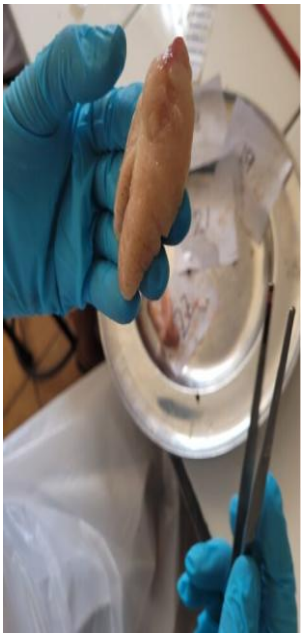
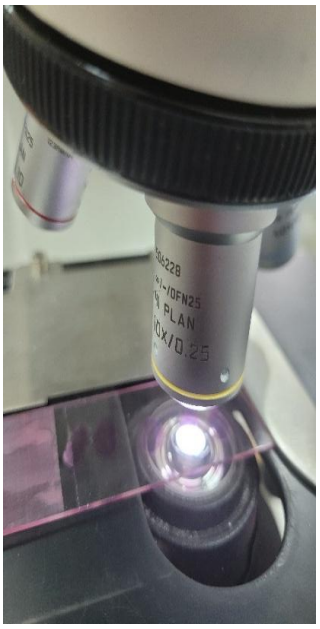
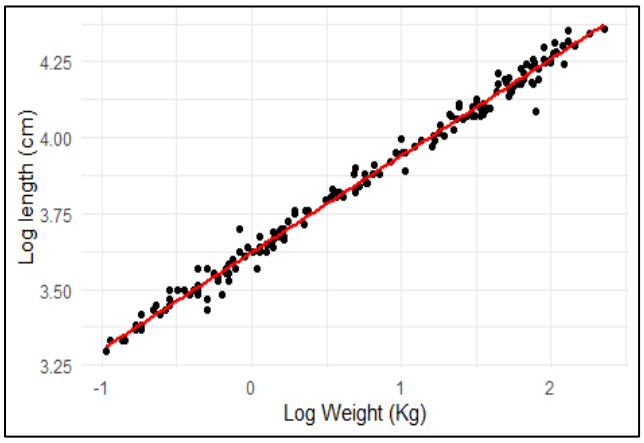
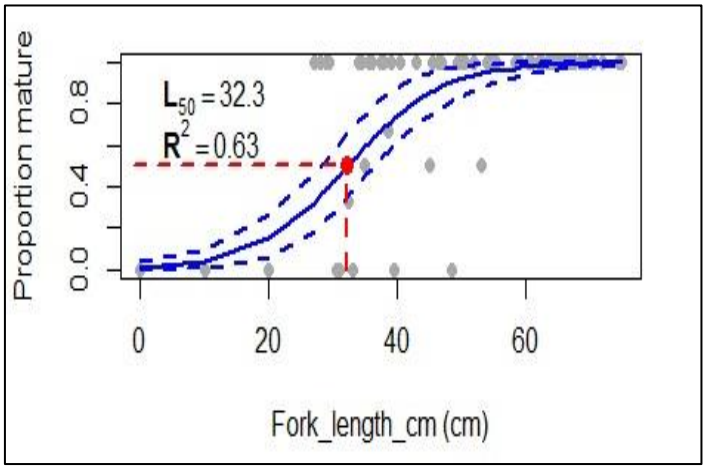
SEYCHELLES FISHERIES AUTHORITY





The investigation of the biological parameters of *Lutjanus sanguineus* (Humphead snapper) on Mahé plateau, Seychelles

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Abstract

Lutjanids are mainly found in reefs of tropical and subtropical region in the Indo-Pacific region. Snappers are species of commercial importance, and it is not an exception in the Seychelles as they are very common in the landings. With the continued rising demands, it is important to safeguard the resources and its associated ecosystems to ensure its sustainability particularly for the artisanal fisheries. Additionally, in the Western Indian Ocean there is a lack of biological information on *Lutjanus sanguineus* and this study presents an opportunity to build knowledge on the species biology and ecology.

The aim of this study was to determine the sex-specific growth parameters and length at sexual maturity. Humphead snappers were collected at sampling sites around Mahé island, with a total of 151 individuals, consisting of 86 females and 65 males during the period of August 2021 until May 2023. The analysis carried out was the length-weight relationship, the female length at maturity and the Gonadosomatic index (GSI). The mean length for all fish sampled was 59.4 cm in Total Length (TL). The length of the females ranged between 46.5 -75.5 cm in total length while the male length was between 45.5 - 77.5 cm total length. The sex ratio was 1: 1.34 (M : F). The overall length-weight for *Lutjanus sanguineus* yielded a b value of 3.71 and a r-squared value (r2) of 0.98 and the same was obtained for the sex specific relationship (Male with a b value of 3.620, r^2 of 0.99 and Female with b value of 3.73 and r^2 of 0.94). This indicated positive allometric growth whereby the weight increases faster than the length suggesting that the fish are accumulating muscle and fat also possibly reproductive structure which showed that they are healthy and have a good environmental condition. The study revealed that the female *L. sanguineus* length at maturity was 50.8 cm, with a coefficient of determination (r2) of 0.6. The GSI analysis was attempted and months of recorded peak spawning was April, September and October. However, the analysis was limited by some months with no or few species.

Keywords: • Humphead snapper • Seychelles • Length at maturity

• length weight relationship • sexual maturity • local fishers

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INTRODUCTION

Background

Research into global fisheries trends has repeatedly shown that the world`s fish stock has been in continuous decline (Hutchings, 2000; Stergiou, 2002 & Coll et al., 2008). This has been attributed to major factors namely overpopulation (Coleman et al., 2000), globalisation (Finley, 2016), overexploitation (Sinclair, 1996) and environmental degradation (Jackson et al., 2001). The monitoring of fish stock is important for coastal communities particularly for Small Island Developing States (SIDS) such as Seychelles (Guillotreau et al., 2012) which have greater dependency on fisheries for their socio-economic wellbeing, food security, economy and employment (Hauge et al., 2009).

The Seychelles artisanal fishery is a multi-species fishery and one of the commercially, exploited species is the Humphead snapper (*Lutjanus sanguineus*) locally known as Bordmar. Humphead snapper is the part of the Lutjanidae Family (Allen,1985). In general, snappers are deep bodied, with preorbital bone thinner than eye diameter, with two nostrils wide apart, head and operculum with bulging grooves and visible ridges, scales on dorsal and anal fins and lastly having lunate to deeply forked caudal fin. As for the Humphead snapper (Figure 1), it is a fish with an angular shaped head, yellow lips, usually red orange with silver gleam in colour, with pink to red fins and caudal peduncle having a large black saddle and white patch. The juvenile has a broad brown bar from the jaw to the dorsal fin over its red body (Allen, 1985). They are slow growing and long-lived, hence indicating that these snappers reach maturity at a late stage in life (Gallaway et al., 2009 & Newman et al., 2016). This has an influence on the rate at which reproduction occurs against the dynamic rate of exploitation (Grandcourt et al., 2008).

