.77%) based on the CHTS for the same period. These percentages are significantly different. The mail survey had a response rate of 24.4% and the CHTS had a response rate less than 20% (Andrews et al, 2014). The potential difference in non-response bias between the two surveys may have contributed to the discrepancy in the percentage estimates of fishing households. The proportion of fishing households represented in the CHTS has significantly decreased over the past 15 years in Hawai‘i (Ma et al., 2017a), which may be related to steadily decreasing coverage of landline telephones (R. Andrews, pers. comm.). If the households with a landline telephone are different in fishing activity from those without a landline telephone, the CHTS will result in bias due to undercoverage. The proportion of fishing households detected was also higher in mail surveys conducted in Florida, Massachusetts, New York, and North Carolina in 2013 than the CHTS estimates during the same time period for those states (Andrews et al., 2014).

The estimated total gear days and main gear days for O‘ahu were 200,982 (SE = 35,577) and 170,632 (29,525) in wave 1 (January–February) 2015, respectively. Total gear days/nights and main gear days/nights were defined in section 3.2. The number of fishing days (daytime only), based on the mail survey, was between 170,632 and 200,982 (i.e. between estimated main gear days and total gear days). In comparison, there were an estimated 100,332 angler trips (SE = 43,581) for shoreline fishing on O‘ahu based on the CHTS during the same period. This was less than the estimate from the mail survey. An angler trip from the CHTS is defined as fishing during part or all of one waking day, which includes fishing done at night. Thus, the angler trip estimates from the CHTS are expected to be greater than the number of trips taken during daytime only (as estimated by fishing days from the mail survey). Andrews et al. (2014) reported that the mail survey estimate of total fishing effort was 4.1 times the corresponding CHTS estimates, based on results from four U.S. east coast states in 2013. The lower proportion of fishing households measured in the CHTS was found to be one of the major contributing factors. It was suggested that a “gatekeeper effect” in the CHTS may result in lower fishing household prevalence estimates. The initial respondent to a household telephone interview may give inaccurate responses to screener's questions to determine whether or not anyone in the household fished during a reference wave (Andrews et al., 2014). The CHTS contacts households without prior notice, and the initial household respondent is expected to describe household-level fishing activity immediately. This may result in difficulty in recalling past events, particularly when they are not especially memorable. The gatekeeper effect may be less problematic for household mail surveys, where the household has more time to determine who should respond to the survey and check records or discuss the questions with other members of the household.

The mail survey on O‘ahu was not stratified in design. When a domain was used to separate Honolulu from other cities on O‘ahu, the estimated prevalence of 2-month fishing households (households with anyone who fished during the past two months) was 8.2% for Honolulu and 12.2% for other cities. The response rates to the mail survey were similar between Honolulu and other cities (24.6% for Honolulu and 24.3% for other cities), which does not indicate nonresponse bias (which would require the use of different weights for Honolulu versus other cities). Demographics information of the target population is often used to compare with the demographics data in the achieved sample to detect non-response bias. Our mail survey only captured age and gender information from fishing households, which was insufficient for examining the potential non-response bias in the sample. For future mail surveys, non-respondents can be re-contacted in a follow-up survey to assess whether they are in some way different from the respondents with respect to fishing activity. At the same time, the survey instrument and survey implementation can be improved to increase the response rate and minimize the impact of potential non-response bias. The proportional estimates of night fishing and fishing from private/restricted areas are less susceptible to the potential non-response bias because the bias may be factored out in a ratio estimate (bias present in both numerator and denominator).

The fisher and rod & reel counts from the roving and the aerial surveys showed some linear relationships (Fig. 7a and b), with R^2 values of 0.407 (P value = 0.019) for fisher counts and 0.389 (P value = 0.023) for rod & reel counts. No significant linear relationships were present for other gears combined (Fig. 7c). In most cases, the counts for fishers and for rod & reel from the roving survey were greater than those on the same segments from the aerial survey (Fig. 7). Some fishers and gears were likely missed in the images captured in the aerial surveys. The high resolution images from the aerial survey had a swath of only ~200 meters. Thus, fishers and gears beyond the 200-m swath would be missed in the images. Because the major shoreline gear type is rod & reel, the images were focused mostly on the shoreline area and may not have adequately captured fishers/gears located further seaward (e.g. spear fishers, gill netters, and throw netters)

4.2. Shore fishing catch rate and catch estimates

Exploring alternative survey designs for shore fishing effort was the major focus of the roving survey. The catch rate and catch were also estimated for three species at a wave level. The catch rate was estimated as a ratio of means. Pollock et al. (1994, 1997) suggested that the mean of individual ratios (of catch divided by effort for each angler) be used for roving surveys to avoid the length-of-stay bias. The probability of intercepting an angler during fishing (in a roving survey) is proportional to the length of the anger's fishing trip. The catch rate may differ for trips of different lengths. In access point surveys, anglers are generally interviewed when they leave the fishery, and the probability of interviewing an angler is the same regardless of the trip length (Pollock et al., 1994, 1997). The catch rate estimates of bluefin trevally (rod & reel fishing) were higher when the mean of individual ratios was used (Fig. 8). The catch rate estimates (by rod & reel) were also higher for bigeye scad and bluespine unicornfish when the mean of ratios was used.

The effort (gear hours, rod & reel) and catch (bluefin trevally) estimates from the roving survey appeared lower than the estimates from HMRFS (error bars did not overlap between two surveys, Fig. 8). For comparison, the catch rate estimates from HMRFS (catch per angler trip) were converted to catch per gear hour based on the mean gear hours per angler trip from the roving catch survey. The effort estimates from the telephone survey were also converted using the same factor. The conversion factor (mean gear hours per angler trip based on the roving survey) for HMRFS catch rate and effort was an approximation. In the roving catch survey, fishermen were interviewed when they were still in the process of fishing (including incomplete fishing trips). On the other hand, the probability of a fisher being intercepted was proportional to the length of the fishing trip. The conversion factor does not affect the catch estimates in HMRFS, and the conversion was used for catch rate and effort comparisons between the roving survey and HMRFS.

