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Life history of the humpnose big-eye bream *Monotaxis grandoculis*

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Abstract

This study provides estimates of growth rate, longevity, maturity, spawning seasonality, and mortality for Hawaiʻi's only lethrinid, the humpnose big-eye bream (known as Mū in Hawaiʻi) *Monotaxis grandoculis,* a commercially and recreationally important species in Hawaiʻi and throughout the Indo-Pacific. *Monotaxis grandoculis* reaches maturity at 303 mm fork length or 3.6 years of age for both sexes combined. Males were significantly larger than females for a given age. The von Bertalanffy growth parameters for males and females were L_∞ = 506 mm fork length and $K = 0.24$ year^{-1}; and L_∞ = 427 mm fork length and $K = 0.33$ year^{-1}, respectively. Both males and females reached ages over 20 years old, with a maximum age of 23 years. *Monotaxis grandoculis* had a distinct spawning season from May through August with corresponding elevated female gonadosomatic index. An age-based multinomial catch curve indicated that the commercial exploitation rate (natural mortality/fishing mortality) was 0.48 year^{-1}, which is considered below the overfishing limit.

Keywords: age, growth, histology, lethrinidae, maturity, otoliths

Introduction

The emperor/Lethrinidae family, which includes 5 genera, are well represented throughout the Indo-Pacific region (Carpenter & Allen, 1989) and are commonly targeted by commercial, subsistence, and recreational fisheries (Currey *et al.*, 2013; Ebisawa & Ozawa, 2009). Due to their importance in coastal fisheries, the biology of lethrinids has been well studied across the Indo-Pacific (Currey *et al.*, 2013; Ebisawa, 1997; Ebisawa & Ozawa, 2009; Grandcourt *et al.*, 2010; Pardee *et al.*, 2020; Taylor *et al.*, 2018, 2017; Young & Martin, 1982). Lethrinids are known to have a moderate life-span ranging from 10-36 years (Currey *et al.*, 2013; Ebisawa & Ozawa, 2009; Grandcourt *et al.*, 2010). Species within the lethrinid family exhibit various reproductive strategies; most are considered to be hermaphroditic, exhibiting protogyny (female to male sex change after maturation) (Young & Martin, 1982). Several species exhibit juvenile hermaphroditism, changing sex before reaching maturity (Ebisawa, 2006; Taylor *et al.*, 2017), while other species are gonochoristic (individuals remain male or female throughout life) (Longenecker *et al.*, 2020). Lethrinids are also known to have distinct spawning seasons and to spawn in aggregations synchronized with environmental cues, such as changes in sea surface temperature (SST), lunar phase, and currents (Ebisawa, 2006; Taylor & Mills, 2013).

While a variety of lethrinids exist throughout the Indo-Pacific, in Hawaiʻi only one species of lethrinid is present, the humpnose big-eye bream (known locally in Hawaiʻi as Mū) *Monotaxis grandoculis* (Forsskål 1775). There are two species in the genera Monotaxis, however only *M. grandoculis* has been recorded in Hawaiʻi. *Monotaxis grandoculis* is a meso-predator that preys on invertebrates and small fish and is found throughout the Indo-Pacific north to Japan

and south to Australia (Carpenter & Allen, 1989). Like the other species in the lethrinid family, *M. grandoculis* is commonly targeted by spear and hook and line (Hawaii Division of Aquatic Resources, 2020; Houk *et al.*, 2012). However, unlike most other species in the lethrinid family, no age or growth information currently exists for *M. grandoculis*.

Because *M. grandoculis* is a commonly targeted and prized species within the Hawaiian fishery (Hosaka, 1973; Titcomb, 1972), a length-based Spawning Potential Ratio (SPR) stock assessment was conducted in 2016 (Nadon, 2017). However, since life-history data are unavailable for *M. grandoculis*, parameters were generated using a stepwise approach. Results of the stock assessment indicated that *M. grandoculis* had an exploitation rate (F/M) of 0.80, which is considered under the overfishing limit (Nadon, 2017). However, length based data-limited stock assessments can be sensitive to life-history information, and the use of stochastically generated life-history parameters instead of empirically derived parameters may result in inaccurate assumptions on stock status (Minte-Vera *et al.*, 2017; Rudd *et al.*, 2019; Sun *et al.*, 2018).

Locally derived life-history information allows for better-informed stock assessments and fishing regulations. The primary goal of this study was to obtain age, growth, maturity, and spawning seasonality estimates for commonly targeted *M. grandoculis* for the Hawaiian fishery using commercially-gathered samples. Based on the age distribution of the market samples, we were also able to compare the exploitation rate from the length-based SPR analysis to an age-based multinomial catch curve using knife edge selectivity.

Methods

Sample protocol

Samples were purchased opportunistically in Oʻahu markets between February 2019 and December 2020 as part of the Hawaiʻi commercial fisheries Bio-Sampling program (Pardee & Wiley, 2020). Additionally, a small portion of specimens (<15%) were sampled from fishing tournaments or donated from local Oʻahu fishers. Fish specimens were weighed to the nearest gram and measured to the nearest millimeter fork length (L_F). From each sample, sagittal otolith pairs were removed, cleaned with ethanol, and stored dry; fresh gonads were extracted, macroscopically sexed, weighed to the nearest 0.001 g, and a small sample was preserved in 10% buffered formalin.

Ethical Statement

Fish were purchased at commercial markets or donated from recreational fishermen at fishing tournaments; no animal experiments were conducted. Therefore, no ethical approval was required.

Age and Growth

A single sagittal otolith was randomly selected, weighed to the nearest 0.0001g, and processed using a 600 grit diamond lapping wheel with continuous water flow following methods detailed in Taylor et al. (2017). The resulting thin (~200μm) transverse section of the otolith was then examined using transmitted light on a stereo microscope. Age was determined by counting annuli (alternating opaque and translucent bands) along a consistent axis on at least two independent occasions by at least two separate readers. A third blind read was conducted when the two age estimates differed. Annual periodicity of otolith bands has been documented for several species in the lethrinid family (Ebisawa & Ozawa, 2009; Grandcourt *et al.*, 2010; Taylor *et al.*, 2018). The precision of age estimates from the first and second reads was calculated using the index of average percent error (IAPE) (Campana, 2001).