To sustainably manage this finite resource, sound decision-making must be guided by evidence-based information such as the length of maturity. Currently, there is a lack of area-specific scientific information on the Humphead snapper (Bordmar) and the outcome of this study was directed towards the knowledge gap which will aid towards

the formulation of management measures as part of the Mahe Plateau trap and line fishery co-management plan.



Figure 1: Humphead snapper (*Lutjanus sanguineus). Photo credit to Thierry Cordenos from iNaturalist*

Aim and objectives

The aim of this study was to collect baseline information on the Humphead Snapper (*L. sanguineus*) caught on the Mahé plateau to determine their growth parameters to support the implementation of phase two of the co-management plan.

The specific objectives were to:

i. Determine sex specific growth parameters (length and weight frequency)
ii. Determine female length at sexual maturity
iii. Determine reproductive periodicity

METHODOLOGY

Study sites

Most commercial vessel operates on the Mahé plateau (Figure 2), which comprises of various fishing banks and favourable habitats which support the population of a wide range of tropical and sub-tropical fish species. Sampling took place from August 2021 to May 2023. Whole, ungutted fish were purchased from catch landings of local fishers around Mahé island namely Bel ombre, La Retraite, Perseverance, Victoria fishing port and Victoria market. Additionally, fish samples were bought according to a size class distribution.

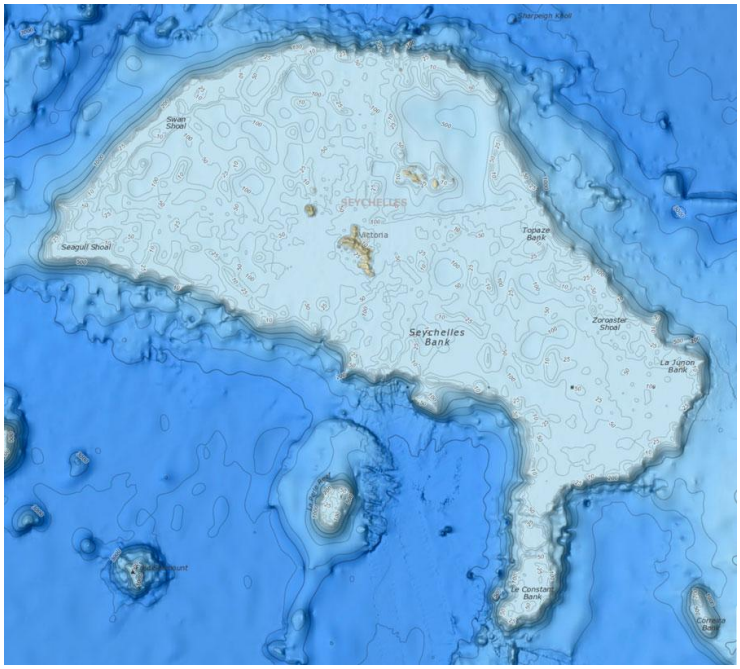


Figure 2: The Seychelles Bank/Mahé plateau Credit: nationsonline.org

Sampling Methodology

Samples were brought to SFA fisheries research laboratory whereby biometric information was gathered from each individual fish. This included total length and weight (whole and eviscerated) and the measurements were recorded to the nearest

centimetre and grammes respectively. The samples were sexed (male and female) and the macroscopic maturity stages of the gonads were determined (Appendix 1). A cross section or the whole gonad was collected and preserved in 10 % formalin for histological analysis (Appendix 2).

Histology slides were viewed under a compound microscope on magnifications of 10 - 40× to observe different reproductive features to determine the reproductive phase (maturity) Brown-Peterson et al., (2011). Female fish were considered functionally mature when ovaries contained vitellogenic oocytes (primary, secondary or tertiary vitellogenesis; Vtg1, Vtg2, Vtg3) with maturity markers or physiologically immature when Cortical Alveoli oocytes were present (Brown-Peterson et al., 2011; Lowerre-Barbieri et al., 2011 & Reed et al., 2023). All the histology slides were further validated by an external expert from Commonwealth Scientific an Industrial Research Organisation (CSIRO), Australia.

Data analysis

The data cleaning and sorting was undertaken using Microsoft excel (Windows 10) and statistical analysis were undertaken and the graphs were produced using the R programme software V4.4.0. A significant threshold of $p > 0.05$ with 95% confidence interval was applied for the statistical tests.

A. Sex ratio

Sex ratio represents the number of males to females in a sample. In sexually, reproducing biological populations, the sex ratio tends to be 1:1 with equivalent numbers of males and females. This is an important measure in population dynamics, as it gives an indication of the reproductive potential of the population. Data collected was used to determine the sex ratio. The sex ratio is given as (M: F) and calculated using the following equation:

$$Sex\ ratio = \frac{\text{Number of Males}}{\text{Number of Females}}$$

B. Size frequency distribution

A statistical representation of the distribution of sizes within a sample. It illustrates the range of sizes amongst individuals sampled from the fishery.

C. Weight frequency distribution

A statistical representation of the distribution of weight within a sample. This distribution will aid towards understanding the variability of the weight amongst the individuals in a dataset.

D. Length-weight relationship

Length-weight relationship is an important aspect in the biology of any fish. Length and weight bear a specific relationship from which the physical wellbeing of a fish can be ascertained for a given body at a given time. The length and weight vary depending on reproductive cycles and environmental factors, availability of foods, the age and the physiological state of the fish (Brown, 1957 & Islam et al., 2002). The relationship between total length and weight of Humphead snapper was determined using the below formula, where a is the coefficient of the power function and b is the exponent.

The graph representation is based on the length and weight with the formula $W=a \times L^b$

$$W = aL^b$$

Where,

W = total weight (g),
L = total length of fish(cm)
a = intercept (initial rate of growth or condition factor: rate of change of weight)
b = exponent weight at unit length (slope; coefficient of growth or relative growth rate)
(b = 3, isometric growth; when b < 3 negative allometric growth and when b > 3, positive allometric growth)

(Fafioye and Ayodele, 2018)

E. Length at maturity (Lm_{50})

The proportion of matured gonad of stage III to stage V of fish sampled was used to deduce the length at which 50% of the sample is maturate. The principle of length at 50% of sexual maturity for fish population is mostly used in fish stock management. The 50% threshold in Lm50 signifies a pivotal point in the life history of the population (Asres

et al., 2023). It is an important parameter of life history where there are significant implications for population dynamics, reproductive ecology, and ecosystem function (Reed et al., 2023).

