AGE, GROWTH, REPRODUCTION, AND MORTALITY OF THE LINED SURGEONFISH (*ACANTHURUS LINEATUS*) FROM SAIPAN, NORTHERN MARIANAS

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Abstract

Fisheries in the Commonwealth of the Northern Mariana Islands (CNMI) consist of shore-based and boat-based catches of coral reef species. Surgeonfish (Family Acanthuridae), especially Lined Surgeonfish *Acanthurus lineatus*, contribute significantly to total landings in the nearshore coral reef fishery of the CNMI. Despite being an important component of the nearshore fishery, there is very little known about the biology and life history of the Lined Surgeonfish in the CNMI. The objective of this study was to investigate the age-based demography and reproductive biology of *Acanthurus lineatus* from Saipan, CNMI to enhance our understanding of their life history. To determine age and growth, longevity, mortality rates, age- and length-at-maturity, and spawning seasonality, fishery-dependent specimens collected during May 2017 to October 2019 were examined. There were no significant mean length differences between the distribution of male and female specimens. The combined length-weight relationship for all specimens across all years was $W = 0.031 \times 10^{-5}(FL)^{2.957}$. Growth model parameters were a mean asymptotic length (L_∞) of 20.5 cm FL, a growth coefficient (K) of 0.24 $year^{-1}$ and a t_0 of -3.2 years. The maximum recorded age was 20 years. Otolith weight was a good predictor of age for both males and females. Estimated total mortality was 0.495 $year^{-1}$, natural mortality (M) was 0.315 $year^{-1}$, and fishing mortality was 0.18 $year^{-1}$. The overall sex ratio was male to female = 1:1.81. For females, the length at 50% sexual maturity (L_{50}) was 18.8 cm fork length and age at 50% maturity (t_{50}) was 6.2 years. Maturity for males was not estimated due to an insufficient number of immature males. Spawning capable and active *A. lineatus* females and males were observed during all months with sample collection, potentially supporting a year-round spawning cycle. The outcomes of the work could be used to inform length-based fishery

regulations and indicator-based single species stock assessment approaches to support the sustainable fishery management of *A. lineatus* in the CNMI.

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Introduction

Coral reef fisheries are a vital component of tropical societies, supporting tens of millions of people with food and livelihoods (Burke et al., 2011). For many Pacific Island communities, coral reef fisheries are fundamental to subsistence and trade as well as of immense social and cultural importance (Boehlert 1993, Dalzell et al. 1996). The critical economic and ecological importance of coral reef fisheries makes their sustainability a primary management and conservation concern in tropical regions (Ault et al. 2014, Cinner et al. 2020, Robinson et al. 2022). Reef fisheries target a suite of species with a wide range of demographic and biological characteristics. A lack of information regarding the life histories of heavily targeted species hinders proper management. Length at age information is necessary to estimate life history parameters such as growth rates and age-specific mortality patterns (Hilborn and Walters, 1992). Such information can serve as a foundation for more comprehensive analyses of life history patterns and single-species stock assessments, and are essential to the management of reef fishes (Walters and Martell, 2004). However, gaps in present knowledge remain in areas of the Pacific where coral reef fisheries represent a significant source of income and protein (Trianni et al., 2018).

Acanthurus lineatus is a common constituent of coral reef communities throughout the Indo-Pacific Region (Fig. 1). They exhibit rapid initial growth in early life and are relatively long-lived coral reef fish species (Choat and Axe, 1996, Craig et al., 1997). They have been observed to reach a maximum size of 23 cm fork length (FL) in American Samoa and 21 cm FL in the Great Barrier Reef (GBR; Choat and Axe, 1996; Craig et al., 1997; Gust et al., 2002).

They are classified as herbivores known to feed on algal mats and have been observed schooling to defend feeding territories (Robertson et al., 1979). This species does not exhibit sexual dimorphism and forms spawning aggregations (Claydon et al., 2014; Robertson et al., 1979). A previous reproductive study by Craig et al. (1997) observed spawning throughout the year, in which groups of 50-200 fish were seen spawning at dawn. Length-weight relations for the sexes in the Mariana Islands did not differ significantly (Kamikawa et al., 2015; Matthews et al., 2019) and half of the population reached sexual maturity (i.e., L_{50}) at about 18 cm fork length (Craig et al., 1997).

Figure 1. Lined surgeonfish *Acanthurus lineatus* (source: Flickr).

Previous age-based studies on *A. lineatus* on the GBR (Choat and Axe, 1996) and American Samoa (Craig et al., 1997) identified several demographic processes, including age-specific variations in growth, reproduction, and mortality rates that influence in the effective management

of reef fishes including surgeonfishes (Taylor and Choat, 2014). Prior work done in the CNMI included life history analysis of parrotfishes and unicornfishes, however, no focused work has been done for *A. lineatus* despite their importance to commercial, recreational, and subsistence fisheries.

A lack of locally collected life history data for species in CNMI's coral reef fisheries has limited assessment efforts (Houk et al., 2012; Trianni et al., 2018). In the Commonwealth of the Northern Mariana Islands (CNMI), surgeonfishes (Family Acanthuridae) are a prime target for coral reef fisheries. Lined Surgeonfish *Acanthurus lineatus* (Linnaeus, 1758), along with other acanthurids, contributed significantly to the total landings in the nearshore fishery of the CNMI, composing approximately 31% of landings by number and weight (Trianni et al., 2018). Although they make up a large component of the fishery catch, there is a lack of life history data generated locally for many coral reef fishes in the Marianas including *A. lineatus.* To address this knowledge gap, the objective of this study is to investigate the reproductive biology, age-based demography, and spawning seasonality of *A. lineatus* from the CNMI using specimens collected over a three-year period (2017-2019) to support sustainable fisheries management for this species.

Methods

Sampling: Otolith and gonad samples from *A. lineatus* were collected from Saipan using night-time SCUBA spearfishing by commercial fishers. The island of Saipan is the largest island in the CNMI at about 19 kilometers (km) long and 9 km wide. The eastern coastline is composed

primarily of rugged, rock cliffs while the western side is bounded by a large lagoon that extends almost the entire length of the island. Samples were collected at Saipan fish markets and provided by the NOAA Fisheries Pacific Islands Fisheries Science Center (PIFSC) Life History Program's (LHP) Biosampling Program for this study. The biosampling program collected 662 specimens from May 2017 to October 2019. Fork length to the nearest 0.1 cm, fish weight to the nearest gram, gonad weight to the nearest 0.001 g, and otolith weight to the nearest 0.001 g were recorded for each specimen. Gonads were weighed and preserved in 10% buffered formalin and sagittal otoliths were removed, dried and weighed, and stored for future processing. Specimens were collected monthly across as broad a size range as possible to attempt to provide sufficient sample sizes and temporal coverage to examine life history traits.

Sagittal Otolith processing for Age/Growth: Sagittal otoliths processing generally followed the criteria outlined by Taylor and Choat (2014). Otoliths were fixed by thermoplastic glue to a clear glass slide and ground along the longitudinal axis to expose the nucleus on a lapping wheel. The ground otolith was removed and fixed to a clean slide with the flat surface down, and then grounded until a thin transverse section (i.e., 300-500 μm) was obtained.

