Implementing a Commercial Fisheries Bio-Sampling Program on Oahu and Maui: Hawaii's Bio-Sampling Program

December 2020

Western Pacific Regional Fishery Management Council
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Cover Photo: Researchers remove gonads while providing outreach on the project to community members at the Kōkua Fishing Tournament in April 2019 (Photo credit: Zachary Yamada)

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HAWAII'S BIO-SAMPLING PROJECT

Final Technical Report

Through the Hawaii Bio-Sampling Program we have measured over 11,000 commercially caught reef fish from markets on Oahu and Maui. We have also sampled over 1,000 fish from 9 species for longevity, growth and reproduction studies. The goal of the Bio-Sampling project is to gather local demography and catch data to better inform stock assessment scientists and fishery managers.

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DECEMBER 2020

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Introduction

Hawai‘i’s nearshore fishery (commercial and non-commercial catch) is valued between 10 to 16 million dollars (Grafeld et al. 2017). Aside from the estimated dollar value of the fishery, the catch provides more than seven million meals annually (Grafeld et al. 2017). The nearshore fishery is composed of many different coral reef associated species from multiple families. Yet Hawai‘i’s nearshore fishery, like most coral reef fisheries, is considered data poor with relatively little information known about the growth and maturity of these commonly caught species. Life history information is a critical component for data limited stock assessments. In a recent Hawaiian stock assessment of 27 commonly targeted coral reef species, 11 species had inadequate or no published growth and maturity information (Nadon 2017). Aside from missing life history information, the commercial catch is also missing catch length data, which is a key component for data-limited stock assessments. The goals of the Bio-Sampling project were to fill the gap of missing life history information for Hawai‘i’s commonly targeted nearshore species as well as attain size at catch data for multiple commercially targeted species.

Methods

Market Sampling

Three Oahu fish vendors were surveyed on a weekly basis from August 2018-July 2019. Three Maui fish vendors were surveyed from June 2019 - August 2019 and from October 2019-November 2019. Sampling in Maui was less consistent due to lack of trained people; June-August were sampled by two local University of Hawai‘i Maui College students trained by PIs and October-November were sampled by students from Kamehameha School- Maui Marine Biology class.

Market sampling took place during normal operating hours. Participating markets were paid $100 a month as an incentive for letting us count, measure, and weigh available reef fish. Market sampling was conducted with a two-person team: one to measure fish, and one to record the data. Species were confirmed to come from Hawaiian based fishermen and not imported from other territories. Fish not easily identified were photographed or purchased and taken to the lab for identification.

A maximum of 100 length and weight samples were taken each month for each species based on market availability. When there were more than 20 fish of the same species at a market, a random sample of 20 fish per species were chosen to measure. For each targeted species, fish were weighed to the nearest gram and measured to the nearest mm fork length (FL). Additionally, market price (USD/pound) for each species was recorded each week.

Average commercial catch length was calculated based on the fork length measurements from local markets. The length and weight measurements for each species was fitted using a power function represented by $W=aL^b$ where weight (W) can be estimated given the length (L) and the two parameters a and b (Schneider et al. 2000).

Life-history sampling

Nine commonly targeted species were selected for further life history studies (Table 1).

Table 1: List of selected species for life history work

Family	Common Name Hawaiian/English	Scientific Name
Acanthuridae	Pualu/Ringtail surgeonfish	*Acanthurus blochii*
Acanthuridae	Palani/Whitespine Surgeonfish	*Acanthurus dussumieri*
Acanthuridae	Na‘ena‘e/Orangebar Surgeonfish	*Acanthurus olivaceus*
Acanthuridae	Pualu/Yellowfin surgeonfish	*Acanthurus xanthopterus*
Acanthuridae	Umaumalei/Orangespine unicornfish	*Naso lituratus*
Carangidae	Ulua aukea/Giant Trevally	*Caranx ignobilis*
Carangidae	Ōmilu/Bluefin trevally	*Caranx melampygus*
Labridae	‘a‘awa/Tableboss	*Bodianus albotaeniatus*
Lethrinidae	Mū /Bigeye Emperor	*Monotaxis gradoculis*

During market sampling (August 2018-July 2019), a subsample of targeted species were randomly selected and purchased for maturity and growth studies based on market availability. Samples continued to be purchased opportunistically from local fish markets on Oahu and Maui from August 2019 through November 2020. Sampling was also supplemented by fishing (spear and hook and line), local tournaments, and donations from local fishermen on both Oahu and Maui.

Samples were measured to the nearest mm FL and weighed to the nearest gram. Paired sagittae otoliths were removed for aging and growth; and gonads were weighed to the nearest milligram and designated macroscopically by sex.

Age and Growth

A single otolith from each fish was randomly selected for aging. The otolith was first weighed to the nearest 0.1mg and compared to age using a linear regression to determine if otolith weight was a good indicator of age. Otoliths were attached to a glass slide so that the sulcul ridge was perpendicular the slide edge and the primordium was slightly inside the edge of the slide using a thermoplastic glue (Crystalbond 509®). A 600-grit diamond lapping wheel with continuous water was used to grind down the otolith until it was in line with the slide edge. The otolith was then removed with heat and flipped so that the newly ground side was attached to the middle of the slide. The otolith was then ground down a second time until a thin (~180-220μm) transverse section encompassing the core was produced. The section was then covered with Crystalbond 509 to improve clarity of the annuli.

Sectioned otoliths were read on a stereomicroscope with reflected and transmitted light. Annuli were identified as alternating translucent and opaque bands along the face of the section and were counted along a consistent axis to estimate age in years. Annual periodicity of otolith bands has been validated for 10 different species of acanthurids including *A. olivaceus* (Choat and Axe 1996). Annuli for each specimen were counted on three separate occasions by at least two different researchers. Final age was determined when at least two counts agreed. If three counts differed by one presumed annulus, the middle age was assigned. A subsample of prepared otoliths were sent to Dr. Brett Taylor for verification on annuli count.

For fish samples less than 100 mm, otoliths were prepared in the same fashion as above and then further polished using a progression of lapping film (9.0, 3.0, and 1.0μm grit) to expose daily growth increments. Age in daily growth increments beyond the settlement ring (Wilson and McCormick 1999) was estimated as the mean of three independent and nonconsecutive age-readings.

The Von Bertalanffy Growth Function (VBGF) was fitted to both sex-specific and combined size-at-age data to estimate growth parameters using the least squares estimation. The VBGF is represented by: $L_t = L_\infty[1 - e^{-K(t-t_0)}]$, where L_t is the mean FL (mm) at age *t* (years), L_∞ is the mean asymptotic FL, *K* is the growth coefficient describing the curvature towards L_∞, and t_0 is the theoretical age at which the FL is equal to zero. Growth between the sexes were compared using a likelihood ratio test (Kimura 1980).

Reproduction

A cross section of fresh gonad lobes were removed and stored in histological cassettes in a 10% buffered formalin solution. Fixed sections of gonad material were imbedded in paraffin wax and cut transversely at 6μm, then stained with hematoxylin and eosin (Sullivan-Brown et al. 2011) at either Hawaii Diagnostic Laboratories in Honolulu, Hawaii or John Burns School of Medicine Histopathology Core Facility at University of Hawaiʻi Manoa. Prepared slides were assessed under a compound microscope with transmitted light to determine the sex and level of reproductive development. Females were classified as: Immature, Developing, Spawning Capable, Actively Spawning, Regressing, and Regenerating following the standardized terminology of Brown-Peterson (2011). Males were classified as either Immature or Mature based on the presence/absence of spermatozoa. A subsample of histology slides were verified by Dr. Eva Schemmel who worked with us on the reproduction analysis for the surgeonfish species.

Size at maturity (L_{50}) was estimated using a logistic regression analysis and fitting the FL as the explanatory variable to the stage of maturity (immature 0, mature 1) as the binomial response variable. The regression was fitted using a binomial GLM (R Core Team 2019). Confidence intervals for size at maturity were derived by bootstrap resampling (1,000 iterations).

Reproductive investment with size was assessed through the gonadosomatic index:

$$GSI = \frac{gonad\ weight\ (g)}{gonad\ free\ body\ weight\ (g)} \times 100$$

GSI was compared across collection months along with the frequency of spawning capable and actively spawning females to identify the spawning season.

Mortality

Age-based catch curves (Ricker 1975), using age distributions of samples from markets and tournaments, were applied to find the total mortality (Z). If a zero-value existed in an age class, it was omitted from the catch-curve analysis. A line was fitted to the natural log of the number of fish per age class versus the corresponding age starting when the fish had fully entered the fishery. The absolute value of the slope of the fitted line represents Z.

Species from the *Acanthuridae* family were also tested for a biphasic mortality schedule, which have previously been described for the genus *Naso* (*N. unicornis* and *N. lituratus*) from multiple regions across the Pacific (Taylor et al. 2019; Pardee et al. 2020). A breakpoint analysis was used to determine the optimal age at which mortality schedules shift. BIC and RSS were compared for a normal mortality schedule (without breaks) and a biphasic mortality schedule (with a single break) to determine which mortality type had the best fit for the age data. For the biphasic mortality schedule, Z was calculated using a segmented analysis that generated a single two-phase model joined at the optimized breakpoint age (Muggeo 2020).

We are currently in different stages of analysis for each of the nine species. Age, growth, and reproduction methods will be the same for all species but as of December 2020 only *A. blochii*, *A. dussumieri*, *A. olivaceus*, and *A. xanthopterus* have been completed.

Results & Discussion

Market Sampling

The length and weight for over 11,000 local reef fish were measured during the market sampling. A total of 70 different species were assessed in the Oahu and Maui markets, which encompassed 17 different families. Five species groups composed over 70% of the commercial catch surveyed in both the Oahu and Maui markets: weke (*Mulloidichthys vanicolensis* and *Mulloidichthys flavolineatus*), ‘ū‘ū (*Myripristis berndti* and *Myripristis amaena*), palani/pualu (*Acanthurus dussumieri*, *Acanthurus blochii*, *Acanthurus olivaceus*, and *Acanthurus xanthopterus*), ta‘ape (*Lutjanus kasmira*), and manini (*Acanthurus triostegus*) (Figure 1). The introduced ta‘ape was the most common in Oahu, while manini was the most common in the Maui markets.

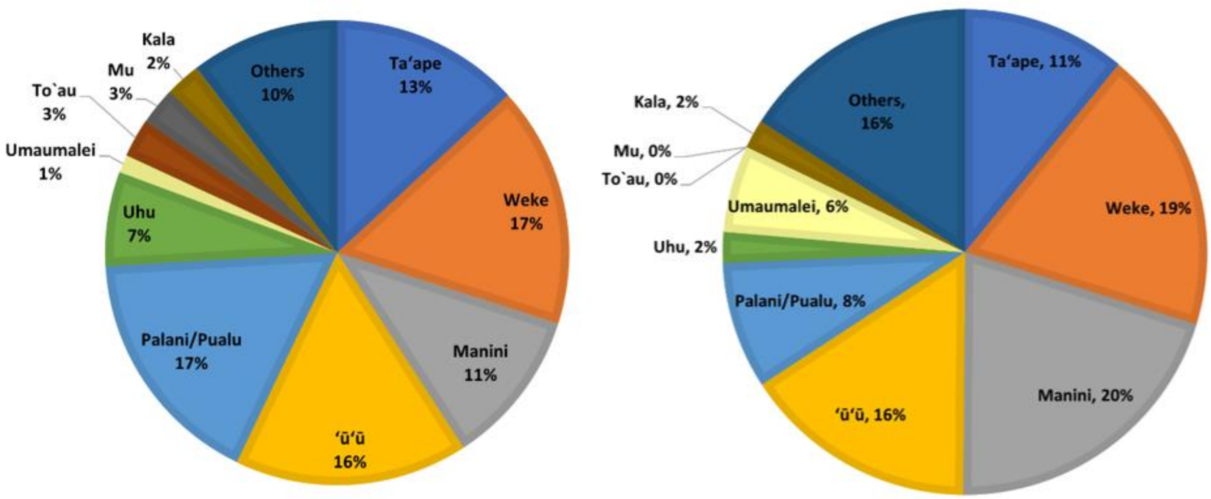

Figure 1: Percentage of number of fish sampled in the Oahu markets (Left) and Maui markets (Right)

The Maui fish markets were much less consistent than markets on Oahu. Maui markets were highly dependent on when fishermen had fish to sell. Many weeks the markets had no new fish to measure. Fish in the Maui markets were significantly larger and more expensive than Oahu (Figure 2).

