Non-commercial Catch Estimation for Deep7 Bottomfish in the Main Hawaiian Islands

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Abstract
Survey data and catch estimates in 2003–2022 from the Hawaii Marine Recreational Fishing Survey (HMRFS) were evaluated to obtain non-commercial catch weight estimates for the main Hawaiian Islands Deep7 bottomfish complex. The current HMRFS estimates do not distinguish between catch to be sold vs. catch not for sale from expense fishers (who sometimes sell fish to cover fishing expenses) or part-time commercial fishers. Fishers selling the catch are required to report the number of fish and weight landed in a commercial reporting system. To provide a non-commercial catch estimate (product of catch rate and fishing effort), catch claimed as unsold in HMRFS was used for catch rate estimation. The catch rate estimates were smoothed by a Kalman filter to reduce unrealistically large fluctuations in annual catch estimates. Fishing effort estimates from a previous telephone survey were adjusted to make the effort estimates similar to the current mail survey for fishing effort. The non-commercial catch estimates from this study will be used in combination with the reported catch from the mandatory commercial fishing reports to obtain total fish removal for the Deep7 bottomfish stock assessment.

Key Words: Hawaii Marine Recreational Fishing Survey (HMRFS), Deep7 bottomfish, non-commercial catch, fishing effort, catch rate, stock assessment

1. Introduction

The bottomfish fishery in the main Hawaiian Islands (MHI) targets snappers and groupers that inhabit deep slopes and banks at depths of 50–200 fathoms. Seven of these bottomfish species, collectively called Deep7 bottomfish, are culturally and economically important. This group includes 1 grouper, hapuupuu (*Hyporthodus quernus*), and 6 snappers: opakapaka (*Pristipomoides filamentosus*), onaga (*Etelis coruscans*), ehu (*Etelis carbunculus*), lehi (*Aphareus rutilans*), gindai (*Pristipomoides zonatus*), and kalekale (*Pristipomoides sieboldii*). In Hawaii, the U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries, Pacific Islands Fisheries Science Center (PIFSC) is responsible for conducting stock assessments of the Deep7 bottomfish complex, providing information on resource status relative to the management reference points (Moffitt et al., 2006; Brodziak et al., 2011; Brodziak et al., 2014; Langseth et al., 2018; Syslo et al., 2021). The Western Pacific Regional Fishery Management Council uses the stock assessment results to recommend an annual catch limit (ACL) for approval by NOAA Fisheries.

The state of Hawaii does not currently require a saltwater fishing license or registration for most recreational/non-commercial fishers. There is a federal permit requirement for non-commercial bottomfishing in federal water. Still, only a few fishers apply for permits every

year because they may opt instead for the state's commercial marine license ($100 annual license fee), which does not impose any bag limits. Non-commercial fishers in Hawaii have a bag limit of five pieces per day for all Deep7 bottomfish species combined. Non-commercial fishing could include recreational fishing, subsistence fishing, fishing for cultural practice, or other non-commercial purposes (e.g., Leong et al., 2020). A recent Hawaii bottomfish heritage project highlighted factors leading to cultural identity, including motivations for bottomfishing, the practice of giving away fish, and concerns about the public perception of fishers (Calhoun et al., 2020). Giving away fish was referenced by most participants as a predominant fishing motivation. Currently, there are virtually no catch reports for non-commercial bottomfishing. Recent stock assessments have used adjustment ratios to account for catches not included in the commercial fishing reports (Courtney and Brodziak, 2011).

1.1 Hawaii Marine Recreational Fishing Survey (HMRFS)

The Hawaii Marine Recreational Fishing Survey (HMRFS) was initiated in the early 2000s to estimate the total statewide recreational catch (weight and numbers) and number of recreational fishing trips (Ma and Ogawa, 2016). The HMRFS surveys consist of an on-site access point angler intercept survey for catch rate (catch number per angler trip) and an off-site survey (telephone or mail) for fishing effort (angler trips). The intercept survey collects angler, trip, and catch number information (and sometimes weight and length) via in-person interviews with fishers at accessible locations statewide (shoreline, boat ramps, etc.). The effort survey used the Coastal Household Telephone Survey (CHTS) prior to 2018. The CHTS was carried out in 2-week periods starting from the last week of a wave (from wave 1 (January–February) to wave 6 (November–December)) and continuing in the first week of the following wave to collect fishing effort data during the 2-month period prior to the phone call. The data collected in the telephone survey included household, angler, and trip information, such as fishing mode (shore fishing vs. boat fishing), fishing methods/gears, state/county of a trip, and fishing trip date. The effort survey was replaced by the Fishing Effort Survey (FES, a mail survey) in 2018. The mail survey includes an initial survey mailing, a follow-up reminder (postcard), and a final follow-up mailing. Fishing data are collected from all household members.

HMRFS does not concentrate on any particular fishery, and the survey covers pelagic, coral reef fish, bottomfish, and other finfish fisheries but not invertebrates. Based on an analysis by Ma and Ogawa (2016), more than 70% of the boat fishing trips surveyed by HMRFS used the trolling method to catch pelagic species. Bottomfish, which are caught primarily off boats using bottom line gear, and other fisheries were encountered less often during the boat-based surveys.

1.2 Commercial Marine Licence and Commercial Fishing Report

Fishers in Hawaii are required to register their vessels annually if they plan to catch any of the Deep7 bottomfish species regardless of whether they are commercial or non-commercial fishers. Individuals or vessels taking, selling, or offering for sale any marine life for commercial purposes must obtain a Commercial Marine License (CML). Every CML licensee must submit a monthly report (http://dlnr.hawaii.gov/dar/fishing/commercial-fishing/). Since September 2011, CML holders who land at least one Deep7 bottomfish have been required to submit a trip report within five days of the trip end date. Based on the recent bottomfish vessel registrants, a majority of the bottomfishers possess a CML (personal communications, J. Helyer, Hawaii Division of Aquatic Resources).