Age Determination: Annuli were delineated following criteria of Choat and Axe (1996). Age was estimated by counting alternating opaque growth zones on transverse sections of the otolith. Otolith procedures were performed as described by Taylor and Choat (2014). Blind readings were made on three separate occasions 1–2 weeks apart and the final age (in years) of an

individual was determined when two or more counts agreed. In cases where agreement was not achieved after three counts, the otolith was excluded from further analysis. Daily increments were not examined to validate annuli counts in this study but prior work has validated daily increments for tropical surgeonfishes (Choat et al., 2009; Choat & Axe, 1996).

Growth and Mortality: Growth was estimated by fitting the von Bertalanffy growth function (VGBF) to length at age data. The VBGF is $L_t = L_\infty(1 - e^{-K(t-t0)})$, where L_t is the predicted L at age t (years), L_∞ is the mean asymptotic L, K is the coefficient used to describe the curvature of fish growth towards L_∞, t represents age (years) and t_0 is the theoretical age at which $L = 0$. Separate von Bertalanffy growth curves were generated for males and females and compared using the function *growthlrt* in the *fishmethods* package (Nelson, 2023) in R version 4.1 (R Core Development Team 2022).

Total mortality (Z) was estimated using the Chapman-Robson (CR) catch curve method (Chapman and Robsonn, 1960). This method provides estimates of annual survival rate (S) and instantaneous mortality rate (Z) from catch-at-age data on the descending slope of a catch-curve, with the first age-group used being one year older than the age of peak abundance. Ages were recoded such that the year after peak abundance was age zero and every age class following +1. The CR variance estimator was corrected for overdispersion to avoid a large negative bias and to reduce the mean square error (Smith et al., 2012). Natural mortality (M) was estimated using the updated Hoenig (1983) estimator based on the t_{max} parameter: $M = 4.899t_{max}^{-0.916}$, where t_{max} is the maximum observed age (Then et al., 2015).

Reproduction/Gonad processing: Fixed samples of gonads were processed for sectioning and staining following methods outlined in Longenecker et al. (2020). An approximate 8-mm^3 sample was cut from each gonad, placed the sample in a 24-well tissue culture plate, and were dehydrated in a graded alcohol series (30 min in each of 50%, 75%, and 95% ethanol). Using plastic embedding medium (JB4, Electron Microscopy Sciences, Hatfield, PA) and following kit instructions, gonad samples were infiltrated in two changes of infiltration solution, transferred into embedding capsules (BEEM®, size 00), and embedded. To ensure that the plastic medium hardened completely, tissue blocks were further dehydrated for 12 hours in a desiccation chamber.

Using an MT1 Porter-Blum ultramicrotome (Sorvall, Inc., Newton, CT) outfitted with a glass knife, 10 tissue sections (approximately 3-5 μm thick) were obtained, distributed evenly throughout each tissue block. The tissue sections were floated on water droplets distributed on microscope slides, and slides dried on a slide warmer. Tissue sections affixed to the slides were stained in alternating solutions of haematoxylin and eosin for approximately 15-30 s. The two compounds provided a counterstaining of tissues to better identify cellular structures. Excess stain was removed with a gentle stream of water, and the slides once again dried on the warmer.

Ovary and testis sections were examined at 400X (total magnification) for evidence of reproductive maturity. Sectioned gonads examined microscopically for 'sexual maturity and development' using criteria from Brown-Peterson et al. (2011) and Longenecker et al. (2020). Females were classified as immature, developing, spawning capable, regressing, and

regenerating, on a modified classification of Brown-Peterson et al. (2011; Table 1). Males were considered mature when the testes contain visible spermatozoa (i.e., sperm cells with tails).

Table 1. Descriptions of the phases in the reproductive cycle of female fishes used to classify the reproductive stage of female Lined Surgeonfish *Acanthurus lineatus* captured from around Saipan, CNMI during May 2017 – October 2019. Abbreviations are CA = cortical alveolar; GVBD = germinal vesicle breakdown; GVM = germinal vesicle migration; OM = oocyte maturation; PG = primary growth; POF = postovulatory follicle complex; Vtg1 = primary vitellogenic; Vtg2 = secondary vitellogenic; Vtg3 = tertiary vitellogenic. Modified from Brown-Peterson et al. (2011).

Phase	Macroscopic and histological features
Immature (never spawned)	Small ovaries, often clear, blood vessels indistinct. No atresia or muscle bundles. Thin ovarian wall and little space between oocytes.
Developing (ovaries beginning to develop)	Enlarging ovaries, blood vessels becoming more distinct. PG, CA, Vtg1, and Vtg2 oocytes present. Some atresia can be present. No evidence of POFs or Vtg3 oocytes.
Spawning Capable (fish are developmentally and physiologically able to spawn in this cycle)	Large ovaries, blood vessels prominent. Individual oocytes visible macroscopically. Vtg3 oocytes present or POFs present in batch spawners. Atresia of vitellogenic and/or hydrated oocytes may be present. Early stages of OM can be present.
Regressing (cessation of spawning)	Flaccid ovaries, blood vessels prominent. Atresia (any stage) and POFs present. Some CA and/or vitellogenic (Vtg1, Vtg2) oocytes present.
Regenerating (sexually mature, reproductively inactive)	Small ovaries, blood vessels reduced but present. Only oogonia and PG oocytes present. Muscle bundles, enlarged blood vessels, thick ovarian wall and/or gamma/delta atresia or old, degenerating POFs may be present.

Size-at-sexual-maturity for each sex were estimated by the size at which a logistic regression of percent mature individuals in each 1-cm size class versus fork length (the average length of individuals within a size class) indicates 50% and 95% of individuals are mature. Following methods by Taylor and Choat (2014), the proportion of mature- females were plotted by length or age class and a logistic curve was fitted to the data as follows: $P_R = (1 +$

$e\left[-\frac{\ln(19)(L-L_{50})}{L_{95}-L_{50}}\right]^{-1}$), where P_R represents the estimated proportion of matured females at a given length (L) and L_{50} and L_{95} are the length at 50 and 95% maturity. Curves were fitted using non-linear least-squares estimation and the corresponding 95% C.I. for each were derived by bootstrap re-sampling (1000 iterations). The same equation was used to determine age at female maturation and the proportion of matured males by length and age.

Results of histological analysis were used to describe reproductive mode. The criteria of Sadovy and Shapiro (1987) was used as evidence of potential hermaphroditism, although it was not expected for this species, including the presence of a sex-based bimodal size distribution, a lumen or brown bodies in testes, and spermatogenic tissue in ovaries. Histograms of length frequency distributions and QQ plots of histologically-determined males and females were visually assessed for normality. Male and female length distributions were tested for normality using a Shapiro-Wilk test and equal variances using a F-test for equality of variances, two-sided. Mean male and female lengths for normal distributions with or without equal variances were compared with a t-test. Non-normal distributions of male and female mean lengths were tested with a Wilcoxon rank sum test. The percentage of females versus the average length in each reproductively mature size class was plotted and exploratory regression analysis was used to evaluate whether sex ratios varied predictably with size. Data collected during whole-specimen processing was used to compute a gonadosomatic index (GSI = 100*(G / (S – G)) where: G is whole gonad weight and S is somatic weight using specimens larger than L_{50}. Gonadosomatic index as a function of date was plotted to search for seasonal variation in reproductive investment. Differences in female GSI by month were tested with a one-way ANOVA.