The catch by gear type in a (2-month) wave was estimated as the product of catch rate at a wave level and the total effort in the wave. For rod & reel, catch rate estimates could have been made at a stratum level for 47 of 48 strata (there were 12 strata in each of the four months). Catch could be estimated for individual strata first and then aggregated over all strata. The aggregated catch estimates for bluefin trevally from individual strata (3,321 fish for wave 1; and 5,359 fish for wave 2 based on Ma et al. (2017a)) are between the two pilot catch estimates shown in Fig. 8c. For hand pole, 15 of 48 strata had gear hour data from the roving catch survey to estimate catch rate at a stratum level. For spear fishing, catch rate could be made at a stratum level for nine (of 48) strata. However, 34 and 39 (of 48) strata had gear hour estimates from the roving effort survey for hand pole and spear, respectively. Many of these strata with effort estimates did not have corresponding catch rate estimates (at a stratum level). For the strata with missing stratum-level catch rate estimates (19 strata for hand pole and 30 for spear), pooled catch rate estimates from other strata would be necessary if catch were to be estimated for individual strata first.

4.3. Access point survey

Interviews from full-time commercial fishermen accounted for less than 2% of the total interviews in the pilot survey, and they were excluded for the catch rate estimation. In 27% of the interviews, fishermen indicated that they sold their catch to cover fishing expenses or earn some income. These interviews were not excluded, to be consistent with HMRFS protocol. Ma and Ogawa (2016) indicated that a significant proportion of HMRFS catch estimates for blue marlin, mahimahi, striped marlin, wahoo, and yellowfin tuna may have been sold. In Hawai‘i, many fishermen do not consider themselves commercial fishermen when they only sometimes sell their catch to cover fishing expenses (Hospital et al., 2011; Chan and Pan, 2017). A difference in the pilot survey (as opposed to HMRFS), was recording boat-based group catch for both available and unavailable catch. This was considered a feasible alternative to recording individual catch. Group catch is often reported within the “available catch” in the HMRFS survey, particularly when the catch is retained in one container, as is typical for boat-based trips.

Recording boat-based catch can reduce the overall time needed to sample each fisher aboard a vessel, allowing the surveyor to process catch more quickly and efficiently. No consistent differences were found between the catch rate estimates for the pilot survey and HMRFS (Fig. 4). In wave 1, there were few interviews with high catch number for mahimahi in the pilot survey and the catch rate was higher (but with large SE) than the HMRFS estimate. In wave 2, the catch rate of skipjack in the pilot survey appeared higher than HMRFS. More than 80% of the skipjack pieces were in the unavailable catch records of the pilot survey whereas the unavailable skipjack accounted for ~50% of the total skipjack pieces in HMRFS. The difference in the unavailable catch contributed to the different catch rate estimates for skipjack in the two surveys. None of the paired catch rate estimates in Fig. 4 are significantly different.

The number of pilot survey assignments for boat fishing on O‘ahu from January–April 2016 was similar to the number of HMRFS survey assignments conducted in the same months. During wave 2, percentage standard error (PSE) of catch rate estimates from the pilot survey was less than those from HMRFS (Table 8). The PSE from the pilot survey was greater than HMRFS during wave 1. The precision of HMRFS estimates was calculated by treating individual interviews as units in a simple random sample. Thus, the variance of HMRFS estimates may be underestimated (NRC, 2006). The PSE of boat fishing effort estimates from the onsite survey was 20.9% and 10.3% for waves 1 and 2, respectively, while the CHTS had PSE greater than 50% (Fig. 5). Despite undercoverage of the access point survey, the effort estimates based on intercept sampling could be incorporated into the total effort estimation to improve the precision.

5. Conclusions and recommendations

Results from the pilot mail survey indicate that night fishing accounted for more than one third of the total trips for rod & reel (the major gear type) and hand pole. Roving surveys at night are currently implemented in some U.S. Pacific island territories. However, some gear types can be difficult to assess in the dark. Surveyor safety at night is also a concern when surveying on uneven terrains, areas with consistent wave exposure, or high crime areas. Given the challenges of onsite surveying at night, the mail survey may be a more efficient option for estimating night fishing effort, especially for the proportion of fishing effort from night fishing. A mail survey may be the current best method to estimate total fishing effort in Hawaiʻi because of its broad coverage and lack of geographic restrictions. The sampling frame used in this pilot survey was a list of general household addresses on Oʻahu. More efficient sampling frames can be developed if a mail survey is adopted for use as an independent survey. The roving catch survey captured a greater diversity of gear types when compared to the HMRFS intercept survey (Ma et al., 2017a). More sites were visited during a roving catch survey assignment, and multiple gear types (if more than one gear type was used) were recorded from a roving catch interview (only the primary gear is recorded in the HMRFS intercept survey). Catch rates for a fish species by different gear types were shown to vary for some species. Developing an effort survey that encompasses gear hours would complement the roving catch survey and may provide more accurate and precise catch estimations.

In the aerial survey, up to 20% of all fishers (27% for rod & reel) counted during daylight hours were from areas not included in the roving survey segments. The aerial survey was expected to get a snapshot of fishing activity from the whole shoreline of Oʻahu. However, the Kāneʻohe Marine Corps Base (the gap between roving segments C and D) was only intermittently covered. Pearl Harbor and Honolulu Airport (the gap between segments E and F) were not covered by the aerial surveys due to air traffic restrictions. Adverse weather conditions also limited the coverage in both restricted and non-restricted areas. Limitations in geographic coverage and visual interpretation by the aerial survey may indicate the mail survey would be more efficient, both to estimate the proportion of fishing in areas not covered by the roving survey and the proportion of night fishing. The pilot mail survey in 2015 did not specify the areas not covered by the roving survey.

Results from the pilot survey for private boat fishing indicated that implementation of a fixed time block sampling design is feasible, at least on O‘ahu. Due to the extensive coastlines, characteristic of the Big Island (Hawai‘i Island) and Maui, it may be necessary to split an island into sub-regions to ensure that sampling is distributed where resources can be utilized efficiently and appropriately. For this pilot survey, single-site clusters were used. When there are adjacent sites with low fishing activity, they can be clustered to form multi-site units in order to increase the inclusion probabilities of the lower activity sites relative to the higher activity sites, resulting in a more even distribution of samples. The effort estimates from the onsite survey had better precision than the telephone survey. Such estimates could ultimately be incorporated into the total fishing effort estimates to potentially improve the precision.