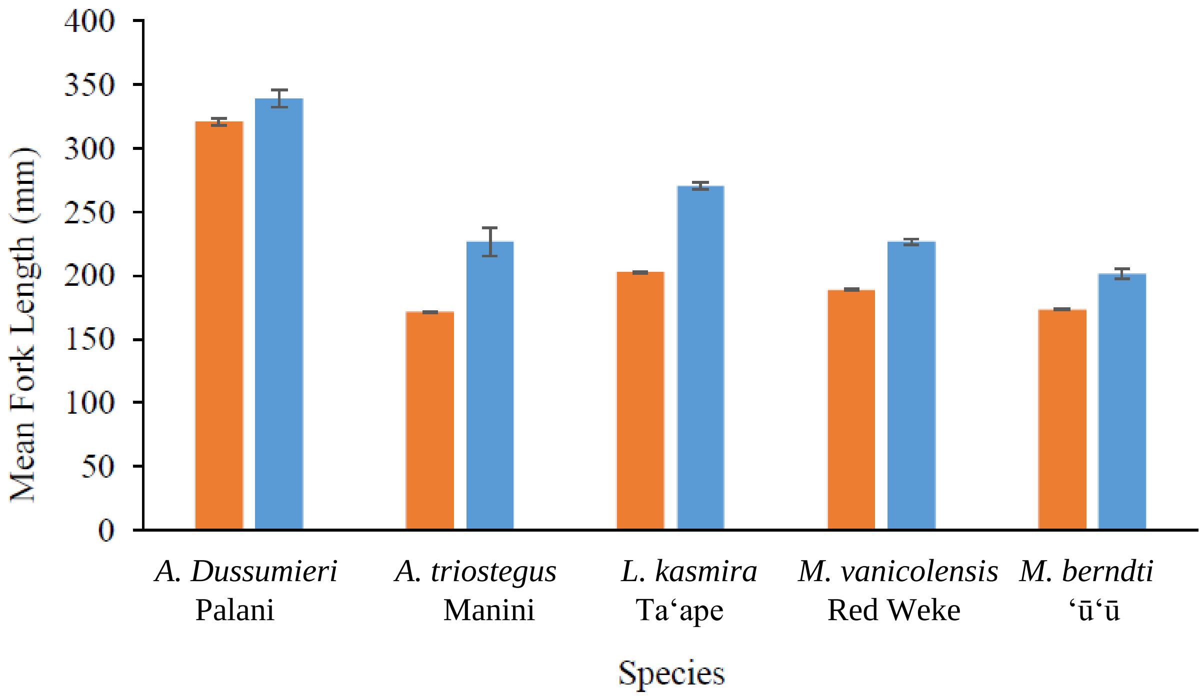

Figure 2: Comparison of Mean Fork Length (mm) between Oahu (orange bars) and Maui (blue bars) markets for the five most represented species.

We assessed temporal trends in species prevalence and price across months for Oahu but did not find any significant trends in the market data. Based on personal observations, during weeks of bad weather, there were less fish in the markets, but these observations did not show up on a monthly scale.

Market survey data was compared to the 2018 Commercial Marine License (CML) catch reports produced by the Division of Aquatic Resources (Hawaii Division of Aquatic Resources 2018). Percent of weight by species to total reef fish caught by weight was compared between data sets. Most species were within five percent between market surveys and the reported commercial catch data (Figure 3).

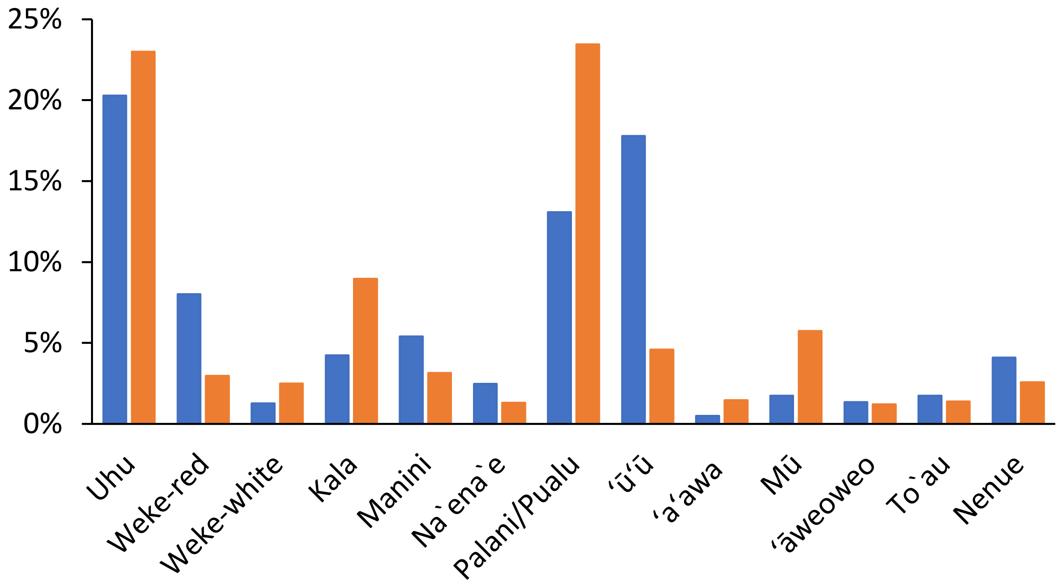

Figure 3: Comparison of market sampling data (orange) to 2018 CML catch reports (blue). Catch is represented by percentage of species weight to total catch weight. Species are by common name as they are reported in the CML records. Uhu, Nenue, u‘u, kala, and Palani/Pualu all represent species complexes and not a single species.

The ‘ū‘ū (*Myripristis* sp.) was the only case where commercial reporting was over 10% larger than market surveys. This can be explained due to the large quantities of ‘ū‘ū in the markets. Our market methodology called for only sampling 20 individuals of each species per market per week. Therefore, we missed the weights on a larger proportion of *Myripristis* spp. than we did for other species. Palani/Pualu (*Acanthurus* spp.) was 10% greater for the market sampling than the commercial catch reports; this may be due to sampler bias since the Acanthuridae family was targeted for life history studies. The bias may also be due to under reporting for that family.

Market surveys preformed for this study gave us the ability to obtain species specific size and length data for many different species that are normally all reported and sold under a species complex common name. For example, surgeonfish (*A. blochii*, *A. xanthopterus*, and *A. dussumieri*) are usually all sold and reported together under the common name Palani, while all seven parrotfish species (Family Scaridae) are reported and sold under the common name Uhu. There are many more examples of species grouping in the commercial reports.

The CML reports do not have individual size measurements so the best that can be assessed from the CML reports is an inferred size from the number of pounds caught divided by the number of pieces. Average catch size from this market sampling coupled with the local demographic data gained from these studies will better inform stock assessment scientists and local managers for future length-based stock assessments and management rules. Average commercial catch size along with length weight relationships for 20 of the most observed species can be found in Appendix 1.

Life-History

In total we sampled 1,402 fish from the nine selected species. Out of the total samples: 62% were purchased from markets; 27% came from tournaments on Oahu and Maui; 7% were self-caught (spear and hook and line); and 4% were donated from local fishers, Division of Aquatic Resources (DAR), Conservation International or University of Hawaiʻi. Table 2 gives the samples size (N) and size range for each of the nine species.

Table 2: Sample size (N) and minimum, maximum and average FL (mm) for selected species for life-history work.

Scientific Name	N	Min	Max	Average
Acanthurus blochii	149	59	390	264
Acanthurus dussumieri	165	109	481	305
Acanthurus olivaceus	189	118	321	219
Acanthurus xanthopterus	195	25	554	324
Naso lituratus	62	78	316	206
Caranx ignobilis	94	287	1220	727
Caranx melampygus	167	209	794	391
Bodianus albotaeniatus	151	180	461	321
Monotaxis gradoculis	151	118	528	349

The majority of *C. ignobilis* and *C. melampygus* came from tournaments on Oahu and Maui. Both the Carangidae species have a minimum size limit of 10 inches (254 mm), therefore we are working with DAR to obtain samples under the legal-size limit. DAR has also given us 139 otolith samples (not listed in Table 2) from both *C. ignobilis* and *C. melampygus* collected between 2009 and 2012 to help with the age and growth. For both *C. ignobilis* and *C. melampygus* we were also missing some of the largest size classes in our sample size. To get the largest samples, we held a virtual tournament from September to October of 2020 looking for *C. ignobilis* over 50 lbs (22,680 g) and *C. melampygus* over 10 lbs (4,536 g). During the tournament we had 21 entries from fishermen on both Oahu and Maui and raised a lot of awareness of the Bio-Sampling project.

Naso lituratus has the fewest collected samples to date. Sampling for *N. lituratus* did not begin until January of 2020 but we hope to continue collecting more samples through fishermen donations in the upcoming months to get to a minimum sample size of 100. There have been two other demography studies of *N. lituratus* one from Guam and one from American Samoa (Taylor et al. 2014; Pardee et al. 2020) that we hope to compare age and growth with in the future.

Aside from *N. lituratus*, these demographic studies will provide the first growth, maturity, and longevity parameters for most of these species in Hawai‘i. The four Acanthurid studies only had one other age study from the Great Barrier Reef (GBR) with smaller sample sizes and no published maturity information (Choat and Robertson 2002). The Carangids both had a growth and maturity study done in Hawai‘i the 1990’s but it had small samples sizes and the age and growth was suspect (Sudekum et al. 1991). More recently a maximum age study for *C. ignobilis* was published but it did not include growth parameters or maturity information (Andrews 2020). There have been no growth, longevity, or maturity studies worldwide for both the endemic *B. albotaeniatus* or the heavily targeted *M. grandoculis.*

Age

We aged over 1,000 otoliths from 8 of the selected species (Table 3), *N. lituratus* has not yet been aged.

Table 3: Sample size (N) of otoliths currently aged for each species with maximum and average ages along with maximum published age from the literature.

Species	N	Max Age	Avg. Age	Published Age	Published Source
Acanthurus blochii	149	26	6	35	Choat & Robertson 2002
Acanthurus dussumieri	165	30	6	28	Choat & Robertson 2002
Acanthurus olivaceus	189	14	4	33	Choat & Robertson 2002
Acanthurus xanthopterus	195	29	5	34	Choat & Robertson 2002
Caranx ignobilis	73	30	9	25	Andrews 2020
Caranx melampygus	132	24	5	7	Sudekum et al 1991
Bodianus albotaeniatus	60	22	5	-	
Monotaxis grandoculis	90	23	7	-	

All species deposited clearly defined annuli signified by alternating translucent and opaque bands characteristic of otolith patterns previously identified for Acanthurids, Carangids, Labrids, and Lethrinids in multiple regions including Hawaiʻi (Figure 4) (Choat and Axe 1996; Grandcourt et al. 2010; Taylor et al. 2014; Andrews et al. 2016; Andrews 2020).

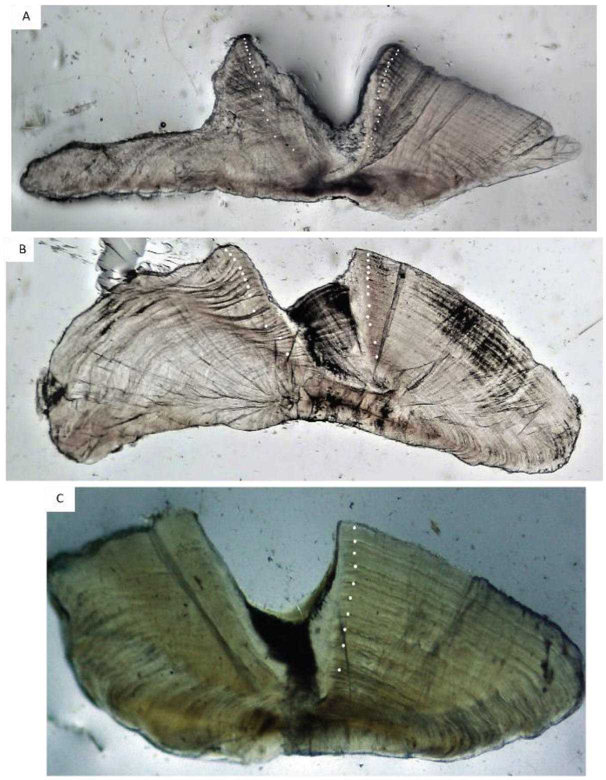

Figure 4: Pictographs of otoliths from three different species: A) *Caranx ignobilis* B) *Acanthurus blochii* and C) *Bodianus albotaeniatus*. Dots reference annuli

Acanthurus Age and Growth

Otolith wight was a strong predictor of age for all four species: *A. blochii*, *A. dussumieri*, *A. olivaceus*, and *A. xanthopterus* (Figure 5). The relationship between otolith weight (otowt) and age was best explained by a standard quadratic equation. Equations are as follows: *A. blochii* age = 2958.3(otowt)^2 + 53.7(otowt) + 1.02 (r^2=0.90); *A. dussumieri* age = 2518.3(otowt)^2 + 12.1(otowt) + 1.65 (r^2=0.89); *A. olivaceus* age = 3238.7(otowt)^2 + 168.3(otowt) – 0.26 (r^2=0.79); *A. xanthopterus* age = 650.1(otowt)^2 + 115.4(otowt) + 0.25 (r^2=0.87). The relationship between otolith weight and age was not significantly different between sexes for the three species.