Results

A total of 435 *A. lineatus* were sampled between May 2017 and October 2019 from Saipan, Northern Marianas and ranged in fork length from 12 – 22 cm (mean $\pm$ S. E. $= 17.3 \pm 0.1$ cm; Fig. 2). Summaries statistics for lengths of the collected specimens demonstrated comparable size ranges between years (Table 2). Fork lengths were similar between sexes identified macroscopically across years with unknown sexes tending to be smaller specimens (Table 3). The groups were not statistically tested since macroscopic sex identification is unreliable. Across the three years, most specimens were collected between April and September with a peak in May with none collected in November or December (Fig. 3). Females ranged from 13.7 – 22.1 cm FL (mean ± S.E. = 17.9 ± 0.1 cm) and males ranged from 14.8 – 22.3 cm FL (mean ± S.E. = 18.2 ± 0.2 cm). Size ranges of fish collected across months were generally similar with some exceptions during months with low sample sizes (Table 4). The combined length-weight relationship for all specimens across all years was $W = 0.031 \times 10^{-5}(FL)^{2.957}$ ($r^2 = 0.956$).

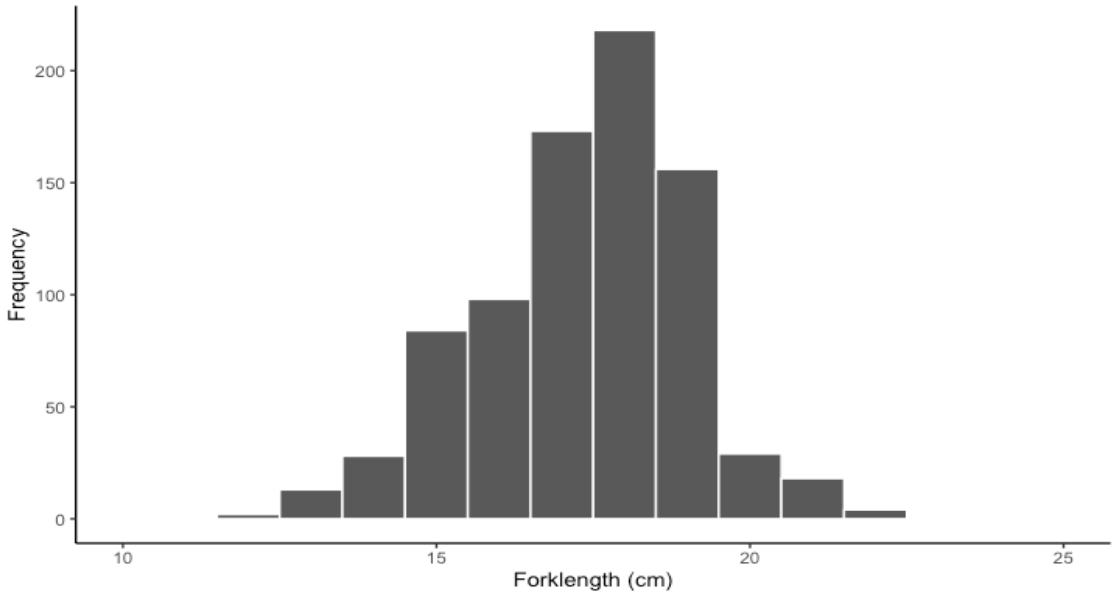

Figure 2. Size frequency distribution in fork length (cm) of the Lined Surgeonfish, *Acanthurus lineatus* specimens collected in the Commonwealth of the Northern Mariana Islands (CNMI), 2017-2019.

Table 2. Annual summary statistics of fork length (cm) of the Lined Surgeonfish, *Acanthurus lineatus* specimens collected in the Commonwealth of the Northern Mariana Islands (CNMI), 2017-2019.

Year	median	Min	max	n
2017	17.1	12.0	21.2	196
2018	17.5	12.7	22.3	281
2019	17.6	13.7	20.0	185

Table 3. Annual summary statistics of fork length (cm) by macroscopically-identified sex of the Lined Surgeonfish, *Acanthurus lineatus* specimens collected in the Commonwealth of the Northern Mariana Islands (CNMI), 2017-2019.

Year	Sex	Median FL (cm)	Minimum FL (cm)	Maximum FL (cm)	n
2017	1 - Female	17.5	14.2	20.7	85
2017	2 - Male	17.2	12	21.2	83
2017	3 - Unknown	15.55	13.9	19.6	28
2018	1 - Female	17.8	13.7	21.5	121
2018	2 - Male	17.7	14.8	22.3	110
2018	3 - Unknown	15	14	18.3	50
2019	1 - Female	17.65	14.6	20	88
2019	2 - Male	17.5	13.9	19.9	83
2019	3 - Unknown	16	13.7	18.9	14

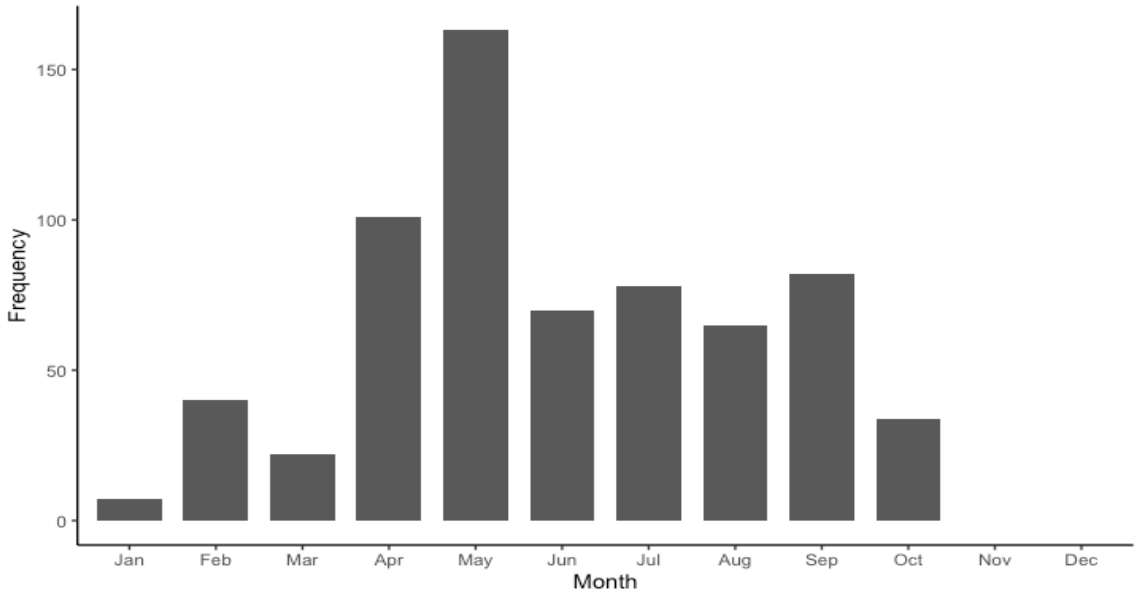

Figure 3. Monthly sample size of the Lined Surgeonfish*, Acanthurus lineatus* specimens collected in the Commonwealth of the Northern Mariana Islands (CNMI), 2017-2019.

Table 4. Monthly summary statistics of fork length (FL) of the Lined Surgeonfish, *Acanthurus lineatus* specimens collected in the Commonwealth of the Northern Mariana Islands (CNMI), 2017-2019. No specimens were available from November or December.