The relationship between otolith weight and age was compared to determine if otolith weight is a useful indicator for age. Sex-specific and combined growth patterns were modeled using the von Bertalanffy growth function (VBGF) $L_t = L_\infty[1 - e^{-K(t-t_0)}]$, where L_t is the L_F (mm) at age t (years), L_∞ is the mean asymptotic L_F, K is the growth coefficient depicting the curvature to L_∞, and t_0 is the theoretical age at which the L_F is equal to zero. Since samples came from commercial markets, we did not have any newly settled specimens, therefore the fitted VBGF was constrained to 38 mm at age 0 based on the size at settlement (Leis & Carson-Ewart, 2000). Growth between the sexes were compared using a likelihood ratio test (Kimura, 1980).

Maturity and Reproduction

Preserved gonad samples were histologically processed at the University of Hawai'i School of Medicine to determine stages of maturation. Gonad material was embedded in paraffin wax, a thin (6μm) transverse section was then stained using hematoxylin and eosin on microscope slides. Maturity and stage of reproductive development was assessed using a compound microscope with transmitted light using the standardized terminology of Brown-Peterson et al. (2011).

Size and age at 50% maturity (L_{50} and A_{50} respectively) were calculated for sex-specific and combined sexes using a logistic regression analysis by fitting the length/age as an explanatory variable to the stage of maturity (0=immature, 1=mature) as the binomial response variable. Confidence intervals were derived using bootstrap resampling with 1,000 iterations.

Reproductive activity based on the female gonadosomatic index (I_G) was calculated as follows: $I_G = \frac{Gonad\ weight\ (g)}{Body\ weight\ (g)} \times 100$ Spawning seasonality was investigated by plotting the immature and mature female I_G values along with the frequency of spawning capable and

actively spawning females across the calendar year. The Spawning seasonality was compared to monthly mean SST for Oahu from 2019-2020 from Pacific Islands Ocean Observing System (NOAA Coral Reef Watch (CRW), 2019).

Mortality

Total mortality (*Z*) was estimated with age samples gathered from commercial fishing markets using an age-based multinomial catch curve with knife edged selectivity, where full recruitment (t_{rec}) is defined as one plus the peak age frequency (Dunn *et al.*, 2002). The per recruit survival (S_t) at age *t* of fish at or above t_{rec} was calculated as $S_t = e^{-Z(t-t_{rec})}$. The expected proportion of full recruited fish at age t ($\hat{P}_t$) was calculated as $\hat{P}_t = \frac{S_t}{\Sigma_{trec}^{tmax} S_t}$ where t_{max} is the maximum observed age from this study. The catch curve was fitted by maximizing the multinomial log-likelihood associated with the observed and expected proportions at age *t*.

Fishing mortality (*F*) was calculated as total mortality (*Z*) minus natural mortality (*M*). Natural mortality was estimated using the equation of Hoenig (1983) based on the observed maximum age (t_{max}) with the assumption that t_{max} reflects the true lifespan where $M = e^{[1.46-1.01*\ln(t_{max})]}$.

Results

In total, 157 *M. grandoculis* specimens were analyzed (37% female, 57% male, 6% unidentified). The modal length for males was larger than the modal length for females (Figure 1). Males ranged in size from 136 mm L_F - 526 mm L_F (mean: 362 mm SD: 97 mm) while female specimens ranged in size from 134 mm L_F - 463 mm L_F (mean: 346 mm SD: 61 mm).

For the age and growth study, 151 specimens were aged. Otoliths showed clearly defined annuli, characteristic of previously identified emperors (Figure 2). Otolith weight was a strong predictor for age with the relationship best explained through a standard quadratic equation. The relationship between otolith weight and age varied substantially between sexes, and this pattern was retained in the length-at-age growth profiles (Figure 3a and b). The relationships between otolith weight and age (t_{yrs}) are: t_{yrs}=889.59 (otolith weight)^2+ 59.76(otolith weight) +0.32 (r^2=0.85) for males; and t_{yrs}=2227.40 (otolith weight)^2- 32.26 (otolith weight) +1.94 (r^2=0.91) for females (Figure 3a).

Age estimates were relatively precise (IAPE=3.68%) and ranged from 1-23 years old with both males and females reaching over 20 years of age. Males were significantly larger than females at a given age (χ^2=37.39, p-value <0.001). The sex specific VBGF L_∞ and K parameters are as follows: L_∞=427, 506 and K=0.33, 0.24 for females and males respectively (Table 1; Figure 3b). Approximately 70% of growth occurred in the first five years of life.

Histological gonad analysis was completed for 114 gonad samples: 60 males (10 immature) and 54 females (14 immature) to determine sex, L_{50}, and A_{50}. Because most of the specimens came from market sampling, several of the gonads sampled were considered too degraded to be used in histological analysis. Combined sex L_{50} and A_{50} were 303 mm (95% CI: 297-323 mm) and 3.6 years (3.4-4.2 years) (Table 1, Figures 4a and 4d). Female L_{50} and A_{50} were 302 mm (292-323 mm) and 3.5 years (3.2-4.3 years) (Table 1; Figures 4b and 4e). Unfortunately, we did not have gonad samples for males between 270-354 mm and there was no overlap between immature and mature specimens; therefore, we were unable to calculate an exact L_{50} for males aside from a range between 270-354 and A_{50} between 3-5 years (Figures 4c and 4f).

Based on ovarian I_G and histological staging results, a distinct spawning season occurred from May to August (Figure 5a and b). We found no histological evidence of spawning activity between September through February, with corresponding low ovarian I_G values during those same months (Figure 5a and b). The increase in I_G and spawning activity corresponds to an increase in SST in Hawai'i (Figure 5a).

Fish fully entered the fishery at 6 years of age corresponding to 26% of estimated maximum age (Figure 6). Total mortality (Z) was calculated at 0.269 year^{-1} (95% CI: 0.195-0.344). Natural mortality (M) was calculated at 0.181 year^{-1} with the assumption that the maximum age was adequately characterized within the sample size of the present study. Therefore, the rate of fishing mortality ($F=Z-M$) is 0.088 year^{-1} (0.014-0.163, 95% CI) equaling a commercial exploitation rate (F/M) of 0.486.