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Appendix A. Point and variance estimators

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Figure Captions

Fig. 1. Roving-survey coastal segments on O‘ahu. Segments A–C are in the rural region and segments D–F in the urban region. Circles represent major public boat ramps (harbors) on O‘ahu which were used for a pilot boat fishing survey (see section 2.3).

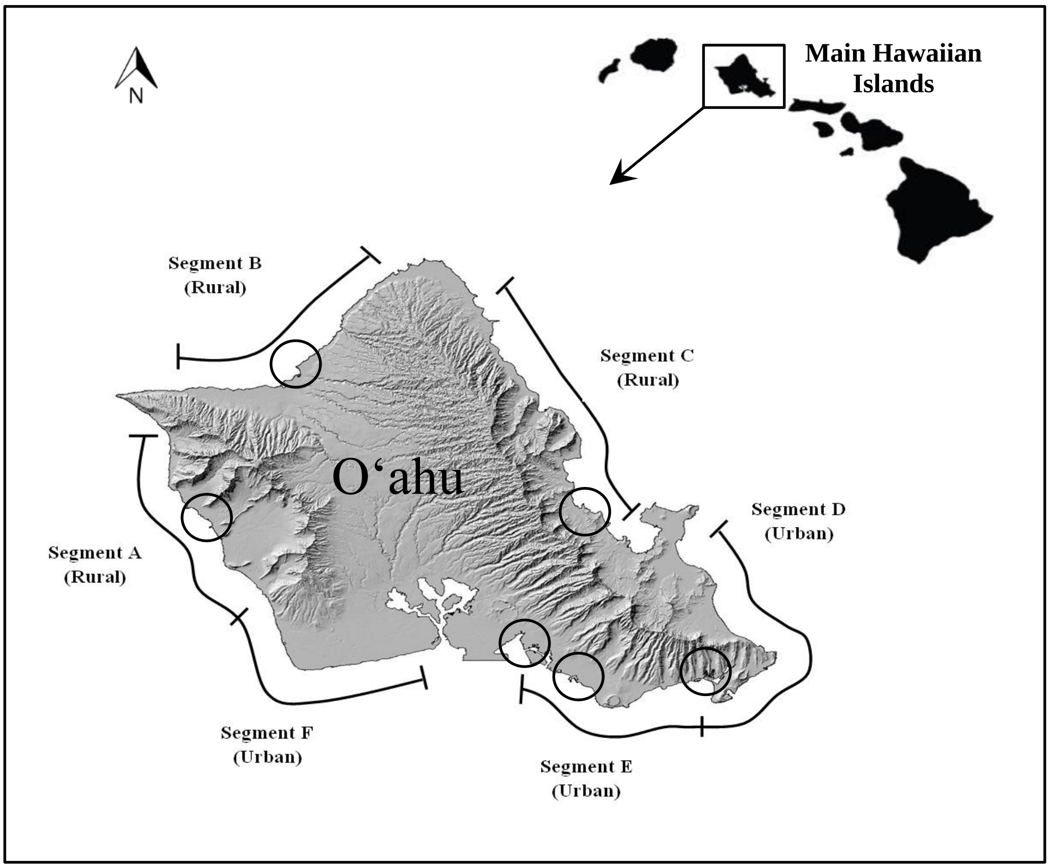
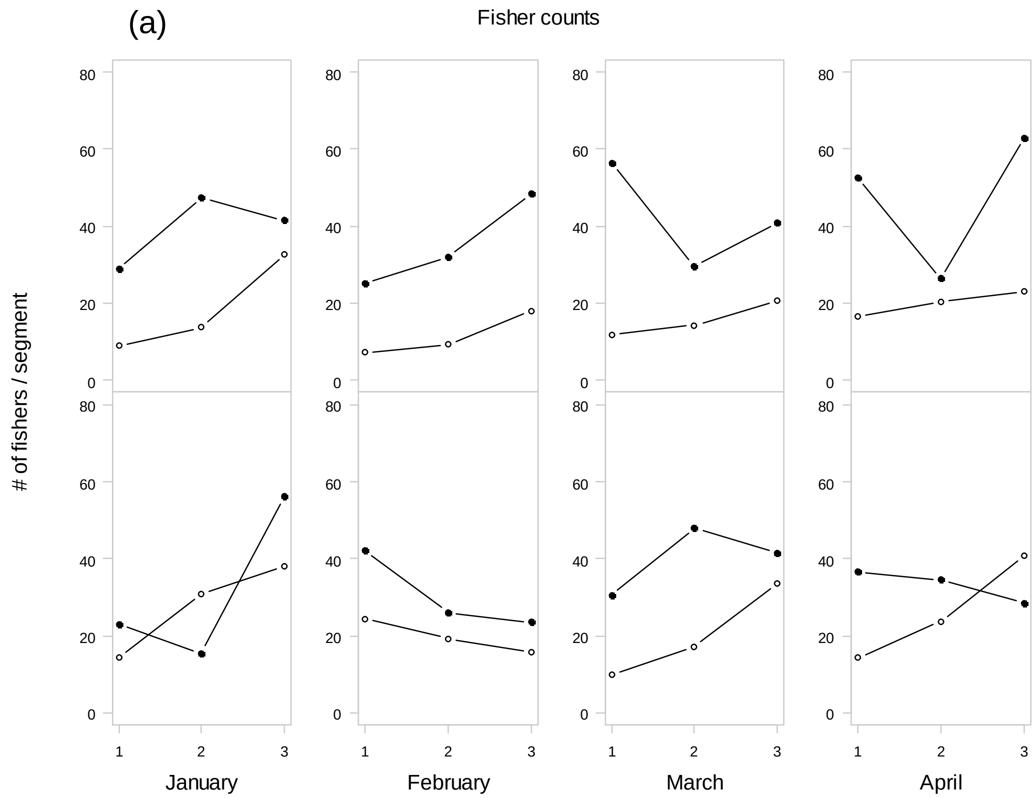


Fig. 2. Fisher (a) and rod & reel (b) counts per segment in shifts 1, 2, and 3. Open circles represent weekdays and filled circles weekends. Upper panels are for the rural region and lower for urban.