The formula is as follows:

$$P_m = \left(\frac{1}{1+ e^{-aL+b}}\right) \times 100$$

Pm= Proportion of mature (%)
L= Length in cm
a= fitted constant
b= fitted constants
(Asres et al., 2023)

F. Gonadosomatic index

Gonadosomatic Index (GSI) is the ratio between the gonad weight and the total weight of the individual. It is used in the comparison of reproductive condition across individuals or across different groups of individuals (Immature specimens not included) over the year.

$$GSI = \left(\frac{Gonad\ weight\ (g)}{Total\ weight(g)}\right) X\ 100$$

RESULTS

A total of 151 individuals were sampled, comprising of 57% female (n=86) and 43 % of male (n=65) (Figure 3). A sex ratio of 1:1.34 was recorded and a chi-squared test was carried which gave a p-value of 0.087, indicating that there was no significant difference between the sexes within the samples.

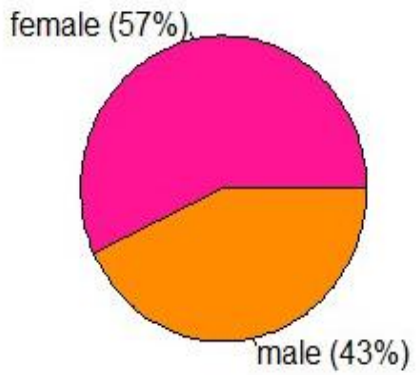


Figure 3: Sex distribution of *Lutjanus sanguineus* sampled (n=151)

Length and weight statistics of *L. sanguineus* (overall and by sex)

Overall, the mean total length was 59.49 cm with a range of 45.5 to 77.5 cm and the overall mean weight was 3.56 kg with weight ranging between 1.26 kg to 6.62kg (Table 1).

Table 1: Summary of descriptive statistics of length and weight of all *Lutjanus sanguineus* sampled between August 2021 and May 2023 (n=151)

Descriptive Statistics	Total length (cm)	Weight (kg)
Mean	59.49	3.56
Median	61.0	3.45
Standard deviation	12.81	43.72
Male range	45.5 -77.5	1.26 – 6.62
Female range	46.5 – 75.5	1.64 – 5.67

In comparison between the sexes, the males were longer than the females, with a mean total length of 63.12 cm compared to 56.76 cm for the females. A similar trend was observed for the weight, with heavier males on average (4.14 kg) than female (3.14 kg) (Table 2). A t-test was conducted on both the total length and the weight of the *L. sanguineus* sampled, resulting in a p-value of 0.0029 and 0.000196 respectively. Both results indicated, a significant difference in the length and weight between the sexes.

Table 2: Summary of descriptive statistics of length and weight of *Lutjanus sanguineus* sampled between August 2021- May 2023 by sex (f= 86, m=65)

Descriptive statistics	Total length (cm)	Weight(kg)
Male		
Mean	63.12	4.14
Median	65.5	4.15
Standard deviation	13.62	1.58
Female		
Mean	56.76	3.14
Median	59	3.17
Standard deviation	11.51	0.99

Length frequency distribution of *L. sanguineus* (overall and per sex)

It could be observed in the overall length frequency distribution (Figure 4) that most of the samples were in the 60 cm cohort and that the range was between 45 – 80 cm.

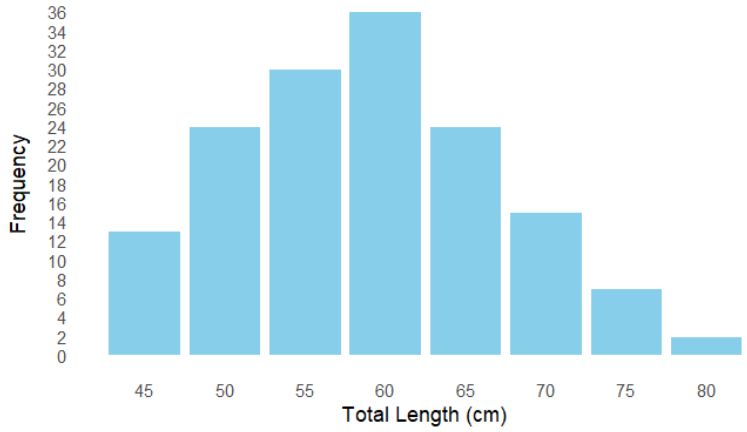


Figure 4: Overall length frequency distribution of *Lutjanus sanguineus* (n=151)

As for the sex specific distribution, most of the females sampled measured 60 cm in Total Length (Figure 5), and as for the males, the 65 cm cohort dominated (Figure 6). In fact, most of the females were on the smaller size, 60 cm and below (TL) (Figure 5) and in contrast the males were bigger. Wilcoxon rank-sum test was undertaken and gave a p-value of 1.53×10^{-5}, indicating that there was statistically significant different in the length of the two sexes.

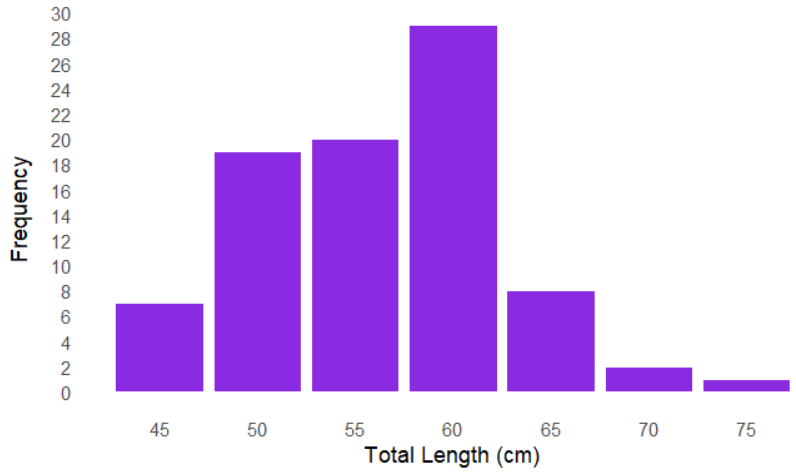


Figure 5: Size frequency distribution of female *Lutjanus sanguineus* (n=86)

