

PACIFIC ISLANDS FISHERIES SCIENCE CENTER



A Review of the Cooperative Hawaiian Bottomfish Tagging Program of the Pacific Islands Fisheries Science Center and the Pacific Islands Fisheries Group

Joseph O'Malley

June 2015



Administrative Report H-15-05

doi:10.7289/V59W0CF7

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Administrative Reports may be cited as follows:

O'Malley, J. 2015. A Review of the Cooperative Hawaiian Bottomfish Tagging Program of the Pacific Islands Fisheries Science Center and the Pacific Islands Fisheries Group. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96818-5007. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-15-05, 36 p. doi:10.7289/V59W0CF7

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ABSTRACT

The Pacific Islands Fisheries Group (PIFG) was awarded a NOAA contract for cooperative research on Hawaii bottomfish in 2007. One of the goals of the cooperative research program with the Pacific Islands Fisheries Science Center was to tag bottomfish in the main Hawaiian Islands. The purpose of this report is to review the tagging program and the data collected to date to determine if the program is meeting the goal of providing sufficient information for life history parameter estimates (growth, mortality, and movement) needed to support single-species stock assessments of the Deep 7 Hawaii bottomfish. Examination of the provided tagging datasheets revealed substantial issues with illegibility, missing data fields, and later editing (sometimes erroneously) of datasheets by unknown persons. This combination of issues compromised some of the recapture information which resulted in lower sample sizes available for life history parameter estimation. Tagging ($n = 8427$) generally occurred across the full size range of each species. Recapture rates were exceptionally low; the opakapaka (*Pristipomoides filamentosus*) recapture rate was 2.5% ($n = 113$), the ehu (*Etelis marshi*) recapture rate was 0.8% ($n = 1$) and no recaptures were reported for the other Deep 7 bottomfish species tagged. Recapture information indicated that opakapaka do not exhibit regular large-scale horizontal movements, with only two fish recaptured more than 30 km from location of release. Opakapaka growth rates estimated using the tag/recapture information generally agree with those estimated using age information derived from hard parts; however, the size range of recaptured fish was extremely limited. Therefore, the growth and movement estimates from this study should be used with extreme caution because they are not representative of the entire population. Mortality estimates were not possible given the extremely low level of recaptures. Currently, the PIFG/PIFSC cooperative tagging program is not meeting the goal of providing information for life history estimates primarily due to the paucity and limited size range of recaptures. If the program were to continue it is recommended that the issues with the data collection be addressed, a well-conceived prioritization of species for tagging be developed, and reasons for the low recapture rates be investigated thoroughly, especially as related to tagging mortality.

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INTRODUCTION

Fisheries researchers are often confronted with the difficult task of accurately assessing fish stocks in a “mixed- species” fishery (i.e., several species are caught together by the same fishing gear). This is especially true when there is a dearth of species-specific life history information for the fishery. Therefore, these stocks are typically assessed as a complex of species (“mixed-species” assessment) rather than as a series of single-species assessments.

In mixed species assessments, no distinction is drawn among the individual species’ population dynamics (recruitment, size/age structure, intrinsic growth rate), life histories (growth, longevity, mortality, size/age-at-maturity, movements) and fisheries dynamics (catchability, selectivity, targeting); single values for each parameter are assumed to represent all of the species in the complex. The output, therefore, reflects the status of the group rather than any single species. In turn, management schemes are often applied to all species in the assessment, but this may prove costly to single species that are being overexploited or to the fishery from species that are being underexploited (Dougherty et. al. 2013). This is the case with the Hawaiian bottomfish fishery. Several snapper species (Family Lutjanidae), jacks (Family Carangidae) and an endemic epinepheline grouper (Family Serranidae) are targeted by fishermen using deep handline gear (Table 1). The fishery historically operated within the main Hawaiian Islands (MHI) (Hawaii Island to Niihau) and the Northwestern Hawaiian Islands (NWHI) (Fig. 1). Presently, all fishing takes place within the MHI; commercial fishing in the NWHI ceased with the establishment of the non-extraction Papahānaumokuākea Marine National Monument in 2006.

Hawaii bottomfish stock status has traditionally been determined for a group of the seven most valuable bottomfish as a complex (the “Deep 7”, Table 1) rather than on a single species basis (Brodziak et al. 2009, 2011; Martell et al. 2011; Moffitt et al. 2006). Data to support the stock assessment include species-specific catch information beginning in 1948, but there is currently little reliable species-specific life history information for any of the species (the exception being recent growth estimates for opakapaka by Andrews et. al 2013). The information available from previous studies published in the 1980s and 1990s is generally considered unreliable because of poor sample sizes and outdated methodologies. Often, when life history information is lacking, information from the same species in a different geographic region or a similar species is substituted. This is a risky endeavor because of interspecific and spatial variability. In the case of Hawaiian bottomfish, it is well recognized that the Deep 7 species vary in their life history and population dynamics, and that assessing them as a group is not ideal. The lack of accurate species-specific life history information is a major deterrent to conducting single-species assessments.

To rectify this situation, the National Oceanographic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center (PIFSC) initiated research programs focusing on acquiring data to estimate the life history parameters needed for species-specific assessments. While the PIFSC Life History Program (LHP) began collecting biological samples in 2005 for estimation of growth, size/age-at-maturity it was realized that additional resources were required for a tag and recapture program that could provide important information on mortality and

movements. The decision to include commercial fishermen in the tag/recapture process was facilitated by the availability of NOAA Cooperative Research funds. This program supports partnerships between the fishing industry, fishermen and other stakeholders with federal and university scientists to collect fundamental fisheries information (<http://www.st.nmfs.noaa.gov/cooperative-research/index>). It was previously used by the PIFSC to successfully provide biological and ecological information about the commercially exploited NWHI spiny lobster and slipper lobster populations (O'Malley 2009, 2011; O'Malley and Walsh 2012).

In 2009, the Pacific Island Fishing Group (PIFG), a consortium of commercial bottomfish fishers in Hawaii, Guam, and Commonwealth of the Northern Mariana Islands was awarded the NOAA Cooperative Research bottomfish research contract. Prior to this, in 2007, PIFG had begun tagging MHI bottomfish using funds from the State of Hawaii. Under the new federal contract, the PIFG was tasked with four goals: 1) participate in a pilot fishery-independent survey of bottomfish in waters around Oahu, Maui, and Guam; 2) provide a platform for a Hawaii bottomfish tagging program; 3) expand fishery-dependent sampling of bottomfish throughout the main Hawaiian Islands (MHI); and 4) educate the community and conduct outreach about these efforts. The overall goal of the tagging program was to provide data for estimation of somatic growth, mortality, and movement on a species- and spatial-specific scale for incorporation into single-species stock assessments.

PIFG Sampling Design and Data Collection Protocols

Details of the PIFG bottomfish tagging sampling design were not available other than being generally described as “opportunistic” (G. DiNardo, PIFSC, personal communication, February 2013). Furthermore, factors regarding a fishermen’s decision to target a particular species and either tag or land a captured fish were not documented.

The following summary of tagging operations was gleaned from the PIFG reports (PIFG 2010). The first group of taggers was fishermen who were already collecting biological samples for the PIFG bottomfish sampling program in the main Hawaiian Islands. Additional taggers were later recruited. Fishers were provided with a tagging kit containing 3.5 inch yellow PDS-2 dart tags (Hallprint Pty, Inc. Hindmarsh Valley, South Australia), each printed with a unique number and contact information; tag applicators; venting tools (for purging the swim bladder to counter the effects of barotrauma); a drop shot (a weighted device designed to quickly return and release the tagged fish to the sea floor); and informational material. All participants were trained to tag and release fish either at a series of workshops or one-on-one by the PIFG staff.

All captured fish were identified to species and immediately placed in a holding tank on deck to assess their suitability for tagging and release. If a fish showed minimal signs of traumatic barotrauma fishermen were instructed to quickly tag, measure (fork length in inches or centimeters), and purge (if necessary) the fish and release it using the drop shot technique (<http://www.fishtoday.org/cooperative-research/bottomfish-tagging/>). The date, location of release (latitude and longitude), release method, and depth of the sea floor (fathoms or feet) were

also recorded. Datasheets were returned to the PIFG and provided by them to the PIFSC for data entry.

All recaptures occurred in the MHI subsistence, commercial, and recreational fisheries. Substantial outreach was conducted by the PIFG to inform all MHI fishermen about the tagging program. Return rates were boosted by rewarding fishermen with a T-shirt if they provided the tag number, species, location, and fork length of recaptured fish. Tagging information was provided to the PIFSC in the spring of 2012 and the spring and fall of 2013 and recapture information was provided in November 2012 and December 2013.

The purpose of this review is to determine if the PIFG tag/recapture program is providing the information necessary for species-specific life history estimation. The basics of the program, including species-specific tagging effort, recapture rates, and the size range of individual bottomfish tagged and recaptured are evaluated to determine if growth rates, survival rates, and movement patterns are estimable. Where possible, life history parameters (growth rates, survival rates, and movement patterns) are estimated. Finally, recommendations to improve the sampling design, the data collection protocol, and the PIFG tagging program as a whole are provided.

MATERIALS AND METHODS

Data Evaluation

Initial evaluation of each tagging worksheet entailed examination by the PIFSC staff for errors, clarification of poor penmanship prior to data entry, conversion of fish length measurements from inches to centimeters (if necessary), conversion of depth recorded in fathoms to meters, and conversion of all latitudes and longitudes from either degrees-minute-seconds, degrees-decimal minutes, or degrees-minutes-decimal seconds to decimal degrees. The data were then entered into a tag release database by the PIFSC data entry group.

The PIFG provided the recapture information in an electronic spreadsheet. This spreadsheet also contained tagging information for some of the individual fishes as well as estimates of distance moved, days-at-liberty (DAL), and growth. Although the PIFG recapture information contained estimates of distance moved, the latitude and longitude of the initial tagging locations were not included and there was no information about how the distances moved were calculated (e.g. great circle distance or Pythagorean theorem equations). A new PIFSC tag/recaptured database was developed by linking the recapture information to the tag release information. The growth rates, DAL, and distances moved were then re-calculated using the information in the PIFSC database. All summaries and analyses presented in this report used the PIFSC tag/recapture data rather than the PIFG tag/recapture data because a comparison of the two databases revealed that the PIFG recapture information did not always link with the correct tagging information and because of the previously mentioned issues with distance moved.

Species-specific Tagging and Recaptures, Size Frequency Distribution Comparisons

Basic tag and recapture information (number tagged, number recaptured and size frequency distributions) was aggregated by species and island of tagging. The PIFG species-specific size frequency distributions were compared to those from the bio-sampling effort of the PIFSC LHP, which specifically targets small and large individuals, to determine if the PIFG tagging and recapture information spanned the full size ranges of the various species.

Growth Analysis

Somatic growth rates based on the tag-recapture information were estimated using two methods:

1) Gulland and Holt (1959) method

The von Bertalanffy growth equation assumes that growth rate declines linearly with increasing length. Therefore, the growth parameters can be estimated using linear regression by fitting a line through a plot of average size vs. annual growth rates, where $-K$ is equal to the slope of the line and L_{∞} is equal to the x -intercept. Individual average lengths were calculated as the average length between release and recapture. Individual annual growth rates (cm/yr) were calculated as the differences in length between release and recapture divided by the DAL and then multiplied by 365.