Discussion

Though *M. grandoculis* is commonly targeted throughout its range, this is the first study to determine its age, growth, and spawning seasonality. In brief, *M. grandoculis* has a moderately long life span of 23 years similar to several other lethrinid species from Australia and Japan (Currey *et al.*, 2013; Ebisawa & Ozawa, 2009). Approximately 70% of growth occurred in the first five years of life, and while males achieved a larger size than females, characteristic of many lethrinid species, we found no indication of protogyny within the species. We found that *M. grandoculis* has a distinct spawning season from May to August coinciding with an increase in SST (Figure 5a).

A maturity study in Micronesia (an island region in the western Pacific Ocean 13° 26' 39.4944" N and 144° 47' 37.4352" E.) observed no indication of sex change within *M.*

grandoculis, labeling these fish as gonochoristic (Longenecker *et al.*, 2020). Our study aligns with these findings, though many other lethrinids have been classified as protogynous hermaphrodites (Currey *et al.*, 2013; Ebisawa, 2006). The smallest gonad sample we analyzed was a 134 mm specimen. It is possible this species exhibits juvenile hermaphrodism such as several other lethrinid species (Currey *et al.*, 2013; Ebisawa, 2006; Taylor *et al.*, 2017), but no indication of sex change in the smallest size classes was observed. Female L_{50} for Micronesia was calculated at 300 mm L_F (Longenecker *et al.*, 2020), which is similar to our calculation of 302 mm in Hawai'i. Male L_{50} for Guam was calculated at 354 mm (Longenecker *et al.*, 2020) which falls within the range for male maturity in Hawai'i.

The duration and season of spawning varies among lethrinids with a majority of species exhibiting spawning activity over multiple months during spring and summer seasons (Currey *et al.*, 2013; Ebisawa, 2006). In the Marianas (15.0979° N, 145.6739° E), several lethrinid species exhibit no annual spawning seasonality and instead spawn year-round based on lunar cycles (Taylor & Mills, 2013; Taylor *et al.*, 2017). We found *M. grandoculis* has a shorter spawning period than other lethrinids (Currey *et al.*, 2013; Ebisawa, 2006; Taylor *et al.*, 2017); with a spawning period of only four months from May to August. The peak spawning period for *M. grandoculis* corresponds with other Hawaiian fish corresponding to an increase in average monthly SST (DeMartini *et al.*, 2014; Luers *et al.*, 2018; NOAA Coral Reef Watch (CRW), 2019; Walsh, 1987).

Many of the life history parameters determined in this study differed from those used in the previous *M. grandoculis* assessment for Hawai'i (Nadon, 2017). The life-history parameters stochastically derived estimated an L_∞ of 527 mm over 50 mm larger and a $K = 0.37$, 0.10 year^{-1} larger than what was described in this paper (Nadon, 2017), suggesting a larger and faster

growing species than was observed. The stochastically derived life history parameters also assumed an L_{50} of 389 mm over 80 mm larger than the combined L_{50} determined by this study, and a maximum age of 21 years, 2 years younger than was found in this study (Nadon, 2017). Natural mortality is highly sensitive to input parameters and two-year difference for maximum age would affect the outcome of that parameter (Then *et al.*, 2015).These differences in life history parameters may affect the outcome of the SPR analysis and yield a different exploitation rate.

The exploitation rate calculated using the length-based assessment was 0.80 year^{-1} which is below the overfishing limit based on the conservative rule that F should not exceed M (Nadon, 2017). The commercial exploitation rate calculated in this study using an age-based multinomial catch curve was 0.486 year^{-1}, which agrees with the conclusions of the length-based SPR analysis that the commercial exploitation rate is below the overfishing limit. However, the age-based exploitation rate was approximately 0.30 year^{-1} lower than the length-based assessment, indicating a lower fishing pressure than was previously assumed.

While the age-based catch curve determined that the commercial exploitation rate was below the overexploitation rate, the assessment did not consider the massive amount of recreational catch in Hawaiʻi, which most likely exceeds that of the commercial catch (McCoy *et al.*, 2018). Even though the total non-commercial catch is larger than the reported commercial catch, the exact amount of non-commercial catch per species in Hawaiʻi is unknown. Therefore, it is difficult to assess the impact the non-commercial fishery has on the *M. grandoculis* stock.

There are currently no regulations in Hawaiʻi for this commonly targeted species. One way to protect the stock for future generations would be to create a minimum capture size based on L_{50} of 303 mm (12 inches). Several other commonly targeted species in Hawaiʻi have a

minimum size limit such as parrotfish, trevallies, and goatfish (HAR§13-95.1, 2014). Currently, approximately 80% of the commercial catch is mature, indicating a relatively healthy fishery. However, recreational catch often has a smaller mean size of capture compared with commercial landings, thus a minimum size limit would ensure that a high portion of landings had at least one chance to spawn. We also found a distinct spawning season from May to August; a closed season during spawning would allow fish to reproduce during peak spawning months without being targeted. Hawai'i also enforces closed seasons on several culturally important food fish: *Mugil cephalus* and *Polydactylus sexfilis* (HAR§13-95.1, 2014). A movement study of two lethrinids (*Lethrinus harak* and *Lethrinus obsoletus)* in Guam determined that even small marine reserves can provide protection for lethrinids with limited and defined home ranges and can protect spawning sites (Taylor & Mills, 2013). Hawai'i has several Marine Life Conservation Districts (MLCD) throughout the state with the goal of conserving and replenishing marine resources, which could potentially protect spawning sites for *M. grandoculis*. However, more research is needed to determine movement and spawning patterns to better predict the influence MLCDs have on the *M. grandoculis* population.

This study provides a comprehensive analysis for age, growth, maturity, and exploitation for *M. grandoculis*, a commonly targeted meso-predator in Hawai'i and across the Indo-Pacific. While age, growth, and maturity can change from region to region, the information provided here is a useful first step for managers and stock assessment scientists. We found that *M. grandoculis* can reach up to 23 years of age and reaches maturity around 3.6 years or 303 mm L_F for both sexes combined. Most of the commercial catch was above size at maturity and the exploitation rate was below the overexploitation level, suggesting that Hawai'i's commercial stock of *M. grandoculis* is healthy. Regardless, educating fishers on the size at maturity and

spawning season, thereby limiting the catch of immature and gravid females, will help ensure this stock remains healthy in the future.