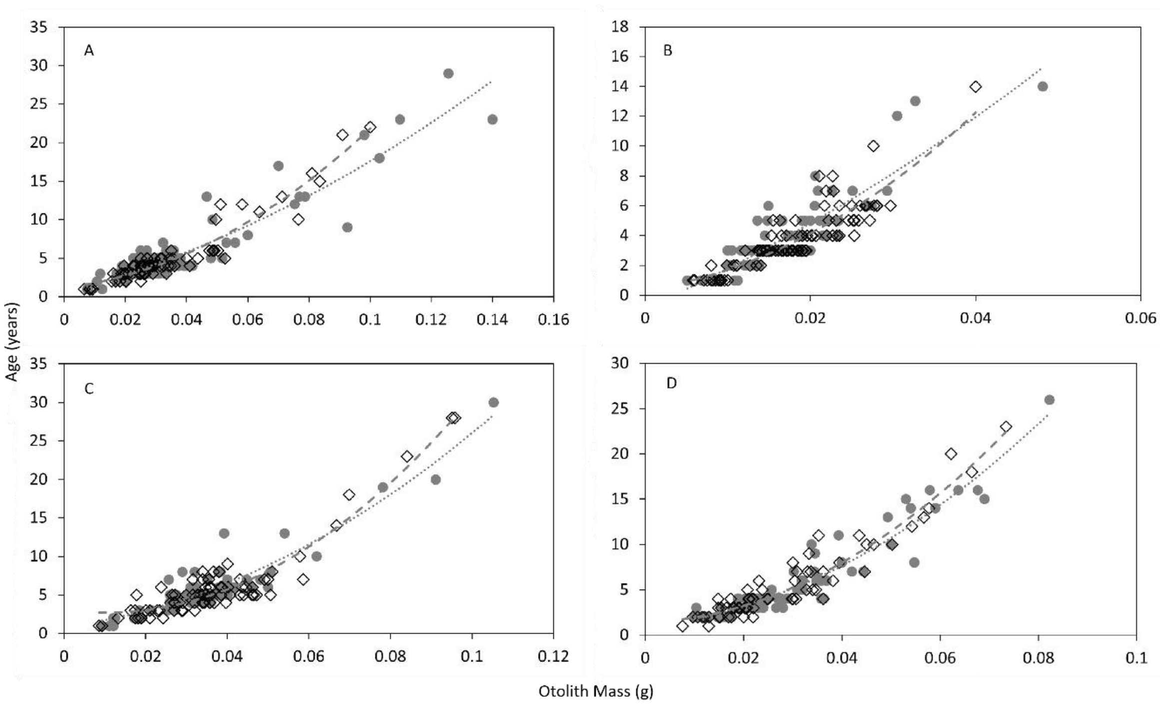

Figure 5: Sex specific relationship between sagittal otolith weight (g) and age for A) *Acanthurus blochii*, B) *Acanthurus dussumieri*, C) *Acanthurus olivaceus*, and D) *Acanthurus xanthopterus*. Open diamonds and gray dashed lines represent males, closed circles and gray dotted line represents females.

Females achieved the largest maximum age for each species except *A. olivaceus* which had both female and male at maximum age of 14 years. Sex specific maximum ages for each species were 26 and 23 for *A. blochii* females and males respectively; 30 and 28 for *A. dussumieri* females and males; and 29 and 22 for *A. xanthopterus* females and males.

Combined sex von Bertalanffy growth parameter values L_∞ and K for each species were as follows: *A. blochii* L_∞= 354 mm and K = 0.27 year^{-1}; *A. dussumieri* L_∞= 367.0 mm and K = 0.40 year^{-1}; *A. olivaceus* L_∞= 248.9 mm and K = 0.87 year^{-1}; and *A. xanthopterus* L_∞= 491 mm and K = 0.24 year^{-1}. Sex specific von Bertalanffy growth models can be found in Table 4. The likelihood ratio test (Kimura 1980) demonstrated that growth profiles for *A. blochii* (χ^2 = 2.84) and *A. xanthopterus* (χ^2 = 4.19) were not significantly different (p-value=0.417 and 0.242 respectively) between females and males (Figure 6A & 6D). However, *A. dussumieri* (χ^2 = 8.10) and *A. olivaceus* (χ^2 = 38.86) did have significantly different growth profiles between females and males (p-value 0.04 and < 0.001 respectively) (Figure 6B &6C).

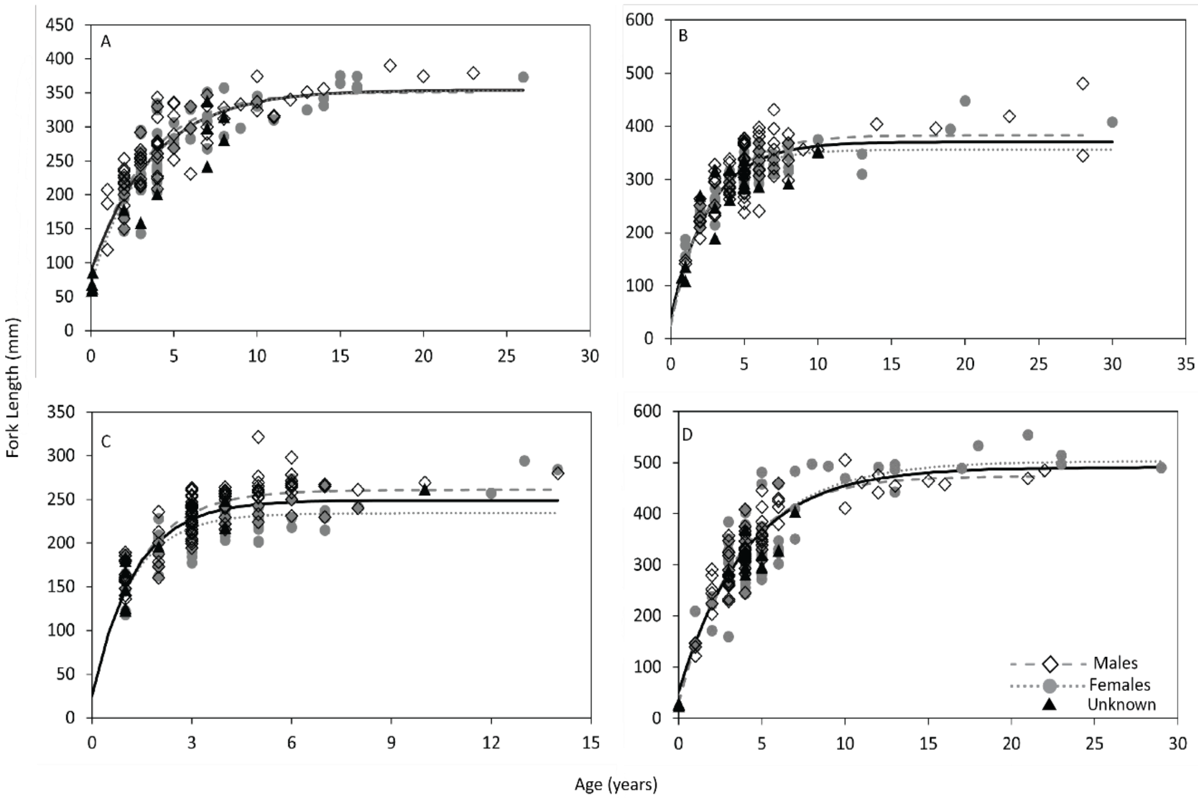

Figure 6: Sex specific and combined von Bertalanffy growth curves for A) *Acanthurus blochii*, B) *Acanthurus dussumieri*; C) *Acanthurus olivaceus*, and D) *Acanthurus xanthopterus*. Open diamonds=males, closed circles = females, black triangles=unknown sex, gray lines represent best fit growth curve for males (dashed) and females (dotted). Solid line represents combined best fit curve for both sexes. See Table 4 for parameter estimates.

Three of the four Acanthurids studied in this project had similar longevities to those aged in the Great Barrier Reef (GBR). Both Hawai‘i and the GBR have similar sea-surface temperatures which is a significant factor in determining the life-span of species (Munch and Salinas 2009; Taylor et al. 2019). The main outlier in terms of longevity was *A. olivaceus*. The maximum age calculated in this study for *A. olivaceus* was 14 years, half that of the other three species and 21 years less than the estimate from the GBR. Based on longevities of other Acanthurids from Hawai‘i and around the Pacific, *A. olivaceus* may live longer than this study found, but the oldest individuals may not have been captured during the sampling process.

Table 4: Summary of life-history traits for four commonly targeted Acanthuridae species of Hawaiʻi.

		L_∞ (mm)	K (year^{-1})	t_0 (year)	N aged	LWa	LWb	L_{50}	A_{50}
Acanthurus blochii	Female	353.0 (333-372)	0.28 (0.22-0.35)	-0.76	68			209.3 (204.8-222.5)	2.4 (2.1-2.8)
	Male	351.4 (333-378)	0.31 (0.22-0.39)	-0.82	69			203.5 (197.3-206.2)	1.6 (1.4-2.0)
	Combined	354.4 (339-370)	0.27 (0.22-0.32)	-1.05	149	4.71E^{-5} (3.5E^{-5}-6.6E^{-5})	2.91 (2.85-2.96)	200.0 (196.5-210.7)	1.5 (1.2-2.3)
Acanthurus dussumieri	Female	356.1 (341-369)	0.42 (0.3-0.49)	-0.17	65			269.0 (267.2-273.8)	3.0 (3.0-3.5)
	Male	383.0 (361-404)	0.38 (0.31-0.44)	-0.18	80			205.6 (194.8-226.5)	2.0 --
	Combined	367.0 (354-379)	0.40 (0.36-0.45)	-0.18	165	2.95E^{-5} (2.9E^{-5}-4.1E^{-5})	2.99 (2.94-3.06)	269.0 (267.1-274.1)	2.0 (1.9-2.4)
Acanthurus olivaceus	Female	234.1 (226-242)	0.86 (0.73-0.99)	-0.13	78			165.7 (163.5-175.0)	1.0 (0.7-1.6)
	Male	260.8 (253-268)	0.73 (0.65-0.82)	-0.14	100			138.0 (130.0-165.2)	1.0 (0.9-1.5)
	Combined	248.9 (243-254)	0.78 (0.72-0.86)	-0.14	189	1.16E^{-5} (5.2E^{-6}-2.2E^{-5})	3.16 (3.04-3.31)	155.1 (150.9-165.3)	1.0 (0.8-1.3)
Acanthurus xanthopterus	Female	503.0 (472-543)	0.24 (0.20-0.29)	-0.42	100			233.7 (226.3- 254.8)	2.1 (1.9-2.9)
	Male	474.3 (449-499)	0.29 (0.24-0.33)	-0.23	76			236.6 (229.5-262.5)	2.2 (2.0-3.0)
	Combined	491.0 (469-513)	0.25 (0.22-0.28)	-0.44	195	3.56E^{-5} (2.9E^{-5}-4.6E^{-5})	2.95 (2.91-2.99)	235.2 (230.1-250.0)	2.2 (2.0-2.5)

Notes: Associated 95% confidence intervals presented in parentheses where appropriate. L_∞ asymptotic length; *K* growth coefficient; t_0 hypothetical age when length equals zero; *n* aged number of specimens used in age analysis; *LWa LWb* parameters for length weight relationship. * *Acanthurus dussumieri* and *Acanthurus olivaceus* growth models were both constrained at 25 mm.

A 2016 Hawaii stock assessment calculated the *A. blochii* stock to be overfished/ overfishing based on the Spawning Potential Ratio using average catch length and inferred life history parameters from the GBR (Nadon 2017). However, average capture size used in the assessment was set at 299 mm, 10 mm smaller than the average catch size this study found from a year of market sampling. The assessment also used an L_{50} 60 mm larger than what was calculated in this study, and an L_{∞} 10 mm larger than this study. Using the localized data could potentially change the stock status of *A. blochii.*

Reproduction

In total 691 gonad samples have been staged and read for 8 species following the standardized terminology for Brown-Peterson et al (2011) (Figure 7). Table 5 shows the number of samples analyzed to date and the number of female and male samples for each species.