2) Francis (1988a) method

Species-specific data were fitted to the von Bertalanffy growth equation following Francis' (1988a) maximum likelihood method using the GROTAG program designed by Simpfendorfer (2000) for the Microsoft Excel solver function (Excel, vers. 2010, Microsoft Corp., Redmond, WA). In this method, a reparameterization of the Fabens' (1965) growth model for tagging data, the usual von Bertalanffy parameters, K and L_{∞} , are replaced by two alternative parameters, g_{α} and g_{β} , which represent mean annual growth increments (mm/yr) at chosen reference lengths α and β (Francis 1988a). These parameters have better statistical properties than K and L_{∞} , particularly when the entire size range of the species is not represented in the data (Sainsbury 1980; Francis 1988a, 1988b). Further, growth rates at these specific sizes are directly observable and are therefore biologically meaningful relative to K and L_{∞} (Francis 1988a, 1988b; Haddon 2001). Species-specific bottomfish reference lengths, α and β , were chosen so that, within each data set, the values were well-represented while maintaining the majority of individuals between the two values (Francis 1988a).

Following Francis (1988a), the expected length increment, ΔL , for a bottomfish tagged at length L_1 at liberty for time ΔT is given by:

$$\Delta L = \left\{ \frac{\beta g_{\alpha} - \alpha g_{\beta}}{g_{\alpha} - g_{\beta}} - L_1 \right\} \left\{ 1 - \left[1 + \frac{g_{\alpha} - g_{\beta}}{\alpha - \beta} \right]^{\Delta T} \right\} \quad (1)$$

The model was fit to the data (observed lengths at release and recapture and DAL) by maximizing the negative log likelihood function (Francis 1988a):

$$\lambda = \sum_i \log[(1 - p)\lambda_i + p/R] \quad (2)$$

$$\text{where } \lambda_i = \exp \frac{-1/2(\Delta L_i - \mu_i - m)^2 / (\sigma_i^2 + s^2)}{[2\pi(\sigma_i^2 + s^2)]^{1/2}}, \quad (3)$$

R = the range of observed growth increments, μ = the expected growth increment, m = the mean measurement error, s = standard deviation of measurement error, and σ = the standard deviation of the growth variability. Also estimated were the coefficient of variation of growth variability (v), and outlier contamination (p). To describe growth variability, σ was related to μ ($\sigma_i = v\mu_i$), assuming an increase in growth variability as the size of the growth increment increases (Francis 1988a).

To compare the Deep 7 bottomfish growth rates with bottomfish growth rates reported in other studies model outputs were converted to the von Bertalanffy growth parameters K and L_∞ following Francis (1988a):

$$K = -\ln[1 + (g_\alpha - g_\beta)/(\alpha - \beta)] \quad (5)$$

$$L_\infty = (\beta g_\alpha - \alpha g_\beta)/(g_\alpha - g_\beta) \quad (6)$$

The first model fitted was the simplest, fitted with only g_α , g_β , and s . Each subsequent model introduced an additional parameter. Likelihood ratio tests (LRT) were used to determine the final best model, where for a significant ($P < 0.05$) improvement in fit, the likelihood value must increase by at least 1.92 with the introduction of one parameter and 3.0 with the introduction of two parameters (Francis 1988a). Ninety-five percent confidence intervals (CIs) were estimated using a bootstrapping method as implemented in GROTAG (Simpendorfer 2000).

Survival

Tag-recapture data were used to construct individual encounter histories to estimate species-specific bottomfish survival. The resulting capture history matrices, which represented the fate of each tagged bottomfish throughout the study period, were used as input files for the software Program MARK (ver. 5.1) (White and Burnham 1999). MARK estimates apparent survival (Φ), defined as the combined probability that an individual released at capture occasion i is still alive and available for recapture at capture occasion $i + 1$, and recapture probability (p) via numerical

maximum likelihood techniques. The Cormack-Jolly-Seber (CJS) model (Lebreton et al. 1992) was used for all species. Models were constructed to determine the effect of time on survival and recapture probability. The recapture probability was expected to be highly dependent on time because fishing effort varied annually for all bottomfish species; therefore only models containing time-varying p (i.e., $p(t)$) were investigated.

General models, which had the maximum parameterization, were used to assess goodness-of-fit using the median \hat{c} , a variance inflation factor approach. Median \hat{c} estimates greater than 3 typically indicate overdispersion in the data and therefore, lack-of-fit (Lebreton et al. 1992).

Models were ranked based on Akaike's information criterion (AIC) adjusted for overdispersion and effective sample size (QAICc). The model with the lowest QAICc was considered closest to full reality, given the data (Anderson 2008). Final model selection was based on Δ QAICc, the differences between the most supported models, and model QAICc weights (w_i). If the top model's Δ QAICc was less than 2 and the ratio of model w_i was less than 1 then model averaging was conducted to account for model selection uncertainty (Burnham and Anderson 2002). Model averaging entails calculating average parameter values and 95% CI averaging over all models weighted by their QAICc w_i (Buckland et al. 1997).

Movement

The straight line distances moved (km) between tagging and recapture locations were calculated using spherical trigonometry (i.e., Great Circle Distance; Beyer and Shelby 1976). All positions were plotted using ArcGIS and visually validated; obviously erroneous release or recapture positions (e.g., on land or high seas) were removed.

RESULTS

Tagging Data

Illegible handwriting was a serious problem encountered while examining tagging datasheets. At some point it was impossible to decipher with accuracy at least one entry in each of the data fields but the fields for 'species' and 'location' were particularly problematic. Despite review of all datasheets, deletion of tagging events that were undecipherable and attempts to interpret and edit other data fields it is likely that the illegibility problem led to interpretation issues during data entry and therefore to significant errors in the database.

A second serious concern was datasheets that were incompletely filled out during tagging operations, with the missing information provided at a later date by unidentified persons. An example of this concern is a recapture event of a different species than what was tagged in the PIFSC tag/recapture database. Examination of the original datasheets suggested that different people had recorded information because both the writing implement (pencil vs. pen) and handwriting on the datasheets differed. In at least two cases, the tagger did not provide the full

tag number, and either the tagger or a different person later erroneously completed the entry, which resulted in duplication of tag numbers. For example, tag numbers H4401-H4427 and H7201-H7209 had been duplicated and therefore were deleted from the tag/recapture database. This necessitated the removal of two recapture events because of uncertainty in identifying the true tagging event. Discovery of such obvious data errors engenders serious concerns regarding the extent to which these types of errors contaminate the database.

A third concern is the editing or revision of the data by unidentified people prior to providing the data to the PIFSC. On numerous datasheets, the original entries were covered with new data on entries affixed with tape. In one case, a comparison of the header information revealed that the original and revised entries for the tagging data were inconsistent. In this case a fish was recaptured during the trip but the PIFG recovery date, and hence the DAL, were unreliable and unusable.

Different units of measurements were used throughout the data collection time series. For instance, some datasheets included fish lengths expressed in both inches and centimeter without indicating where the switch had occurred. Latitude and longitude were reported in three formats (degrees-minute-seconds, degrees-decimal minutes, degrees-minutes-decimal seconds) which made conversion to decimal degree for movement estimates difficult. Depth was also recorded in fathoms and feet which made conversion to meters similarly cumbersome.

Data fields were left blank in many datasheets. Missing information for tagged fish included 73 capture dates, 11 species names, 150 locations (latitudes and longitudes), 37 fish lengths, and 68 depths. Also, 24 fish were identified as “reds” which could represent onaga or ehu, or other species, and therefore were excluded from analysis.

Tagging Effort

Fish representing all seven species within the Deep 7 bottomfish complex as well as kamala, kuku, and luau were tagged by the PIFG MHI tagging program. Tagging occurred throughout the MHI (Fig. 2) with most tagging done by Oahu fishermen (Table 2). It is important to note that very little tagging occurred on the windward side of the islands (Fig. 2) which is likely a reflection of the spatial extent of the fishery. Of the Deep 7, opakapaka was tagged in the highest numbers followed by kalekale and ehu (Fig. 3).

The majority of tagged opakapaka were released using just purging (68%) followed by no purging or drop shot (16%), purge and drop shot (11%) and drop shot only (6%).

Recapture Rates, Time-at-Liberty

Only opakapaka and ehu were reported as recaptured; there were no recaptures of gindai, hapu'upu'u, kalekale, lehi or onaga. Single recapture rates of opakapaka (113 recaptures – 2.5%) and ehu (1 recapture – 0.08%) were low. Two opakapaka were recaptured twice. Opakapaka days-at-liberty (DAL) ranged from 6 to 2029 (N = 111) with an average DAL of 325 (SD = 368). However, the tagging date was missing from two individuals that were recaptured. Sixty-six

percent of recaptures were at liberty for < 1 year, 22% were at liberty between 1 and 2 years, 7% were at liberty between 2 and 3 year, 2% were at liberty between 3 and 4 years, 1% was at liberty between 4 and 5 years and 1% was at liberty for > 5 years.

The release method was recorded for 108 of the 113 recaptured opakapaka. Percentages of recaptures by release method were 2.4% for just purging, 1.9% for no purging or drop shot, 1.9% for purge and drop shot, and 0.7% drop shot only.

Size Frequency Distribution Comparisons

Plots of the PIFG tagging data and the PIFSC LHP sampling program fish lengths displayed differences in the size structure between datasets for all species except for gindai (Figs. 4, 5, 6, 7, 8). The range of fish lengths differed for all species and distributions were significantly different ($P < 0.05$) for all species except for gindai ($P = 0.3$) (Table 3). Plots also revealed differences in the opakapaka size ranges between the PIFG tagging data, the PIFSC LHP and the recapture size-at-tagging datasets. The primary difference was in the range of size at tagging for recaptured opakapaka. This was extremely limited, with minimum and maximum of 30 and 55 cm, respectively (Fig. 8).

Inspection of the ehu (Fig. 4) and kalekale (Fig. 6) size frequency distributions reveal the presence of a few inordinately large PIFG tagged specimens. The presence of these individuals is likely related to the previously described data recording/entering issues rather than fishermen misidentifying species.

Growth

Of 113 recapture opakapaka, 4 were missing either length-at-tagging or length-at-recapture information and 2 were missing either date tagged or date recaptured. Nine opakapaka were reported to have negative growth > 1 cm and were removed from the growth analysis. Nine other individuals were reported to have negative growth < 1 cm and, in these cases, growth was assumed to be zero. Two opakapaka had implausible estimates of growth (fish #1 grew 7 cm in 12 days, fish #2 grew 3 cm in 20 days) and therefore they were removed from further analysis.

The growth of the remaining 96 individuals was examined using two methods:

Gulland and Holt (1959) Method

Consistent with the Gulland and Holt (1959) model, negative slopes were found when linear regressions were fitted to the opakapaka mean fork length vs. annual growth rate (Fig. 9). The estimate of K was 0.15 yr^{-1} and L_{∞} was 71.55 cm (28.17 inches).

Francis (1988) Method

The von Bertalanffy growth model containing g_a , g_b , s , and v resulted in the best fit to the opakapaka data, although all of the models provided similar parameter estimates of K and L_{∞} .

(Table 4). Inclusion of the parameter m slightly increased the negative log likelihood, but the estimate was negative. The introduction of parameters p did not result in a significant improvement in fit, as evident in the likelihood ratio tests. No individuals had absolute standardized residuals greater than 3.0; therefore, the exclusion of p from the final model was warranted as also evident by the lack of improvement of fit with its inclusion.