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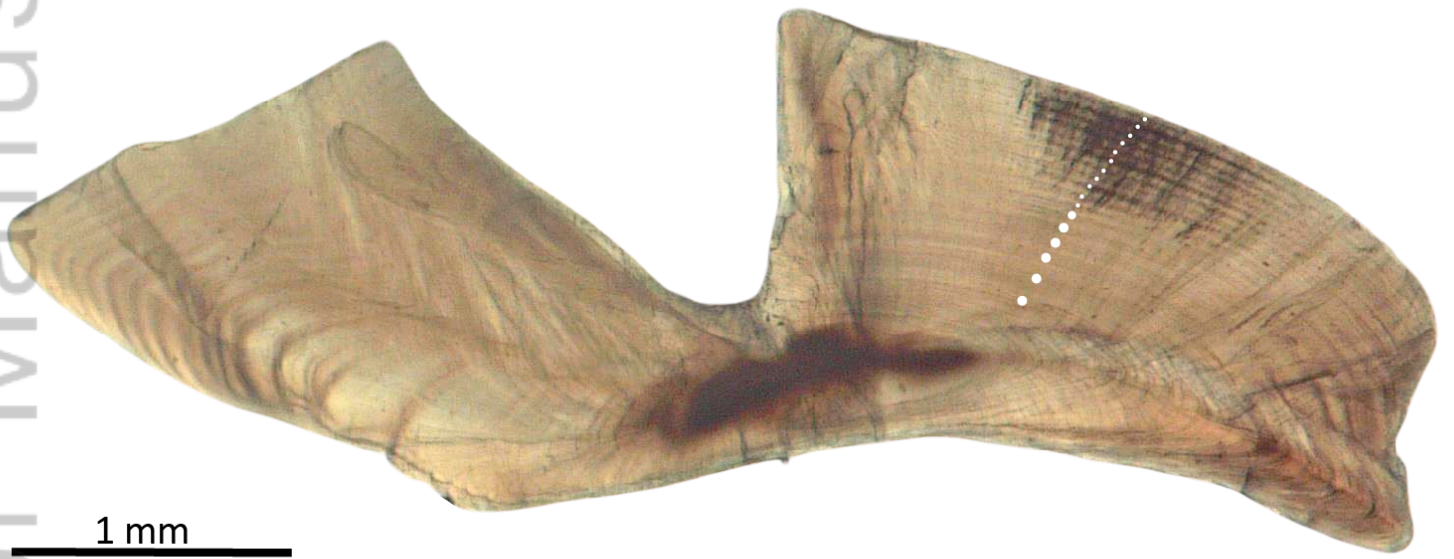Young, P. C., & Martin, R. B. (1982). Evidence for protogynous hermaphroditism in some