Month	Median FL (cm)	Minimum FL (cm)	Maximum FL (cm)	n
January	16.1	13.9	19.2	7
February	18.0	15.5	20.0	40
March	16.8	15.0	19.1	22
April	17.3	13.7	19.3	101
May	17.5	12.0	21.2	163
June	17.7	14.7	19.9	70
July	17.6	14.2	22.0	78
August	17.4	14.0	21.5	65
September	15.7	12.7	20.6	82
October	18.2	14.7	19.6	34

Age, Growth, and Mortality

Annuli were identified in 319 of the 359 *A. lineatus* otoliths examined. Approximately 50% of individuals sampled were less than four years of age. The maximum age for *A. lineatus* observed in this study was 20 years. For fishes with known sex, maximum age recorded for females was 17 years and males 18 years. Sex-specific VBGF coefficients were not different (χ^2 = 1.9, p = 0.17 for L_∞; χ^2 = 1.4, p =0.24 for K; χ^2 = 1.65, p =0.20 for t_0), so female, male, and unknown sex length-at-age data were pooled and a single VBGF fitted to the entire sample. *Acanthurus lineatus* VBGF parameters were a mean asymptotic length (L_∞) of 20.5 cm FL [95% CI = 19.7, 21.5], a growth coefficient (K) of 0.24 $year^{-1}$ [0.18, 0.31] and a t_0 of -3.2 years [-4.56, -2.34] (Fig. 4). Otolith weight was a good predictor of age for both males and females (r^2 = 0.88; Fig. 5). Estimated total mortality (Z) using a Chapman-Robson estimator was 0.495 $year^{-1}$ (Fig. 6)

and natural mortality (M) using the updated Hoenig estimator was 0.315 $year^{-1}$ which provided an estimate of fishing mortality (F) of 0.180 $year^{-1}$ (from $F = Z - M$).

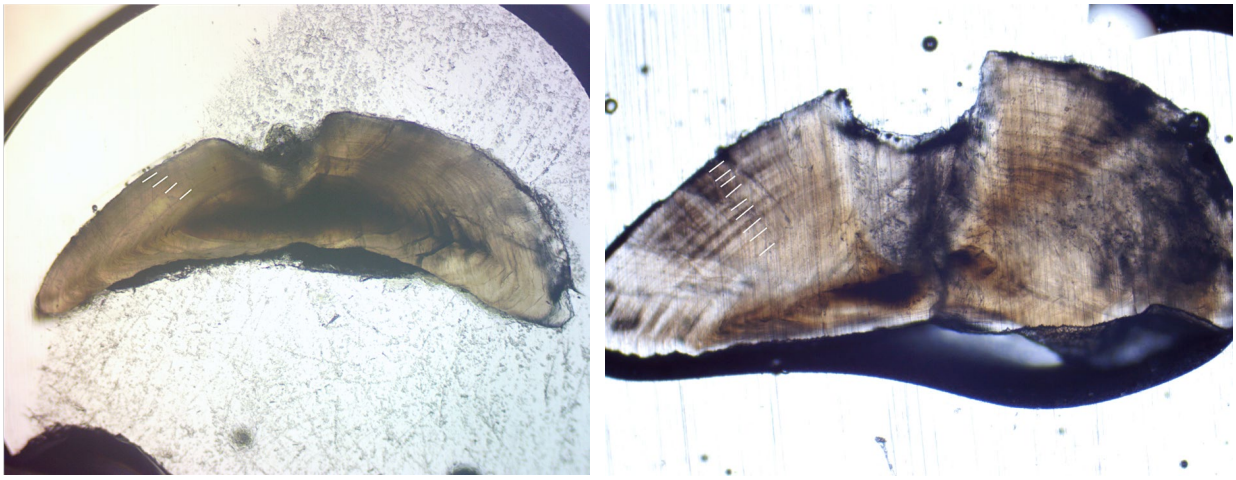

Figure 4. Sectioned sagittal otoliths from the Lined Surgeonfish, *Acanthurus lineatus* collected in the Commonwealth of the Northern Mariana Islands (CNMI) from 2017 – 2019, with age estimates of 4 years (left panel) and 9 years (right panel) indicated.

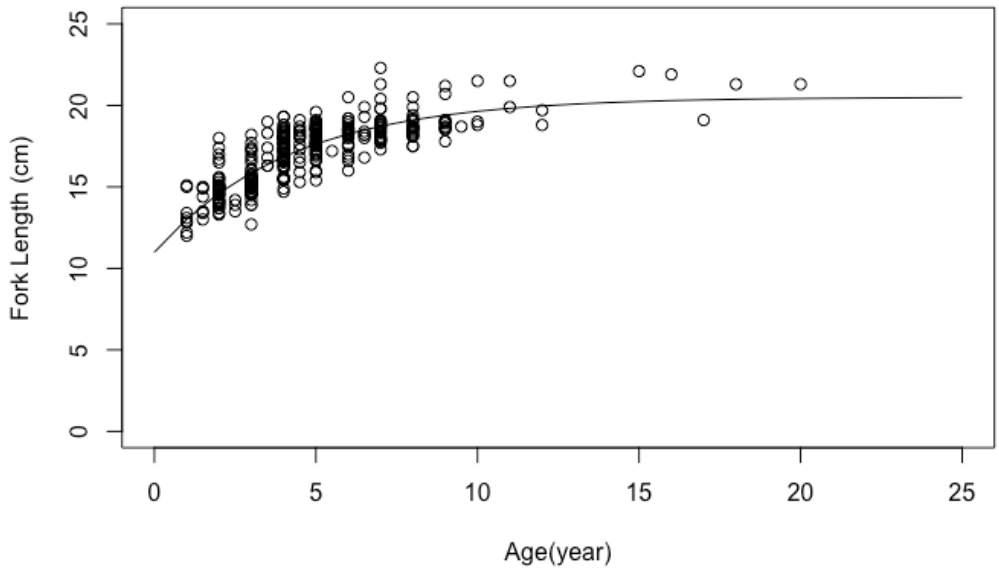

Figure 5. Size-at-age relationship for the Lined Surgeonfish, *Acanthurus lineatus* from the Commonwealth of the Northern Mariana Islands (CNMI) collected in 2017 – 2019 with best-fit von Bertalanffy growth function (VBGF) curve (n = 319, K = 0.24).

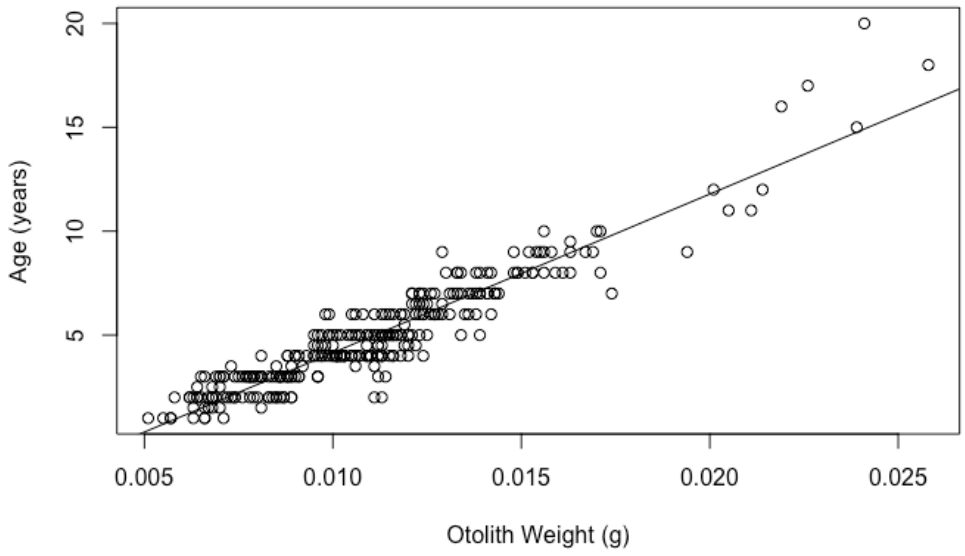

Figure 6. Relation between age and sagittal otolith weight for the Lined Surgeonfish, *Acanthurus lineatus*, collected in the Commonwealth of the Northern Mariana Islands (CNMI) from 2017 – 2019 (n = 319, r^2 = 0.88).