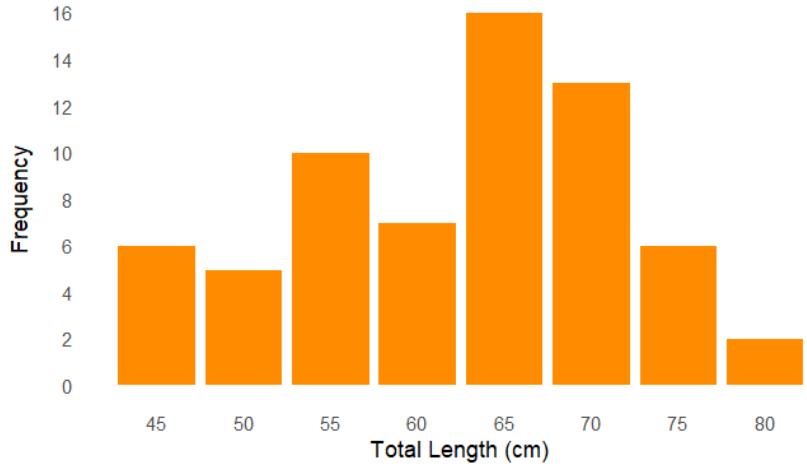


Figure 6: Size frequency distribution of male *Lutjanus sanguineus* (n=65)

Weight frequency distribution of *L sanguineus* (overall& by sex)

Overall, the weight distribution showed that most individuals weighed 3.5 kg and it was also observed that most of the samples were between 1- 3.5kg (Figure 7), while the largest ones were fewer in numbers.

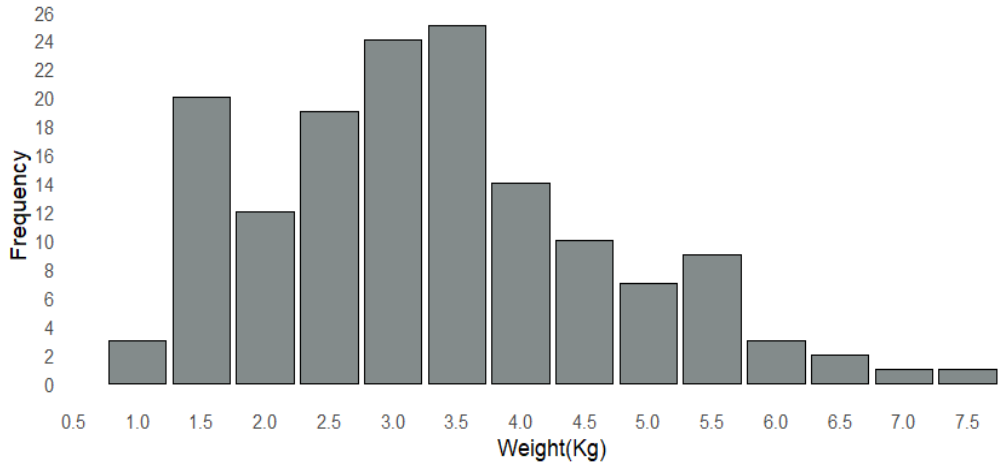


Figure 7: Overall weight frequency distribution of *Lutjanus sanguineus* (n=151)

The weight of the male Humphead snappers were found to be between 1.0kg and 7.5kg, with most weighting 4.5 kg (Figure 8). Whist, the females ranged from 1.0kg up to 5.5 kg in weight, with the highest number of females being recorded in the 3.5 kg category (Figure 9).

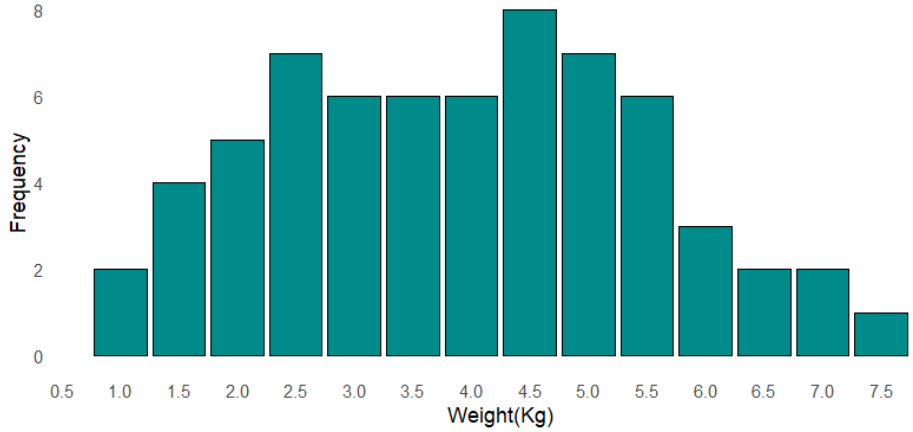


Figure 8: Weight frequency distribution of male *Lutjanus sanguineus* (n=65)

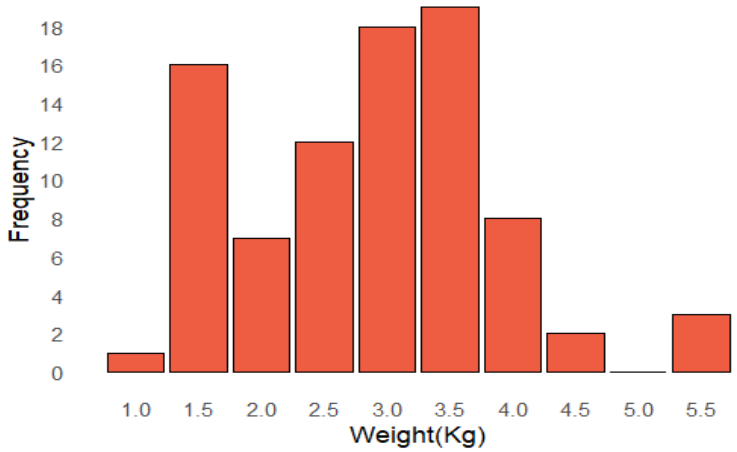


Figure 9: Weight frequency distribution of female *Lutjanus sanguineus* (n=86)

Length weight relationship (overall and by sex)

The overall length-weight regression showed positive correlation between the length and weight. A r^2 value of 0.92 (92%) was obtained, signifying a strong relationship between the weight and length (Appendix 5). A b value of 3.72 was attained, indicating positive allometric growth in the Humphead snappers sampled.