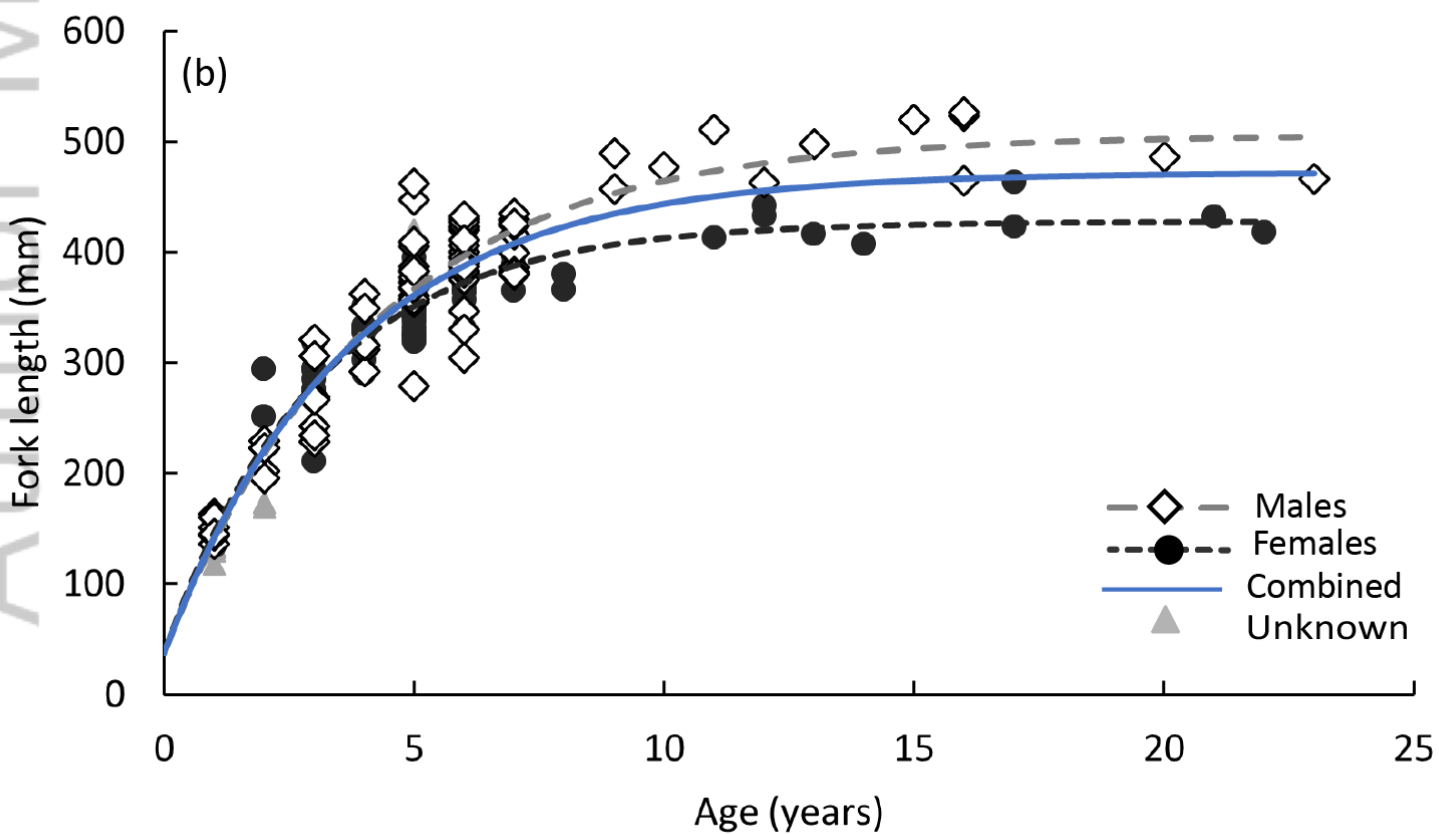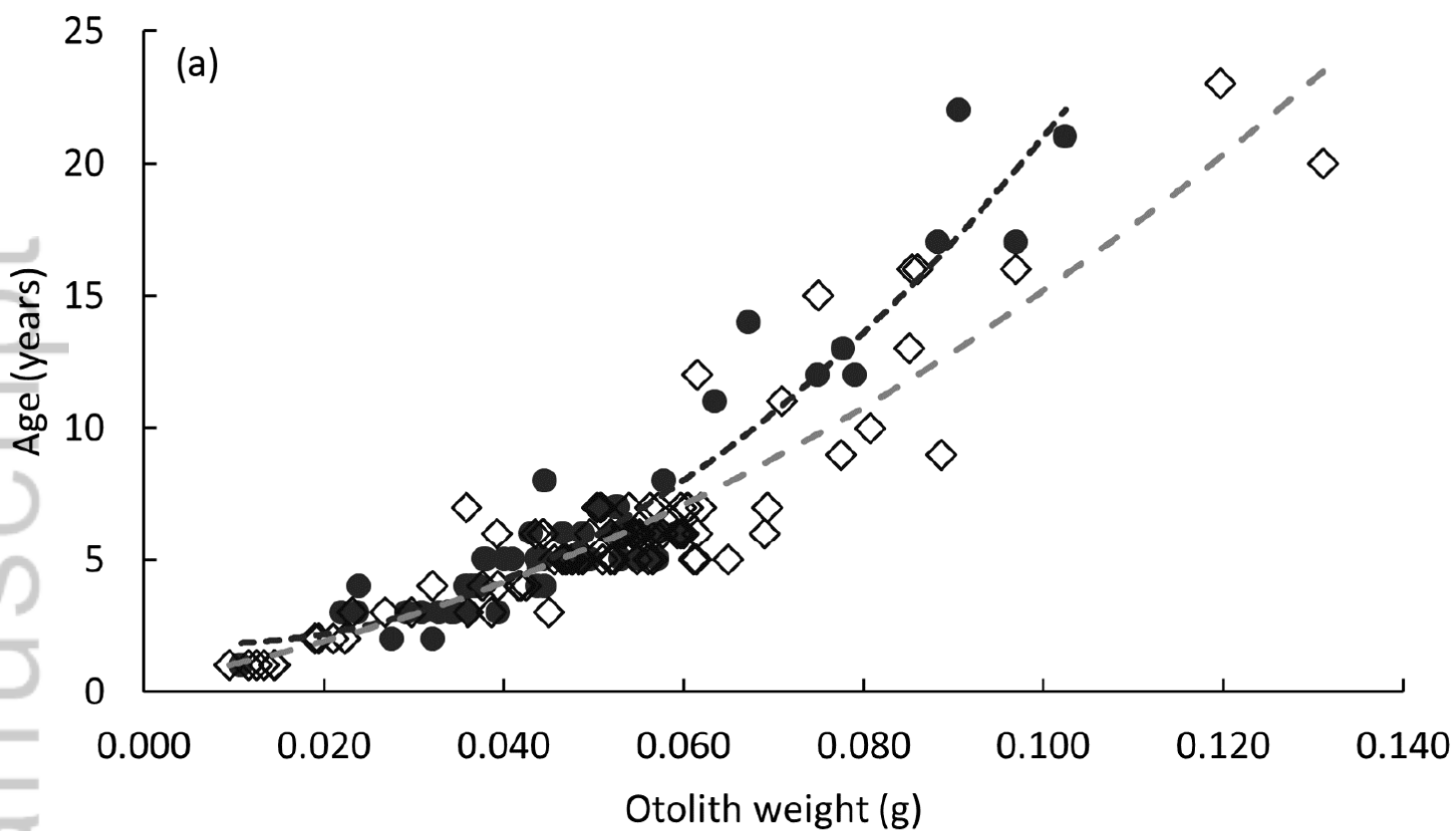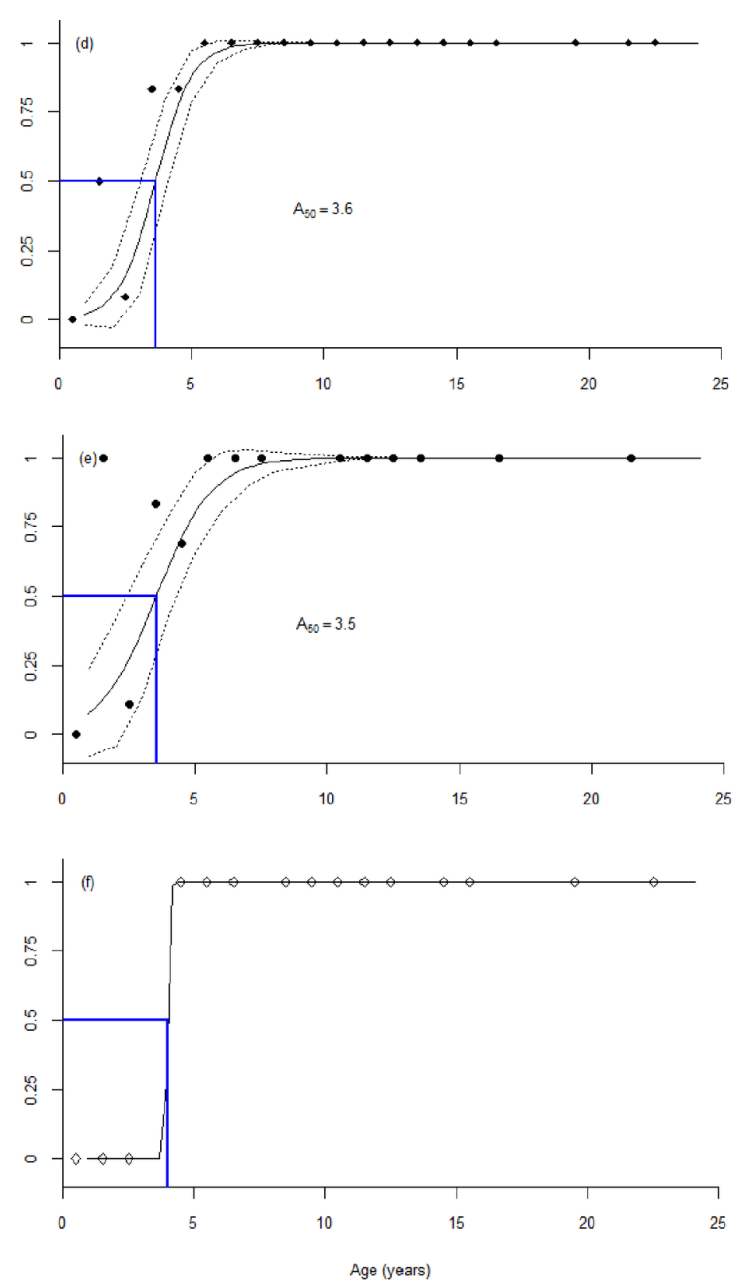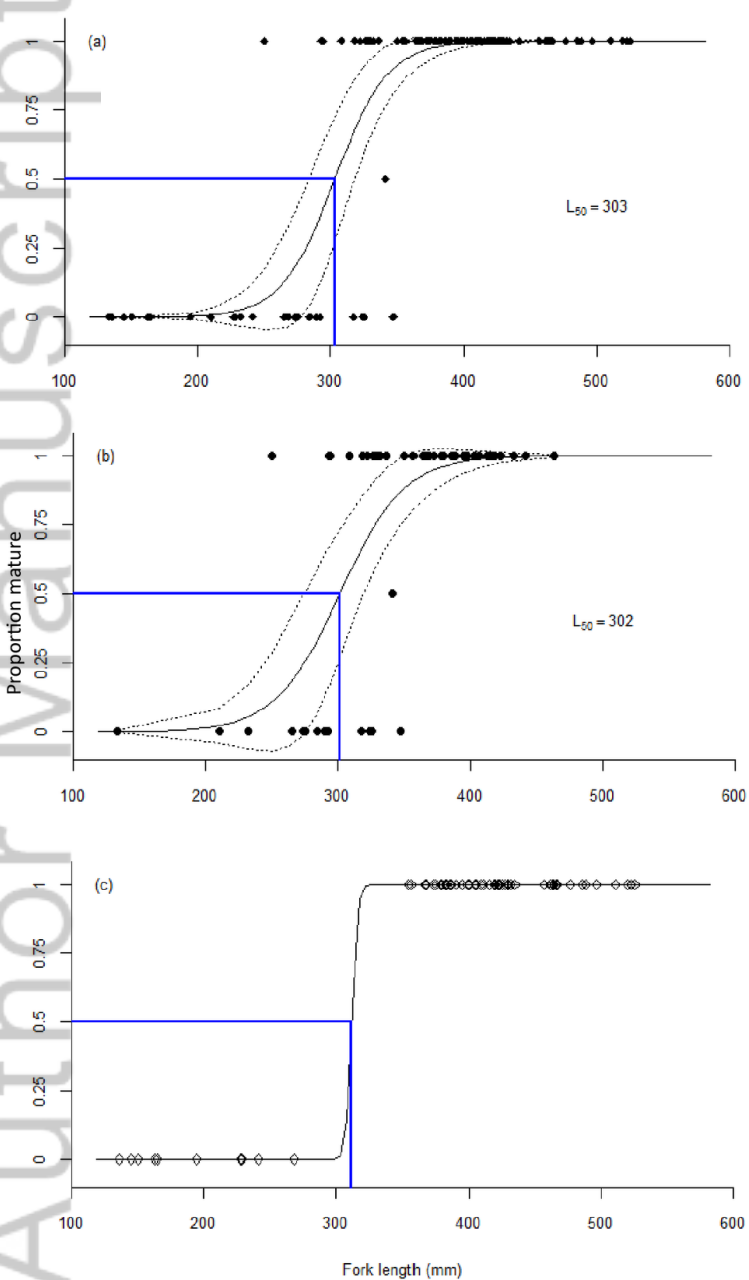