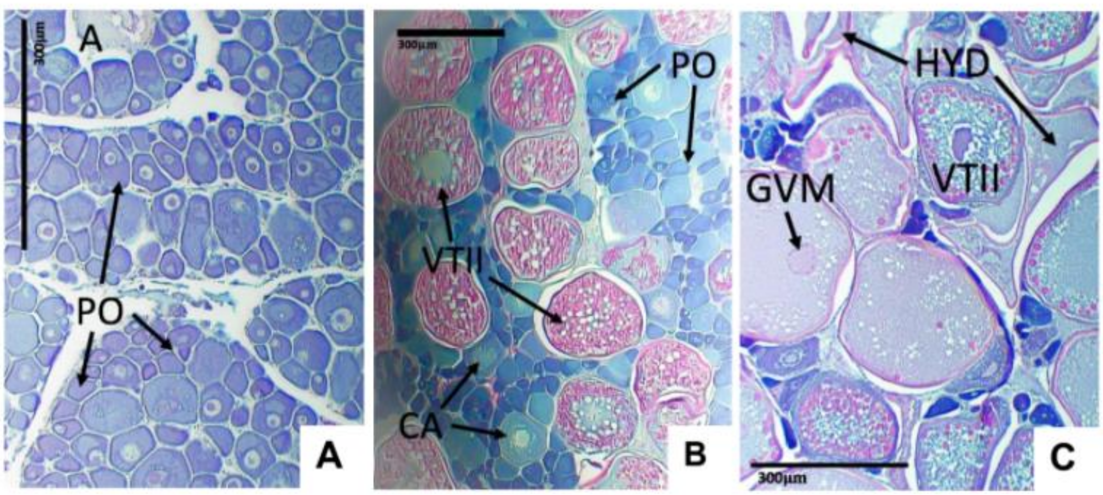

Figure 7: Microscopic photographs of ovarian phases for *Acanthurus olivaceus*. A) Regenerating Phase A=Atresia, PO= Primary oocytes B) Developing oocytes; VTII= stage II vitellogenic oocytes, CA= Cortical alveolar C) Actively spawning Female; GVM=Germ Vesicle migration, HYD= Hydrated oocytes.

Table 5: Processed gonad samples for selected species and corresponding published size at maturity (L_{50}).

Species	F	M	Published L_{50}	Source
Acanthurus blochii	64	39	276*	Nadon -unpublished
Acanthurus dussumieri	53	42	282*	Nadon-unpublished
Acanthurus olivaceus	91	62	180	Choat & Robertson 2002
Acanthurus xanthopterus	92	45	-	
Caranx ignobilis	11	13	839	Sudekum 1991
Caranx melampygus	44	33	476	Sudekum 1991
Bodianus albotaeniatus	34	12	-	
Monotaxis grandoculis	20	35	389*	Nadon & Ault 2016

* L_{50} were derived using a stepwise approach with other life history parameters

Acanthurus Reproduction

Female size (L_{50}) and age (A_{50}) at maturity for each species was 209 mm (205-223 mm 95% CI) and 2.4 years (2.1-2.8 years 95% CI) for *A. blochii*; 269 mm (267-274 mm 95% CI) and 3 years (3.0-3.5 years 95% CI) for *A. dussumieri*; 166 mm (164-175 mm 95% CI) and 1 year (0.7-1.6 years 95% CI) for *A. olivaceus*; and 234 mm (227-255 mm 95% CI) and 2.1 years (1.9-2.9 years 95% CI) (Table 4 & Figure 8).

Males reached maturity at a smaller size than females except for *A. xanthopterus.* Male size and age at maturity was as follows: 204 mm (197-206 mm 95% CI) and 1.6 years (1.4-2.0 years 95% CI) for *A. blochii*; 206 mm (195-227 mm 95% CI) and 2 years for *A. dussumieri*; 138 mm (130-165 mm 95% CI) and 1 year (0.9-1.5 years 95% CI) for *A. olivaceus*; and 237 mm (221-252 mm 95% CI) and 2.2 years (2.0-3.0 years 95% CI) for *A. xanthopterus* (Table 4 &Figure 9).

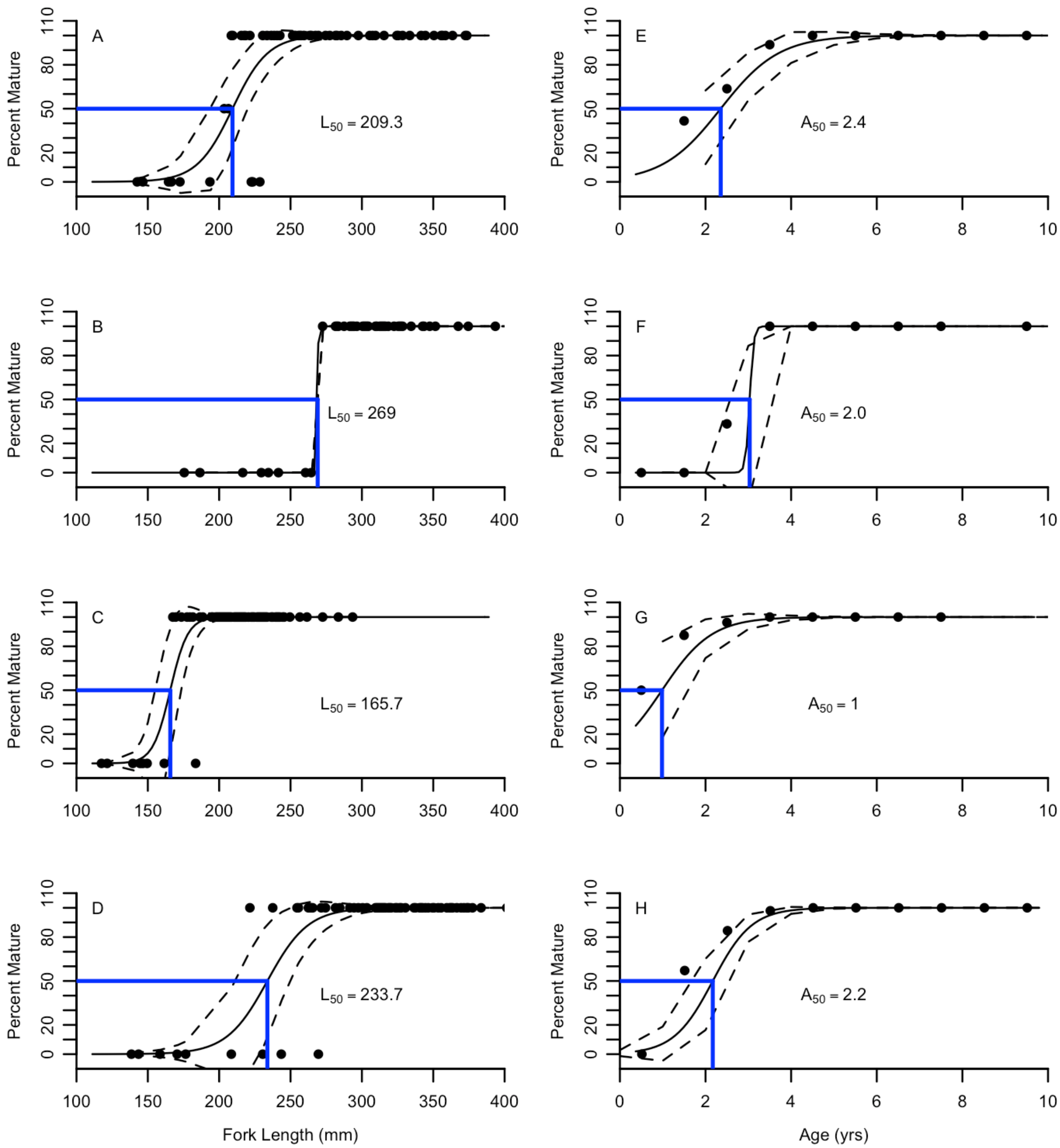

Figure 8: Female L_{50} (A-D) and A_{50} (E-H) for A) & E) *Acanthurus blochii*, B) & F) *Acanthurus dussumieri*; C) & G) *Acanthurus olivaceus*, and D) & H) *Acanthurus xanthopterus*. Dashed lines indicate 95% confidence intervals and blue lines indicate L_{50} /A_{50}.

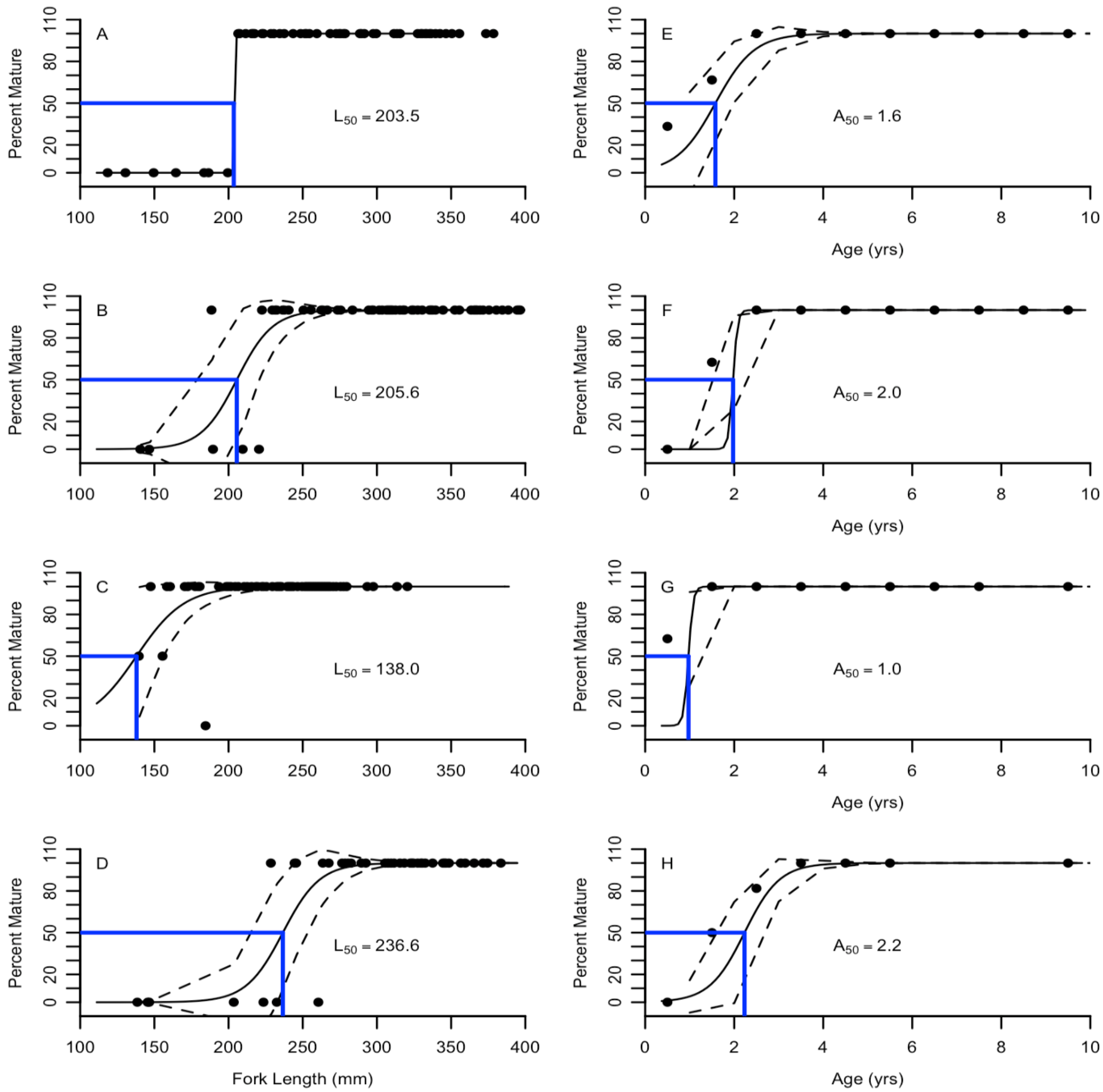

Figure 9: Male L_{50} (A-D) and A_{50} (E-H) for A) & E) *Acanthurus blochii*, B) & F) *Acanthurus dussumieri*; C) & G) *Acanthurus olivaceus*, and D) & H) *Acanthurus xanthopterus*. Dashed lines indicate 95% confidence intervals and blue lines indicate L_{50} /A_{50}.

Spawning season was assessed for all four Acanthurids and was found to be highly variable between and within species, with spawning activity occurring throughout the year (Figure 10). Our sampling was unable to determine the spawning season of *A. xanthopterus* as the GSI remained low throughout the year and we only had four histology samples that were spawning capable or actively spawning.