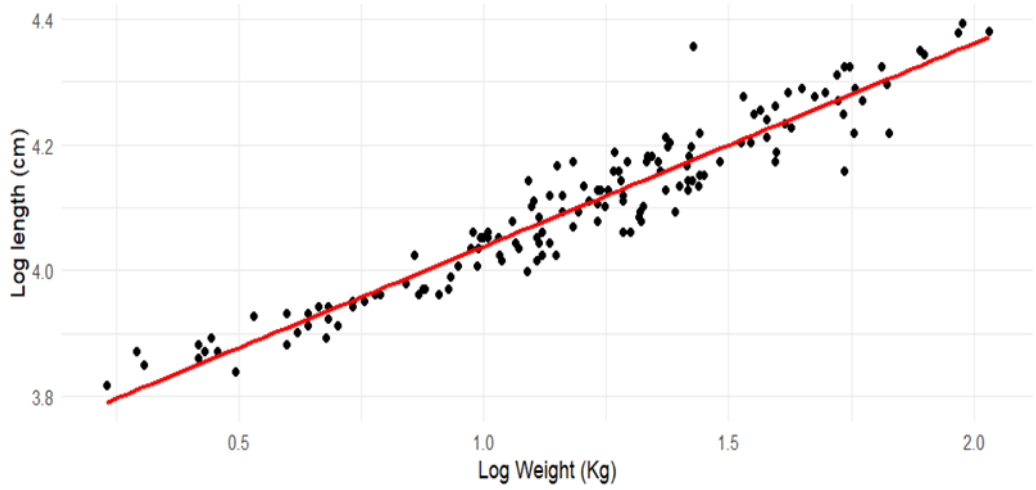


Figure 10: Overall length weight linear regression of *Lutjanus sanguineus* (n=151)

For the male specific length-weight analysis, a r^2 value of 0.94 was obtained (Appendix 6) which described a strong relationship between weight and length. A similar b value of 3.72 was obtained as in the overall analysis, equally indicating a positive allometric growth (Figure 11).

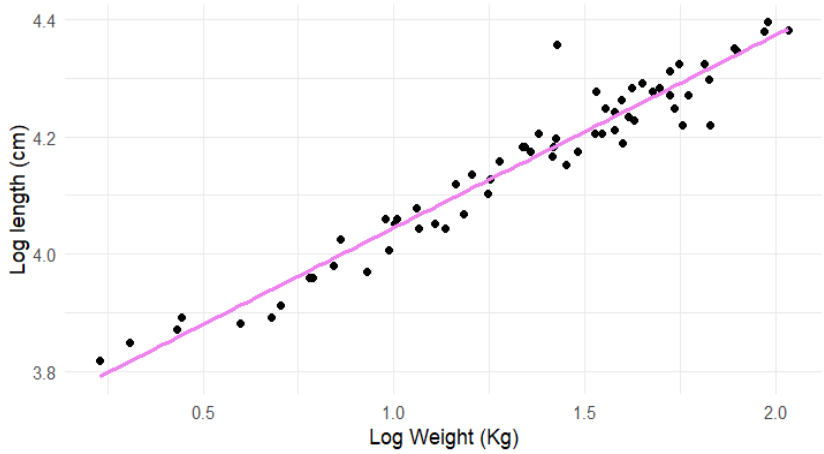


Figure 11: Length weight linear regression of male *Lutjanus sanguineus* (n=65)

A similar relationship was observed from the analysis for the females (Figure 12), with a slightly lower r^2 value of 0.87 and a b value of 3.73 (Appendix 7). Likewise, this indicated positive allometric growth.

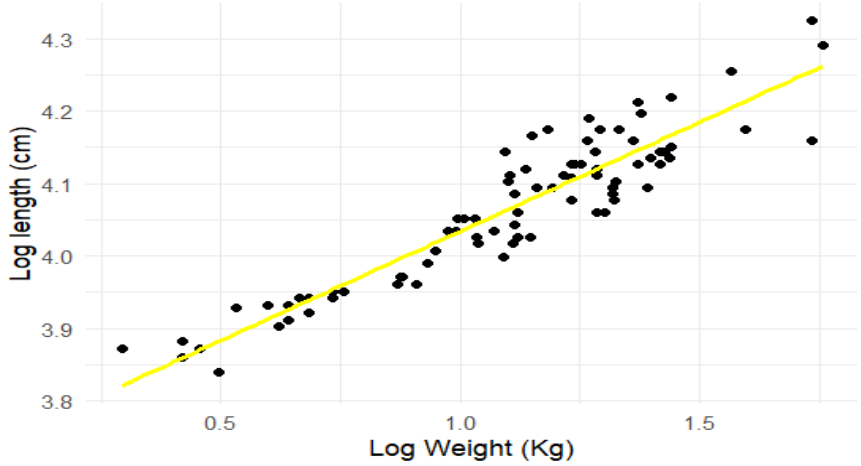
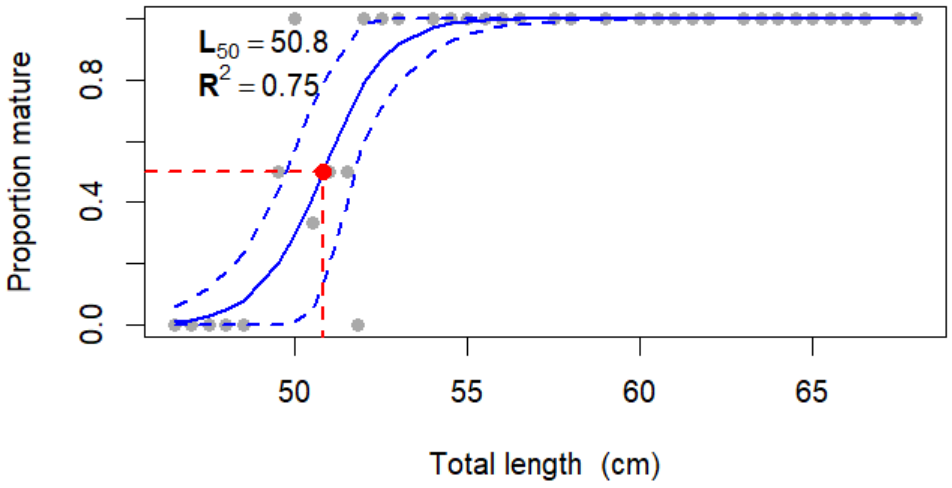


Figure 12: Length weight linear regression of female *Lutjanus sanguineus* (n=86)

Length at sexual maturity of *L. Sanguineus* (females only)

Length at maturity of 50% of the female within the sample of *L. sanguineus* was investigated using the total length and it was found to be 50.8 cm (Figure 13). The female length at maturity had an r^2 value 0.75, in such case the model provides a somewhat good fit to the data.



