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# Reproductive features of data-deficient yellowfin snapper, *Lutjanus xanthopinnis* (Actinopterygii: Eupercaria: Lutjanidae), from east-coast of Peninsular Malaysia: Implications for sustainable fisheries management

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## Abstract

Understanding the reproductive biology of fishes is crucial to making accurate and scientifically sound recommendations for fisheries management. The presently reported study is the first to report the reproductive characteristics of the data-deficient and recently described yellowfin snapper, *Lutjanus xanthopinnis* Iwatsuki, Tanaka et Allen, 2015, collected from the eastern South China Sea, Malaysia. A total of 572 fish specimens were sampled monthly from March 2022 to April 2023 using a gillnet and a trawl net. Subsequently, these specimens were measured and weighed. Their total length (TL) ranged from 15.3 to 26.8 cm (19.25 ± 2.04 cm; mean ± SD). Their body weight ($W_B$) ranged from 53.5 g to 279.7 g (114.5 ± 40.3 g; mean ± SD). For the reproductive biology study, the following parameters were determined: the sex ratio, gonadosomatic index (GSI), hepatosomatic index (HSI), spawning period, fecundity, condition factor ($K$), length at maturity, and the gonadal maturity stages. In the sex ratio, males (M) were significantly dominant over females (F) (M:F = 1:0.75) ($\chi^2$ = 11.18). Consequently, the monthly mean GSI of pooled sex revealed a consistent trend from January to August, indicating spawning seasons with peak periods in March and April. The batch fecundity of 67 mature females (16.0–25.2 cm TL; 64.5– 279.3 g $W$), was determined to range from 16 405 to 94 357 oocytes. The fecundity increased with gonad weight in contrast to weight and length. The length at first maturity of females and males was 14.53 and 20.56 cm, respectively. Females matured earlier than males. Macroscopic and histological examination of gonads revealed monthly variation in the ratio of gonad stages for males and females. This study offers crucial data on the reproductive biology of *L. xanthopinnis*, which will help with sustainable fishery management in this area and can be used as a reference for the management of similar fish populations in other regions of the world.

## Keywords

east coast of Peninsular Malaysia, fecundity, length at maturity, marine fish, spawning season

## Introduction

Fishes of the family Lutjanidae, commonly known as snappers, are ecologically and economically imperative in tropical and sub-tropical regions (Allen 1985; Messias et al. 2019). The majority of species within the family Lutjanidae are represented by the genus *Lutjanus* (see Allen 1985), and species of this genus are highly prized and consumed in numerous countries worldwide (Adibah and Darlina 2014). The yellowfin snapper, *Lutjanus xanthopinnis* Iwatsuki, Tanaka et Allen, 2015, is a small lutjanid species previously misidentified with *Lutjanus madras* extensively distributed through the eastern Indian and western Pacific oceans, ranging from Sri Lanka to the Andaman Sea and the Malay Peninsula, southeast to Bali, Malaysia, Brunei, to the Philippines, north to China and Taiwan, and south to Japan (Iwatsuki et al. 2015). Due to this, relatively little information is available about this species, so it is listed as Data Deficient (IUCN 2019). Nevertheless, this species has also been used for commercial purposes, and its harvest is included in Malaysia's annual fish landing statistics. Species of *Lutjanus* make up a significant share of landings in Malaysia, which have been continuously increasing over the past ten years (2013–2022), with the mean value of 15 391 tonnes per year (DOF 2023).

Fish reproductive biology, including spawning timing and duration, sex ratio, maturity stages, length at maturity, and fecundity, is essential for managing stocks and assessment of fisheries (Tsikliras et al. 2013; Alam et al. 2020). To comprehend the reproductive biology of fishes, many researchers have studied these parameters. For example, Palla and Sotto (2021) studied *Lutjanus vitta*, Araki and Tachihara (2021)—*Lutjanus quinquelineatus* Iwatsuki, Tanaka et Allen, 2015, and Fernandes et al. (2022)—*Lutjanus synagris* (Linnaeus, 1758). Despite the importance of the biology of fish in some nations, the lack or unavailability of fisheries data results in overfishing of the stocks and in some cases, management failure (Kinas 1996; Alves and Minte-Vera 2012). For rendering reliable scientific recommendations in fishery management, the knowledge of species' various reproductive aspects is crucial (Khatun et al. 2019; Longenecker et al. 2022). Fisheries managers must have a thorough knowledge of a species' reproductive biology to provide effective fisheries management to ensure sustainability (Coulson et al. 2019). However, there is a scarcity of comprehensive data pertaining to the biology and ecology of *L. xanthopinnis* globally (Arai et al. 2023). In addition, no published data is hitherto available on the reproductive biology of *L. xanthopinnis* in Malaysia or any other geographical location.