To assess final model fits, residuals and standardized residuals (residuals divided by σ_i , which, in the selected models, equals s) were plotted against length-at-release and predicted growth (Fig. 10). The typical pattern consists of decreasing residuals with increasing length-at-release because mean growth declines with length (O'Malley 2009, 2011), but that pattern was not clearly observed in this analysis. The likely reason is that the recapture data did not encompass the complete size range of opakapaka. The residuals in this study varied directly with increasing predicted growth, which is typically indicative of a good fit. A plot of the standardized residuals on the size at tagging showed no pattern, while there was a slight decreasing pattern in predicted growth. Overall, it appears that the model assumption that growth variability is dependent on mean growth was not necessarily violated (Francis 1988b). Residual plots indicated that the fits were satisfactory, and therefore the final fitted models were suitable for use with the opakapaka tag/recapture data.

The best fit model yielded the following growth-at-size estimates: $g_{30} = 6.83$ cm/yr. and $g_{45} = 3.14$ cm/yr. These values converted to $K = 0.28$ yr⁻¹ (95% CI 0.25 – 0.31) and $L_{\infty} = 57.80$ cm (95% CI 55.97 – 58.67) (Table 4). The large value of v (0.66) suggests substantial individual variability in opakapaka growth (Table 4).

Survival

The small number of recaptures and smaller number of multiple recaptures caused survival estimation to be problematic. The majority of the cells in the opakapaka capture history matrix, which is used as the input file for the survival estimator, were zero.

Median \hat{c} estimates were greater than 3 for all models which clearly indicated overdispersion in the data and therefore, lack-of-fit (Lebreton et al. 1992). Because the number of recaptures was low and the data were overdispersed, all survival estimates were considered highly biased and unusable and are not reported.

Movements

Of the 113 recaptured opakapaka, 3 tagging and 27 recapture events were missing latitude and longitude information. Recording errors were also found in the movement analysis. For instance, the latitude of the fish tagged with tag numbers H7636 – H7645 was recorded as 29° N, which is clearly implausible. Tag numbers H7637 and H7639 were recaptured but because of the incorrect tagging location they had to be deleted from movement analysis. Because of missing and incorrect location information, movement analysis used the information from only 81 recaptured opakapaka.

Opakapaka straight line distance directional movement estimates ranged from 0 to 61 km (Fig. 11). The greatest movement was by an individual that moved 61 km in 44 days (Fig. 12). It was tagged on the north side of Maui and recaptured on the south side. Another fish moved 33 km across the Kalohi Channel in 574 days. Both of these fish moved greater distances than reported because the straight line movements crossed land (Fig. 12). One fish tagged on the north side of Penguin Banks was recaptured off the Makapu'u Ledge, a straight line movement of 8.61 km in 48 days (Fig. 13). However, the majority of tagged opakapaka didn't move very far: 53% moved < 1 km, 33% moved 1-5 km, 5% moved 5-10 km, 4% moved 10-20 km, and 6% moved > 20 km.

The first opakapaka that was recovered twice moved 9 km in the first 48 DAL, but then returned to the original tagging location during the following 200 DAL. The other opakapaka that was recovered twice did not exhibit movement between the tagging location and the first recapture 22 days later or the second recapture 5 days thereafter.

The sole recaptured ehu did not exhibit detectable movement during its 324 DAL.

DISCUSSION

Tagging and Recapture Data

Two primary sources of error in data collection and preparation that typically concern researchers are data recording and data entry. The large number of illegible data sheets is probably the most egregious example in the PIFG tagging project not only because of the resulting loss of data but also misinterpretation errors by the PIFSC data entry staff. The current data collection protocol of the PIFG MHI bottomfish tagging program is characterized by another source of potential error, which is the post-tagging completion and editing of the datasheets either by the fisherman at a later date before submitting the data or by the PIFG staff after receipt of the data sheets. All such errors are easily avoided. Hence, steps should be taken to minimize them. Obvious errors can be identified through careful review of the data by the PIFSC staff prior to data entry but given the amount of datasheets generated by the PIFG checking each one is time intensive and cumbersome and identifying an error doesn't necessarily result in proper correction.

The ramifications of erroneous data are straightforward and serious—all estimates of spatial size structure, growth, movement, and survival are obtained from such values would be unreliable. Use of such unreliable estimates may introduce significantly bias into future estimates of relative abundance and associated management measures.

*Recommendations:

- 1) Illegible handwriting and incomplete datasheets. It is highly disadvantageous to any research program when data must be discarded because of illegible handwriting or

missing pertinent information. Data collectors must complete the datasheets legibly, fully and promptly. The difficulty of doing so while at-sea is not lost on the author, but if it is determined that it is infeasible to do so, the alternative recommendation is that the program be discontinued. A potential way to overcome the issues with species name is to utilize species codes (i.e., numbers).

- 2) Standardized data collection. The PIFG and the PIFSC need to agree on specific units of measurement for each piece of information collected. Doing so will significantly reduce the time spent editing the datasheets for data entry. It is recommended that fish length be recorded in millimeters, location in degree decimal minutes, and depth in fathoms.

Tagging Effort and Size Distribution of Tagged Fish

Almost 8500 fish were tagged during the first 6 years of this tagging program, more than half of which were opakapaka. Given the low tagging numbers of the other species it is apparent that opakapaka was targeted for either tagging or fishing by the PIFG fishermen.

A comparison of the PIFG and the PIFSC size frequency distributions indicates that the tagging program tagged fish across a large size range of all species. This is a commendable accomplishment. In most cases, the PIFG data contained a larger size range relative to the PIFSC LHP biosampling data, the exception being small opakapaka. Although smaller fish of all species are needed to complete the growth curve, small fish are likely outside the range of the usual PIFG fishing grounds.

***Recommendation**

- 1) Prioritization of species for tagging based on need for specific life history information. The PIFSC should develop a list of priorities of species for the PIFG to tag. The list should reflect the availability of reliable species-specific life history information and the needs for such information in species-specific stock assessments. If recapture rates across the size ranges of all species cannot be increased, it is recommended that growth be estimated from information collected in ageing studies using hard parts (i.e., providing growth estimates is no longer a goal of the PIFG tagging program). Growth of opakapaka was recently estimated using ageing information (Andrews et al. 2012) and estimation of hapu'upu'u growth rates is close to completion (A. Andrews, PIFSC. personal communication 2014). Survival and abundance estimates are not possible for any of the tagged species given the low recapture rates.
- 2) Complete size range. It is recommended that smaller fish be targeted for tagging to complete the size range although they may be outside the range of the PIFG fishermen.

Recapture Rates

Recapture rates of Hawaii bottomfish were exceptionally low. No gindai, hapu'upu'u, kalekale, lehi or onaga were recaptured and there was only 1 recaptured ehu. Although opakapaka had the

greatest tagging effort the recapture rate was only 2.5%, which is low for a commercially fished species with seemingly low movement ranges. For comparison, the recapture rates of other deep-water species ranged from 0 to 20.1% (Table 5). Fowler and Stobo (1999) considered the 4.3% NW Atlantic haddock recapture rate “extremely low”.

It is difficult to determine why recapture rates have been so low, but at least 4 possibilities could have contributed. The first is non-reporting, but in this case the PIFG appears to have done an excellent job notifying the fishing community about the program. The second relates to tagging areas vs. fishing areas. If fish were tagged away from the primary fishing grounds and then remained in those areas, the commercial fleet would not have recaptured them. However, conversations with the PIFG contact, and the release data (Figure 2) suggest that fish were tagged on the primary fishing grounds. Thirdly, there is no information about tag application, whether it was uniform across taggers, and whether tag shedding could have been a significant factor in the low recapture rates. The fourth possible reason for the low recapture rates is also of greatest concern—that the process of tagging and releasing of fish causes high mortality primarily because of barotrauma. Hawaii bottomfish are physoclystic, i.e., their gas bladders are closed off from the gut and expand when brought up from depth. The rapid large change in pressure results in rapid expansion of the gas bladder which typically leads to internal injuries, embolism in body tissues, and stomach eversion. Hawaii bottomfish suffering from barotrauma can also exhibit exophthalmia in which the eyes protrude outward from the orbit. An examination of the release method recorded by the fishermen indicated that the majority purged the fish and did not use the drop shot. Based on the low number of recaptures there is no clear indication that recapture rates were improved by use of either purging alone or purging and using the drop shot relative to releasing fish with no treatment.

Research of other deep-water fishes suggests that the fish-handling methods currently employed by the PIFG/PIFSC tagging program (allowing the fish to recover in a tank of seawater, purging, using the drop shot) may be causing the high mortality and hence, low recapture rates. The first two methods are particularly suspect. Increased surface holding time, especially when there is a large temperature difference between the capture depth and the air, is harmful (Jarvis and Lowe 2008). The water temperature of typical MHI bottomfish habitat is 16.4°C (Kelley and Moriwake, 2012) and the sea surface temperature is 25°C, generally. Holding fish in tanks containing water that is 9°C warmer than the temperatures they normally experience is significant and likely induces stress. Parker et. al. (2006) found that less time on deck and rapid recompression reversed all externally visible signs of barotrauma in black rockfish (*Sebastes melanops*) and China rockfish (*S. nebulosus*). The effectiveness of the second fish handling method, purging of the stomach, is highly species-specific (Brown et al. 2008, Sumpton et. al. 2010) and it can prove harmful to the fish due to infections. Wilde (2005) used relative risk to summarize the results of 39 sample estimates comparing survival and recapture rates of purged and unpurged fish. The meta-analysis indicated that there was little evidence that purging increased fish survival in general and that purging was increasingly harmful for fish captured in progressively deeper waters. Wilde (2005) concluded that purging should be prohibited rather than required by regulation. The third fish handling method, the use of recompression devices such as drop shots and release cages, has been found to be an effective way to reduce the impact of barotrauma (Hannah et al. 2012, Hochhalter and Reed 2011). The California Department of

Fish and Wildlife, the Oregon Department of Fish and Wildlife, and the Alaska Department of Fish and Game don't encourage purging yet currently promote minimization of time on deck and recompressing fish by using a drop shot or a weighted cage with a trap door to protect the fish from predation on its way down.

***Recommendations:**

- 1) Low recapture rates. Recapture rates are clearly too low for all species to recommend continuation of this tagging program using the current methodology. Zero recaptures of gindai, hapu'upu'u, kalekale, lehi and onaga and the low numbers of opakapaka and ehu are unacceptable.
- 2) Assess treatment and release of tagged fish. If the tagging program is to be continued, it is highly recommended that a dedicated research program investigate tag-related mortality of each species. Post-tagging mortality of MHI bottomfish can be assessed by capturing fish, exposing them to various deck times and treatments (i.e., purging vs. non-purging) and lowering them to the seafloor in holding cages (Hannah et al. 2012). Cages can be retrieved after specific times on the bottom and survival directly assessed. The impacts of barotrauma on survival can also be assessed histologically (Parker et. al. 2006, Pribyl et al. 2012) and in the tank system at the PIFSC.
- 3) Reduce time on deck, use the drop shot, and eliminate purging. In the absence of dedicated studies examining the effects of the individual methods of releasing tagged Hawaii bottomfish, it is recommended that fishermen reduce the amount of time a fish spends on deck to the best of their ability (i.e., don't wait for a fish to recover in a tank of water), no longer purge fish, and to use the drop shot for every release.