lethrinid fishes. *Journal of Fish Biology, 21*, 475–484.
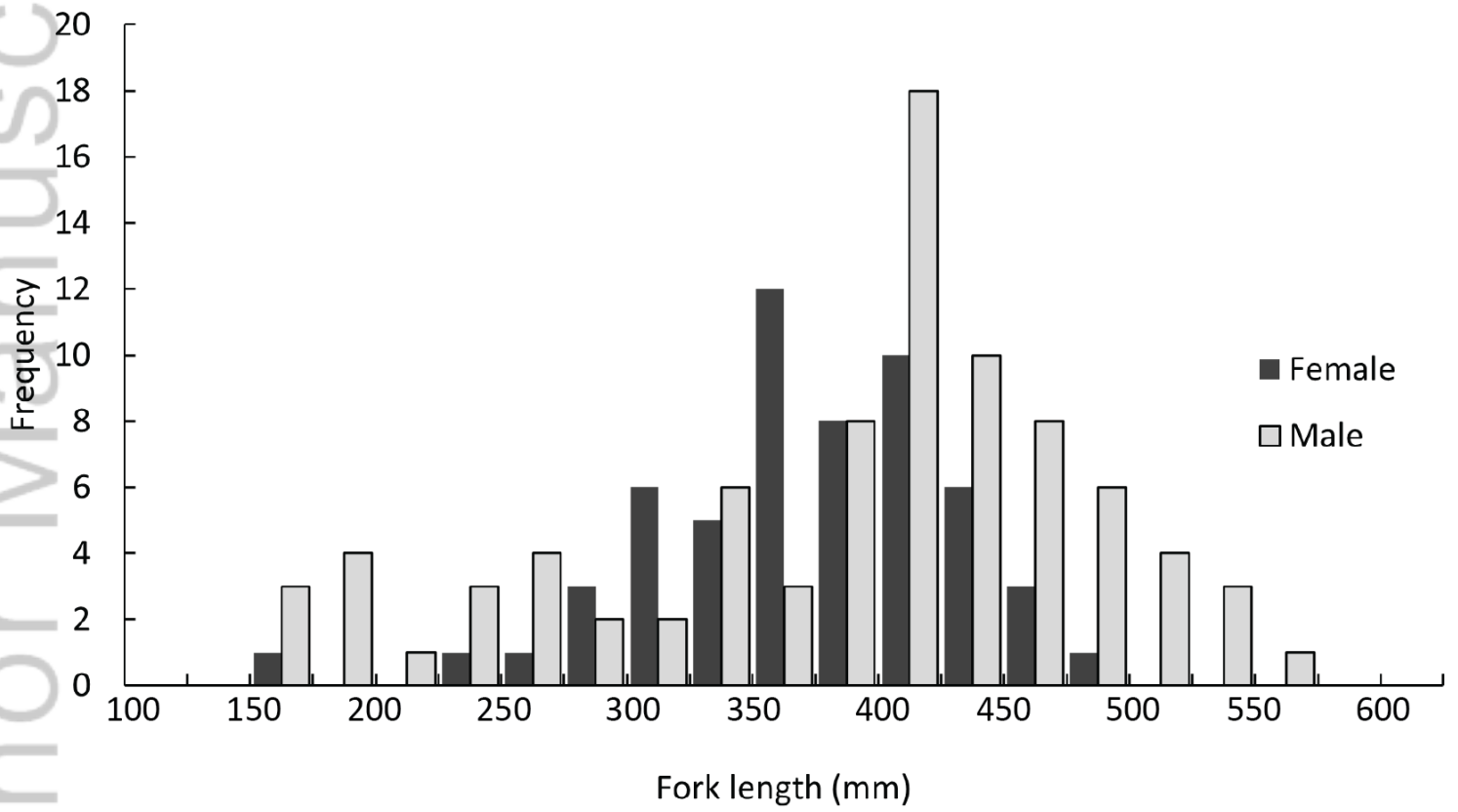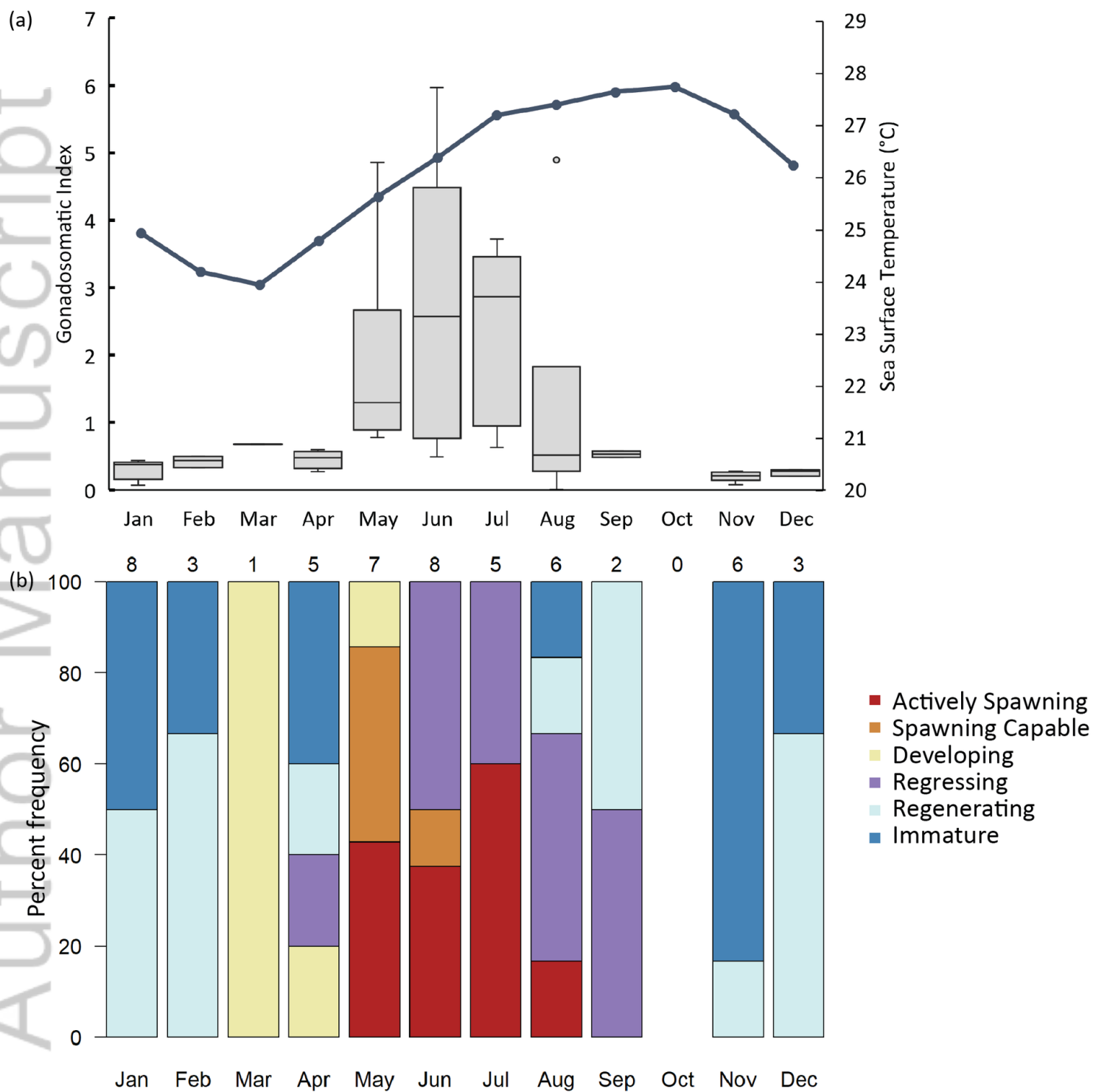