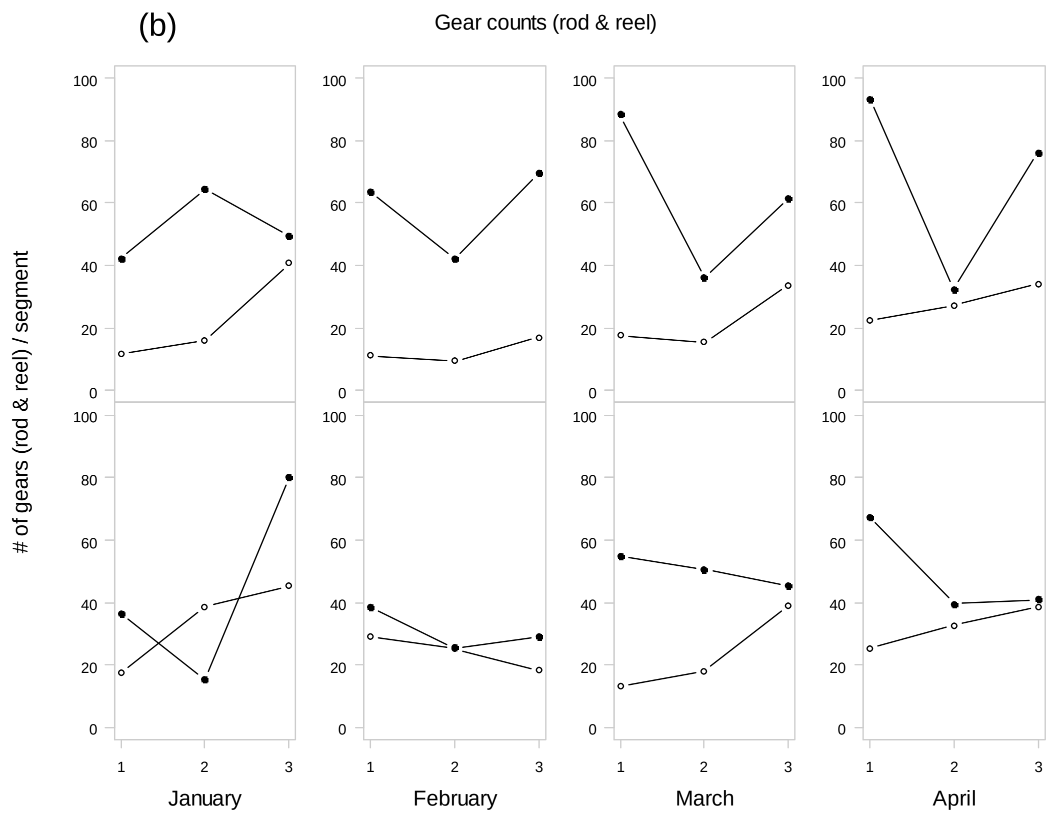

(b)
Gear counts (rod & reel)
# of gears (rod & reel) / segment
100
80
60
40
20
0
1
2
3
January
February
March
April

Fig. 3. Expanded estimates of total gear hours during day (gray bars) and night (black bars) for all households on Oʻahu in January–February 2015.

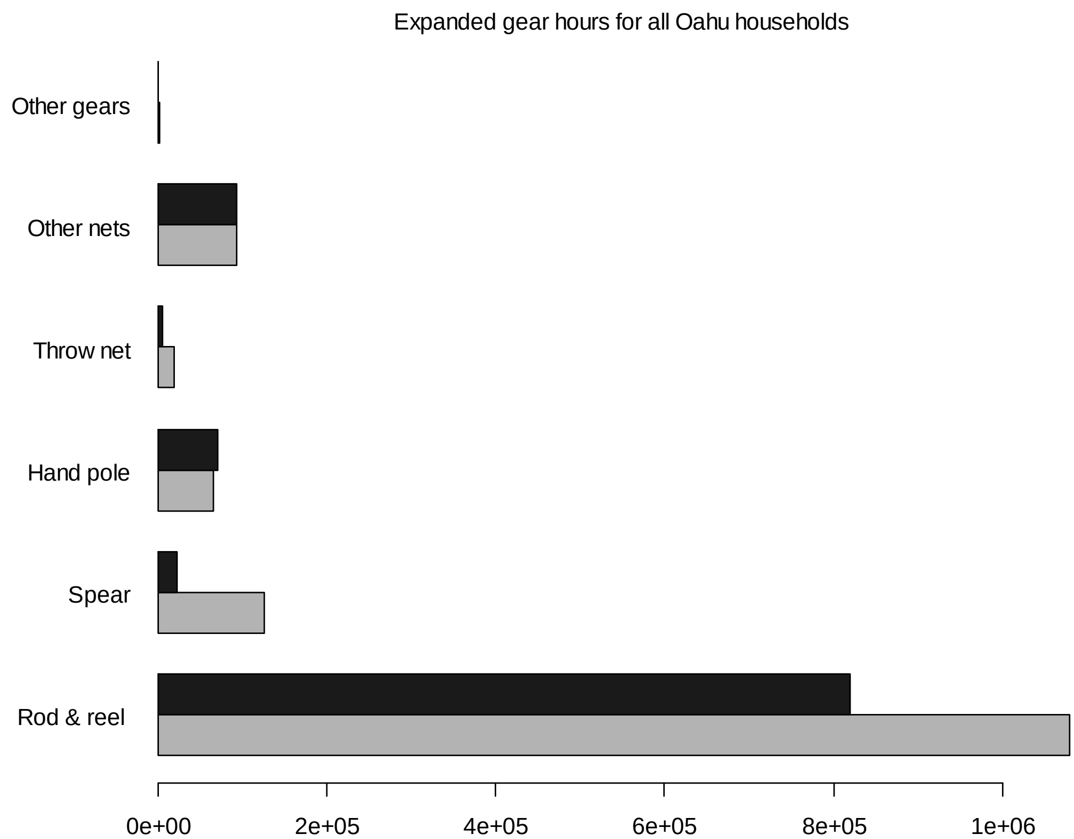


Fig. 4. Catch rates (total catch) for pilot and regular HMRFS surveys on O‘ahu. Error bars show SE for catch rate estimates. Catch rates (and SE) from HMRFS were multiplied by 2.25 (average number of fishers on a vessel trip, based on HMRFS data from O‘ahu) to estimate catch per vessel trip.