Growth

The two different methods of estimating opakapaka growth produced different values of K and L_{∞} . This was not unexpected given that the size range of recaptured fish did not span the full size range. The Gulland and Holt estimate of K was lower and the L_{∞} was higher relative to the Francis method, as would be expected because the Gulland and Holt method tends to underestimate growth rate and overestimate L_{∞} when the size range is truncated. The Francis method resulted in more accurate estimates of growth (as evident in residual plots) given the data set. However, the size range of recaptured fish was insufficient to generate reliable, accurate growth estimates so any of these estimates must be used with caution.

Andrews et al. (2012) reported similar opakapaka von Bertalanffy growth parameter estimates ($K = 0.24 \text{ yr}^{-1}$, $L_{\infty} = 67.51 \text{ cm}$) based on otolith growth zone enumeration and bomb radiocarbon validation. However, Francis (1988b) demonstrated that growth parameters, particularly L_{∞} , estimated from these two types of data have different meanings and are not directly comparable. Even if they were comparable, estimates provided by the age-length study would be considered more accurate given the limited size range of the tag/recapture data.

***Recommendation**

- 1) Limited size range effect on growth rates. The only way for the tagging program to produce data necessary for accurate growth estimation is to boost the number across the entire size range of recaptures. If this is not possible then accurate growth estimates will not be attainable.

Survival

Survival estimates are not possible given the limited number of recaptures.

***Recommendations**

- 1) Limited recapture numbers on survival estimates. The only way for the tagging program to produce accurate survival information is to boost the number of recaptures. It would be particularly advantageous if fishermen who catch a tagged fish would record the data and then release these fish. Multiple recaptures greatly enhance the accuracy of survival estimates

Movements

This tag/recapture dataset indicates that Hawaiian opakapaka tend to not make large-scale movements. Although one fish moved from one side of Maui to the other and another crossed the Kalohi Channel 88% were recovered less than 5 km from the tagging site. However, it is important to note that the recapture size range and recapture rate were insufficient to detect ontological or seasonal movements.

***Recommendations**

- 1) Accurate movement information and tag returns. More tag returns across the full size range are needed for accurate and representative estimation of fish movements.
- 2) Archival tags. More detailed movements can be detected with archival tags than with conventional tags. Although more expensive per tag, a suitable number can be deployed at a comparable or possibly lower cost than a large-scale tagging program that uses conventional tags. An additional advantage of these tags would be the ability to acquire vertical movement data that would improve our limited understanding of diel movements and habitat of bottomfish.

SUMMARY/CONCLUSION

The PIFG MHI bottomfish tagging program has done an admirable job tagging all HI bottomfish species across a large size range. Most fish tagged, and almost all fish recaptured, were opakapaka. The PIFG fishermen may not have been instructed to tag the smallest fish possible or they may not have encountered smaller fish because of size segregation (i.e., nursery areas vs. adult habitats). The consequence is that the opakapaka recapture rates and the limited size range of recaptures render the data almost useless. Coupled with the zero recapture rates of the remaining Deep 7 bottomfish species, it is apparent that as currently structured and implemented the PIFG/PIFSC tagging program is not accomplishing its goal of providing the pertinent life history information necessary for single-species stock assessments.

Although the lack of recaptures and the limited size range of those recaptures are the primary concerns there are other areas demanding improvement if the PIFG/PIFSC bottomfish tagging program were to continue. These can be summarized as a pressing need for better data recording, a well-conceived prioritization of species for tagging, and detailed investigation of the reasons for low recapture rates, especially as related to tagging mortality.

ACKNOWLEDGMENTS

Clay Tam represented the PIFG and provided the data. Special thanks to M. Sundberg for assisting with the movement maps and to R. Humphreys, B. Richards, and W. Walsh for providing reviews.

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TABLES

Table 1.-- List of Deep-7 bottomfish species and other bottomfish species included in the Hawaiian bottomfish management unit species (BMUS) complex.

Common name	Local name	Scientific name	Deep 7 species	Primary bottomfish species
Pink snapper	Opakapaka	<i>Pristipomoides filamentosus</i>	X	X
Longtail snapper	Onaga	<i>Etelis coruscans</i>	X	X
Squirrelfish snapper	Ehu	<i>Etelis carbunculus</i>	X	X
Sea bass	Hapu'upu'u	<i>Hyporthodus quernus</i>	X	X
Grey jobfish	Uku	<i>Aprion virescens</i>		X
Snapper	Gindai	<i>Pristipomoides zonatus</i>	X	X
Snapper	Kalekale	<i>Pristipomoides seiboldii</i>	X	X
Blue stripe snapper	Taape	<i>Lutjanus kasmira</i>		
Yellowtail snapper	Yellowtail kalekale	<i>Pristipomoides auricilla</i>		X
Silver jaw jobfish	Lehi	<i>Aphareus rutilans</i>	X	X
Amberjack	Kahala	<i>Seriola dumerili</i>		
Thick lipped trevally	Butaguchi	<i>Pseudocaranx dentex</i>		X
Giant trevally	White luau	<i>Caranx ignobilis</i>		X
Black jack	Black luau	<i>Caranx lugubris</i>		X

Table 2.--Number of annual and total main Hawaiian bottomfish tagged by species and island.

Island	Year	Species							Annual total
		ehu	gindai	hapu'upu'u	kalekale	lehi	onaga	opakapaka	
Hawaii	2008	27	12		12		2	23	76
	2009	34	6		129	2	7	47	225
	2010	4	6		18	4	1	88	121
	2011	38	44		157	3	3	170	415
	2012	98	21		377	1	6	170	673
	2013	108	18		226		119	324	795
Maui	2008	25	1		2			41	69
	2009	3					2	131	136
	2010	72	103			1	82	410	668
	2011	42			124	4	42	219	431
	2012	70		2	59		67	204	402
	2013	64			24		31	376	495
Molokai	2007	4					37	21	62
	2008	47					67		114
	2009	13					93	75	181
	2010	53					16	100	169
	2011	16					34	16	66
	2012						9		9
	2013							100	100
Oahu	2007	6			1		7	317	331
	2008	5			10			604	619
	2009	3			11			205	219
	2010	44			34		11	272	361
	2011	57	5		39		16	136	253
	2012	64	1	1	176	1	9	278	530
Kauai	2013	49	1		74		8	138	270
	2007	22	4		25		1	39	91
	2008	7	3				6	1	17
	2009	84			26		97	1	208
	2010	57	4	2	16		37	3	119
	2011	18	1				28	61	108
	2012	45	5	1	4				55
	2013	28	3		7			1	39
	Species total		1207	238	6	1551	16	838	4571

Table 3.--Minimum and maximum fork lengths (FL) of PIFG tagged fish, PIFSC LHP biosampling program fish, and recaptured tagged fish by species. Kolmogorov-Smirnov test statistics (D, P) comparing the size distributions of fish by species in the different databases.

Species	PIFG		LHP		recapture		Kolmogorov–Smirnov test					
	FL min (cm)	FL max (cm)	FL min (cm)	FL max (cm)	FL min (cm)	FL max (cm)	PIFG vs. LHP		PIFG vs. recapture		LHP vs. recapture	
							<i>D</i>	<i>P</i>	<i>D</i>	<i>P</i>	<i>D</i>	<i>P</i>
ehu	11	115.32	14.60	64.00			0.64	<0.001				
gindai	17.15	97.03	15.90	44.40			0.11	0.3				
kalekale	11.50	92.96	16.8	47.00			0.09	0.01				
onaga	15.24	76.20	20.2	93.25			0.45	<0.001				
opakapaka	21	124.46	13	74.6	25.4	49.23	0.37	<0.001	0.07	0.75	0.36	< 0.001

Table 4. --Negative log-likelihood values for differently parameterized von Bertalanffy growth models (Francis 1988a) used in selection of the optimal model of Hawaiian opakapaka (g_α , g_β = mean annual growth increments [cm/year] of chosen reference lengths α and β ; s = SD of measurement error; ν = coefficient of variation of growth variability; m = mean measurement error; and p = outlier contamination). Bold indicates parameter estimates for final model selected with 95% confidence intervals in parentheses.

Model	Log likelihood	g_α	g_β	s	ν	m	p	K	L_∞
g_α, g_β, s	-228.13	7.52	3.36	2.60				0.33	57.1
$g_\alpha, g_\beta, s, \nu$	-182.90	6.83 (5.73-7.97)	3.14 (2.42-3.80)	0.10 (0.00-0.22)	0.66 (0.53-0.80)			0.28 (0.19-0.40)	57.80 (52.76-66.95)
$g_\alpha, g_\beta, s, \nu, m$	-179.05	7.43	3.43	0.05	0.59	-0.12		0.31	57.88
$g_\alpha, g_\beta, s, \nu, m, p$	-179.05	7.43	3.43	0.05	0.59	-0.12	0	0.31	57.88
$g_\alpha, g_\beta, s, \nu, p$	-182.94	6.8	3.14	0.10	0.66		0		57.80

Table 5.--Number tagged and recaptured, percent recaptured, and study location of deep-water species.

Species	N tagged	N recaptured	% recaptured	Study location	Reference
Cod					
<i>Gadus morhua</i>	81,449	16,352	20.1	NW Atlantic	1
Haddock					
<i>Melanogrammus aeglefinus</i>	43,999	2,043	4.6	NW Atlantic	1
Gag					
<i>Mycteroperca micropelis</i>	3,876	435	11	SE Atlantic	2
Brown rockfish					
<i>Sebastes auriculatus</i>	1,453	247	17.0	California	3
Copper rockfish					
<i>Sebastes caurinus</i>	2,828	117	4.1	California	3
Greenspotted rockfish					
<i>Sebastes chlorostictus</i>	56	1	1.8	California	3
Starry rockfish					
<i>Sebastes constellatus</i>	478	18	3.8	California	3
Calico rockfish					
<i>Sebastes dalli</i>	82	0	0.0	California	3
Widow rockfish					
<i>Sebastes entomelas</i>	128	3	2.3	California	3
Yellowtail rock- fish					
<i>Sebastes flavidus</i>	71	5	7.0	California	3
Giant seabass					
<i>Stereolepis gigas</i>	14	2	14.3	California	3

1 – Fowler and Stobo (1999)

2 – McGovern et. al. (2005)

3 – Hanan and Curry (2010)