In the HMRFS catch records from intercept surveys, a significant proportion of the Deep7 bottomfish catch was claimed to be sold. Therefore, total catch estimates from HMRFS can overlap with the catch from the CML fishing reports. Current HMRFS total estimates do not distinguish the proportion of catch claimed for sale by the interviewed fishers. This paper defines the proportion of total catch estimates from HMRFS that were not claimed to be sold by fishers as non-commercial catch. The main objective of this study is to separate the proportion of sold catch in the survey data to estimate non-commercial catch weight more accurately. The non-sold catch rate is then smoothed to reduce fluctuations in annual catch estimates. These non-commercial catch weight estimates are combined with the reported commercial catch to define the total fishing removal for the ongoing stock assessment. The non-commercial catch estimation method developed in this contribution can also be applied to HMRFS catch estimates for pelagic species, coral reef fish, and other bottomfish.

2. Methods

2.1 Catch and Effort Estimation

HMRFS is part of the NOAA Fisheries Marine Recreational Information Program (https://www.st.nmfs.noaa.gov/recreational-fisheries/MRIP/). During the HMRFS intercept survey, the catch reported by a fisher (catch numbers only) but not examined by a surveyor is called unavailable catch. The catch examined by the surveyor and measured for length and weight is defined as available catch. Available and unavailable catches are computed separately when estimating the catch rate. Both catch rate (based on onsite intercept surveys) and fishing effort (based on telephone surveys before 2018 or mail surveys beginning in 2018) are estimated for each wave in a year (wave 1 through wave 6), separated by fishing mode (shore fishing or boat fishing, without further separation by fishing gear/method). Catch is calculated as the product of catch rate and fishing effort; catch number is estimated first, and catch weight is calculated as the product of catch number and mean weight in a wave (see Ma and Ogawa, 2016 for more details on HMRFS sampling and estimation). The variance of a product of two independent random variables $var(x \times y)$ is estimated by $x^2 \times var(y) + y^2 \times var(x) - var(x) \times var(y)$ (Goodman, 1960).

2.2 Data Used

Records for available and unavailable catch as well as the catch estimate files for the Deep7 bottomfish species from HMRFS (2003–2022) were queried, downloaded, or requested from the NOAA Fisheries Marine Recreational Information Program (https://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/queries/index). Catch estimates from 2003–2010 were adjusted by 82% (= 1/1.22) to account for an error in the population household count for Maui County identified in 2010 (Ma, 2013). The reported commercial catch summary came from fishing reports submitted by CML holders to the Hawaii Division of Aquatic Resources (DAR). The fishing reports include, among other fields, day fished, DAR fishing grid area, species name, number of fish landed, and pounds landed. The reported commercial catch of Deep7 bottomfish in 2003–2022 was queried from fishing areas within the MHI.

2.3 Data Analyses

For available catch records containing length measurements only (i.e., fish were not weighed), the length and weight relationships established by Ault et al. (2018) for the MHI Deep7 bottomfish were used to estimate the weight. The length (L)-weight (W) relationship of a fish is often described by the allometric growth model, $W = \alpha L^{\beta}$ where α and β can be estimated through linear or non-linear regressions (e.g., Quinn and Deriso, 1999). The

mean weight for a species was estimated by the overall mean of the directly measured weights and additional length-based weights (derived from the length-weight relationship) from 2003–2022. The mean weight for individual years or waves was not estimated due to a limited number of weight samples.

The catch dispositions for Deep7 bottomfish from available and unavailable catch records only included "sold/plan to sell" and "eaten/plan to eat" (see the intercept survey form for all dispositions at http://dlnr.hawaii.gov/dar/files/2014/05/hmrfs_int_surv_form.pdf). Only non-sold catch was included for catch rate estimation. The catch rates for available catch and unavailable catch were estimated separately and are additive. The combined catch rate estimates (including available and unavailable catch) from boat fishing at a wave level were then smoothed using the Kalman filter and smoother function "KFS" in the KFAS package (Helske, 2017). The ratio of the observation error variance to the process error variance was chosen based on explorative analyses. When the variance ratio between observation error and process error was 1, the smoothed catch rate estimates from the KFAS package were not sensitive to the exact variance value provided. The smoothed catch rates with a higher ratio for the variances of observation error vs. process error were also explored for sensitivity analyses. The catch number estimate is the product of smoothed catch rate and the fishing effort estimate. An overall mean weight (based on weight measurements and length-derived weights from 2003–2022) was used to estimate catch weights from annual catch number estimates.

Fishing effort estimates before 2018 were based on a previous Coastal Household Telephone Survey (CHTS) that contacted households with landline telephones. A pilot mail survey was conducted in Hawaii in 2017 side-by-side with the CHTS; and the Fishing Effort Survey (FES, a mail survey) has been used since 2018. The annual boat fishing effort estimate from the pilot mail survey was 2.33 times the estimate from CHTS. Boat-fishing effort estimates from CHTS decreased from 2003–2017, likely caused by the progressive decrease in survey coverage and survey response. A linear multiplier was developed to calibrate fishing effort estimates from the telephone survey to make the calibrated estimates comparable with the estimates from the current FES. Before 2000, under-coverage in CHTS due to cellphone-only households was negligible and the phone survey response rate was similar to the current FES (personal communications, R. Andrews, NOAA Fisheries Office of Science and Technology). The multiplier's value was set to be 1 in 1999 (immediately before 2000), and its value increased linearly from 1 to 2.33 between 1999 and 2017.

The effort estimates from CHTS in other states on the U.S. East Coast and along the Gulf of Mexico have been calibrated by the NOAA Fisheries Marine Recreational Information Program (**https://www.fisheries.noaa.gov/event/fishing-effort-survey-calibration-model-peer-review**). The ratios of the calibrated estimates to the original phone survey estimates in these states from individual years were used to construct alternative multipliers for sensitivity analyses. One of the alternative multipliers had two anchor points, one in 2003 and the other in 2017. This multiplier's values in 2004–2016 were linearly interpolated. The multiplier's value in 2017 was still 2.33. The multiplier's value in 2003 was 1.56 based on the average ratio (0.67) of the calibration multiplier in 2003 to the multiplier in 2017 from 16 other states. The other alternative multiplier had one anchor point for each year from 2003–2017. The anchor point in 2017 had a value of 2.33. The anchor point value in another year (other than 2017) was based on the ratio of the calibrated

effort estimate to the original phone survey estimate in that year, relative to the ratio in 2017.