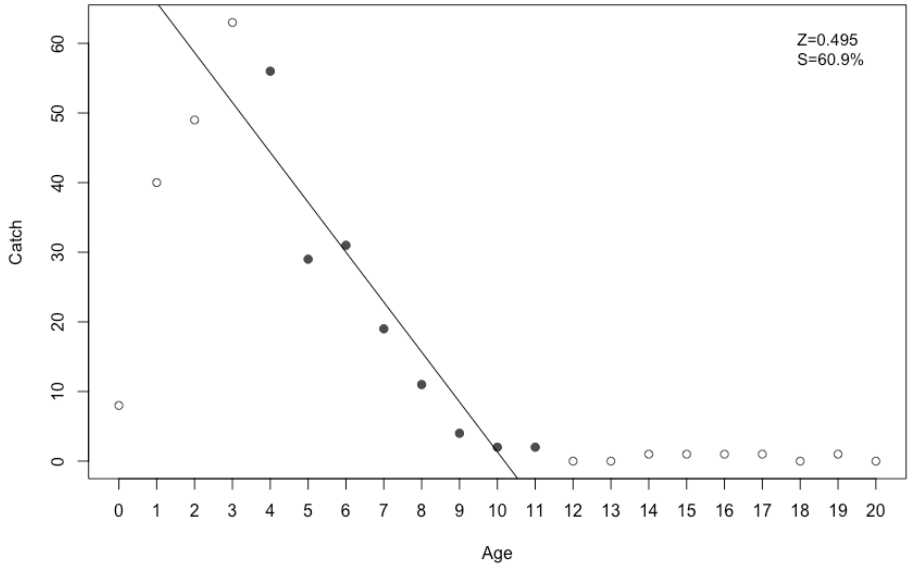

Figure 7. Age-based catch curve of the Lined Surgeonfish, *Acanthurus lineatus*, collected in the Commonwealth of the Northern Mariana Islands (CNMI) from 2017 – 2019, estimating instantaneous total mortality (Z) and survival rate (S) using the Chapman-Robson catch curve method.

Sexual Maturity, Development, and Reproductive Seasonality

Gonads of 344 individual *A. lineatus* were examined using methods following criteria outlined in Brown-Peterson et al. (2011) and Longnecker et al. (2020). *A. lineatus* ovarian and testicular histology illustrated immature and spawning capable phases for both sexes (Fig. 7). The overall sex ratio was male to female = 1:1.81. Female samples included 90 immature, 32 developing, 71 spawning capable, and two regressing (cessation of spawning) females. Male samples included 13 immature and 92 mature males. There was no evidence of hermaphroditism for this species. The length frequency of histologically-determined females was not normally distributed (W = 0.95963, $p = 0.00028$), so the non-parametric Wilcoxon rank sum test was used to compare male and female lengths. The mean fork lengths of males and females were not significantly different (W = 6099, $p = 0.1657$).

A low number of *A. lineatus* were sampled in January, and no samples were collected in November and December of each year so GSIs were not available for all months. Spent females were found in February and September of 2019. Low GSI values were only observed in non-consecutive months (Fig. 8). Female mean GSI values were not significantly different between months ($F_{1,41} = 0.692$, $p = 0.41$). Male mean GSI values by month were not tested due to the inability to estimate a male L_{50}. Monthly male GSI values were plotted for all males to visual temporal trends but should be evaluated rigorously only after an male length at maturity is estimated (Fig. 9). Spawning capable and active *A. lineatus* females and males were observed during all months with sample collection, potentially supporting a year-round spawning cycle (Fig. 9). The length at 50% sexual maturity (L_{50}) was estimated as 18.9 cm fork length for

females (Fig. 10). Female age at 50% maturity (t_{50}) was estimated at 6.2 years (Fig. 11).

Maturity for males was not estimated due to an insufficient number of immature males.