FIGURES

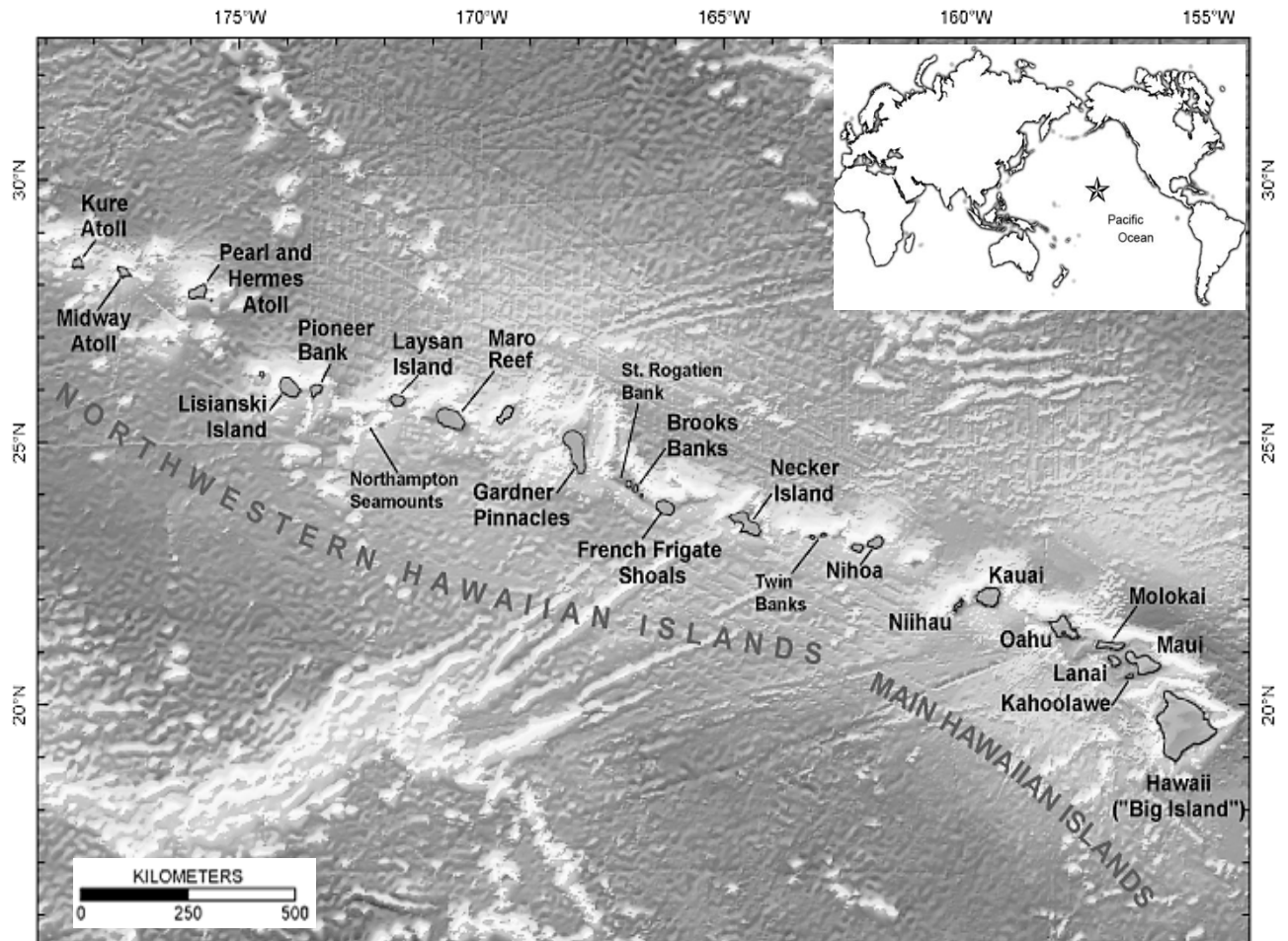


Figure 1.--Map of the Hawaiian Archipelago, including the Northwestern Hawaiian Islands. Contour of Northwestern Hawaiian Islands represents 20-fathom (37 m) curve. Base bathymetric map from Pacific Islands Benthic Habitat Mapping Center, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa.

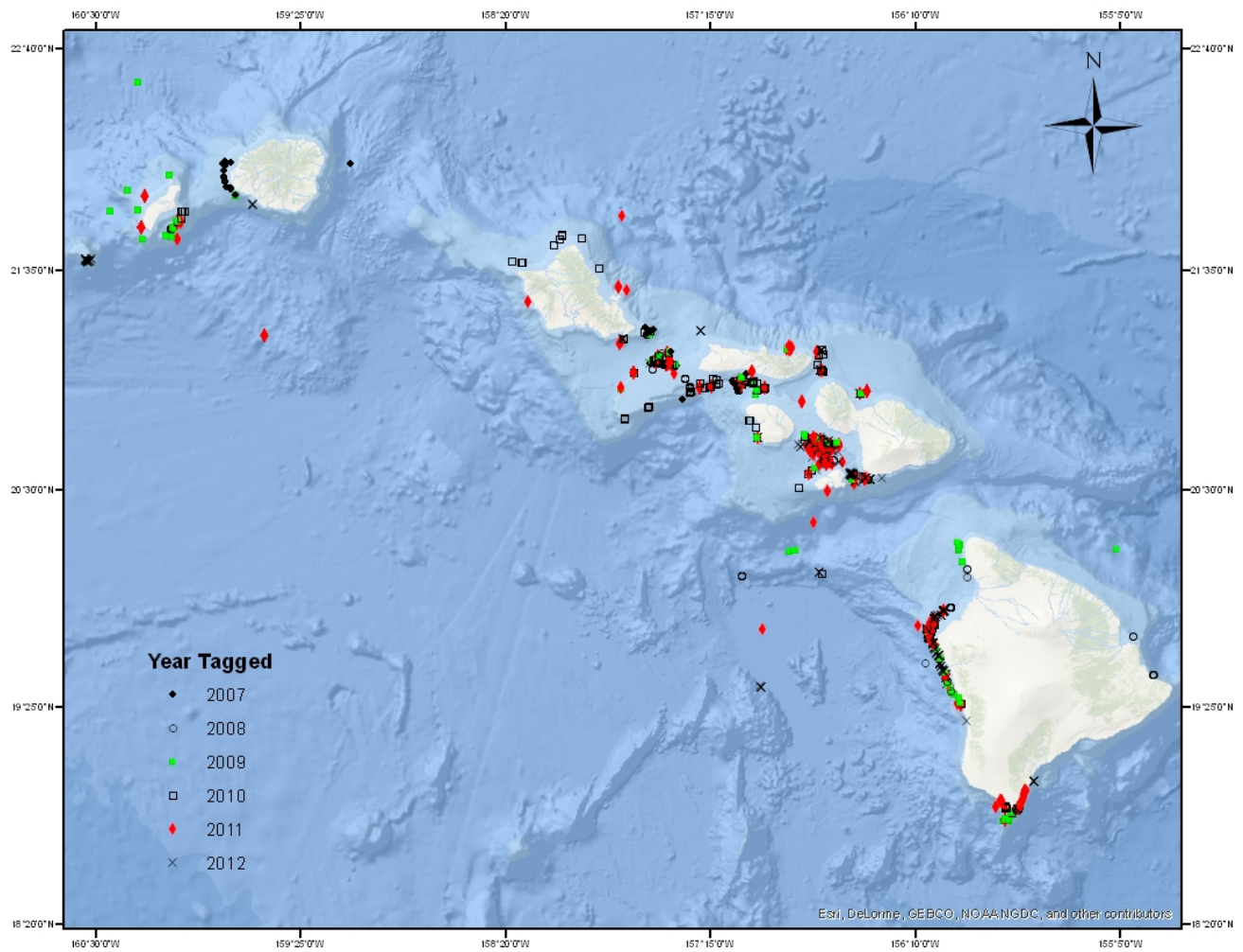


Figure 2.--Locations of all PIFG tagging events in the main Hawaiian Islands 2007-2013.

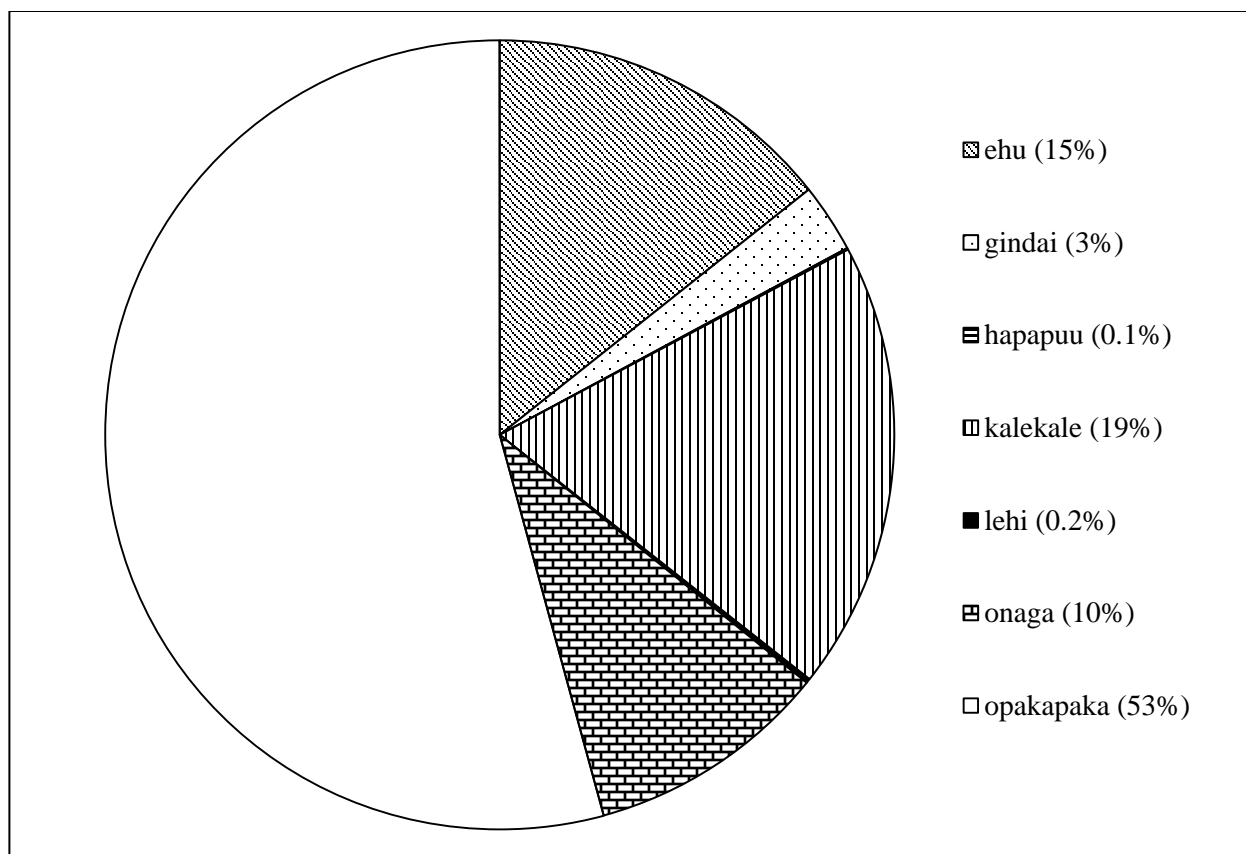


Figure 3.--Percent species composition of Deep 7 Hawaiian bottomfish tagged by the PIFG from 2007 to October 2013.