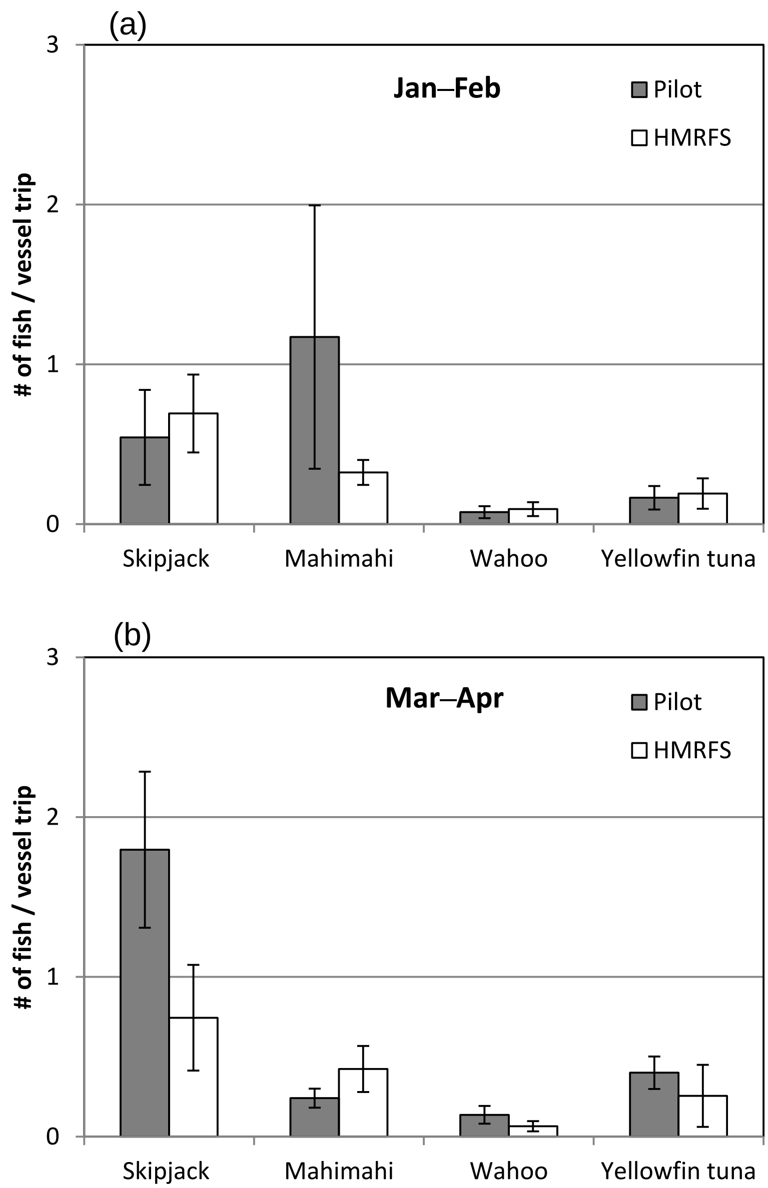


Fig. 5. Expanded vessel trips (SE) from the pilot survey (filled bars) and vessel trips (SE) estimated using CHTS data for O‘ahu in 2015 (open bars).

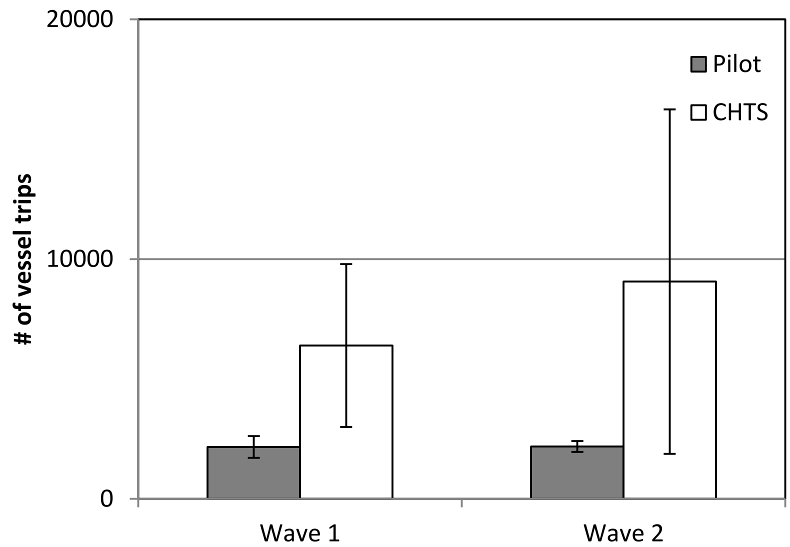


Fig. 6. Estimated total catch (SE) from the pilot survey and HMRFS. Effort estimates from the CHTS were used for catch estimation in both surveys.