Therefore, this study aims to explore the reproductive aspects of *L. xanthopinnis*, including its sex ratio, gonadosomatic index, spawning season, condition factor, hepatosomatic index, batch fecundity, and length at maturity in the eastern South China Sea, Malaysia. The findings of this study will enhance the existing knowledge referring to this particular species providing valuable insights for the future sustainable management of snapper fisheries. Furthermore, these findings can serve as a model for managing this fish species in other geographic regions, offering guidance and direction for effective fishery management.

## Materials and methods

**Area of study and sample collection.** Fresh specimens of *Lutjanus xanthopinnis* were sampled monthly from March 2022 to April 2023 from commercial fish landing port (Pulau Kambing, eastern South China Sea) (05°19′20.3″N, 103°07′42.6″E), east-coast of Peninsular Malaysia (Fig. 1). A total of 572 specimens (326 males and 246 females) were collected using gillnet and trawl net. Gillnets made of nylon netting with a 45 to 48 mm mesh size were used in water depths of 5 to 20 m, while trawl net with 38 mm codend mesh was used at depths of 20 to 40 m. The obtained samples were stored in ice and transported to the Fisheries Science Laboratory, Universiti Malaysia Terengganu (UMT), for further analysis and identified using multiple systematic morphological features mentioned by Iwatsuki et al. (2015).

**Morphometrics, determination of sex, and sex ratio.** Each specimen's total length (TL) and standard length (SL) were measured to the nearest 0.1 cm by using an L-shaped board, and an electronic balance was used to record body weight ($W_B$) to the nearest 0.1 g. All of the fish specimens were dissected, and the sex of each individual was determined visually by examination of the gonads. Subsequently, the gonads of each specimen were removed and weighed using an electronic balance (ATX224 SHIMADZU) to the nearest 0.0001 g. In the presently reported study, the sex ratio was calculated by the proportion of male (M) and female (F) numbers and expressed as M:F ratio. The total number of both sexes was used to calculate monthly variations in sex ratios. The Chi-square ($\chi^2$) test was used to estimate the discrepancies in the expected sex ratio 1:1.

**Gonadal histology and identification of maturity stages.** Autopsied fish gonad tissue (25 samples per month) was put in a histological cassette and fixed in 10% neutral buffered formalin. After 24 h, fixed gonads are transferred to 70% ethanol and then dehydrated with a series of ethanol dilutions (vacuum automatic tissue processor Leica TP1020). The gonads were embedded in paraffin using Leica HistoCore Arcadia H, cut on 5-µm thick sections with Galileo SEMI Series 2 rotary microtome, and counterstained with hematoxylin/eosin then mounted on a glass slide using cover slip. Then, the histological slides were photographed with Nikon Eclipse 80i. For each individual, the stage of gonad development was identified. Five gonadal maturity stages of *L. xanthopinnis* were distinguished based on

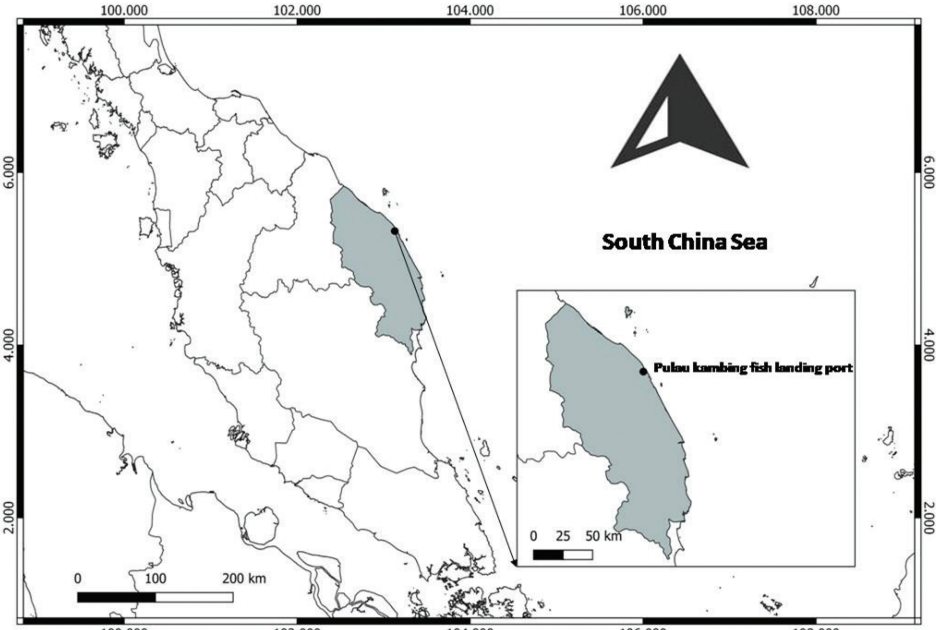


**Figure 1.** Map depicting the study area (Pulau Kambing Fish Landing Port in Terengganu, east-coast of Peninsular Malaysia).