Length at maturity	50.8
Confidence intervals	49.8 - 51.7
R-square value	0.75

Figure 13: Length at maturity (Lm_{50}) logistic curve of female *Lutjanus sanguineus* (n=70)[1]

[1] Throughout the histology processes, some slides sustained some damaged and therefore were excluded from the analysis. Only 70 slides of female gonads were used in the length at maturity and GSI analysis

Gonadosomatic Index (GSI) (female only)

The Gonadosomatic Index (GSI) showed differences in the reproductive pattern during the sampling periods of 2021 to 2023. The GSI peaked during April, September and October which indicated either pre-spawning and spawning phases whereby the fish gonad increases in size and thus increase in weight. Lower GSI was recorded in July and November whereby the gonads were smaller in size. Some months (January, February, June and December) are not represented on the figure as no gonad were collected for those months (Figure14). With the lack of consistent monthly samples, the result should therefore be interpreted with caution.

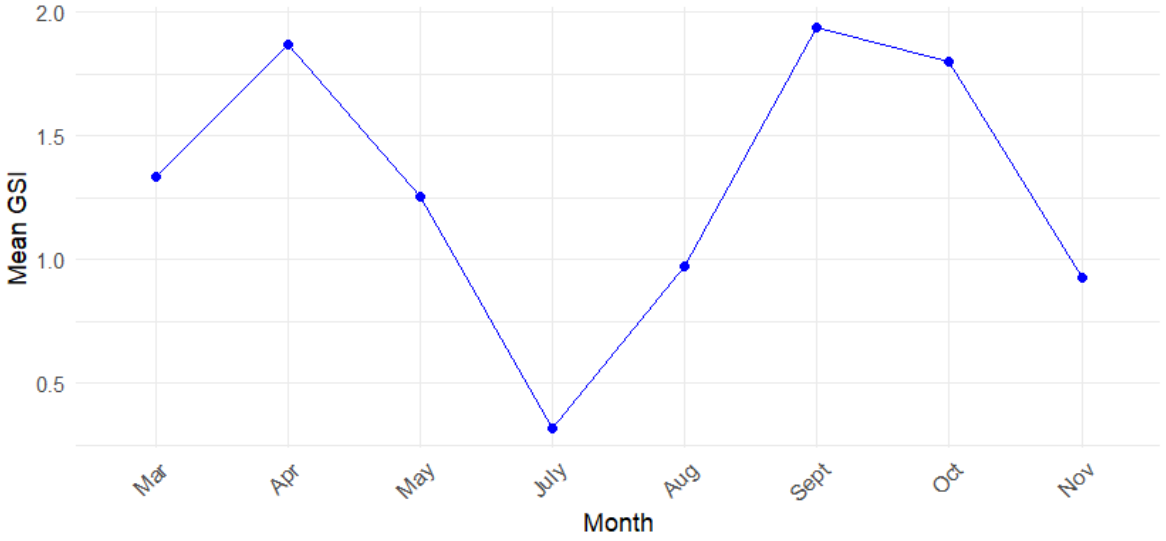


Figure 14: Gonadosomatic Index (GSI) by month of female *L. sanguineus* (n= 70)

DISCUSSION

The study on the reproductive biology of Humphead snappers on Mahé Plateau provided some very insightful preliminary findings such as the range of length, the health of this species, its growth and the length at sexual maturity.

The overall mean total length (59.5 cm) from this study somewhat conforms with other studies on the same species, such as documented on Fishbase, where the common recorded length is 70 cm and the biggest recorded catch of Humphead snapper reached 100 cm total length (TL). Studies by Senta and Peng (1977) found that *L. sanguineus* collected through trawl fishing mostly ranged from 55 to 70 cm in total length, with the highest abundance observed between 42 and 50 cm. Similarly, Senta et al., (1977) reported a length range of 10 to 80 cm, while Odeya (2016) recorded a mean total length of 41.2 cm. Regarding weight, Odeya (2016) reported values ranging from 0.49 kg to 1.9 kg which is lower compared the recorded 3.56 kg overall mean total weight and the range of 1.26 – 6.62 kg of fish sampled during this study.

The length–weight relationship, a commonly used indicator of fish's growth pattern and it is attributed to factors such as reproductive cycles, age, physiological state, and environmental conditions like food availability (Brown 1957; Islam et al., 2002). The cubic relationship of body length is direct proportionality with body weight. A b value of 3.72 from the length weight analysis indicated a positive allometric growth which means as length increases, the weight increases at a faster rate which shows that the species is fit and is well supported by its environmental conditions. The R-squared value which gives information about the goodness of the fit of the model was high (0.92 for overall, 0.94 for males and 0.87 for females).

In addition to growth patterns, reproductive traits such as length at sexual maturity are essential for understanding the life history of fish species. It is the mean length at which 50% of the females reaches maturity (with gonad development in phase III to V). It provides key information to fisheries managers in enabling them make informed decisions, in the formulation of management advice and measures such as the introduction of minimum landing size, with the aim of protecting the juveniles and to maintain fish stocks (Sadovy,1996). The determined Lm50 for *L. Sanguineus* was 50.8

cm. The model had a R-squared value of 0.75 which means that the model accounted for 75% of the variability in length at maturity based on the predictors. In comparison with other sources and studies, this result conformed to that of other studies such as those reported on Fishbase (maturity of 55.1 cm and 47.5cm) (Fishbase, n.d). Lai and Liu (1974) conducted studies in two regions, the Arafura Sea and Northwest Australia, reporting length at maturity of 50.3 cm and 52.2 cm, respectively. In a later study, Lai and Liu (1979) examined populations in the Tonkin Gulf and South China Sea near North Sunda, with similar findings of length at maturity of 50.3 cm and 52.2 cm. Kendidi and Bouhlel (1985) reported a length at maturity of 47 cm in Djibouti, while an earlier study by the same authors (Kendidi and Bouhlel, 1985) recorded a slightly lower length of maturity 46.9 cm in the same region. Lee and Albaz (1989) documented a maturity length of 47.3 cm in Kuwait.

Gonadosomatic index (GSI) can display seasonal trend in the gonad development over the year (Marriot et al., 2007). The GSI data showed peaks during April, September and October. While literature on the GSI (spawning periodicity) of Lutjanidae family is available, no studies specifically addressed the reproductive periodicity of *Lutjanus sanguineus*. In Seychelles, research carried out on *Lutjanus sebae*, provided insight on spawning pattern which was found to be February to April and September and October (Grandcourt et al., 2008). Studies on lutjanids in Gopalpur India (Swain et al., 2023) showed that spawning was high during June to December and December to early April; and a study carried in Reunion Island on 10 species from the Lutjanid family, showed that most spawning occurred between January-April and September to December (Mahé et al., 2024).

Limitation and recommendation

In carrying out this study, some setbacks were encountered and these include:

- The availability of *L. sanguineus* especially during the Southeast monsoon.
- Logistical setback when it came transportation and work schedule which encouraged sampling at the Victoria market, the Victoria fishing port and nearby landing sites
- Availability of funds to purchase fish were either limited or at times there was delay in receiving the funds.