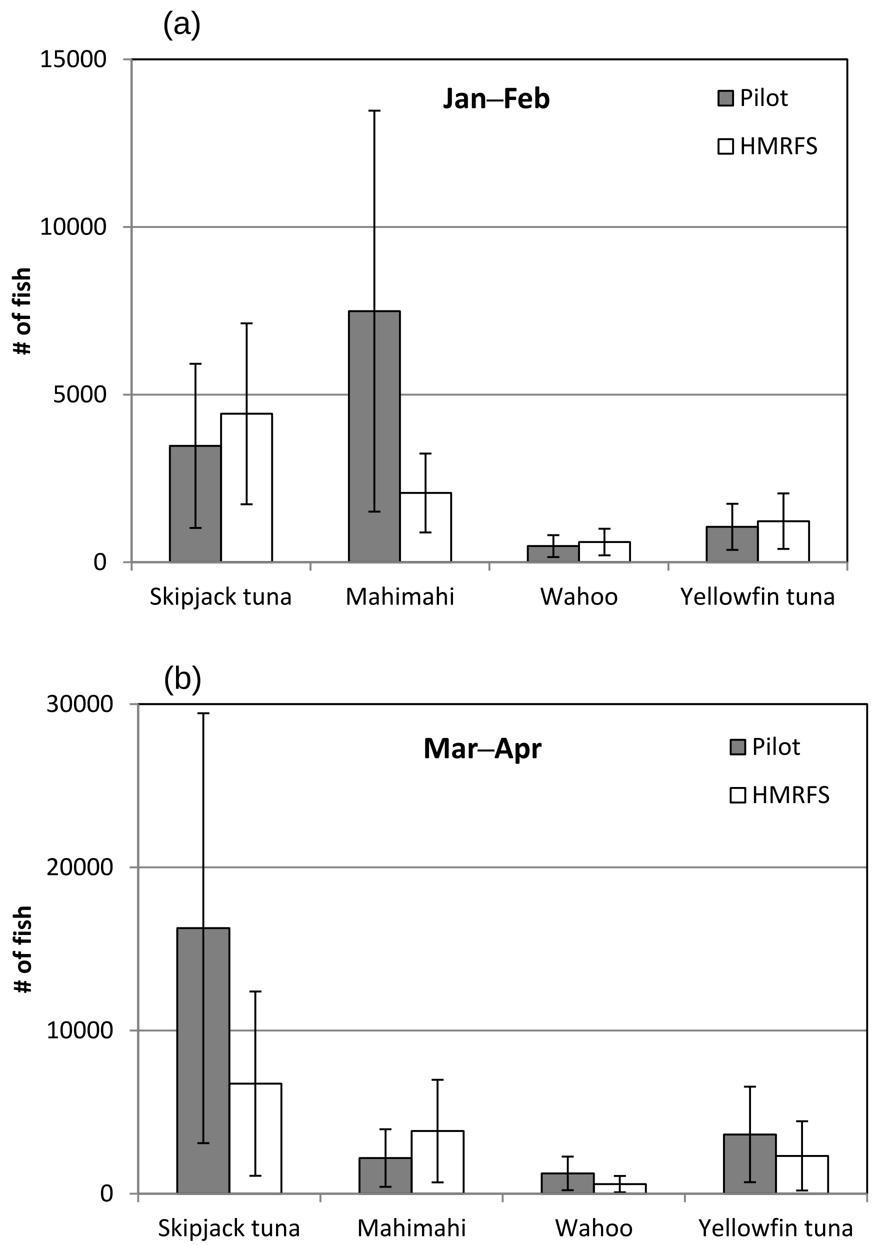
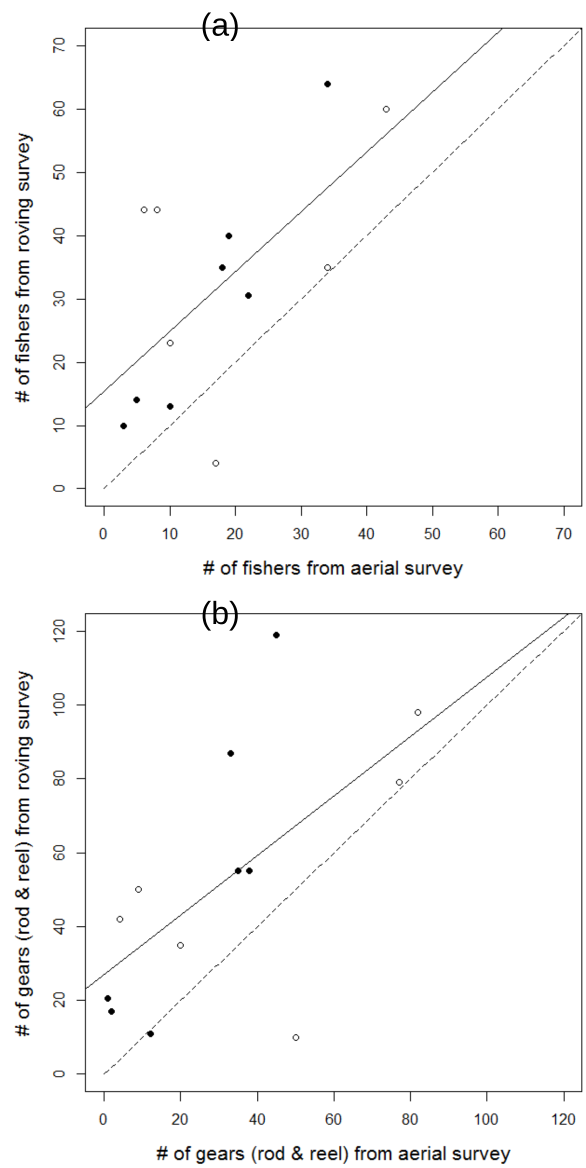
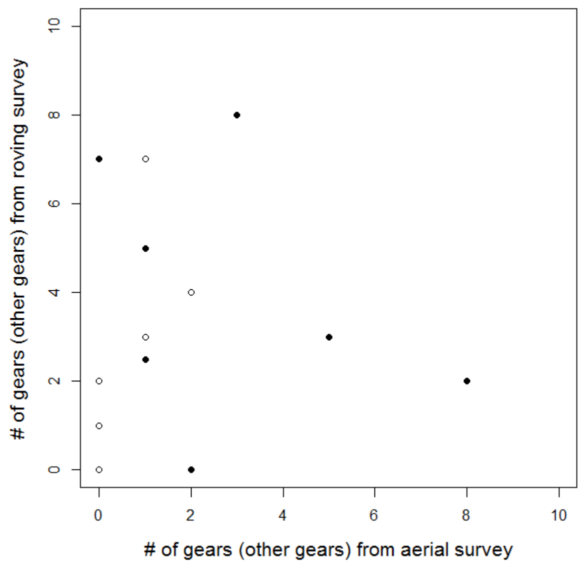


Fig. 7. Fisher (a), rod & reel (b), and other gear (c) counts in individual segments from roving and aerial surveys on the same days. Solid lines are linear fit lines and dashed lines represent where y = x. Filled circles represent counts in the same coastal segments where sample times of roving and aerial surveys overlapped. Other gears include spear, hand pole, throw net, other nets, and other gears.