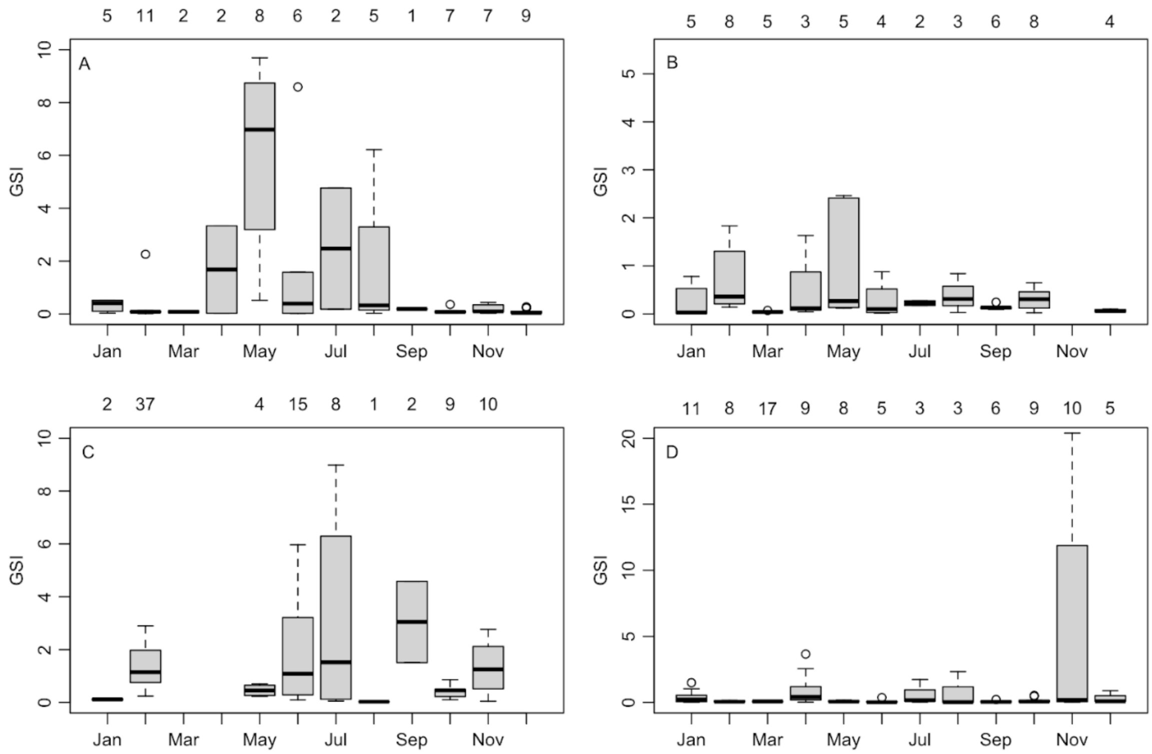

Figure 10: Mature female mean gonadosomatic index (GSI) per month for A) *Acanthurus blochii*, B) *Acanthurus dussumieri*; C) *Acanthurus olivaceus*, and D) *A. xanthopterus*. Numbers above the box plots indicate sample size per month.

Size limits have been implemented for Hawaiian parrotfish and *N. unicornis* to protect important coral reef herbivores (HAR §13-95 2010). Setting a size limit at 10 inches (254mm) would allow *A. blochii*, *A. dussumieri*, and *A. xanthopterus* to reach maturity before they were caught. All three of these species are commonly targeted together and *A. blochii* and *A. xanthopterus* both have the same common name Pualu so a common size limit would work the best for these three species. *Acanthurus olivaceus* has unique coloring and is not confused with other species so a separate size limit of 7 inches (178 mm) would allow *A. olivaceus* to reach maturity before being targeted.

Mortality

The targeted surgeonfish fully entered the fishery between two and five years of age (Figure 11). Based on BIC and RSS values, a two-phase mortality schedule fit all four species better than a single mortality value (Table 6). All four species demonstrated steeper mortality rates in the earlier stages of life. The breakpoint for each species occurred at 11 years for *A. blochii*, 9 years for *A. dussumieri* and *A. olivaceus*, and 8 years for *A. xanthopterus* (Figure 11). Z was estimated at 0.29 year^{-1} for the first nine years, and 0.06 year^{-1} for the later part of the lifespan for *A. blochii*; 0.82 year^{-1} and 0.04 year^{-1} for *A. dussumieri*; 0.53 year^{-1} and 0.17 year^{-1} for *A. olivaceus*; and 0.78 year^{-1} and 0.04 year^{-1} for *A. xanthopterus*. The mortality rate prior to the breakpoint was at least 3 times higher than the rate after the breakpoint for all four species, with *A. olivaceus* having the smallest difference and *A. xanthopterus* with the largest difference between mortality rates of faster vs. slower growing individuals.

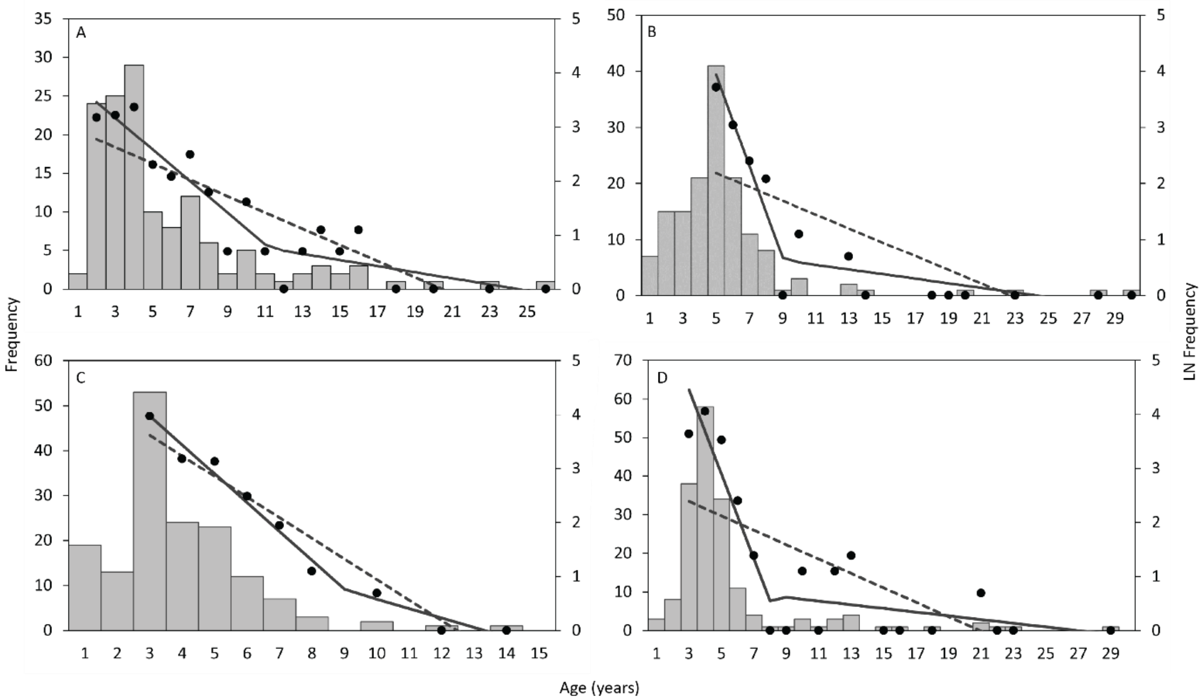

Figure 11: Age based catch curve for A) *Acanthurus blochii*, B) *Acanthurus dussumieri*; C) *Acanthurus olivaceus*, and D) *Acanthurus xanthopterus*. Shaded bars represent samples in each age class. Dots are the LN of the counts per each age class. The solid line represents the fitted biphasic regression, and the dashed line represents the single fitted regression.

The 2016 Hawai‘i length based Spawning Potential Ratio stock assessment assumed a constant natural mortality across time which is standard practice in most stock assessments (Nadon 2017). However, all four species of Acanthurids demonstrated a two-phase mortality creating two distinct mortality schedules which results in the uncharacteristic combination of high mortality and a long life span. Using only maximum age to produce a natural mortality estimate, does not consider the younger/high mortality portion of the population and can lead to estimates of higher fishing pressure. This abnormal characteristic of long life and high natural mortality found in the Acanthurids may facilitate greater species resilience to exploitation than previously assumed with a standard single natural mortality derivation (Taylor et al. 2019).

Table 6: Total mortality estimates for all four targeted Acanthurus species. Single mortality and biphasic mortality with confidence intervals and BIC and RSS values for each model. Plot of residuals can be found in Figure 12.

	Acanthurus blochii			***Acanthurus dussumieri***			***Acanthurus olivaceus***			***Acanthurus xanthopterus***		
	Single	**Biphasic**		**Single**	**Biphasic**		**Single**	**Biphasic**		**Single**	**Biphasic**	
Z	0.15	0.29	0.06	0.12	0.82	0.04	0.38	0.53	0.17	0.13	0.78	0.03
CI	(0.11-0.19)	(0.18-0.40)	(0.02-0.13)	(0.06-0.19)	(0.18-1.45)	(0.01-0.91)	(0.30-0.47)	(0.39-0.68)	(0.09-1.44)	(0.06-0.21)	(0.36-1.20)	(0.02-0.09)
BIC	41.27	31.92		43.22	19.67		12.67	4.11		59.37	41.15	
RSS	6.13	2.36		10.2	1.08		1.04	0.19		17.62	3.96	

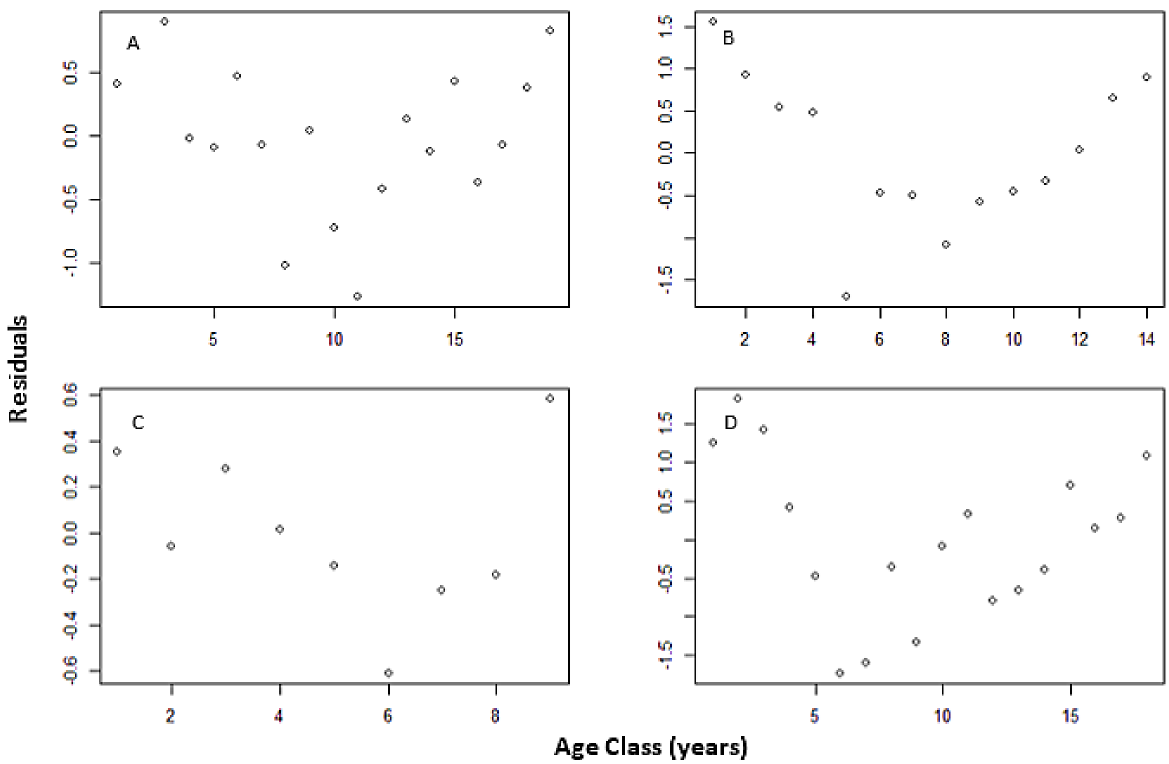

Figure 12: Plots displaying the pattern of residuals for single age-based catch curves for A) *Acanthurus blochii*, B) *Acanthurus dussumieri*; C) *Acanthurus olivaceus*, and D) *Acanthurus xanthopterus*. The U-shaped pattern reflets non-linear fit across age-classes.