3. Results

3.1 Total HMRFS Catch Number Estimates and Catch by Disposition (2003-2022)

Among the Deep7 species, opakapaka had the highest total catch (i.e., sold and unsold dispositions combined) (Figure 1). Onaga, ehu, and kalekale had intermediate annual catches. Each species had large fluctuations among the total annual catch estimates. Significant proportions (30–50%) of catches were claimed to be sold for opakapaka, onaga, ehu, and kalekale, the species with the highest catches (Figure 1 and Table 1). For most species, the non-commercial catch estimates (excluding sold catch) did not fluctuate as much as the total catch.

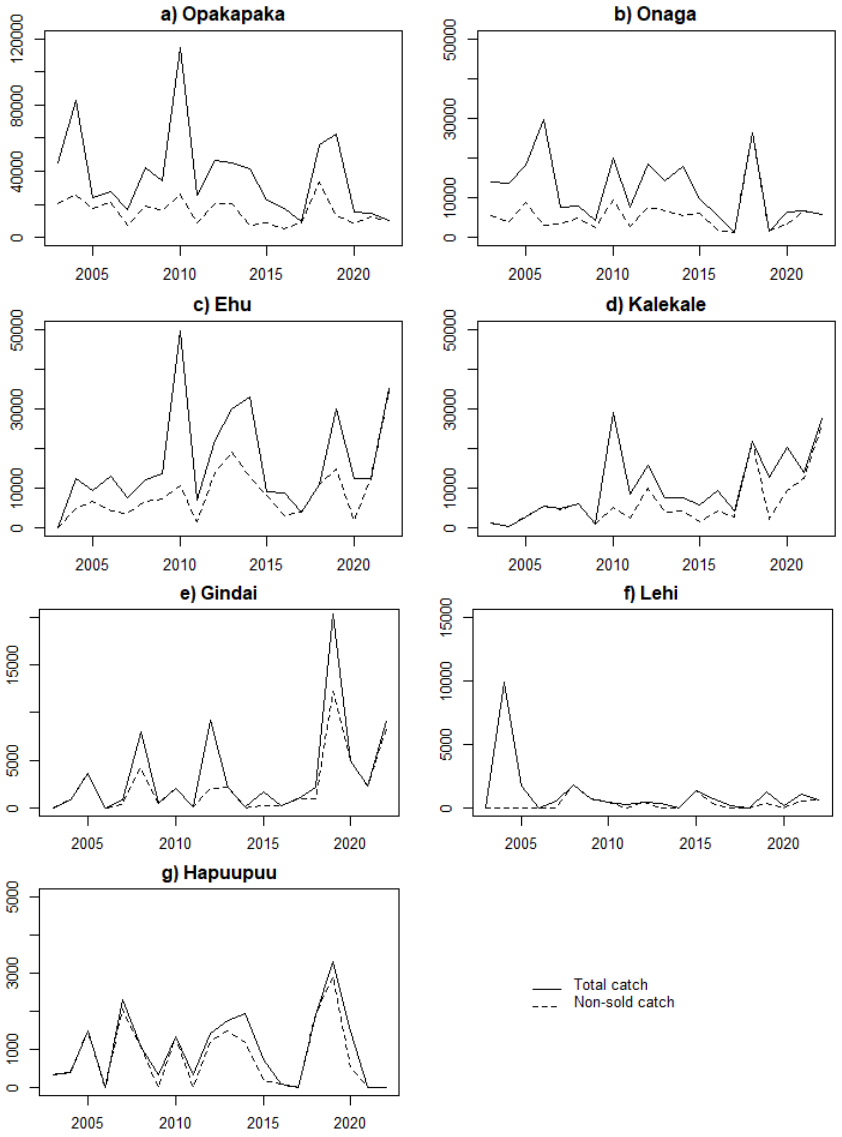


Figure 1: Total catch (solid line) and non-sold catch (dashed line) estimates (in numbers) during 2003–2022.

Table 1: Percent of catch numbers with disposition "sold/plan to sell" (62 = 62%). Blank cells indicate zero total catch.

Year	*Hapuupuu*	*Onaga*	*Ehu*	*Opakapaka*	*Kalekale*	*Lehi*	*Gindai*
2003	0	60		55	0		
2004	0	71	61	69	0	100	0
2005	0	51	31	27	0	100	0
2006		89	68	23	0		
2007	11	55	53	55	5	100	60
2008	0	38	45	56	0	0	47
2009	100	44	46	54	0	0	0
2010	0	53	79	78	82	0	0
2011	100	62	77	65	71	100	0
2012	15	59	37	57	37	0	78
2013	16	54	37	55	49	100	0
2014	40	69	62	83	45		100
2015	74	39	10	61	75	0	82
2016	0	66	64	69	56	43	0
2017		0	0	12	38	100	0
2018	0	0	0	41	0		54
2019	12	0	51	79	83	68	40
2020	63	45	84	41	54	100	0
2021		0	0	15	11	50	0
2022		0	3	0	7	0	8
All years	27	43	43	50	31	54	26

3.2 Fishing Effort Estimates

There was a decreasing trend in the original fishing effort estimates from the telephone survey during 2003–2017 ("Original" in Figure 2(b)). A linear multiplier adjusted the original phone survey estimates. The multiplier's value linearly increased from 1 to 2.33 between 1999 and 2017 (Figure 2(a)). The calibrated fishing effort estimates varied from 400,000 to 900,000 angler trips annually ("Baseline" in Figure 2(b)).