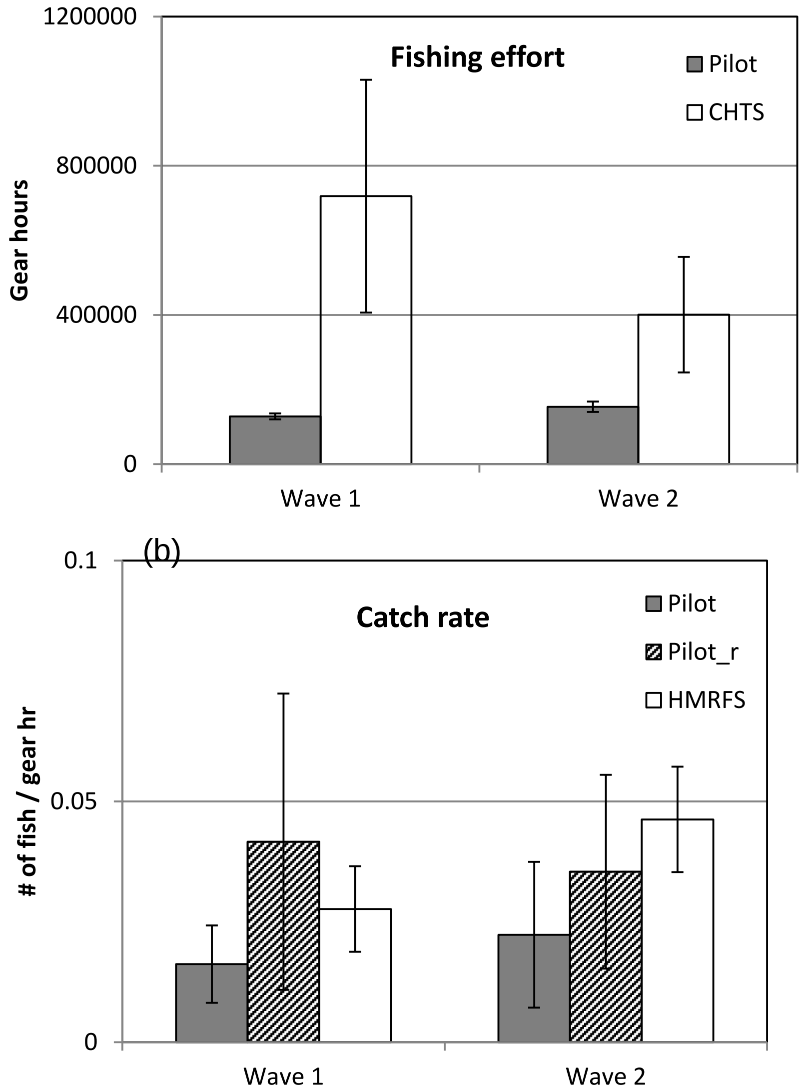
(c)



# of gears (other gears) from roving survey
0
2
4
6
8
10
0
2
4
6
8
10
# of gears (other gears) from aerial survey

Fig. 8. Bluefin trevally catch rate and catch estimates from the roving survey and HMRFS. Error bars show SE. Catch rate and catch estimates using the mean of ratios are represented by hatched bars. For comparison, angler trip estimates from the telephone survey were converted to rod & reel gear hours based on mean gear hours per angler trip from the roving survey. HMRFS catch rate estimates were also converted using the same factor.

(a)



(c)

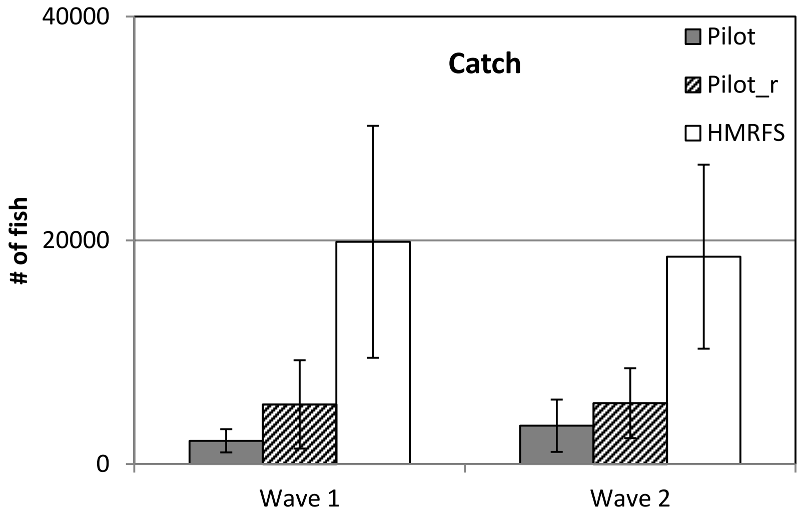

Catch
40000
20000
0
# of fish
Pilot
Pilot_r
HMRFS
Wave 1
Wave 2

Table 1: Sample allocations across 48 strata for each survey type (effort or catch survey) in January–April 2015. There were 9 weekend days and 22 weekdays in January, 8 weekend days and 20 weekdays in February, 9 weekend days and 22 weekdays in March, and 8 weekend days and 22 weekdays in April. The numbers in parentheses for individual strata are the number of possible segment days (3 segments × number of weekdays or weekend days in a month) in the sampling frame.

Shift	**Region**	**Weekend**				**Weekday**			
		January	February	March	April	January	February	March	April
6:30–10:30	Rural	2 (27)	2 (24)	2 (27)	2 (24)	3 (66)	3 (60)	3 (66)	3 (66)
	Urban	2 (27)	2 (24)	2 (27)	2 (24)	3 (66)	3 (60)	3 (66)	3 (66)
10:30–14:30	Rural	2 (27)	2 (24)	2 (27)	2 (24)	3 (66)	3 (60)	3 (66)	3 (66)
	Urban	2 (27)	2 (24)	2 (27)	2 (24)	3 (66)	3 (60)	3 (66)	3 (66)
14:30–18:30	Rural	2 (27)	2 (24)	2 (27)	2 (24)	3 (66)	3 (60)	3 (66)	3 (66)
	Urban	2 (27)	2 (24)	2 (27)	2 (24)	3 (66)	3 (60)	3 (66)	3 (66)

Table 2: Key estimates made for each survey and linkages among different surveys.

Survey	**Estimates**	**Linkages**
Roving effort survey	Gear hours	Gear hours were combined with roving catch rate to estimate catch for shore fishing
Roving catch survey	Catch rate (# of fish / gear hour)	Catch rate was multiplied by effort to get catch estimates
Access point catch survey	Catch rate (# of fish / vessel trip)	Catch rate estimates were combined with vessel trip estimates from CHTS to estimate catch
Mail survey	Proportion of night fishing, proportion of fishing in private/restricted areas, gear hours	Proportions of night fishing and fishing in private/restricted areas represent fishing activity missed in roving survey
Aerial survey	Proportion of gear/fisher counts in different areas, especially in areas not covered by roving survey (during daytime)	Proportion estimates indicate range of roving survey undercoverage during daytime

Table 3: Estimated total gear hours and fisher hours (standard error in parentheses) during daytime in each month from January to April 2015 based on the roving effort survey.