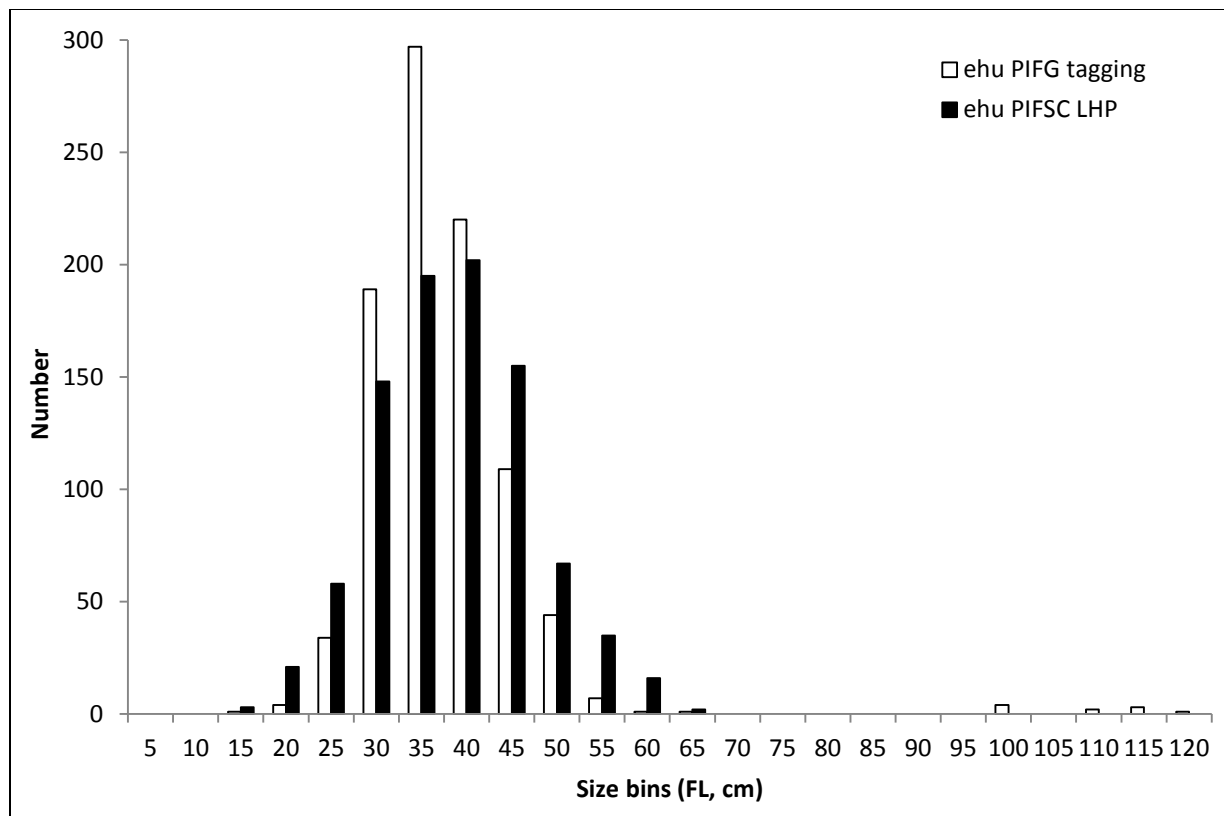


Figure 4.--Size-frequency distributions of MHI ehu tagged by PIFG and observed in PIFSC LHP samples.

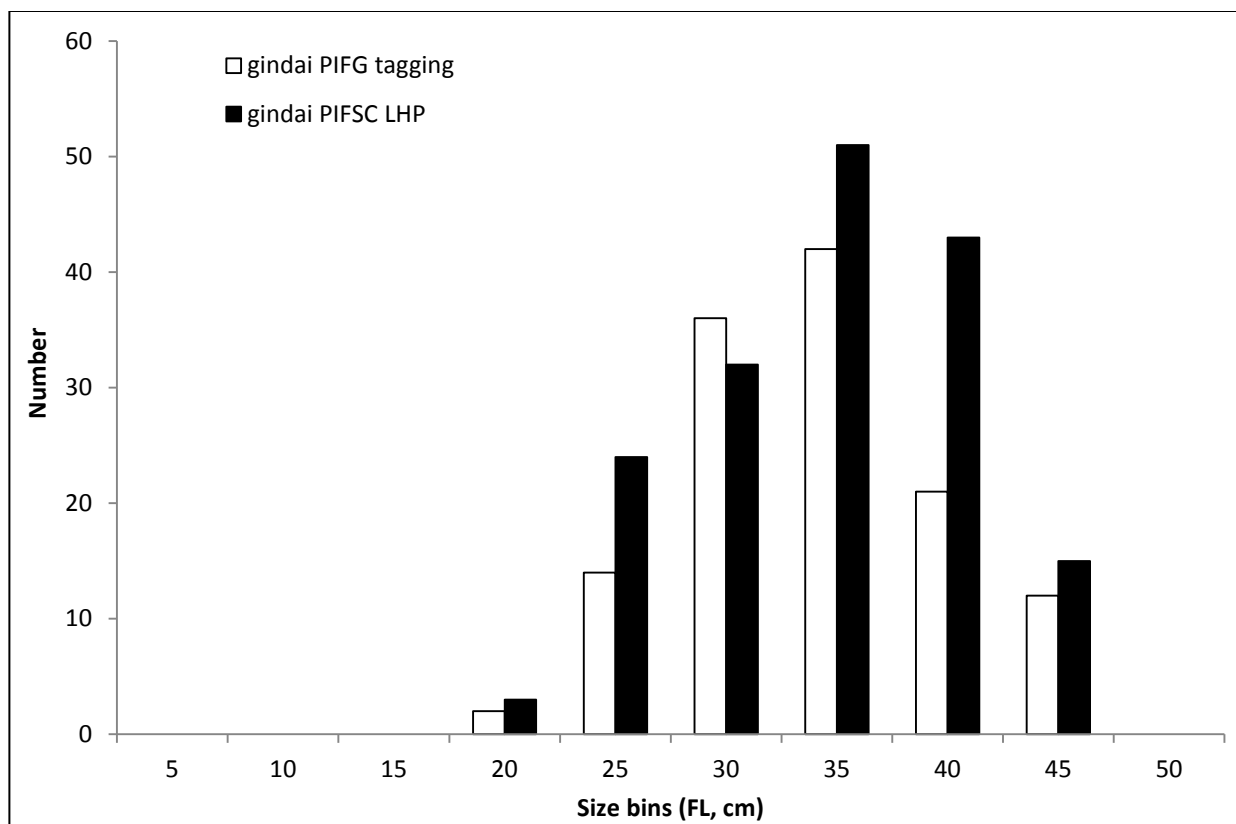


Figure 5.--Size-frequency distributions of MHI gindai tagged by PIFG and observed in PIFSC LHP samples.

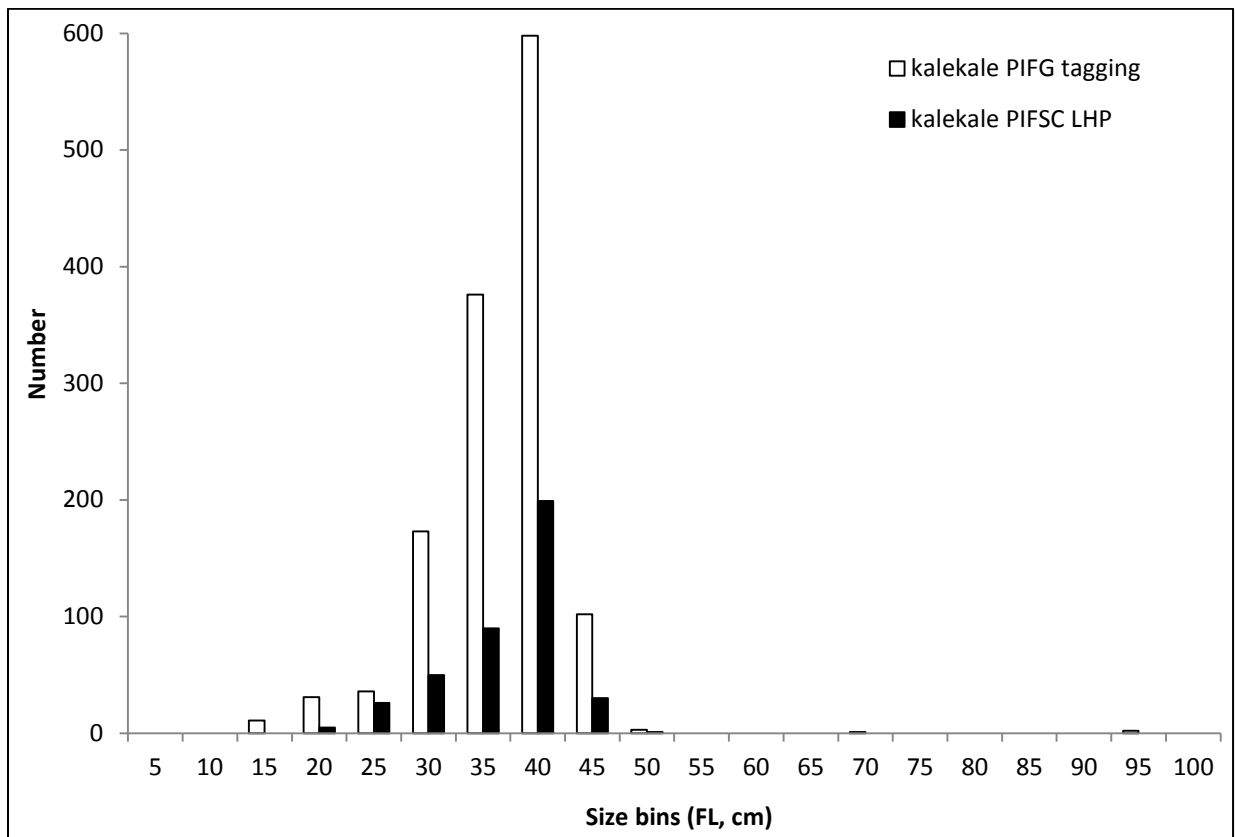


Figure 6.--Size-frequency distributions MHI kalekale tagged by PIFG and observed in PIFSC LHP samples.

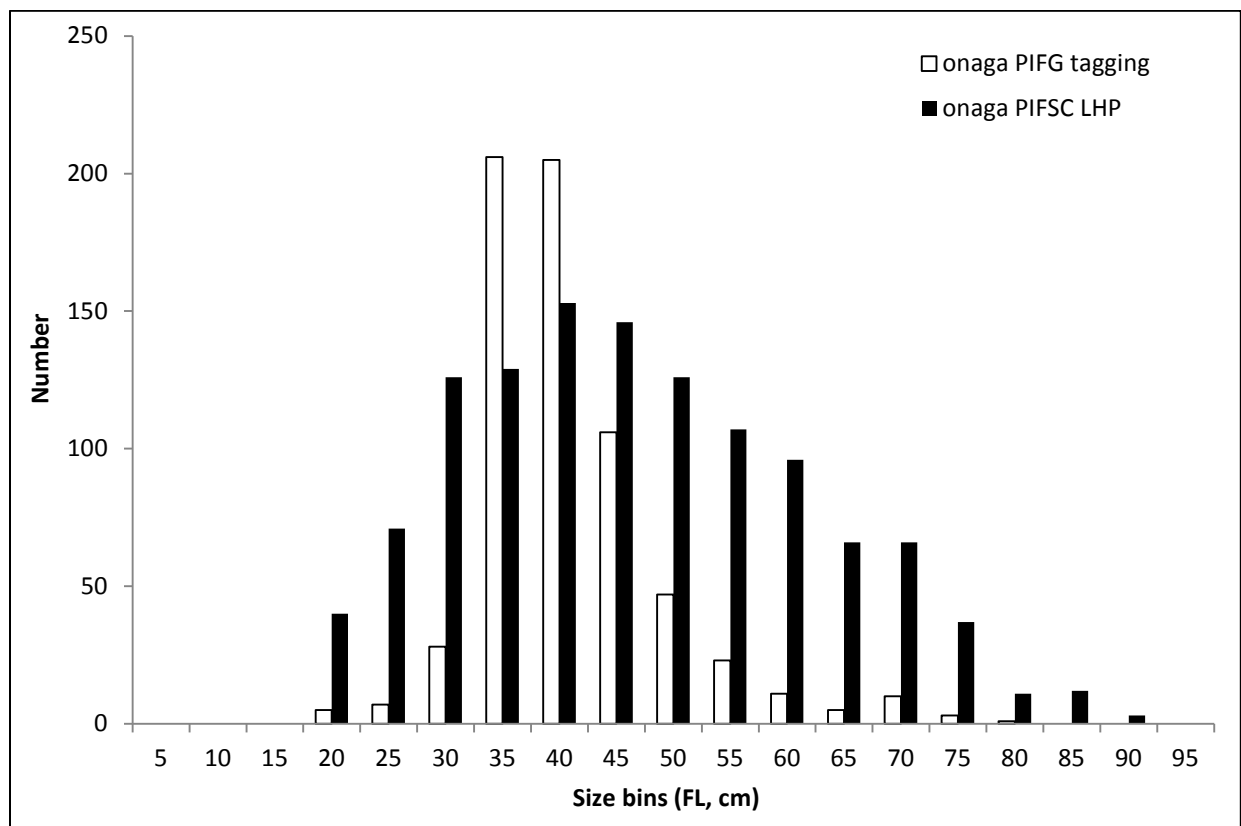


Figure 7.--Size-frequency distributions of MHI onaga tagged by PIFG and observed in PIFSC LHP samples.