- Attaining samples across the entire size range was challenging.
- The sampling timeframe of one year was tight given that there were other projects and programmes running simultaneously.
- The paraffin histology and reading process is technical, requiring specialized skill. This was limited in terms of the availability of well-trained personnel to undertake the given task.
- In regards to the GSI (spawning periodicity), the overlapping sampling years caused some difficulty to make year-to-year comparisons and to make any link to annual environmental variabilities.

Recommendation

In terms of lessons learned from the implementation of this project and its associated outcomes it is recommended that there is:

- Collaboration with the fisher's association to facilitate the acquisition of samples of various sizes. Also, it would be a way for engagement, education and awareness and knowledge sharing.
- Pre-sampling phase to enable the establishment of contacts, agreement on prices and communication channels etc.
- Sampling period needs to be extended beyond one year, most preferably 2 years and the whole project being 3 years. This will ensure better allocation of resources (staff and transport)
- Capacity building of staff particularly in all phases of paraffin histology processing to reading stage.

CONCLUSION

The investigation of the reproductive biology of *Lutjanus sanguineus (*Humphead snapper), and other fish species on the Mahé plateau, remains one of SFA's main objectives. Studies focused on the reproductive biology of *Lutjanus sanguineus* is limited and this initiative contributed to the knowledge gap in the Indo-pacific region. Such project allowed us to engage with fishers and in turn the fishers can be informed on findings which can encourage them to see that such finite resources require some level of management to ensure its sustainable exploitation to maintain their own livelihood and to continue to provide food for the local community.

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LIST OF APPENDICES

Appendix 1: Female and Male gonad macroscopic identification

Macroscopic gonad stage	Female Description	Male Visual observation
Immature	Ovaries pinkish, translucent. Eggs (oocytes) not visible to naked eye.	Testis whitish. Thin thread-like
Developing	Wider Gonad. Pinkish to yellow-green colour; Blood vessel more apparent; Eggs not visible to naked eye.	testis whitish, symmetrical. Enlargement of testis becoming rounded and whitish-grey. Generally thin and smooth testicular wall
Spawning capable/Ripe	Larger oocyte, ovary pinkish to yellow green color with granular appearance. Not transparent eggs and blood vessel are visible	Testis larger and sperm often visible in sinuses. Exudes milt with light abdominal pressure
Active spawning/ Spent	Flaccid occupying less than 1/3 of body cavity. Slight brown and orange with heavy discharge of blood from the blood vessels.	Testis bloodshot and flabby Testis flaccid and thick walled, generally bloody red in colour
Regression	Flaccid oocyte. Small and broad ovaries, slightly brown colour, blood vessels less prominent	
Regenerating	Small ovaries blood vessels reduced but present.	

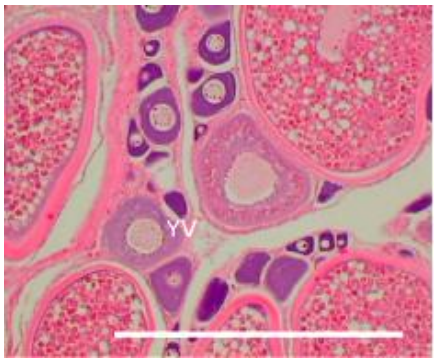
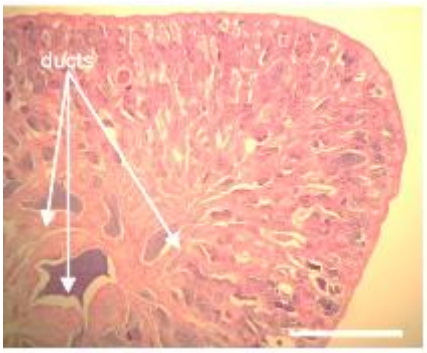
(Robinson et al., 2007) (modified from de Souza 1988; Ntiba and Jaccarini 1990; Samoilys and Roelofs 2000; West 1990)

Appendix 2: Paraffin Histology processes

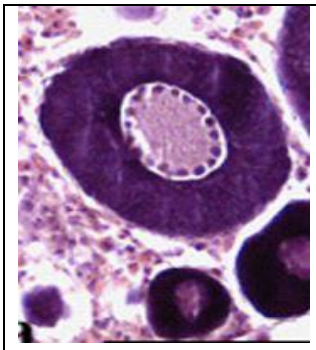
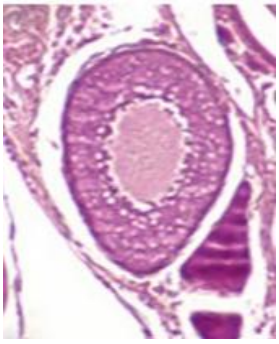
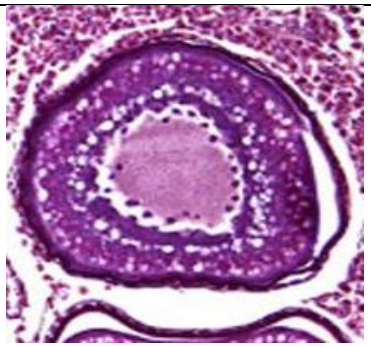
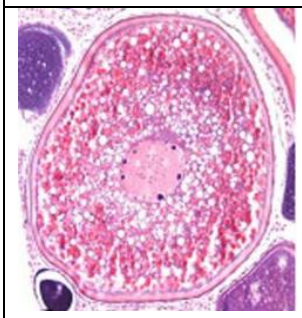
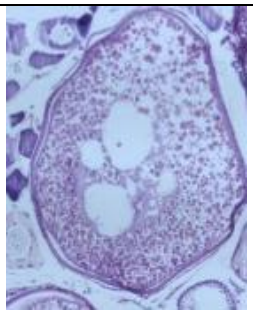
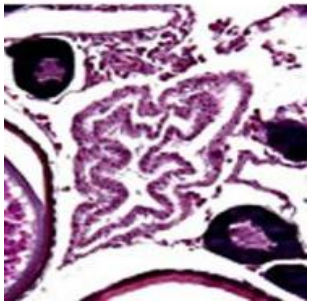
Tissue Fixation – Gonad was placed to set/fix in a 10 % formalin solution. Fixation allows for preservation of the tissue structures
Tissue processing - Dehydration – This process carried out by immersing specimens in a series of ethanol solutions of increasing concentrations, then in a xylene solvent then liquid paraffin. This process allows the tissue to be fixed to maintain its structure for the rest of the process. The cassettes are then removed after 16 hours (overnight).
Embedding – Wax is placed in a wax embedding machine a day prior turned on and left to melt. For the embedding, the cassette is opened and the cross section is placed in a mould. The mould is filled with liquefied paraffin, and the cassette is placed into it. The paraffin in filled to topped then let the paraffin solidify on the cold plate or on the side of the wax machine. The mould with the cross section is then removed and cleaned reading for sectioning.
Tissue sectioning - The blocks are mounted on a microtome. The paraffin block containing the gonad is first trim 10 µm thickness to remove some paraffin and better access the embedded gonad, then cut at a 5 µm thick. The resulting ribbons is placed in waterbath (40° c). A microscope slide is used to scoop the ribbon and adjusted to slide. The slides are left dry overnight. The slides are then collected in a slide rack.
Tissue staining – The slide rack was taken to the staining station. The gonad slides go through a cycle of submersion in various chemical 1. Ethanol 2. Ethanol 3. Tap or Distilled water 4.Hematoxylin 5. Tap or Distilled water 6. Acid alcohol (0.5 %) 7. Distilled water 8. Eosin 9.Ethanol 10. Ethanol 11. Xylene 12. Xylene
Slide coverslip mounting – The slides in the slide rack are kept in xylene taken to the fume hood. Using a pipette place Eukitt glue was placed on the cover slip. Add a few drops of xylene on the cover slip then slowly placed in a horizontal manner on the slide. Carefully adjust the cover slip and the slide using a tweezer, press the cover slip to stick without bubbles and uneven glue (this is to prevent distorting the gonad cross section). Allow slides to set for 1-2 days after which reading can be done on the slides.