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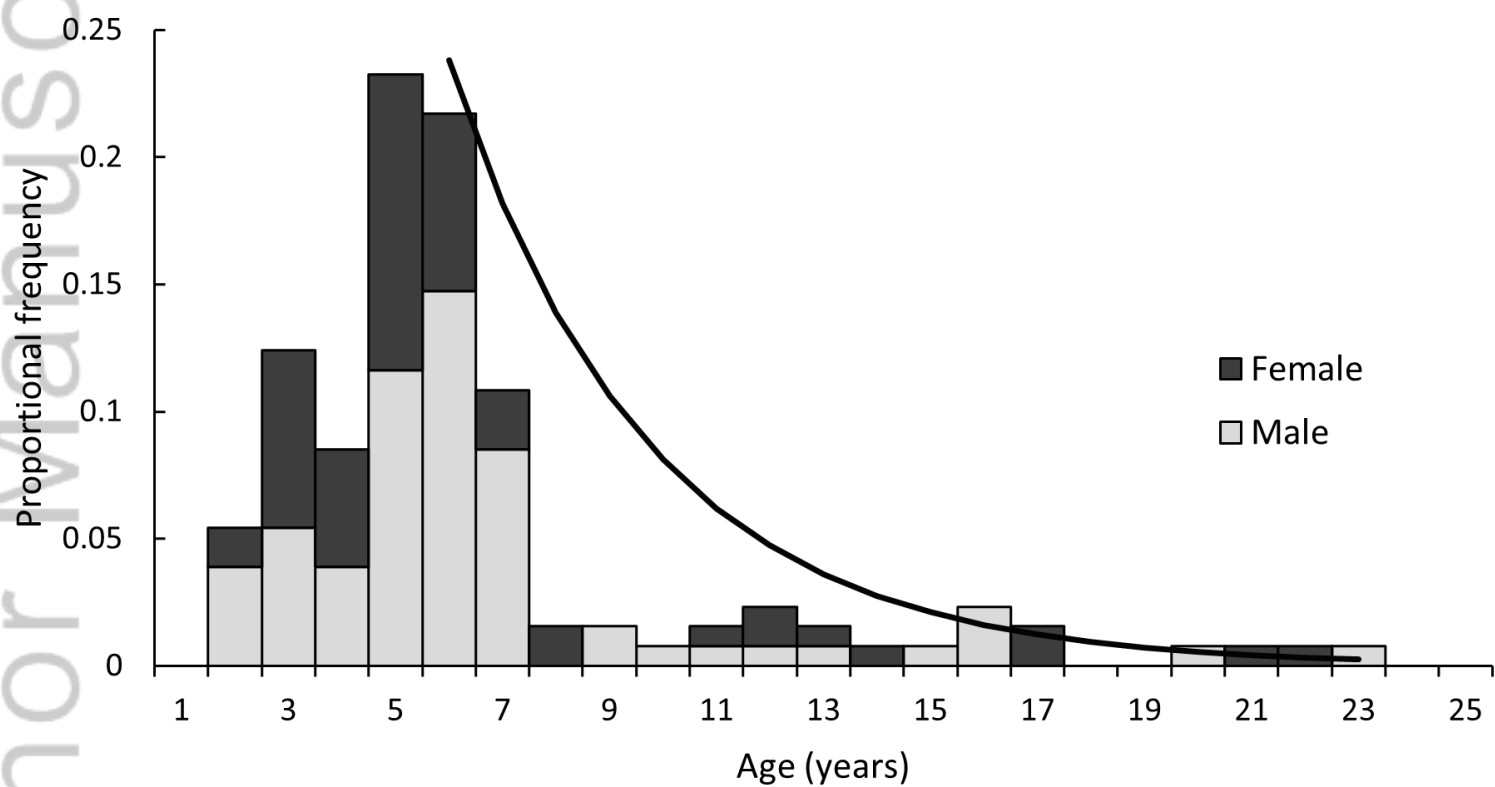
JFB_15065_Fig 3. growth.png