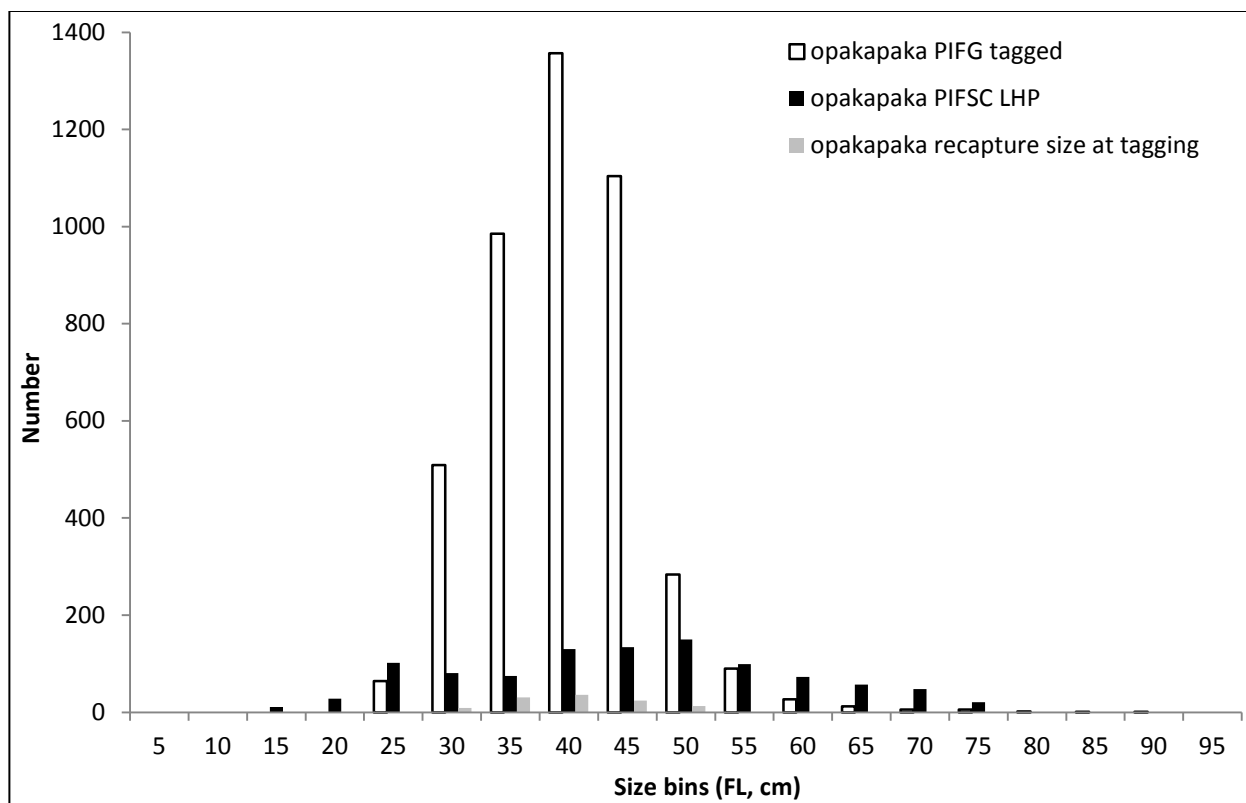


Figure 8.--Size-frequency distributions of MHI opakapaka tagged by PIFG and observed in PIFSC LHP samples, and distribution of size- at-tagging for recaptured opakapaka.

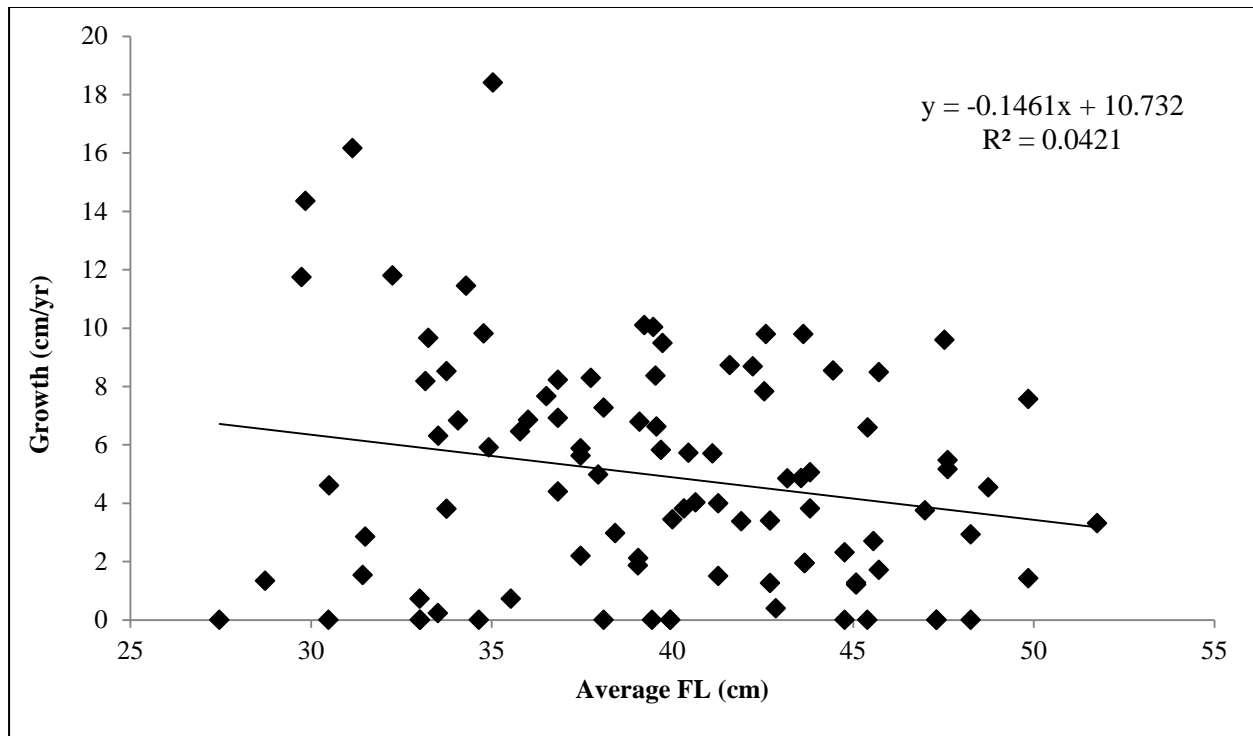


Figure 9.--Gulland and Holt (1959) regression plot between mean fork length (cm) and growth rate (cm/yr) for recaptured MHI opakapaka. Growth parameters are estimated from the numerical value of the slope and the x -axis intercept.

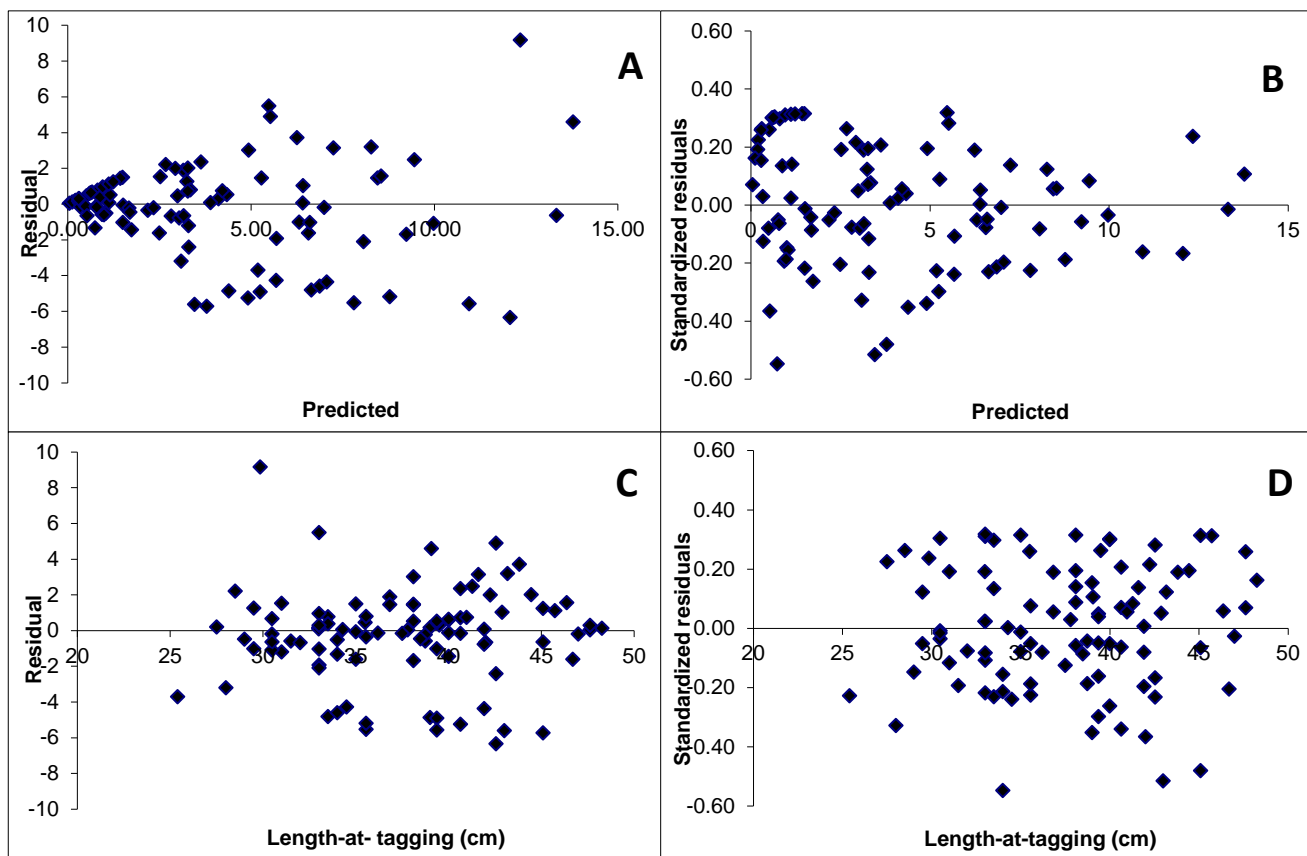


Figure 10.--Plots of best fit von Bertalanffy growth model residuals (observed minus predicted) against **A** predicted growth (cm yr^{-1}) and **C** length-at-tagging (cm) and standardized residuals against **B** predicted growth (cm yr^{-1}) and **D** length-at-tagging (cm) for MHI opakapaka.