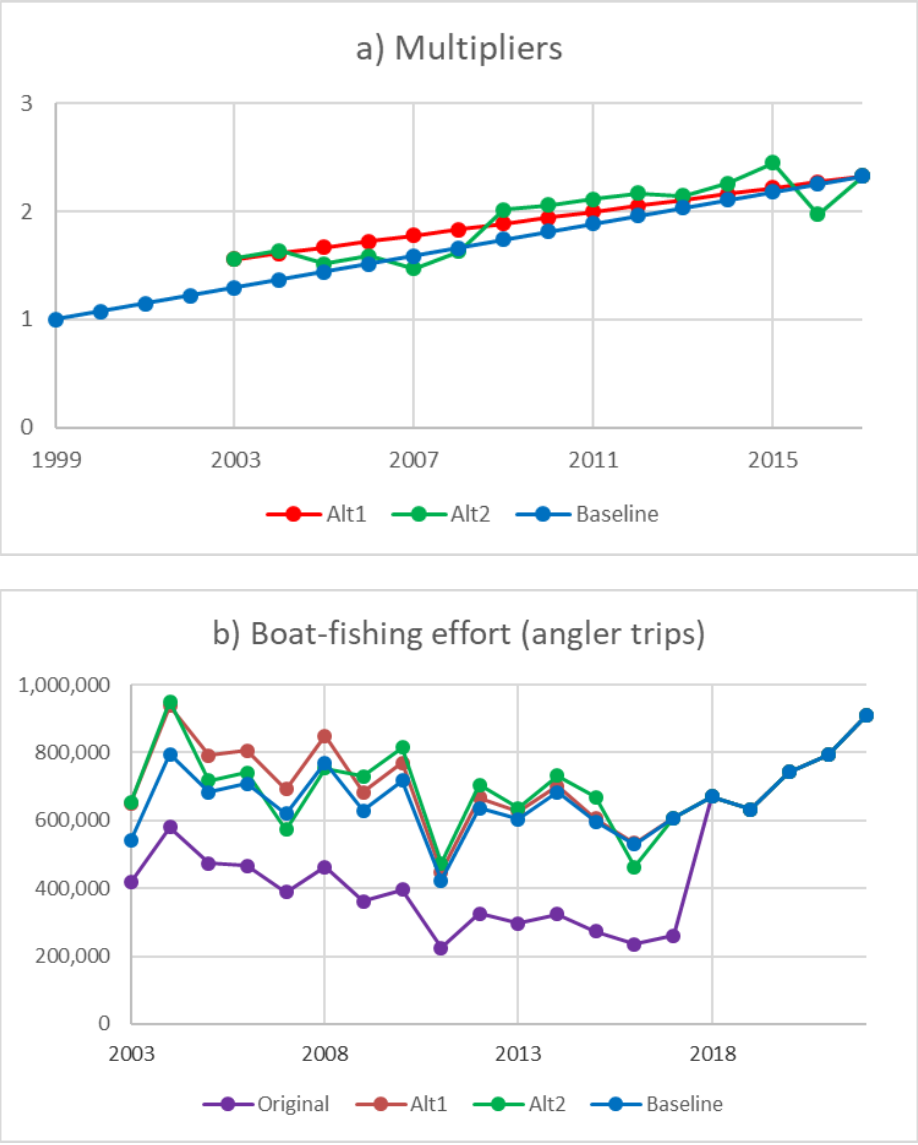


Figure 2: Values for the baseline and two alternative multipliers (a) and fishing effort estimates from private boat fishing in 2003–2022 (b). The estimates during 2003–2017 were based on a telephone survey, which was replaced by a mail survey in 2018. The original fishing effort estimates during 2003–2017 ("Original") were adjusted by a baseline multiplier and by two alternative multipliers ("Alt1" and "Alt2").

Two alternative multipliers were constructed based on the calibrated results from 16 other states on the U.S. East Coast and along the Gulf of Mexico. One of the alternatives had two anchor points; the other had multiple anchor points. The adjusted effort estimates using alternative multipliers were slightly larger at the beginning of 2003–2017, and the differences decreased toward 2017 (Figure 2(b)). Differences among various multipliers were small relative to each multiplier's divergence from the original estimate.

3.3 Non-commercial Catch Weight Estimates

Opakapaka had the highest catch weight estimates, followed by onaga and ehu (Figure 3). The highest annual catch estimates for onaga, kalekale, gindai, and lehi were moderately

reduced in the smoothed catch estimates. There were only minor changes in the smoothed catch for the other three species. A moderate smoother was used to preserve the seasonal pattern in the proportion of bottom fishing trips in the intercept survey data. The non-commercial catch weight estimates averaged across years were similar to or larger than the reported commercial catch (Figure 3), with the ratios varying from 0.71 to 2.03 (Table 2).