macroscopic and histological examination of gonads described by Russell et al. (2003), Grandcourt et al. (2006), Brown-Peterson et al. (2011), and Fakoya and Anetekha (2019):

- Immature (stage I),
- Developing/regenerating (stage II),
- Spawning capable (stage III),
- Actively spawning (stage IV), and
- Regressing (stage V).

**Gonadosomatic index, hepatosomatic index, and condition factor.** The gonadosomatic index (GSI) was assessed monthly for both sexes to understand the spawning season. The mean GSI for each month was calculated using the following formula

$$\mathrm{GSI} = \{W_G \times (W_B - W_G)^{-1}\} \times 100,$$

where $W_B$ is the body weight [g] and $W_G$ is the gonad weight [g] (Pacicco et al. 2023). A line graph was used to display the monthly mean GSI. The increasing peak of the GSI depicts the spawning season for this species. The monthly pattern of the hepatosomatic index (HSI) (Costa 2019; Fadzli et al. 2022) utilizing the following equation

$$\mathrm{HSI} = (W_L \times W_B^{-1}) \times 100,$$

where $W_L$ is the liver weight [g]. The relative condition factor ($K$) for each *L. xanthopinnis* specimen was estimated using the formula developed by Le Cren (1951), which is stated as follows

$$K = (W_{BE} \times W_{BC}^{-1}),$$

where $W_{BE}$ is the empirically determined body weight [g] of studied fish and $W_{BC}$ is the calculated body weight resulting from length–weight relations (modified from Rahman et al. 2023).

**Length at maturity.** We estimated size at maturity as the length predicted to comprise 50% mature individuals ($L_{50}$). This was calculated based on the percentage of matured individuals (stage III and IV) suggested by Palla and Sotto (2021) of each 2-cm size class. A line drawn against the midpoint of each size class (TL) for matured females ($N$ = 162) and males ($N$ = 132) out of 572 fish was carried out according to (King 2007) utilizing the logistic equation as follows

$$\ln[(1 - R_M) \times R_M] = rL_{50} - rL,$$

where $R_M$ is the mature individuals rate, $rL_{50}$ is the intercept $a$, $-r$ is the slope of line, $r$ is $-b$, and $L$ is the total length of fish. For the calculation of $r$ and $L_{50}$, values of $\ln[(1 - P) \times \mathrm{P}^{-1}]$ were plotted opposed to the midpoint of each size class as: $L_{50} = a/r$.

**Batch fecundity.** Batch fecundity (BF) is the number of eggs each fish releases during a single spawning phase (Gonçalves et al. 2009). The oocytes from (stages III and IV) were used to determine the batch fecundity of mature females (BF). The ovary was divided into three sub-samples, taken from the front, center, and back and weighed to the nearest 0.1 g. Oocytes ($N_O$ = 67) were separated from the connective tissue and observed under a dissecting microscope (OLYMPUS SZ51) to calculate. Then, BF is estimated by the following (Fry et al. 2009)

$$\mathrm{BF} = (N_{ES} \times W_G) \times W_{GS}^{-1},$$

where $N_{ES}$ is the egg count in a subsample, $W_G$ is the weight of the (whole) gonad, and $W_{GS}$ is the weight of the subsample gonad.

**Statistical analysis.** The data were analyzed using Excel 2010 and PAST 4.09 (Hammer et al. 2001). Chi-Square ($\chi^2$) analysis was used to assess the sex ratio for any variations beyond the expected 1:1. The correlations between BF and body weight, total length, and gonad weight were derived using regression analysis. The analysis also took into consideration a significance level of $P < 0.05$.

## Results

**Morphometric measurement and sex ratio.** The TL for males of *Lutjanus xanthopinnis* varied from 16 to 26.8 cm (19.53 ± 2.28 cm; mean ± SD), and females ranged from 15.3 to 25.2 cm (18.88 ± 1.58 cm). Moreover, the BW for males ranged from 59.5 to 279.7 g (120.5 ± 45.8 g), and females varied between 53.5 and 279.3 g (106.4 ± 29.6 g), respectively. The monthly sex ratio analysis showed that this species favored males over females. An overall sex ratio of 1:0.75 (M:F) was found among the 572 fish examined, with 326 (57%) males and 246 (43%) females (Table 1). Nevertheless, the statistical analysis revealed that the overall population of the monthly sex ratio differed significantly ($\chi^2$ = 11.18) from the expected (1:1) ratio. Additionally, the sex ratio concerning size depicted in Table 2, showed that males dominated over female fish. Females utterly dominated over males in the 14 to 16 cm class range. Overall, statistical analysis shows the sex ratio also significantly varied ($\chi^2$ = 11.18) for size groups.