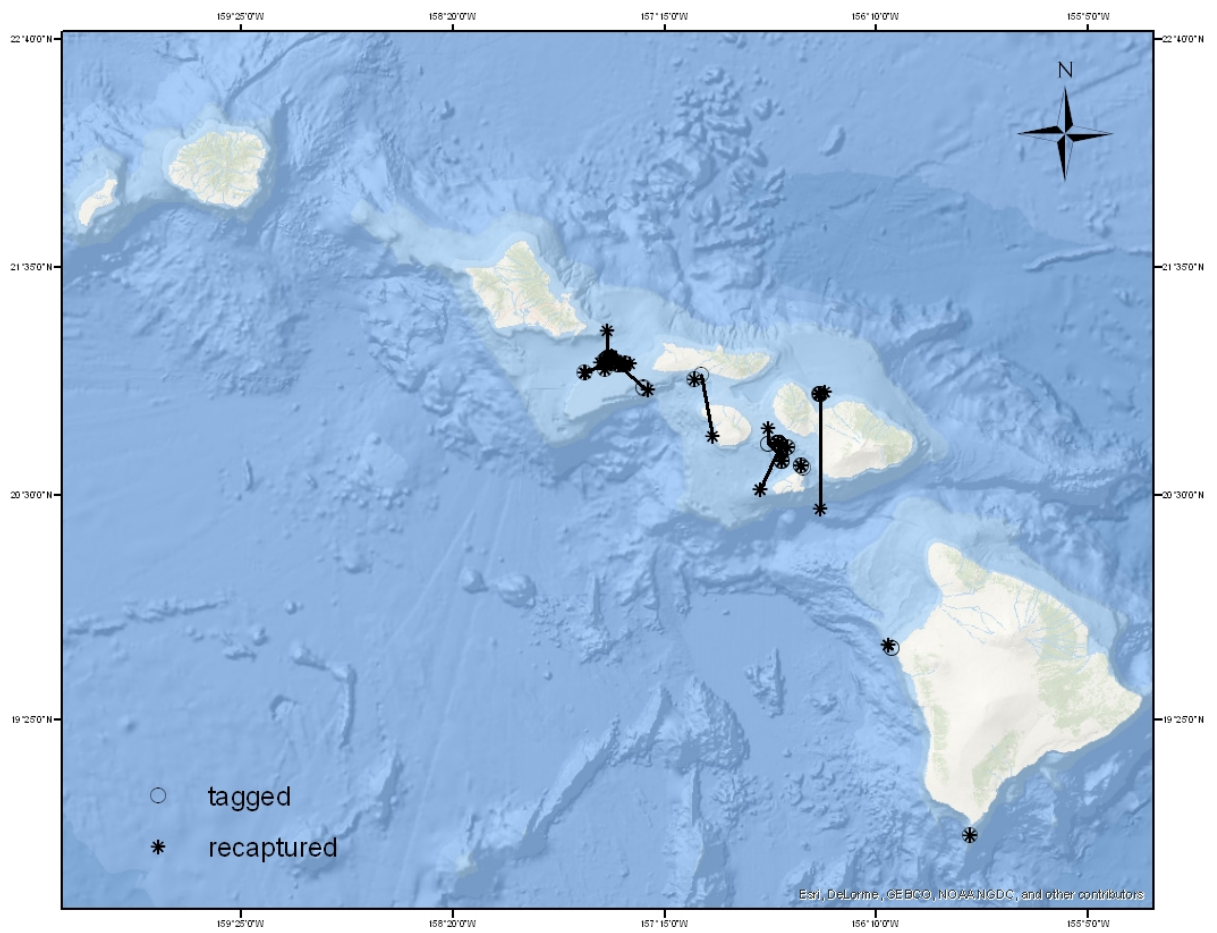


Figure 11.--Map of movement patterns of tagged and recaptured opakapaka in the main Hawaiian Islands.

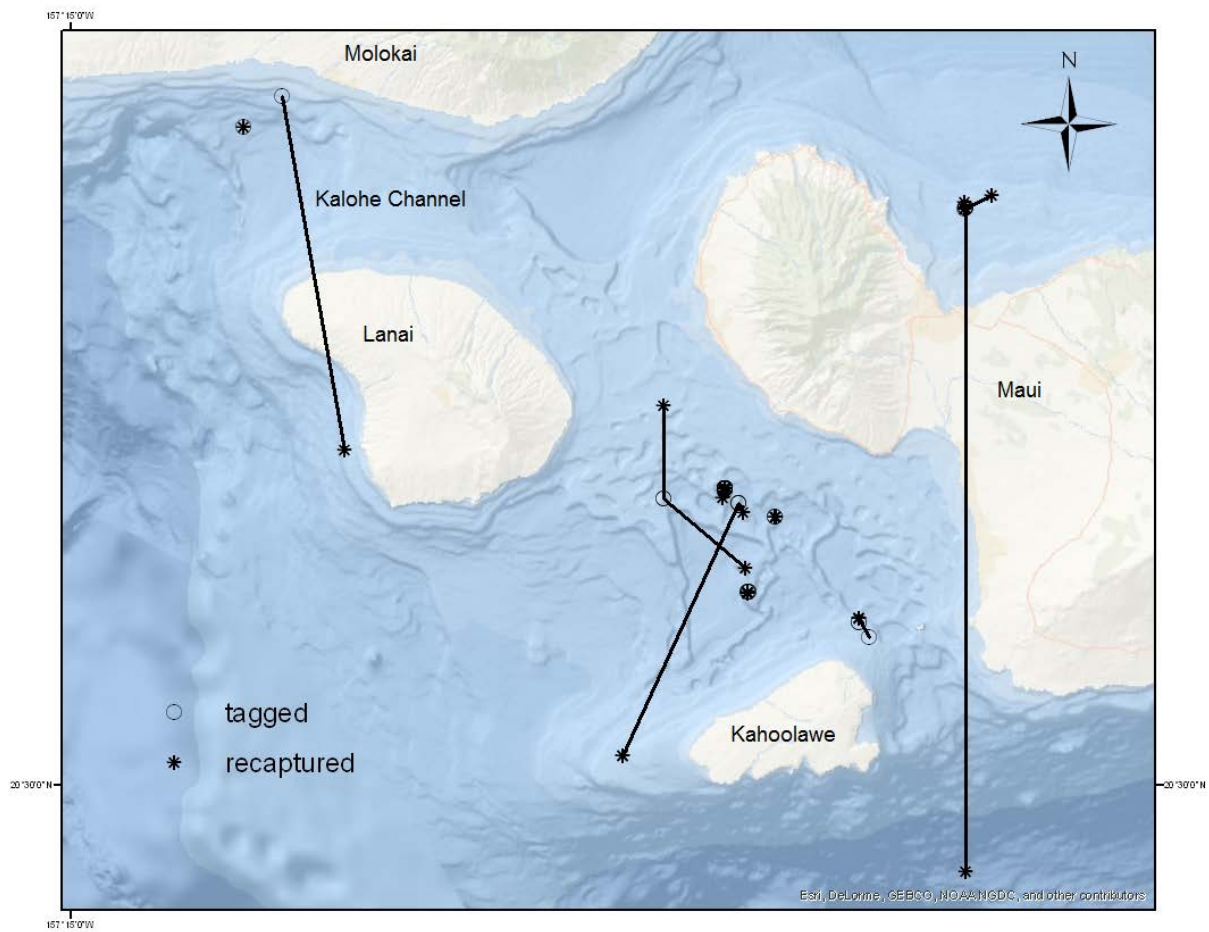


Figure 12.--Close-up of movement patterns of tagged and recaptured opakapaka from the Maui Nui complex.

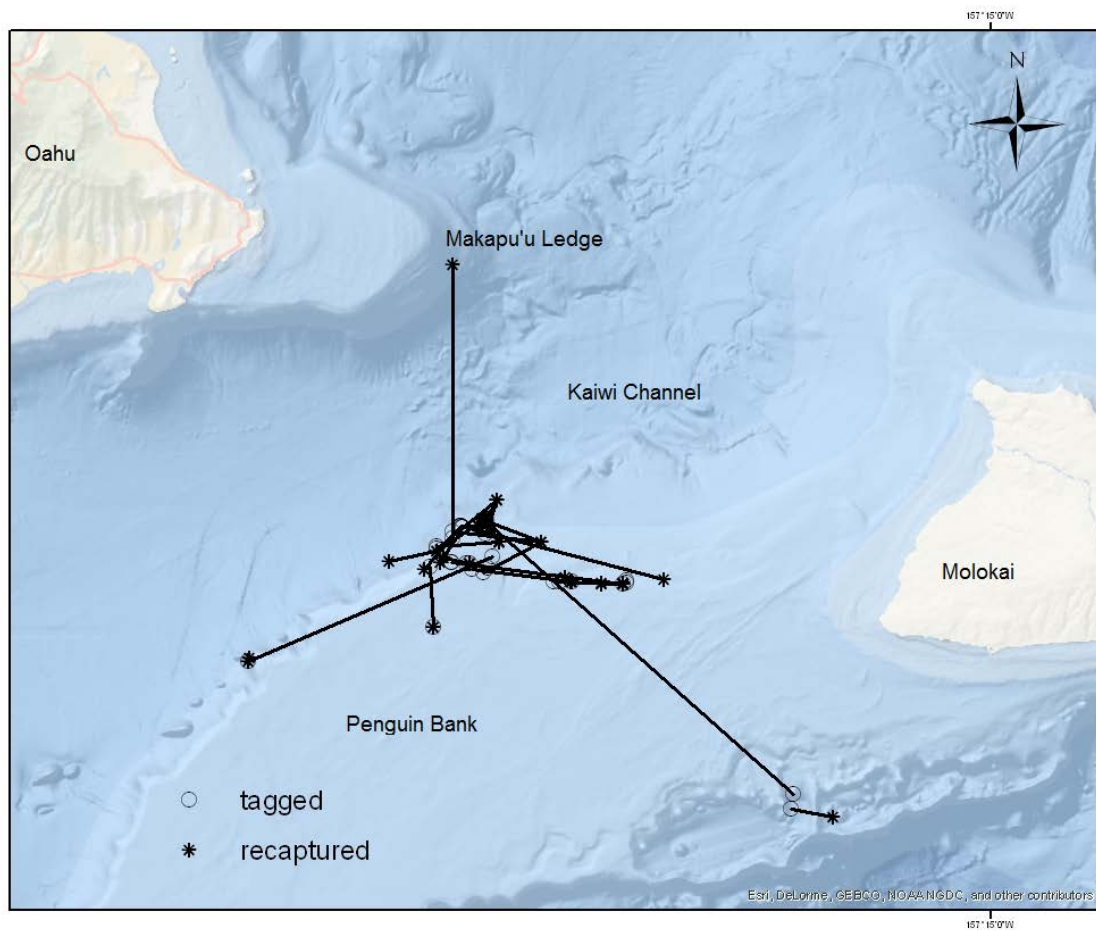


Figure 13.--Close-up of movement patterns of tagged and recaptured opakapaka from Penguin Banks in the Kaiwi Channel.