	January	February	March	April
Rod & reel	76,035 (4,722)	52,101 (6457)	72,586 (7,566)	81,188 (11,645)
Spear	4,590 (993)	4,194 (991)	5,201 (1,106)	2,808 (715)
Hand pole	2,464 (616)	1,726 (915)	3,705 (2,125)	3,052 (1,383)
Throw net	1,143 (434)	464 (209)	284 (146)	1,044 (307)
Other nets	88 (88)	190 (163)	669 (360)	164 (83)
Other gears	396 (132)	0 (0)	0 (0)	0 (0)
Fisher	59,528 (4,594)	41,422 (5,232)	55,029 (4,730)	59,874 (8,755)

Table 4: Total catch (number of fish) and catch rate (catch / gear hour) estimates for bluefin trevally, bigeye scad, and bluespine unicornfish based on the roving catch and effort surveys. SE = standard error.

Period	Species	Gear	Catch rate	SE (catch rate)	Catch	SE (catch)
Jan–Feb	Bluefin trevally	Rod & reel	0.0162	0.0080	2,078	1,036
	Bigeye scad	Rod & reel	0.0018	0.0015	235	197
		Hand pole	0.1222	0.0755	512	334
	Bluespine unicornfish	Rod & reel	0.0000	0.0000	0	0
		Spear	0.2760	0.2668	2,425	2,346
Mar–Apr	Bluefin trevally	Rod & reel	0.0223	0.0151	3,429	2,338
	Bigeye scad	Rod & reel	0.0081	0.0043	1,241	669
		Hand pole	0.0831	0.0482	562	368
	Bluespine unicornfish	Rod & reel	0.0026	0.0017	399	265
		Spear	0.0677	0.0697	542	557

Table 5: Number of fishing nights/days and gear nights/days in January–February 2015 from 701 households on O‘ahu. SE = standard error.

	Private & restricted areas	All areas	% Nights/(nights + days) (SE)
Fishing nights	55.0		45.83 (6.58)
Fishing days	65.0		
Total gear nights		238.5	34.79 (4.48)
Total gear days		447.0	
Main gear nights		192.5	33.65 (4.77)
Main gear days		379.5	

Table 6: Number of days, nights, and hours fished for individual gear types from 701 households that responded to the survey. For a fisher, gear hours = # of fishing nights or day by gear type × typical trip length × typical # of each gear used. In spear fishing, only one gear was assumed to be actively used at a time even though a fisher may have several spears available on a trip. SE = standard error.

Gear	Gear nights	Gear days	Gear hours (night)	Gear hours (day)	% Nights (SE)	% Night hours (SE)
Rod & reel	186.5	317.0	1,822.0	2,401.8	37.04 (5.10)	43.14 (4.81)
Spear	8.0	70.0	50.0	282.0	10.26 (5.05)	15.06 (8.72)
Handpole	21.0	25.0	157.0	147.0	45.65 (8.42)	51.64 (11.09)
Thrownet	1.0	9.5	12.0	44.3	9.52 (7.40)	21.33 (9.97)
Other nets	22.0	23.0	206.0	208.0	48.89 (2.13)	49.76 (0.76)
Other gears	0	2.5	0	6.3	0	0

Table 7:Fisher counts (a) and gear counts (b) in "remote" areas (areas not covered by the roving survey) and in "total" areas (areas covered by the aerial survey). The gap between segments A and B is labeled as AB, and EF for the gap between segments E and F. Segments or gaps not covered by the aerial survey or covered less than 50% (shown with *) are listed in the last column. Percentages of fishers and gears in remote areas represent approximations due to variability of coverage in the aerial survey.

(a) Fisher counts

Day	Time	Remote	Total	% Remote	Not covered
Feb 15 (WE)	12:00-13:15	10	157	6.4	E*, EF
Feb 28 (WE)	8:30-10:00	4	63	6.3	C*, CD, EF
Feb 19 (WD)	9:00-10:00	1	5	20.0	C*, CD, D*, E, EF
Feb 27 (WD)	8:40-10:18	6	31	19.2	CD, EF
Mar 23 (WD)	9:40-11:00	3	63	4.8	CD, EF
Mar 29 (WE)	10:00-11:30	1	110	0.9	AB, B, BC, C*, EF
Apr 10 (WD)	11:20-12:41	14	99	14.1	CD, EF
Apr 11 (WE)	8:50-10:20	33	207	15.9	EF

(b) Rod & reel counts (all gears in parentheses)

Day	Time	Remote	Total	% Remote	Not covered
Feb 15 (WE)	12:00-13:15	14 (16)	276 (286)	5.1 (5.6)	E*, EF
Feb 28 (WE)	8:30-10:00	1 (4)	88 (102)	1.1 (3.9)	C*, CD, EF
Feb 19 (WD)	9:00-10:00	1 (1)	12 (12)	8.3 (8.3)	C*, CD, D*, E, EF
Feb 27 (WD)	8:40-10:18	11 (11)	41 (48)	26.8 (22.9)	CD, EF
Mar 23 (WD)	9:40-11:00	4 (4)	83 (97)	4.8 (4.1)	CD, EF
Mar 29 (WE)	10:00-11:30	3 (3)	171 (190)	1.8 (1.6)	AB, B, BC, C*, EF
Apr 10 (WD)	11:20-12:41	50 (50)	265 (268)	18.9 (18.7)	CD, EF
Apr 11 (WE)	8:50-10:20	90 (98)	481 (519)	18.7 (18.9)	EF

Table 8: Relative standard error (= standard error / point estimate) for catch rate estimates from the pilot survey and HMRFS. SE and catch rate estimates are shown in Fig. 4.

Species	**Wave 1**		**Wave 2**	
	Pilot	HMRFS	Pilot	HMRFS
Skipjack tuna	0.5475	0.3523	0.2719	0.4447
Mahimahi	0.7037	0.2414	0.2483	0.3392
Wahoo	0.4978	0.4608	0.4079	0.4926
Yellowfin tuna	0.4461	0.4952	0.2535	0.7612