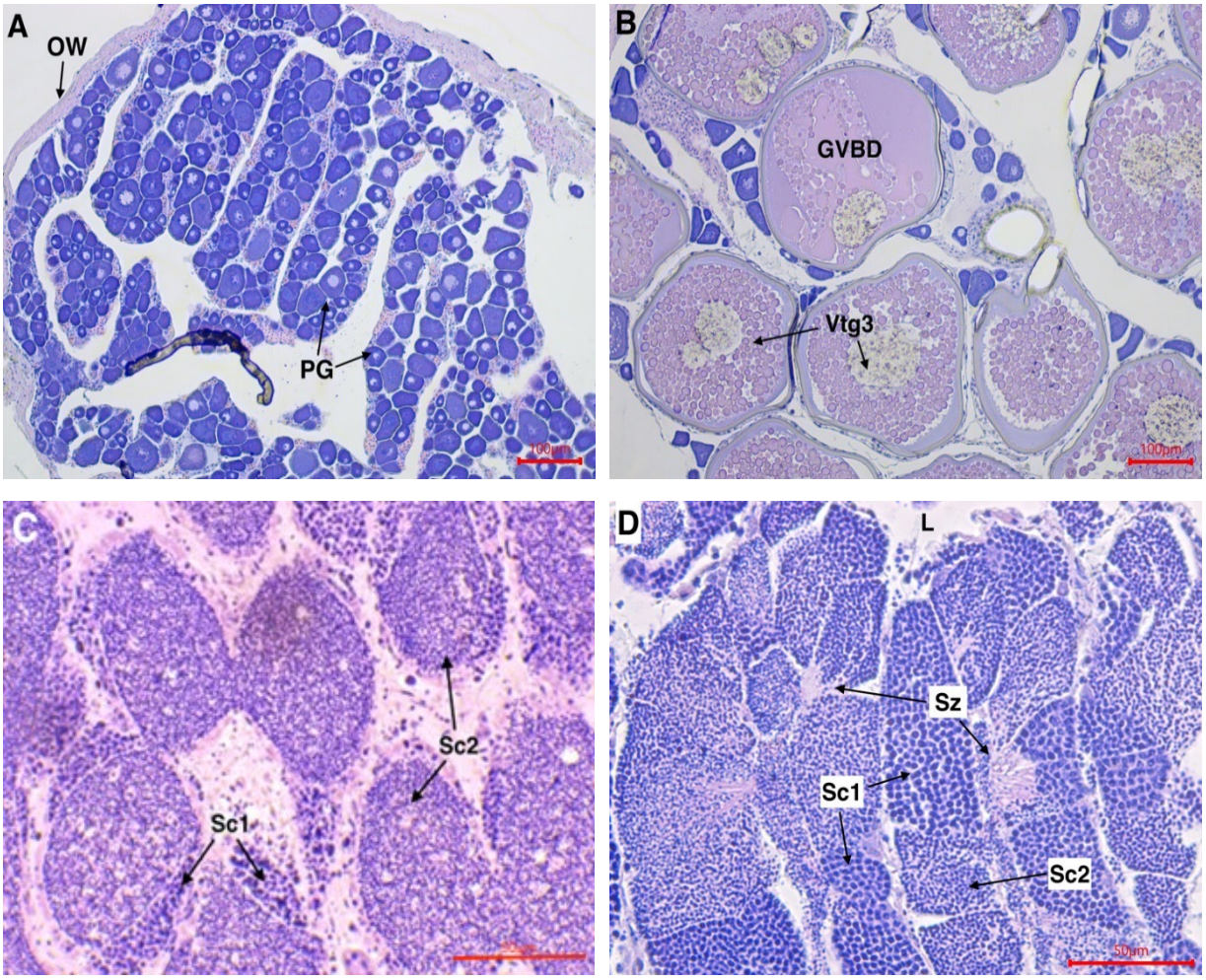

Figure 8. Photomicrograph of ovarian and testicular histology of the Lined Surgeonfish, *Acanthurus lineatus* collected in the Commonwealth of the Northern Mariana Islands (CNMI) from 2017 – 2019, illustrating immature and spawning capable phases for both sexes. (A) Immature female characterized by tightly packed primary growth (PG) oocytes. (OW = ovarian wall) (B) Mature female fish in the 'actively spawning subphase with the presence of oocytes undergoing germinal vesicle breakdown (GVBD) (Vtg3 = tertiary vitellogenic). (C) Immature male with primary spermatocytes (Sc1), secondary spermatocytes (Sc2), and a lack of

spermatozoa (Sz) (D) Mature, spawning capable male characterized by the presence of spermatozoa. (Brown-Peterson et al., 2011, Longenecker et al., 2020).

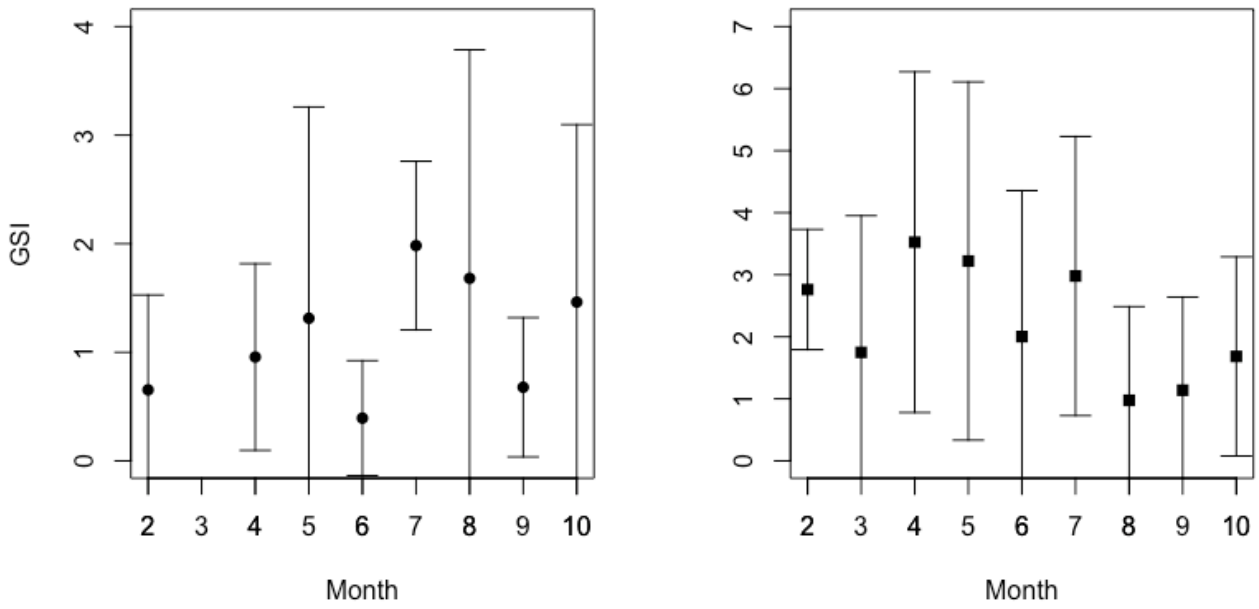

Figure 9. Monthly mean ± S.E. gonado-somatic index (GSI) values for mature females (•) and males (■) of the Lined Surgeonfish, *Acanthurus lineatus* collected in the Commonwealth of the Northern Mariana Islands (CNMI) from 2017 – 2019.