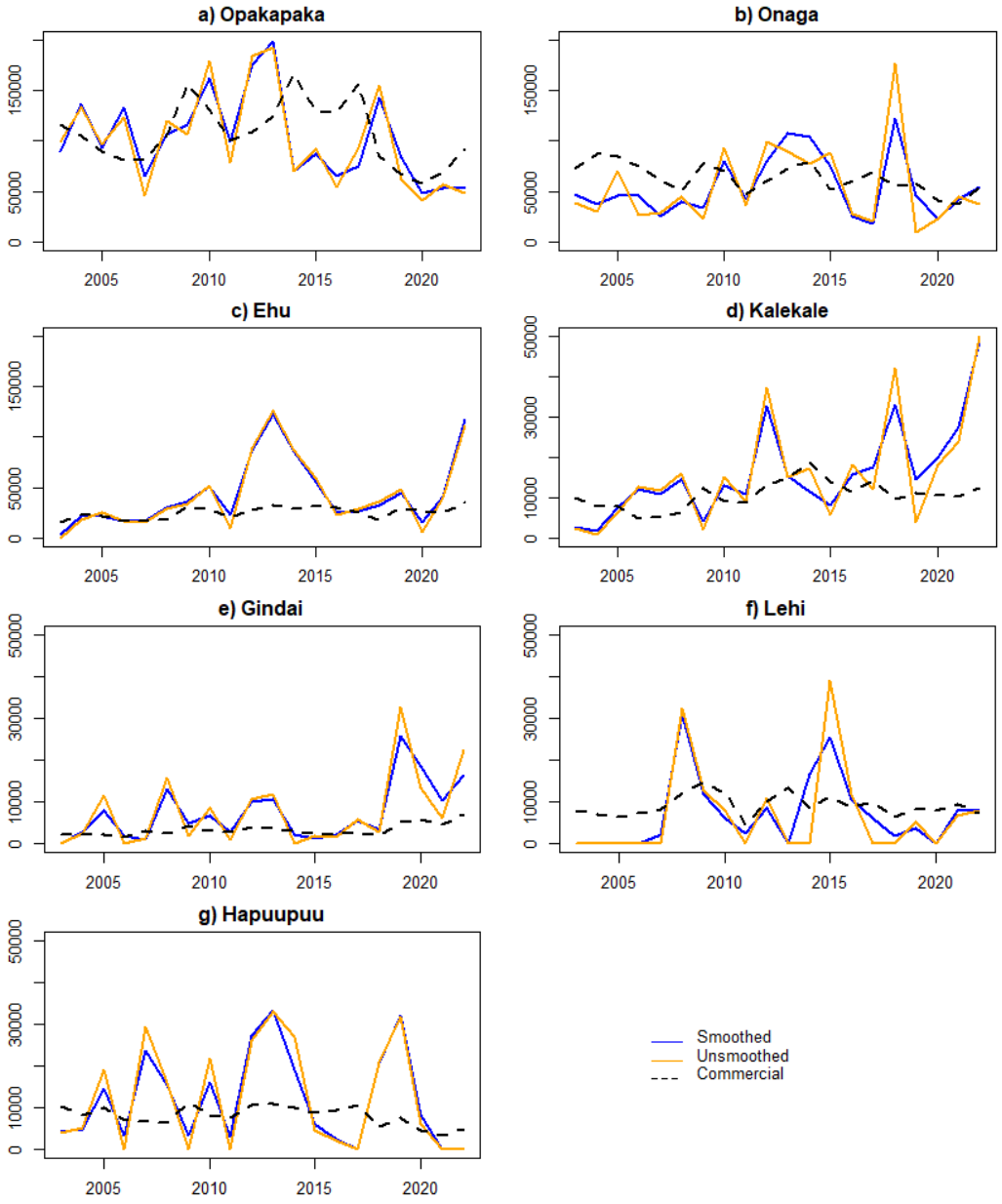


Figure 3: Non-commercial catch weight estimates (lb). Catch estimates with smoothed catch rates are shown in blue, and unsmoothed catch estimates are in orange. Reported commercial catches (dashed lines) are included for comparison.

Table 2: Ratios of non-commercial catch (smoothed) to the reported commercial catch.

Year	*Hapuupuu*	*Onaga*	*Ehu*	*Opakapaka*	*Kalekale*	*Lehi*	*Gindai*
2003	0.41	0.65	0.27	0.77	0.28	0.00	0.00
2004	0.59	0.43	0.92	1.31	0.21	0.00	1.31
2005	1.45	0.54	0.98	1.05	0.97	0.00	3.83
2006	0.48	0.61	0.95	1.63	2.42	0.00	1.33
2007	3.52	0.41	1.00	0.80	2.09	0.27	0.34
2008	2.44	0.78	1.69	1.01	2.24	2.57	5.13
2009	0.31	0.43	1.13	0.75	0.33	0.83	1.12
2010	1.96	1.13	1.87	1.24	1.44	0.50	2.13
2011	0.38	0.91	1.11	0.99	1.26	0.52	1.03
2012	2.54	1.31	3.10	1.61	2.46	0.84	2.60
2013	3.06	1.49	3.78	1.60	1.04	0.00	2.86
2014	1.93	1.31	3.03	0.42	0.61	1.95	0.71
2015	0.69	1.43	1.77	0.68	0.58	2.25	0.51
2016	0.27	0.41	0.83	0.51	1.36	1.24	0.88
2017	0.01	0.26	1.04	0.48	1.22	0.61	2.08
2018	3.75	2.20	1.82	1.68	3.40	0.27	1.91
2019	4.30	0.78	1.48	1.25	1.29	0.45	5.02
2020	1.80	0.55	0.57	0.82	1.88	0.01	3.17
2021	0.01	1.11	1.63	0.77	2.66	0.83	2.18
2022	0.00	0.99	3.37	0.60	3.96	1.09	2.37
All years	1.50	0.89	1.62	1.00	1.59	0.71	2.03

4. Discussion

4.1 Non-commercial Catch, Recreational Catch, and Unreported Catch

This paper's main purpose was to produce the non-commercial catch estimates to be combined with the reported commercial catch to obtain total fish removal for the Deep7 bottomfish stock assessment. The HMRFS survey data show no way to distinguish catch from the Commercial Marine License (CML) holders and non-CML fishers. The term "non-commercial catch" was used in this paper to indicate the HMRFS catch not claimed to be sold by the fishers, intended to represent the catch not captured in the commercial fishing reports. Courtney and Brodziak (2011) used "unreported catch," and Martell et al. (2011) used "recreational catch" for similar purposes.

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) defines commercial fishing as fishing in which the fish harvested are intended to enter commerce or enter commerce through sale, barter, or trade and recreational fishing as fishing for sport or pleasure (16 U.S.C. § 1802). In the Pacific Island Region, the term "non-commercial" has been adopted to describe fishing that is not considered commercial but does not fit within the MSA definition of recreational fishing (Leong et al., 2020). As an umbrella term, non-commercial fishing can include fishing for food, cultural practice, and fun (Leong et al., 2020).