Outreach & Trainings

One of the goals of the Bio-Sampling project was to increase local awareness about the importance of life history data and build a relationship with local fishers. Throughout the project we worked with local fishers at fishing tournaments on Oahu and Maui and within the community to collect samples of the targeted fish. During tournaments we talked with people and explained our project and why the information will be helpful for future rules and regulations. In general, most people were interested and willing to let us sample their fish (Figure 13). In 2020 we started hosting our own monthly tournaments to get different sized fish from the selected species.

Figure 13: Photos of various tournaments and outreach events

Aside from tournaments, we talked about our project and shared initial results by speaking with different classes at Hawaii Pacific University (HPU) University of Hawaii (Manoa and Maui), and a class at Kamehameha High School on Maui. We also talked at local fishing clubs throughout Oahu; the Fishers Forum, had articles in Hawaii Fishing News, been on Keiki Fishing Adventures, been on Go Fish with Mike Buck, and via social media on Facebook and Instagram. Some of the outreach materials we produced can be found in Appendix 2.

Throughout this program we worked to build local capacity by training and mentoring local college students. We trained 10 college students from HPU, UH Maui College and UH Hilo College teaching students fish ID through market surveys, fish dissections, grinding and analyzing otoliths for aging, and analyzing gonads for reproduction. We also worked with a high school Marine Biology class at Kamehameha School Maui to do market sampling and fish IDs for us.

Acknowledgements

Funding for this project was provided by the Western Pacific Regional Fishery Management Council through its cooperative agreement with the NOAA Coral Reef Conservation Program (Award No. NA17NMF4410251). Mahalo to the three fish markets on Oahu: Da Fish Market in Waipahu, Rainbow Farm and Produce in Kalihi and Tamashiro Market in Kalihi and the three fish markets on Maui: Oki's Seafood Corner-Kahalui, Pacific Fish Market-Wailuku, and Paradise Supermarket-Kahalui who allowed us to sample their catch. Thanks to Matt Ramsey from Conservation International Hawaii for supplying small juvenile samples for size at settlement. Thanks to Dr. Eva Schemmel and Dr. Brett Taylor for donating your time and expertise in gonads and otoliths to ensure we were doing everything correctly. Mahalo to all the fishers on Oahu and Maui who caught fish for us in this study, without your support we would not have gotten the smaller immature sample sizes. And finally thank you to all our HPU interns who helped us in the lab dissecting fish, preparing and aging otoliths, and reading prepared gonad slides.

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Appendix 1: Length Weight Relationships for Coral Reef Fish of Hawaii

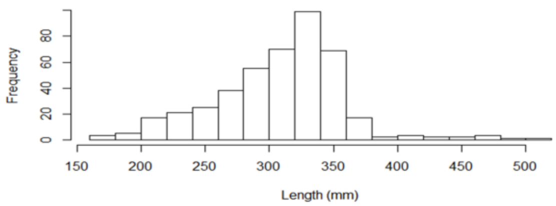
Acanthuridae (Surgeonfish/Unicornfish) **2-3**
Acanthurus blochii /Pualu /Ringtail Surgeonfish........ 2
Acanthurus dussumieri /Palani /Whitespine Surgeonfish........ 2
Acanthurus leucopareius /Maikoiko /Whitebar Surgeonfish........ 2
Acanthurus olivaceus /Na`ena`e /Orangebar Surgeonfish 2
Acanthurus triostegus /Manini /Convict Tang 3
Acanthurus xanthopterus /Pualu /Yellowfin Surgeonfish........ 3
Naso lituratus /Umaumalei /Orangespine Unicornfish 3
Naso unicornis /Kala /Bluespine Unicornfish........ 3
Carangidae (Jacks) **4**
Caranx ignobilis /Ulua aukea /Giant Trevally........ 4
Caranx melampygus / Ōmilu /Bluefin Trevally 4
Holocentridae (Soldierfish) **4**
Myripristis amaena / ʻūʻū /Redfin soldierfish 4
Myripristis berndti / ʻūʻū /Bigscale soldierfish 4
Labridae (Wrasse)........ **5**
Bodianus albotaeniatus / ʻaʻawa /Table Boss 5
Lethrinidae (Emperorfish) **5**
Monotaxis grandoculis / Mū /Bigeye Emperor 5
Lutjanidae (Snapper) **5**
Lutjanus fulvus /To`au /Blacktail Snapper 5
Lutjanus kasmira /Ta`ape /Bluelined Snapper........ 5
Mullidae (Goatfish) **6**
Mulloidichthys flavolineatus /Weke`a /Yellowstripe Goatfish........ 6
Mulloidichthys vanicolensis /Weke`ula /Yellowfin Goatfish 6
Priacanthidae (Bigeye) **6**
Heteropriacanthus cruentatus / ʻāweoweo /Glasseye 6
Scaridae (Parrotfish)........ **6**
Scarus rubroviolaceus /Uhu /Redlip Parrotfish........ 6

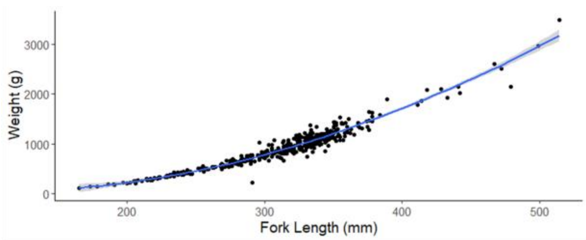
All length and weight data were collected from local fish markets on Oahu between July 2018 and July 2019. The species represented had over 100 samples. Species were sampled weekly throughout the year with a maximum of 20 fish per species per market per day and 100 fish per species per month to get a broad sample throughout the year.

All photos are used with permission from Keoki Stender
https://www.marinelifephotography.com/fishes/fishes.htm

ACANTHURIDAE- Surgeonfish/Unicornfish

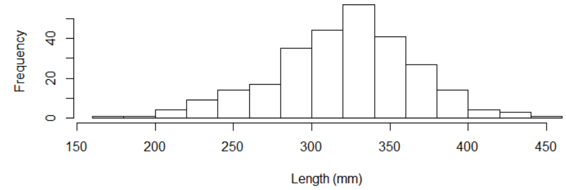
Acanthurus blochii
Pualu
Ringtail Surgeonfish
Mean L: 31 cm (SE 2.40)
N=433

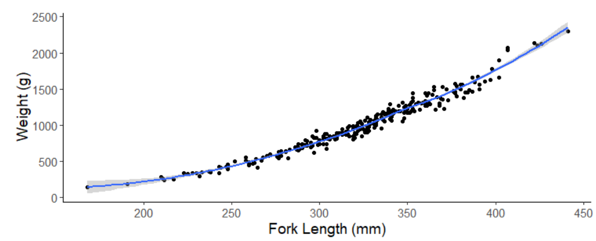




$W_g = 4.706 \times 10^{-5}(FL_{mm})^{2.91}$ (r^2= 0.917)

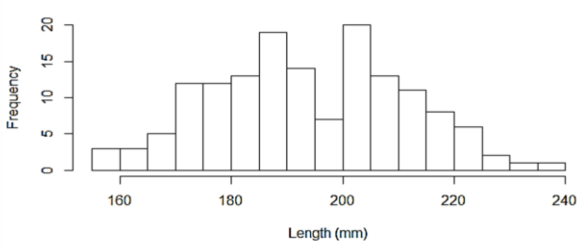
Acanthurus dussumieri
Palani
Whitespine Surgeonfish
Mean L: 32 cm (SE 2.74)
N=272

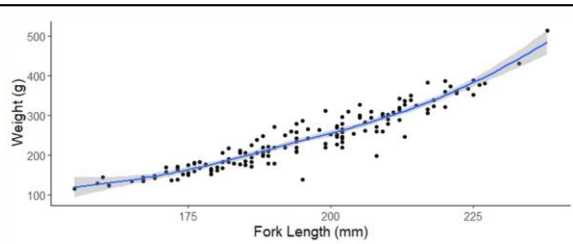




$W_g = 2.953 \times 10^{-5}(FL_{mm})^{2.99}$ (r^2= 0.977)

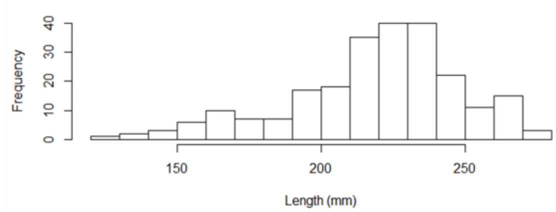
Acanthurus leucopareius
Maikoiko
Whitebar Surgeonfish
Mean L: 19 cm (SE 1.41)
N= 150

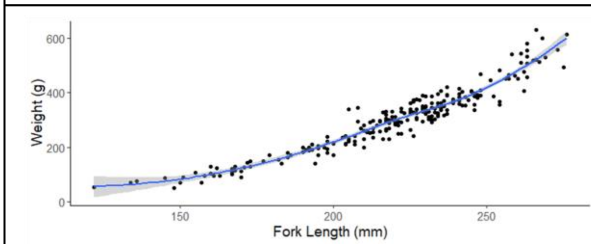




$W_g = 8.592 \times 10^{-6}(FL_{mm})^{3.247}$ (r^2= 0.891)

Acanthurus olivaceus
Na`ena`e
Orangebar Surgeonfish
Mean L: 22 cm (SE 1.92)
N= 237

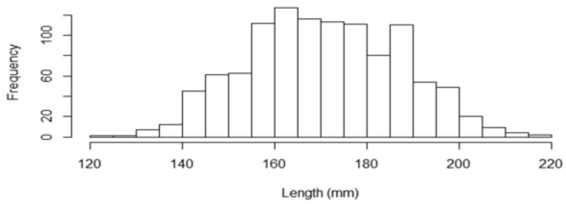


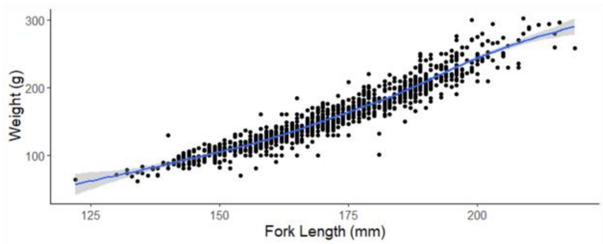


$W_g = 1.155 \times 10^{-5}(FL_{mm})^{3.157}$ (r^2=0.943)

ACANTHURIDAE- Surgeonfish/Unicornfish

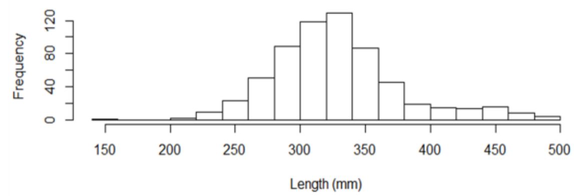
Acanthurus triostegus
Manini
Convict Tang
Mean L: 17 cm (SE 0.49)
N= 1097

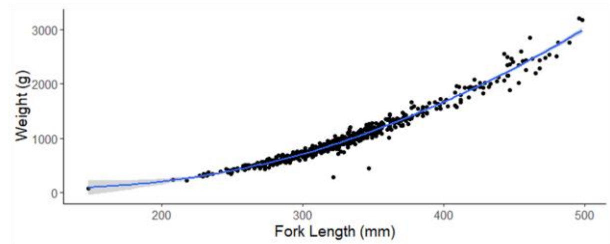




$W_g = 4.751 \times 10^{-5}(FL_{mm})^{2.914}$ (r^2= 0.915)

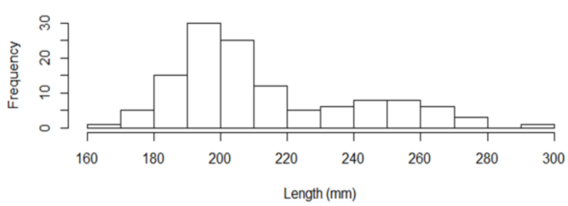
Acanthurus xanthopterus
Pualu
Yellowfin Surgeonfish
Mean L: 33 cm (SE 1.96)
N= 630

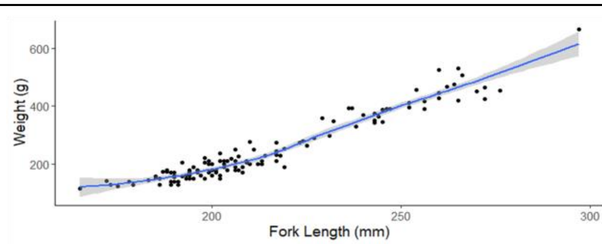




$W_g = 3.560 \times 10^{-5}(FL_{mm})^{2.945}$ (r^2= 0.960)