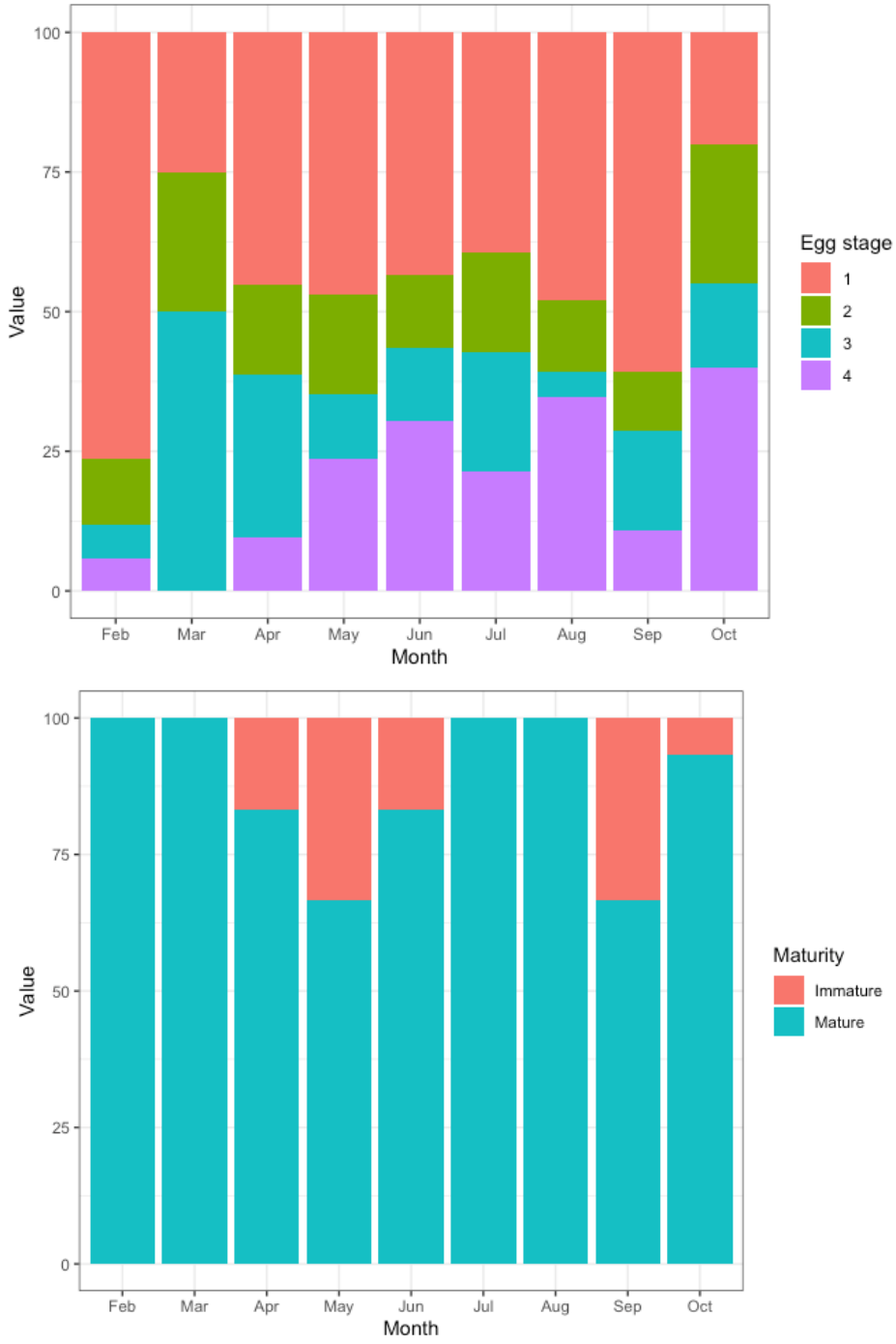

Figure 10. Proportion of the Lined Surgeonfish, *Acanthurus lineatus* female (top panel) and male (bottom panel) reproductive stages by month collected in the Commonwealth of the Northern Mariana Islands (CNMI) from 2017 – 2019.

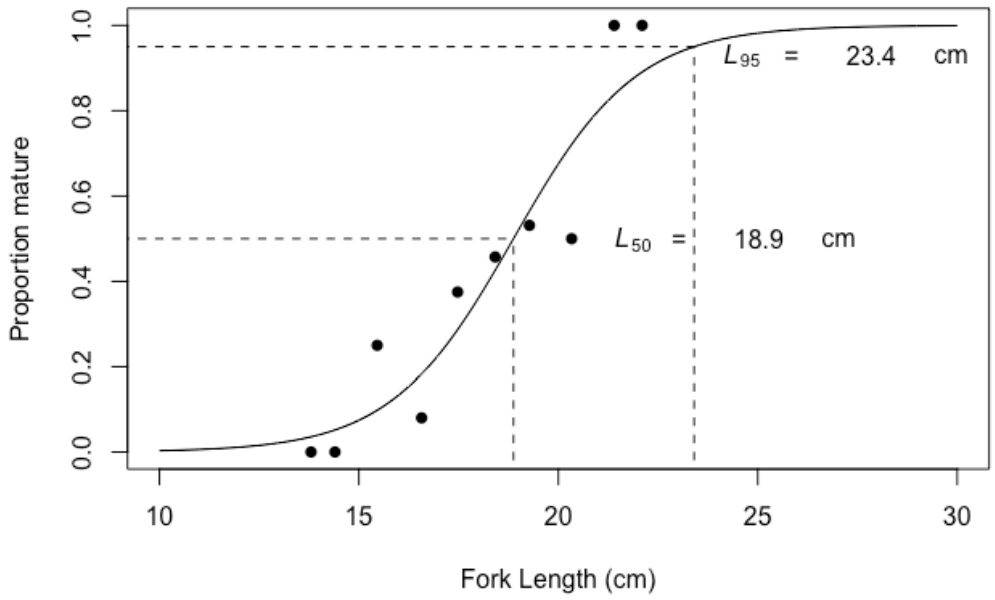

Figure 11. Proportional frequency of mature female Lined Surgeonfish, *Acanthurus lineatus* by fork length collected in the Commonwealth of the Northern Mariana Islands (CNMI) from 2017 – 2019. Logistic curve was derived using logistic regression analysis (n= 195). The estimated length at 50% sexual maturity (L_{50}) was 18.9 cm FL.

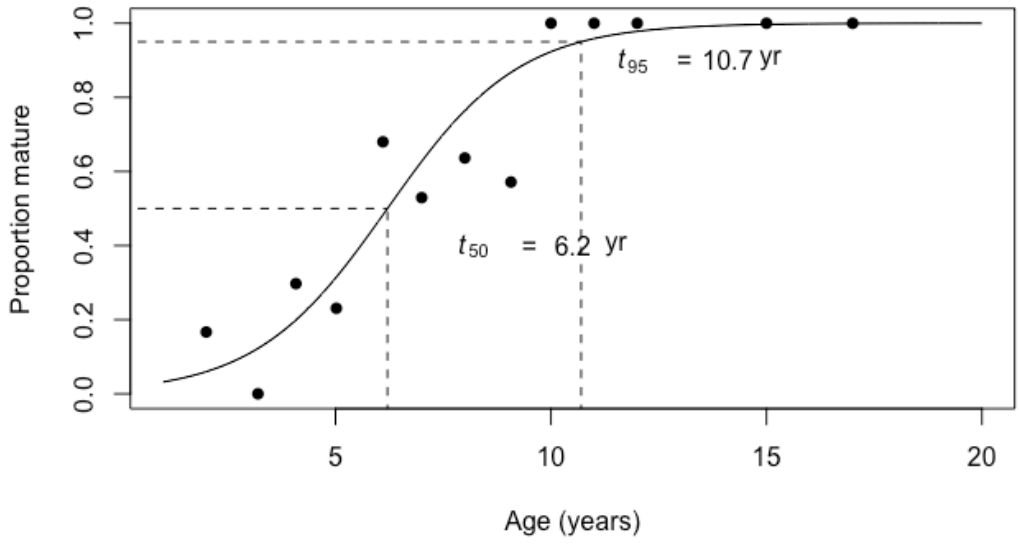

Figure 12. Proportional frequency of mature female Lined Surgeonfish, *Acanthurus lineatus* by age collected in the Commonwealth of the Northern Mariana Islands (CNMI) from 2017 – 2019. Logistic curve was derived using logistic regression analysis (n= 146). The estimated age at 50% sexual maturity (t_{50}) was 6.2 yr.

DISCUSSION

Limited information exists regarding the life histories of coral reef fishes throughout the global tropics. For example, worldwide, reproductive size is unknown for approximately 83% of exploited fishes (Froese and Binohlan 2000). In the US Pacific Islands region, a concerted effort has been made by NOAA to increase the number of fishery species with locally-derived life history parameters over the past 15 years (pers. comm. O'Malley). To support their effort, this study investigated life history data for *A. lineatus* from specimens collected by NOAA with the intent that the data would be used for future length- and age-based stock assessments and regional demographic comparisons of the species.

Life history traits can vary geographically for coral reef fishes (Gust et al., 2002; Taylor et al., 2019). This inherent variability introduces a potential problem for the accuracy of fishery stock assessments that incorporate life history parameters for a targeted fish species collected from a different geographic region. A comparison of the results from other regions with this study demonstrate the range of variability in growth and longevity of *A. lineatus* (Table 5). For example, the growth rate to approach the asymptotic length in the Saipan populations (indicated by K = 0.24) was slower than that in the GBR (0.34 – 0.68) (Fig. 13). A comparison of growth is difficult with the American Samoa population because of the parameters were presented for two models representing the juvenile and adult phases. The maximum recorded longevity was also considerably lower in Saipan (20 years) than for the GBR (42 years). The length at maturity (L_{50}) was similar between American Samoa and Saipan but larger than the GBR populations.