Under the State of Hawaii fishing regulations, individuals or vessels engaged in taking, selling, or offering for sale any marine life for commercial purposes must obtain a Commercial Marine License (CML). Commercial purpose means taking marine life for profit or gain or as a means of livelihood. Every commercial marine licensee shall furnish a monthly report concerning marine life taken. In Hawaii, many fishers do not consider themselves commercial fishers when they only periodically sell their catch to cover fishing expenses (Hospital et al., 2011; Chan, 2023). They were often defined as recreational expense fishers (e.g., Allen and Bartlett, 2008) or expense fishers (Hamilton, 1998). Commercial fishers are generally regarded as those who sell fish to pay for living expenses (income). Pure recreational fishers never sell any of their catch. Commercial fishers in Hawaii must have a CML. Recreational expense fishers may have a CML (when they sell their catch) and report the sold catch in the commercial fishing reports. In a survey by Hospital and Beavers (2012, 2014), many bottomfishing CML holders identified themselves as recreational (36%) or subsistence (14%) fishers. The Marine Fisheries Advisory Committee (MAFAC) Recreational Fishing Working Group (2014) defined subsistence fishing as "… fishing in which the fish or marine resources harvested from waters customarily fished by that community are intended for personal, family, or community consumption or traditional uses through sharing or customary exchanges" (cited in Leong et al., 2020). A recent survey of the Hawaii small boat fishery (with fishers holding a CML) showed that recreational expense was most identified as the primary fishing motivation (34%, Chan, 2023). "Subsistence" and "purely recreational" were selected by 16% and 8% of the fishers, respectively as their primary motivation. Therefore, the terms "commercial" and "non-commercial" are not clearly distinguished in Hawaii.

4.2 Non-sold Catch Estimates and Catch Rate Smoothing

Catch interviews from self-declared full-time commercial fishers are not included for catch rate estimation in HMRFS (Ma and Ogawa, 2016; Ma et al., 2018). Still, significant proportions (30–50%) of catches of opakapaka, onaga, ehu, and kalekale, the species with the highest catches, were claimed to be sold in HMRFS (Figure 1 and Table 1). If the sold catches were not excluded, the total HMRFS catch estimates would be 2.3 times the reported commercial catch for Deep7 bottomfish during 2003–2022 (Figure 4). When only non-sold catch was included, the catch estimates from HMRFS were, on average, equal to the reported commercial catch. The differences between the total HMRFS catch and non-sold catch estimates (orange line vs. blue line in Figure 4) represent the contribution of sold-catch (in the survey data) in the catch estimates. Such differences were insignificant in some years (e.g., 2017, 2021, and 2022) but were very significant in other years (> 2 times the reported commercial catches in 2004, 2010, 2012, and 2014). In 2008, 2015, and 2016, the differences were almost identical to the reported commercial catches. The large fluctuations in HMRFS sold catch estimates were likely due to the variation in the number of commercial fishers and the kind of catch (sold vs. non-sold) declared by the fishers in the survey each year.

Commercial fishing reports from 1948–2002 included fields of pounds caught and pounds sold, and annual totals for pounds caught and pounds sold were similar during this period (differed by < 5% on average; Yau, 2018). In 2000, the Hawaii Division of Aquatic Resources began to collect sales data directly from commercial fish dealers, which captures the sold portion of the commercial catch. Under this program, fish dealers must submit a Commercial Marine Dealer's Report each month. Since 2002, sold catch is no longer collected in the monthly commercial fishing reports. Fishers have reported more fish in their commercial fishing report (as landed, including unsold catch) by weight than reported by dealers because managers and scientists have emphasized the importance of reporting

all catch to the fishing community in recent years. Since 2015, fishers (with CML) have reported, on average, 10% more Deep7 bottomfish by weight than dealers report. The non-sold catch estimates from this study may still have some overlap with the catch in the commercial fishing reports. Considering the amount of sold catch removed from the total HMRFS catch estimates (Figure 4) and the 10% difference between the reported commercial catch versus the catch in the dealers' report, the additional overlap will likely to be minor.

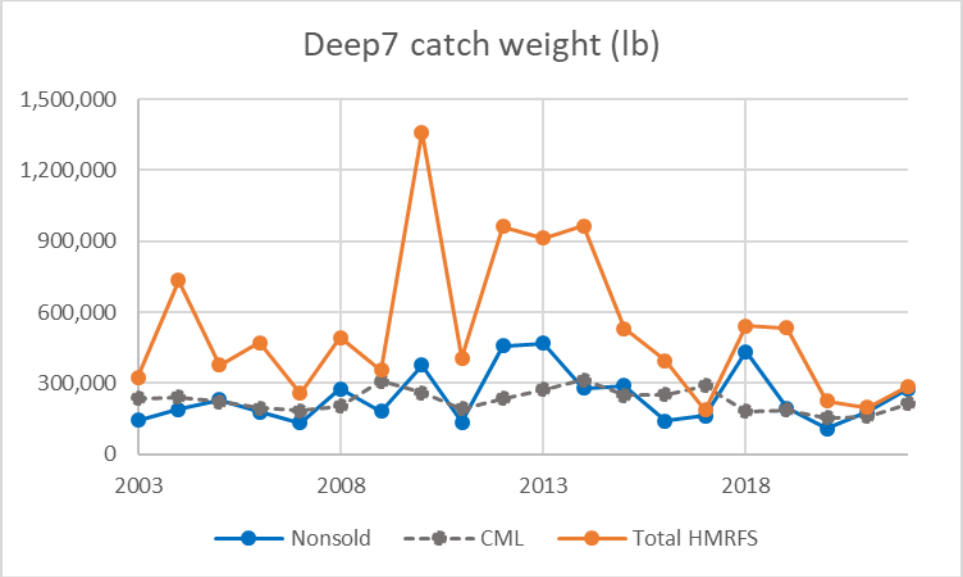


Figure 4: Total catch estimates of Deep7 bottomfish (lb) from HMRFS ("Total HMRFS") and the catch estimates when catch with disposition "to be sold" was excluded ("Nonsold"). Reported commercial catches ("CML") are included for comparison.