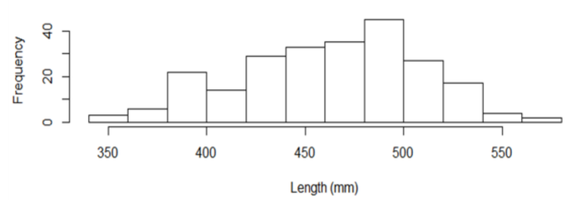
Naso lituratus
Umaumalei
Orangespine Unicornfish
Mean L: 21 cm (SE 2.43)
N= 125

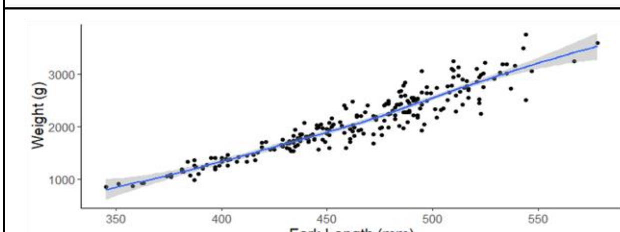




$W_g = 6.113 \times 10^{-6}(FL_{mm})^{3.252}$ (r^2= 0.923)

Naso unicornis
Kala
Bluespine Unicornfish
Mean L: 46 cm (SE 2.98)
N= 237

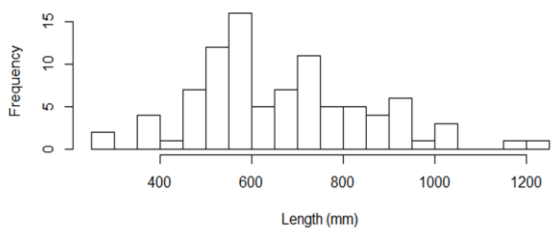


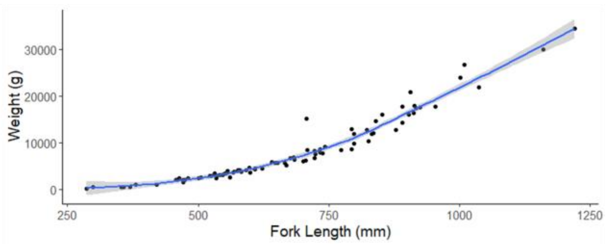


$W_g = 4.417 \times 10^{-5}(FL_{mm})^{2.874}$ (r^2= 0.915)

CARANGIDAE – Jacks **HOLOCENTRIDAE- Soldierfish**

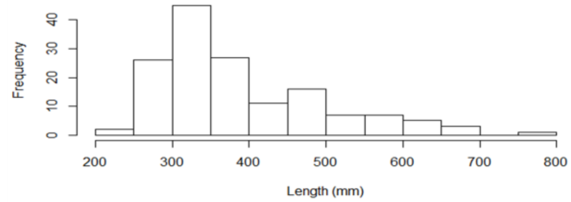
Caranx ignobilis*
Ulua aukea
Giant Trevally
Mean L: 67 cm (19.60 SE)
N= 91

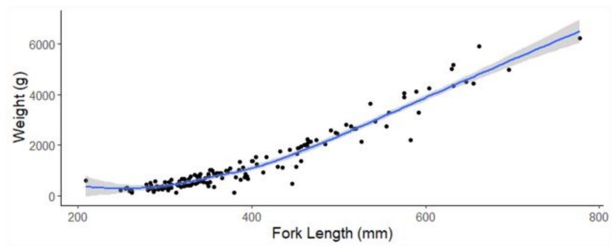




$W_g = 2.260 \times 10^{-6}(FL_{mm})^{3.338}$ (r^2= 0.971)

Caranx melampygus*
Ōmilu
Bluefin Trevally
Mean L: 39 cm (8.80 SE)
N= 150

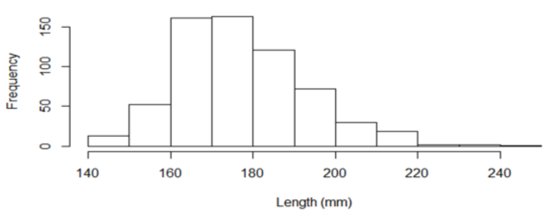


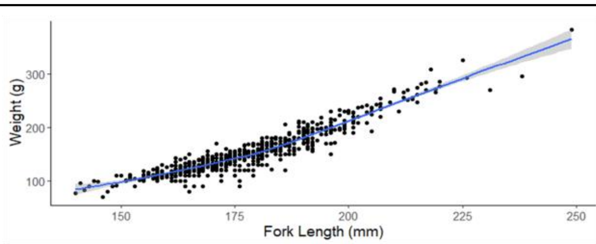


$W_g = 2.763 \times 10^{-6}(FL_{mm})^{3.293}$ (r^2= 0.849)

*Lengths and weights for *C. ignobilis* and *C. melampygus* came from local fishing tournaments on Oahu and Maui

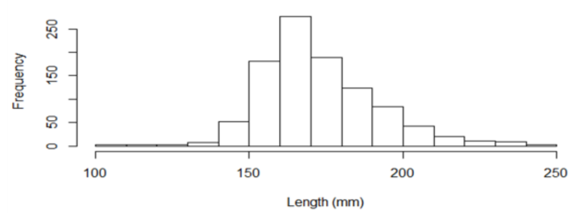
Myripristis amaena
ʻūʻū/Mempachi
Redfin Soldierfish
Mean L: 18 cm (SE 0.62)
N= 635

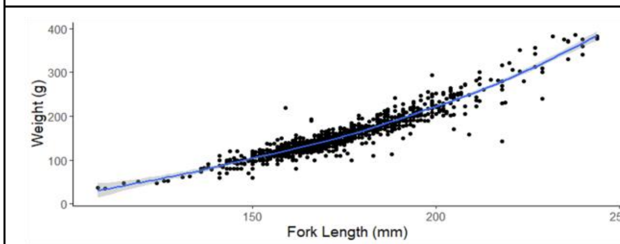




$W_g = 9.756 \times 10^{-5}(FL_{mm})^{2.750}$ (r^2= 0.868)

Myripristis berndti
ʻūʻū/Mempachi
Bigscale Soldierfish
Mean L: 17 cm (0.60 SE)
N= 1003

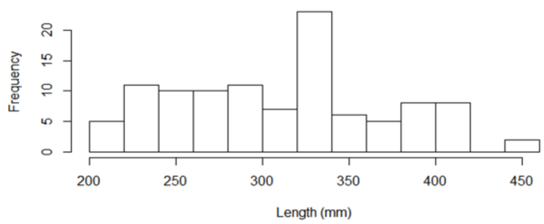


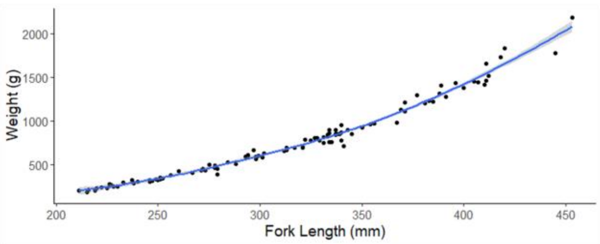


$W_g = 1.69 \times 10^{-4}(FL_{mm})^{2.713}$ (r^2= 0.891)

LABRIDAE – Wrasse **LETHRINIDAE- Emperorfish** **LUTJANIDAE-Snapper**

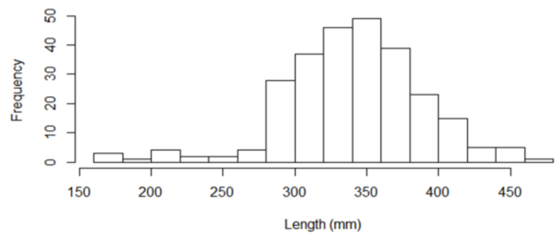
Bodianus albotaeniatus
ʻaʻawa
Hawaiian Hogfish/Table Boss
Mean L: 31 cm (5.82 SE)
N= 106

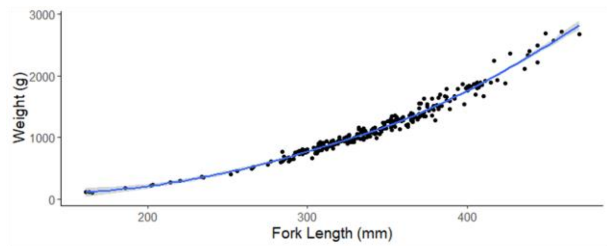




$W_g = 2.013 \times 10^{-5}(FL_{mm})^{3.017}$ (r^2= 0.989)

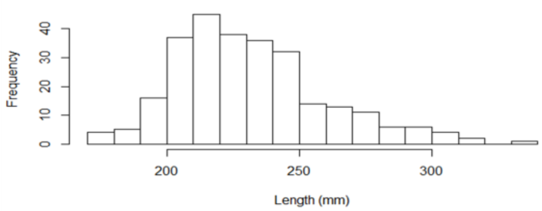
Monotaxis grandoculis
Mū
Bigeye Emperor/Bream
Mean L: 34 cm (3.02 SE)
N= 264

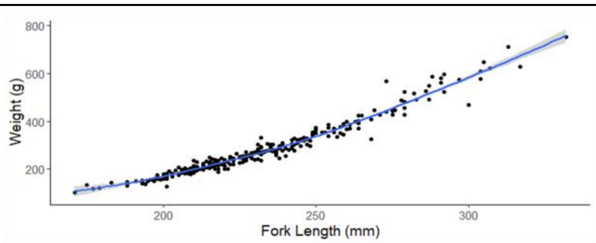




$W_g = 3.327 \times 10^{-5}(FL_{mm})^{2.969}$ (r^2=0.985)

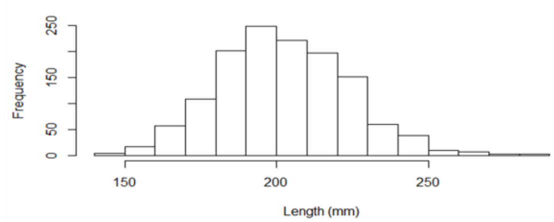
Lutjanus fulvus
Toʻau
Blacktail Snapper
Mean L: 23 cm (1.73 SE)
N= 270

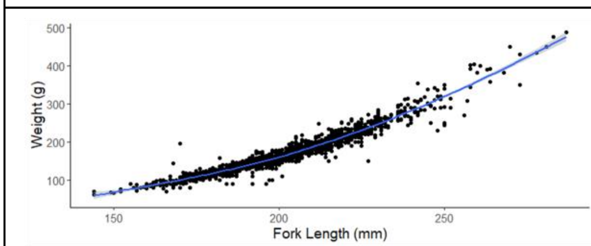




$W_g = 1.728 \times 10^{-5}(FL_{mm})^{3.040}$ (r^2=0.966)

Lutjanus kasmira
Taʻape
Bluelined Snapper
Mean L: 20 cm (0.59 SE)
N= 1326

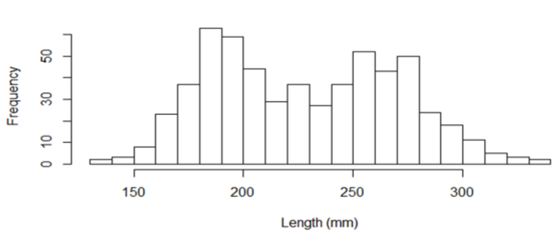


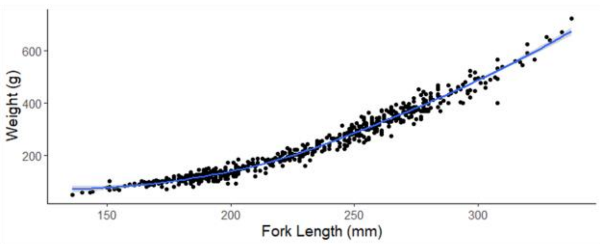


$W_g = 1.822 \times 10^{-5}(FL_{mm})^{3.019}$ (r^2= 0.939)

MULLIDAE – Goatfish **PRIACANTHIDAE- Bigeyes** **SCARIDAE-Parrotfish**

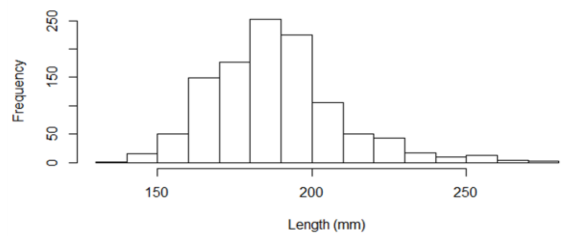
Mulloidichthys flavolineatus
Weke'a
Yellowstripe Goatfish
Mean L: 23 cm (1.75 SE)
N= 577