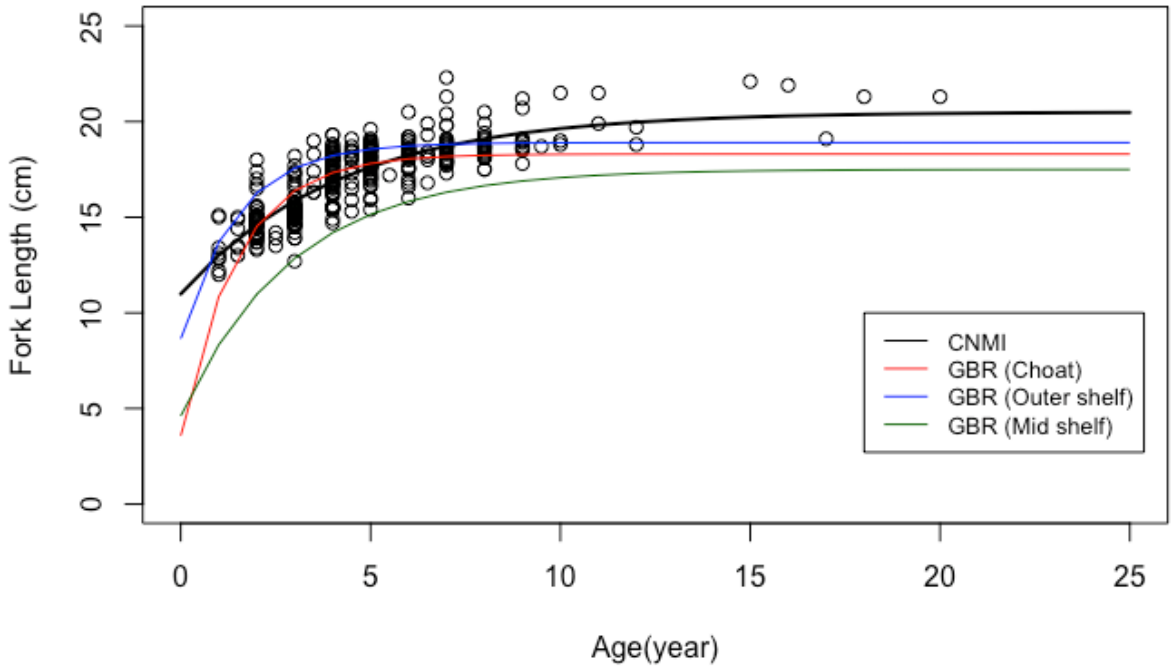

Figure 13. Comparisons of size-at-age relationship for populations of the Lined Surgeonfish, *Acanthurus lineatus* from the Commonwealth of the Northern Mariana Islands (CNMI) collected in 2017 – 2019 with populations from the Great Barrier Reef (GBR) with best-fit fit von Bertalanffy growth function (VBGF) curve (n = 319, K = 0.24 $year^{-1}$, L_∞ = 20.5 cm FL, t_0 = -3.2 years).

Table 5. Comparison of growth parameters and life history estimates for the Lined Surgeonfish, *Acanthurus lineatus* between this study (in Saipan) and previous age-based studies in American Samoa and the Great Barrier Reef, Australia. L∞ is the mean asymptotic length, K is the growth coefficient, and t_0 is the theoretical age at which L = 0 for the von Bertalanffy growth model. L_{50} is the length at which 50 % of fish are mature. A_{max} represents maximum age in years.

Location	L_∞	**K**	t_0	L_{50}	A_{max}	**Source**	**Details**
Am. Samoa	18.3	1.1	-0.2			Craig et al. 1997	Juvenile phase
Am. Samoa	22.1	0.12	-15.6	18.0		Craig et al. 1997	Adult phase
GBR	18.9	0.68	-0.9			Gust et al. 2002	Mid shelf
GBR	17.5	0.34	-0.9			Gust et al. 2002	Outer shelf
GBR	18.3	0.46	-0.32	16.0	42	Choat & Robertson 2002	
Saipan	20.5	0.24	-3.2	18.9	20	This study	

One of the basic concepts of sustainable fishery practices is to target fish after they have reached reproductive size (Froese 2004) but this information is not available for most fish species. For *A. lineatus*, length at 50% maturity was 18.9 cm FL in Saipan which corresponded to an age of 6.2 years. In American Samoa, the L_{50} was 18.0 cm FL but that corresponded to an age of approximately 4 years (Craig et al., 1997). Thus, Saipan populations of *A. lineatus* tend to have slower-growing, later-maturing, and shorter-lived fishes than the GBR. These differences highlight the importance of collecting local life history data for fisheries assessment and management purposes.

Mortality estimates for *A. lineatus* in Saipan suggest that the fishing mortality during 2017-2019 was relatively low. Catch curve analysis estimated an instantaneous total mortality rate of 0.495 and the longevity-based estimate of instantaneous natural mortality was 0.315 giving a fishing mortality rate of 0.18. This fishing mortality rate corresponds to about a 16.5% exploitation rate (i.e., percent of population harvested in a particular year). These estimates should be interpreted conservatively but provide useful information for the management of a data-limited reef fish species.

Analysis of trends in monthly GSI and female gonad stages suggests that spawning output was spread across many months if not throughout the year (Figs. 8, 9). Monthly samples consistently comprised a low proportion of large reproductively active females. In American Samoa, spawning also occurred year-round but peaked during summer months (Craig et al, 1997). From Saipan, the lack of samples in November and December and low number of samples in January hampered an ability to detect a summer peak or winter decline in GSI trends.

Additional specimens from the winter months would have allowed a better characterization of temporal trends in reproductive activity. The body morphology of *A. lineatus* may influence the reproductive strategy of the species since a laterally compressed body has limited space for gonads (Sadovy, 1996). Thus, more frequent spawning events would compensate for lower output per spawning event due to physiological constraints. While there was evidence for consistent spawning throughout the year, the lack of enough fine-scale temporal samples prevented an in-depth analysis of tidal or lunar influences on reproductive cycles that were documented for this species in Palau (Robertson, 1983). While this study did not analyze lunar or tidal relationships to GSI, the evidence of year-round spawning suggests a reproductive mechanism that would contribute to the ubiquitousness of the species on reefs and typically high annual catches. Female GSI values are typically higher than males for Acanthurids and have been shown in previous studies (DeMartini et al., 2014; Schemmel, 2021). In this study, males displayed higher monthly GSI values than females. This may be due to a fat body that is often mistaken for testes located near the gonad (Longenecker et al., 2020) – increasing the measured gonad weight for this study.

While the study provides new information on the growth and reproductive traits of *A. lineatus* in Saipan, there were elements of the work that could have been improved. For example, age- and length-based estimates of maturity were not determined for *A. lineatus* males. Males < 16.0 cm FL displayed mature testes with the smallest observed mature male being 15.0 cm FL. This is compared to estimates from American Samoa that found ~90% of males were immature at that size range (Craig et al, 1997). It is unclear if the difference in male maturity between the two regions was due to a size sampling issue or geographic variation. For this study, the

collection of additional specimens between 5.0-15.0 cm FL would have allowed a better attempt to document patterns in male maturity in the Saipan population.

Acanthurus lineatus is a common component of coral reefs and fishery landings in Saipan, CNMI, but previously had insufficient local life history data that could effectively inform their fishery status. This study provided a comprehensive evaluation of the weight and length relationship, growth function, longevity, size- and age-at-maturity, and spawning seasonality for *A. lineatus* in Saipan. The results of this demographic analysis provide information for size-based stock assessment models that are being more widely applied for nearshore fishery species in the region by US federal and territorial fishery agencies. Our intent is that this information will be used for the sustainable fishery management of this species to provide for the sustenance and livelihoods of people in the CNMI.

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