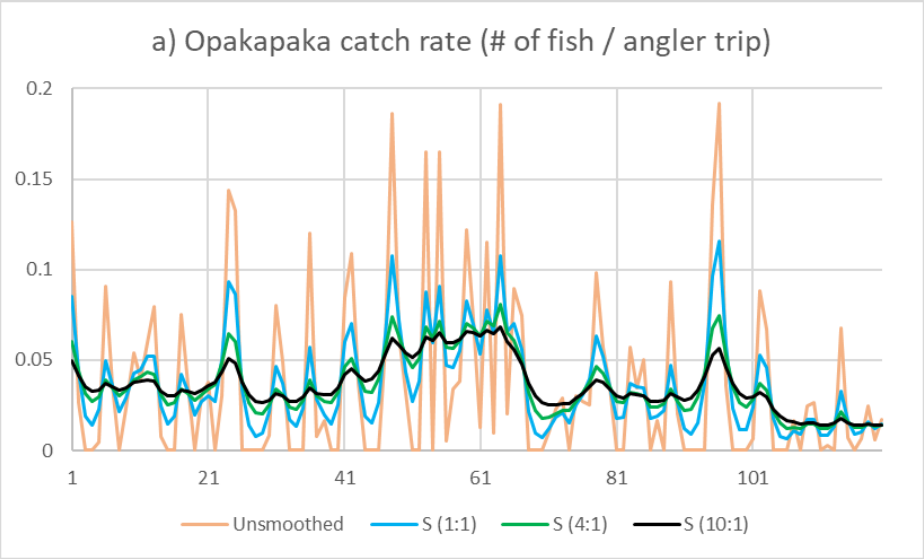
At a species level, annual non-commercial catch estimates were not precise and the percent standard error (PSE) was greater than 30% (Table 3). The PSE for hapuupuu, kalekale, lehi, and gindai was mostly greater than 50%, not meeting the recreational fishing survey and data standards established by MRIP. For Deep7 as a group, the PSE for annual catch weight estimates was less than 30% for most years from 2003–2022.

Table 3: Percent standard error (PSE) for non-commercial catch number estimates. Blank cells indicate zero catch.

Year	*Hapuupuu*	*Onaga*	*Ehu*	*Opakapaka*	*Kalekale*	*Lehi*	*Gindai*
2003	98	70		40	71		
2004	99	53	57	35	100		99
2005	81	40	44	41	77		81
2006		67	57	61	70		
2007	71	72	70	68	77		100
2008	72	53	56	40	49	100	100
2009		49	45	34	67	99	77
2010	72	50	48	43	92	100	65
2011		48	53	42	54		100

Year	*Hapuupuu*	*Onaga*	*Ehu*	*Opakapaka*	*Kalekale*	*Lehi*	*Gindai*
2012	41	55	34	33	36	100	45
2013	44	35	29	30	49		54
2014	77	52	72	54	100		
2015	100	52	42	37	69	56	100
2016	100	45	38	40	56	101	71
2017		63	45	41	68		43
2018	52	43	55	39	41		73
2019	40	99	42	50	62	100	56
2020	73	66	50	53	54		43
2021		42	43	45	44	100	43
2022		56	45	45	44	100	53

Varying levels of the variance ratio for observation errors to process errors were explored (from 1 to 10) to smooth the catch rate estimates. The stronger smoothers (ratios of 4 and 10) resulted in minor additional changes in annual catch estimates when compared to the moderate smoother (Figure 5(b) and Figure 5(c)). However, a ratio of 1 (moderate smoother) was chosen as the baseline smoother to preserve the seasonal variation in bottom fishing as shown in Ma and Hamm (2015) and Ma and Ogawa (2016).