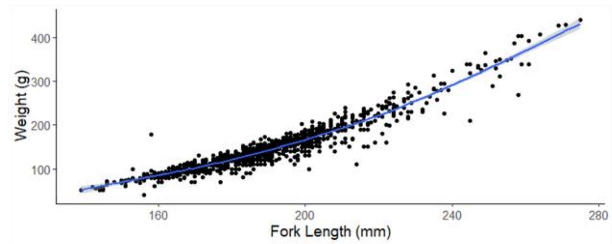




$$W_g = 2.117 \times 10^{-5}(FL_{mm})^{2.970} \quad (r^2 = 0.967)$$

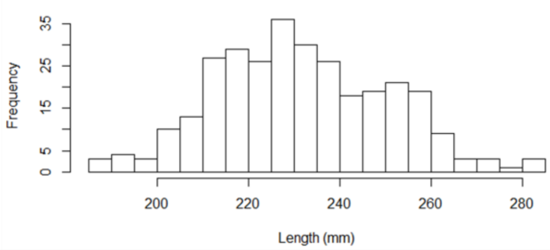
Mulloidichthys vanicolensis
Weke 'ula
Yellowfin Goatfish
Mean L: 19 cm (0.63 SE)
N= 1114

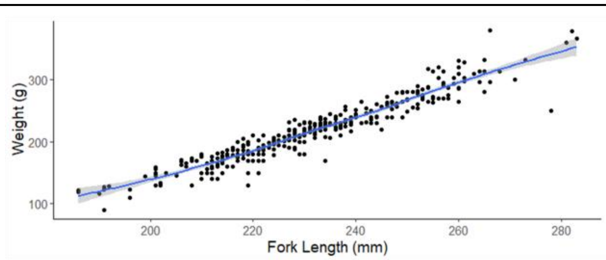




$$W_g = 1.692 \times 10^{-5}(FL_{mm})^{3.038} \quad (r^2 = 0.903)$$

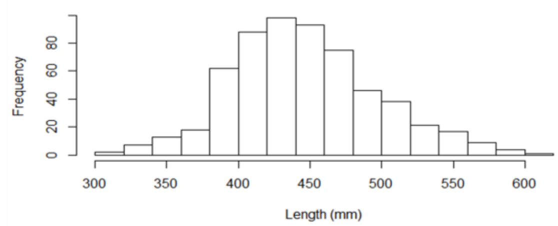
Heteropriacanthus cruentatus
'āweoweo
Glasseye
Mean L: 23 cm (1.09 SE)
N= 303

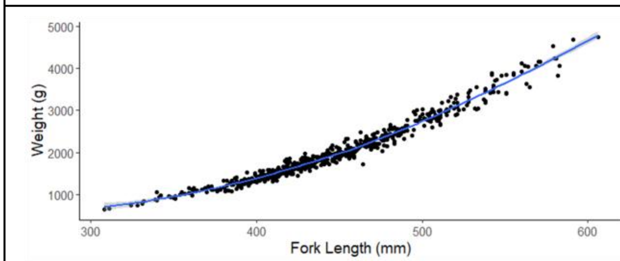




$$W_g = 3.875 \times 10^{-5}(FL_{mm})^{2.851} \quad (r^2 = 0.907)$$

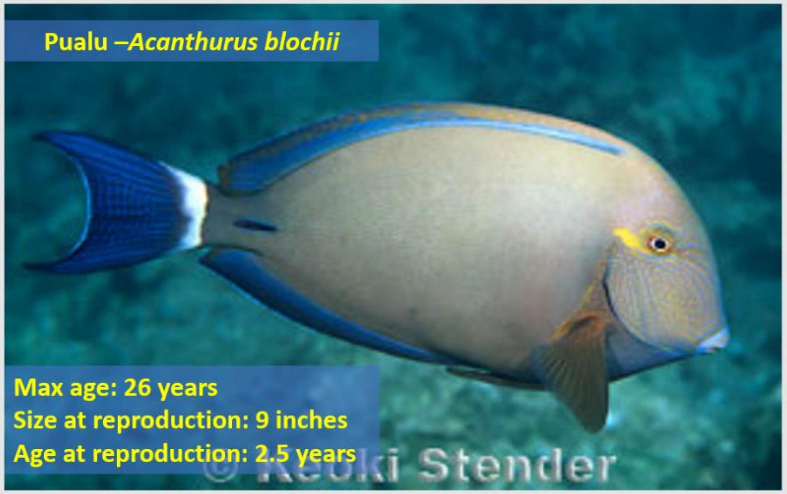
Scarus rubroviolaceus
Uhu
Redlip Parrotfish
Mean L: 45 cm (2.09 SE)
N= 592

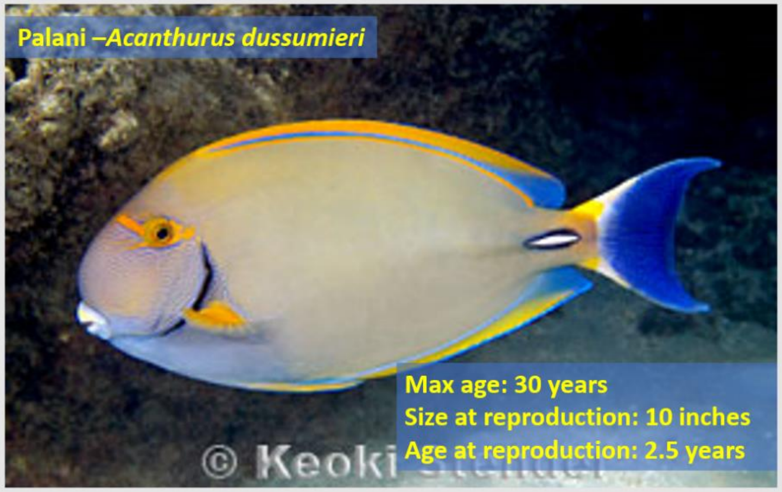




$$W_g = 2.071 \times 10^{-5}(FL_{mm})^{3.008} \quad (r^2 = 0.975)$$

Appendix 2: Outreach Material





Samples Gathered so far

Ulua aukea
Caranx ignobilis
22 samples
18-45 inches
4-65 pounds
4-18 years old

ʻŌmilu
Caranx melapygus
28 samples
10-26 inches
0.3-13 pounds
2-17 years old

Papa Ulua
Carangoides orthogrammus
6 samples
14-22 inches
2-9 pounds
2-7 years old

Pake Ulua
Caranx sexfasiatus
3 samples
19-27 inches
4-11 pounds
3-17 years old

Barred jack
Carangoides ferdau
1 sample
15 inches
3 pounds
15 years old

We still need help gathering more samples of different sizes to get a better idea of growth, age, and maturity

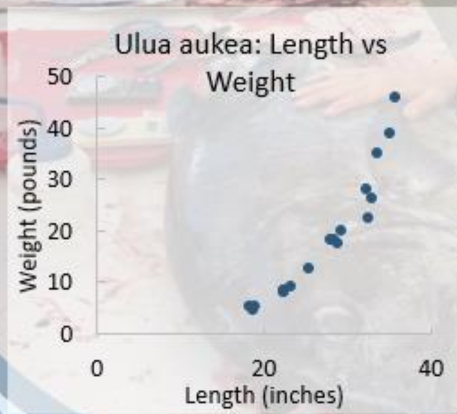
If you would like to help collect ulua and papio samples please contact:

Cassie Pardee: (808)464-6083

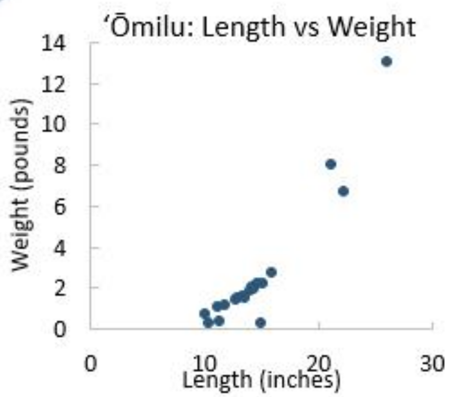
John Wiley: (808) 464- 6055

Papio and Ulua Life History Data...So Far

Poseidon Fisheries Research



By gathering length and weight data we can estimate the size of the fish based on just the length or the weight. This data also helps us learn how fast the fish grow.



How Old is my Fish?

Otoliths (Ear bones) are used to age fish. Just like tree rings, scientists can count the rings to determine how old the fish was.

Ages so Far

Ulua aukea (*Caranx ignobilis*)

- 18-32 inches~ 4 -7 years old (13 samples)
- 28-35 inches~ 9-15 years old (3 samples)
- 34-36 inches ~16-18 years old (4 samples)

'Ōmilu (*Caranx melampygus*)

- 10-15 inches~2-4 years old (18 samples)
- 14-22 inches~5-10 years old (3 samples)
- 26 inches~ 17 years old (1 sample

*Some fish we were unable to get age samples

What else can we learn

Maturity

By looking at gonad samples we can learn about what age and size papio and ulua start reproducing as well as when the fish are spawning.

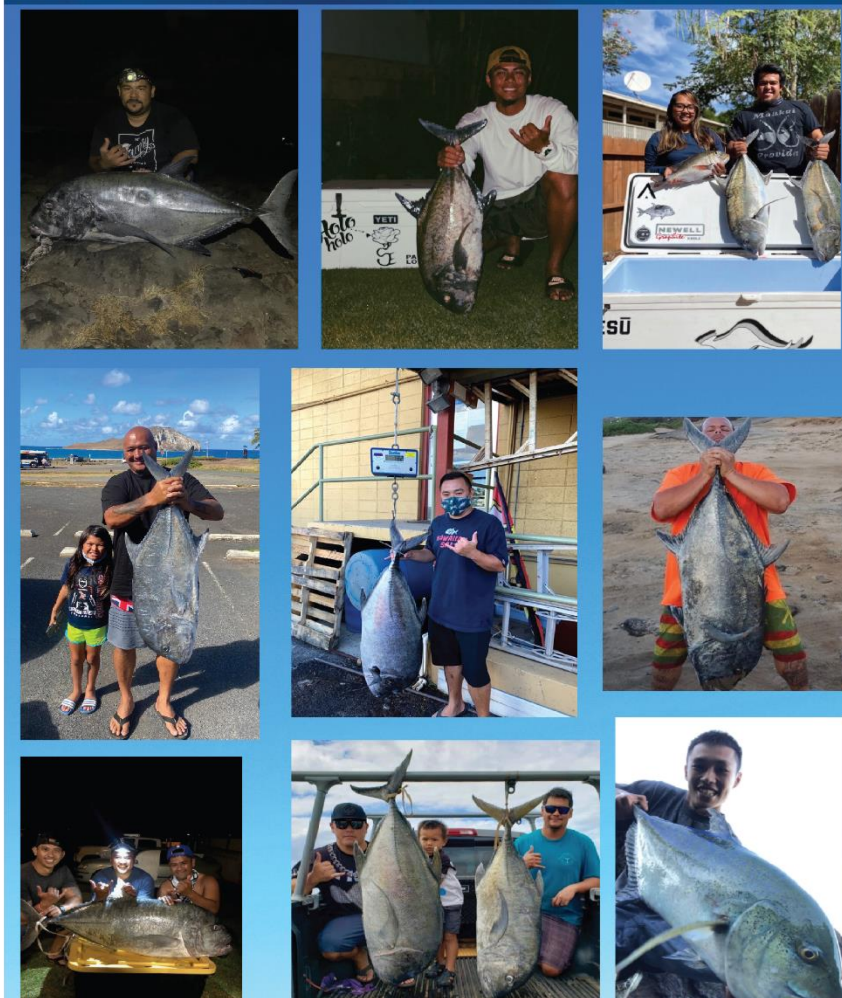
Growth

By gathering more age and size data we can learn how fast these fish grow and how old they can get.

FREE ENTRY FISHING TOURNAMENT

September - October 2020

FINAL LEADERBOARD



Poseidon Fisheries Research

WBRPT

NĀPU'UOMALEI

OMILU (≥ 10 LBS.)

1. KEITH	20.3 LBS - 16 YRS	(OAHU)
2. ADAM	20.0 LBS - 17 YRS	(OAHU)
3. JUSTIN	18.0 LBS - 19 YRS	(MAUI)
4. KAINOA	16.4 LBS - 17 YRS	(MAUI)
5. CHRIS	14.4 LBS - 18 YRS	(MAUI)

ULUA AUKEA (≥ 50 LBS.)

1. SHELTON	78.7 LBS - 26 YRS	(MAUI)
2. ROMEO	74.4 LBS - 21 YRS	(MAUI)
3. BRANDON	62.5 LBS - 19 YRS	(OAHU)
4. DONALD	62.0 LBS - 20 YRS	(OAHU)
5. CASEY	59.7 LBS - 11 YRS	(OAHU)