JFB_15065_Fig 4. Maturity.png

JFB_15065_Fig 5. Spawning season 2.0.png

JFB_15065_Fig 6. Multinomial CC.png

Figure Captions

Figure 1: Sex specific length-frequency distributions for females (black bars) and males (light gray bars) for *Monotaxis grandoculis* from Hawaiʻi.

Figure 2: Photomicrographs of transverse otolith section for *Monotaxis grandoculis*. Annual increments are denoted by white markers.

Figure 3: Sex-specific relationships for (a) sagittal otolith weight (g) and annual age (represented by number of annuli) and (b) von Bertalanffy growth curve. The solid blue line represents the combined best fit curve for both sexes. See Table 1 for parameter estimates.

Figure 4: *Monotaxis grandoculis* size at maturity (L_{50}) (left column) and age at maturity (A_{50}) (right column) for combined sexes (a & d), female (b & e), and male (c & f). Dashed lines indicate 95% confidence intervals and blue lines indicate L_{50}/A_{50}.

Figure 5: Spawning seasonality for *Monotaxis grandoculis* (a) mean female gonadosomatic index (I_G) per month (box plot) with associated monthly mean sea surface temperature (SST) (line graph) from Honolulu, HI (NOAA Coral Reef Watch (CRW) 2019) and (b) frequency of female reproductive phases per month. Numbers above the box plots indicate sample size per month.

Figure 6: Sex-specific age frequency distribution of *Monotaxis grandoculis* from the Hawaiian commercial fishery. The curve line represents the expected proportion of individuals at age from the multinomial catch curve with logistic selectivity.

Significance Statement

This study provides age, growth, maturity, and mortality information for the commonly targeted emperor species: *Monotaxis grandoculis*, which is the only Lethrinid found in Hawaiʻi. This is the first robust demography study producing sex specific age, growth, and maturity data for this species.

Table 1: Summary of life history traits for *Monotaxis grandoculis* from Hawai'i.

	A_{max}	L_∞ (mm)	K (year^{-1})	t_o (years)	L_{50}	A_{50}	Z_{age}
Females	22	427 (411-443)	0.33 (0.30-0.36)	-0.29	302 (292-323)	3.5 (3.2-4.3)	
Males	23	506 (482-527)	0.24 (0.22-0.27)	-0.32			
Combined	23	472 (457-487)	0.27 (0.25-0.29)	-0.31	303 (297-323)	3.6 (3.4-4.1)	0.27 (0.20-0.35)

Notes: Associated 95% confidence intervals presented in parentheses where appropriate. A_{max} maximum age; L_∞-asymptotic fork length; K-growth coefficient; t_0 hypothetical age when length equals zero; A_{max} maximum age; L_{50} length at 50% maturity; A_{50} age at 50% maturity; Z total mortality. Growth model constrained at 38 mm at age 0.