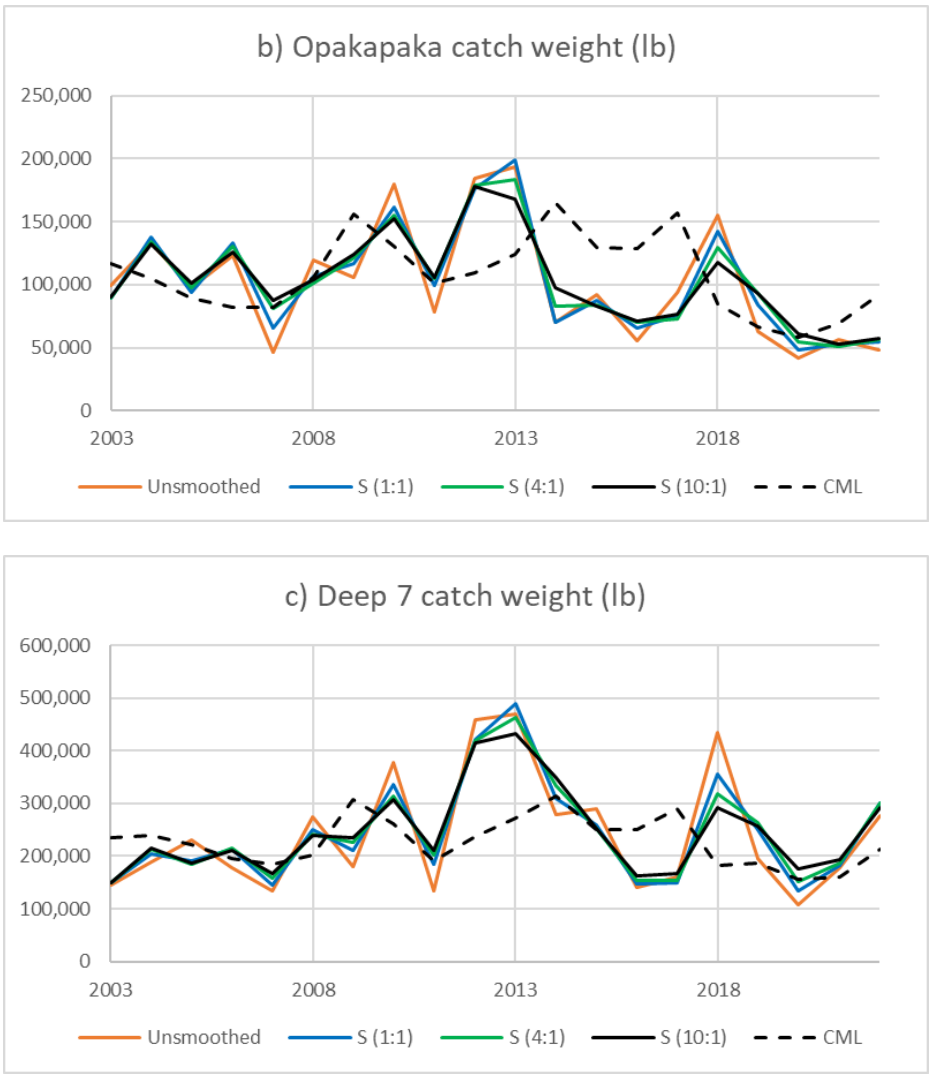


Figure 5: Unsmoothed (orange) and smoothed (blue, green, and black) (a) catch rate by wave for opakapaka, (b) annual catch estimates (lb) for opakapaka, and (c) annual catch estimates (lb) for all Deep7 bottomfish. Baseline smoothing ("S (1:1)") is shown in blue. Smoothing with a stronger smoother ("S (4:1)", ratio of the observation error variance to the process error variance = 4) and smoothing with another stronger smoother ("S (10:1)", ratio = 10) are shown in green and black, respectively.

4.3 Transition in Fishing Effort Survey

The effort survey in HMRFS transitioned from the Coastal Household Telephone Survey (CHTS) to the Fishing Effort Survey (FES, a mail survey) in 2018. CHTS only covered households with a landline telephone; cellphone-only households gradually increased to account for 50% of the population near the end of the phone survey period (2003–2017). Fishing effort from cellphone-only households could differ from households that maintained a landline telephone. In addition, the telephone survey response rate gradually decreased to less than 10% near the end of the survey period (personal. communications, R. Andrews, NOAA Fisheries Office of Science and Technology). Without calibrating the fishing effort estimates from CHTS, a very distinct change in both fishing effort and catch estimates would be exhibited from 2017 to 2018 (Figure 2(b) and Figure 6).

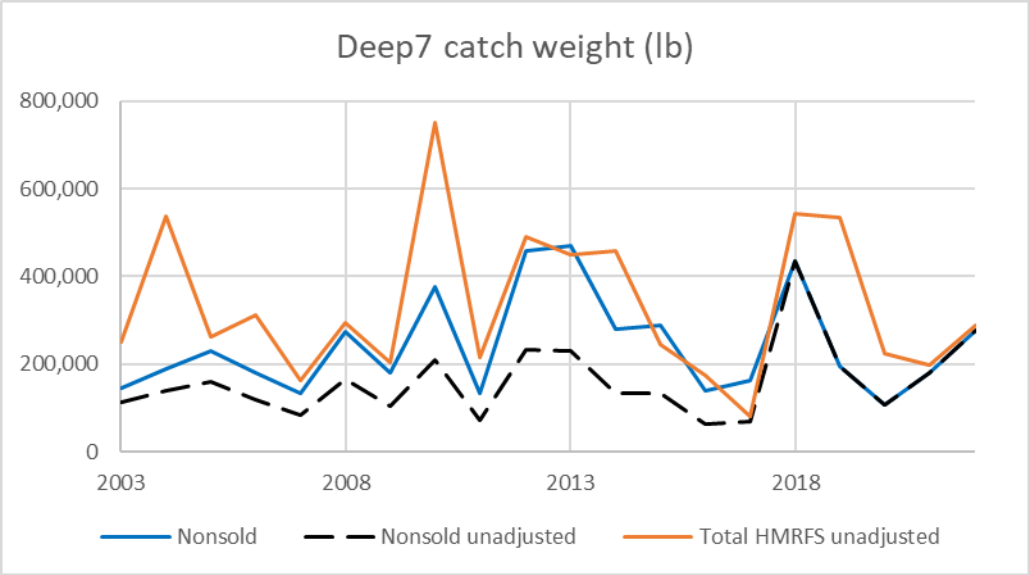


Figure 6: The total HMRFS catch weight estimates ("Total HMRFS unadjusted" shown in orange) are based on the HMRFS catch number estimates without any adjustments for the sold catch in the survey data and without adjusting the fishing effort estimates from previous CHTS. The non-sold catch estimates with effort adjustments are shown in blue, and the non-sold catch without effort adjustment in a dashed line.

In the previous CHTS, non-commercial fishing trips from recreational expense fishers and part-time commercial fishers were included for fishing effort estimation (Allen and Bartlett, 2008). Like the catch rate estimation, survey data from full-time commercial fishers were excluded. In addition to fisher categorization, fishing method information was also collected for profiled shore fishing or boat fishing trips in the previous CHTS. McCoy et al. (2018) estimated annual non-commercial catch of reef-associated fish in MHI during 2004–2013 using gear-specific catch rate and fishing effort. The survey questionnaire is simplified in the current FES: only the number of recreational shore fishing trips and the number of recreational boat fishing trips (regardless of fishing gears/methods used) from individual household members are collected. The corresponding catch rate and catch estimates are also currently separated by fishing mode (shore fishing or private boat fishing). If the fishing method information (e.g., bottom fishing or trolling) is gathered from the fishing effort survey, method-specific catch rate can be used to potentially better estimate Deep7 bottomfish catch in the future.

In summary, the calibration of fishing effort estimates from CHTS resulted in significant changes in catch and effort estimates from 2003–2017. By separating the sold catch from HMRFS, the resulting non-commercial catch estimates better account for catch from non-CML holders and potential underreporting of non-sold catch by CML fishers. Without excluding the sold catch in catch rate estimation, the non-commercial catch may be overestimated even when the fishing effort estimates from the previous CHTS were not calibrated (orange line vs blue line in Figure 6). The approach developed in this paper, including catch partitioning based on disposition, catch rate smoothing, and fishing effort calibration can be applied to HMRFS catch estimates for pelagic fish and coral reef fish to better characterize non-commercial catch in these fisheries.

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