(Balette, 2023 & Wijayanti et al., 2017)

Appendix 3: Female and Male gonad transection microscopic identification (Marriot et al., 2007)

1  	1 
Microscopic view of a Female gonad (© Marriot et al.,2007)	Microscopic view of a Male gonad (© Marriot et al.,2007)

Appendix 4: Female teleost gonad development stages

		
1)Immature Oocytes are small, irregular shaped but circular nucleus and prominent pale circular nucleus containing multiple nucleoli. Nucleus occupies less 30% of cell space. The zona radiata is absent	1) Immature Thicker gonad wall than immature females, no evidence of prior spawning (see below). Tightly packed previtellogenic oocytes throughout lamellae	2) Maturing (Developing) Cell outline/oocytes is smooth. Moderately-dark-staining cytoplasm contain many pale lipid vesicles. Nucleus become irregularly shaped
		
3) Ripe (non-spawning) Cell with uniform vitellin globules which stain moderately with toluidine blue/purple. Globules initially appear at the oocyte periphery then distribute evenly throughout cytoplasm. Cytoplasm lighter than previous stages. Zona radiata and follicular layer prominent	4) Spent (spawning) Cells double-in-size when compared to previous stage. Nucleus indistinct or absent. Vitellin coalesces into larger globules of different sizes or forming uniformly staining "sheets" within cytoplasm. Lipid vesicles(non-staining) also coalesce into larger droplets. Cells shape becoming irregular. In late maturation zona radiata may thin and pull away from follicle	5) Regressing Only oogonia and PG oocytes present, muscle bundle, enlarged blood vessels, thick ovary wall, gamma/ delta atresia and post-ovulatory follicles present in ovary indicate recent spawning

(Brown-Peterson et al., 2011, Longenecker & Langston, 2020 and Yamaguchi et al., 2006)

Appendix 5: Overall summary of L. sanguineus length weight statistics

Overall L. sanguineus length weight statistics summary

Residuals:

```
Min       1Q        Median      3Q        Max
-0.117342 -0.027445  0.003685  0.028189  0.179861

Coefficients:
Est. Standard Error     t value     Pr(>|t|)
(Intercept)         3.715032   0.010007  371.24   <2e-16 ***
LsLgtWt_fishdata$logW1:  0.323419   0.007957   40.65   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.03861 on 149 degrees of freedom
Multiple R-squared:  0.9173,    Adjusted R-squared:  0.9167
F-statistic:  1652 on 1 and 149 DF, p-value: < 2.2e-16
```

Appendix 6: Summary of Female L. sanguineus length weight statistics

Female L. sanguineus length weight statistics summary

Residuals:

```
    Min         1Q        Median      3Q         Max
-0.096769 -0.025812   0.000119   0.020890   0.087254


Coefficients:
 Est. Standard. Error    t value    Pr(>|t|)
(Intercept)       3.73256    0.01426  261.79   <2e-16 ***
LsMod_female$logW  0.30146    0.01258   23.96   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.03796 on 84 degrees of freedom
Multiple R-squared:  0.8723,            Adjusted R-squared:  0.8708
F-statistic:   574 on 1 and 84 DF, p-value: < 2.2e-16
```

Appendix 7: Summary Male L. sanguineus length weight statistics

L. sanguineus Male length weight statistics summary

Residuals:

```
 Min       1Q       Median   3Q       Max
-0.09756 -0.02357  0.00654  0.02336  0.17105

Estimate Std. Error t value Pr(>|t|)
(Intercept)     3.71641    0.01515  245.4  <2e-16 ***
LsMod_male$logW 0.32863    0.01078   30.5  <2e-16 ***
---

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.03745 on 63 degrees of freedom
Multiple R-squared:  0.9366,          Adjusted R-squared:  0.9356
F-statistic: 930.1 on 1 and 63 DF,  p-value: < 2.2e-16
```

Appendix 8: Summary of Female L. sanguineus length at maturity statistics

	Estimate Std.	Error	z value	Pr(>|z|)
(Intercept)	-51.4203	18.96	-2.713	0.00667
Total length	1.0129	0.372	2.726	0.0064
Null deviance:	67.600 on 70 degrees of freedom			
Residual deviance:	23.895 on 69 degrees of freedom			
AIC:	27.895			

Appendix 9: Comparison of other studies on *Lutjanus sanguineus* length at maturity

Author	Research Year	Country	Region	Length at maturity (Lm)
Lai, H. & Liu, H	**1979**	**PNG, Indonesia Timor-Leste and Australia**	**Arafura Sea**	**52.1 cm**
Lai, H. & Liu, H	**1979**	**Australia**	**NW Australia**	**50.8 cm**
Lai & Liu	**1974**	**Taiwan**	**S China Gulf of Tonkin**	**50.3 cm**
Lai & Liu	**1974**		**S China N Sunda**	**52.2 cm**
Kedidi & Bouhlel	**1985**	**Djibouti**	**Indian Ocean**	**47 cm**
Sanders & Morgan	**1989**	**Djibouti**	**Indian Ocean**	**46. 9 cm**