**Gonad development and identification of maturity stages.** Five gonad maturation stages were recognized in *L. xanthopinnis* (Figs. 2, 3), which include immature (stage I), developing/regenerating (stage II), spawning capable (stage III), actively spawning (stage IV) and regressing (stage V). The macroscopic and histological investigation of the gonad revealed the monthly ratio of males and females at various gonadal stages off Pulau Kambing Fish Landing Port in Terengganu, as depicted in (Fig. 4). In addition, the reproductively active stages of gonads (spawning capable and actively spawning) for both sexes were observed in January to August as also depicted in (Fig. 4). This finding suggests that the studied fish species has an extended spawning season from January to August.

**Gonadosomatic index, hepatosomatic index, and condition factor.** The mean GSI values for male and female individuals varied from 0.43 to 2.7 and from 0.95 to 3.9, respectively. However, the monthly GSI trend for both sexes was consistent from January to August (1.14–2.7 in males; 1.8–3.9 in females) with peaks in March and April (Figs. 5A, 5B). On the other hand, the mean monthly GSI for both sexes drastically declined from September to December (0.43–0.96 in males; 0.95–1.16 in females) (Figs. 5A, 5B). In addition, the monthly mean GSI of pooled sex revealed a consistent trend from January to August, indicating this species spawning seasons with peak periods in March and April (Fig. 5C). Conversely, the monthly mean GSI significantly dropped for pooled sex from September to December (Fig. 5C), which corresponds to the specimen resting period. On the contrary, the monthly HSI for males and females ranged from 0.53 to 1.22 (Fig. 5A) and 0.72 to 2.09 (Fig. 5B), respectively. Monthly changes in *K* and HSI were used to analyze the energy consumption patterns of fish during the reproductive phase. Moreover, the monthly mean *K* for both sexes was very consistent, except that it differed slightly in December. The monthly *K* for males and females varied from 1.01 to 1.07 and 1.00 to 1.25 (Figs. 5A, 5B), showing that they are growing in good health. The monthly values of *K* were inversely related to the evolution of GSI. However, a distinct pattern was observed in the relations between GSI and HSI.

**Table 1.** Sex ratio of *Lutjanus xanthopinnis* by month with consequent Chi-square ($\chi^2$) values from eastern South China Sea, Malaysia.

| Month | Total (*N*) | Male (*N*) | Female (*N*) | Male [%] | Female [%] | Sex ratio (M:F) | $\chi^2$ |
|---|---|---|---|---|---|---|---|
| Mar | 37 | 16 | 21 | 43.24 | 56.76 | 1:1.31 | 0.67 |
| Apr | 47 | 28 | 19 | 59.57 | 40.43 | 1:0.67 | 1.72 |
| May | 40 | 31 | 9 | 77.5 | 22.5 | 1:0.29 | 12.1$^S$ |
| June | 41 | 27 | 14 | 65.85 | 34.15 | 1:0.52 | 4.12$^S$ |
| July | 35 | 19 | 16 | 54.29 | 45.71 | 1:0.85 | 0.26 |
| Aug | 45 | 31 | 14 | 68.89 | 31.11 | 1:0.45 | 6.42$^S$ |
| Sep | 43 | 25 | 18 | 58.14 | 41.86 | 1:0.72 | 1.14 |
| Oct | 42 | 19 | 23 | 45.24 | 54.76 | 1:1.21 | 0.38 |
| Nov | 36 | 20 | 16 | 55.56 | 44.44 | 1:0.8 | 0.44 |
| Dec | 39 | 15 | 24 | 38.46 | 61.54 | 1:1.6 | 2.07 |
| Jan | 42 | 33 | 9 | 78.57 | 21.43 | 1:0.28 | 13.71$^S$ |
| Feb | 48 | 19 | 29 | 39.58 | 60.42 | 1:1.53 | 2.08 |
| Mar | 34 | 25 | 9 | 73.53 | 26.47 | 1:0.36 | 7.52$^S$ |
| Apr | 43 | 18 | 25 | 41.86 | 58.14 | 1:1.38 | 1.13 |
| Total | 572 | 326 | 246 | 57.00 | 43.00 | 1:0.75 | 11.18$^S$ |

$^S$ = significant difference at a level of 5%.

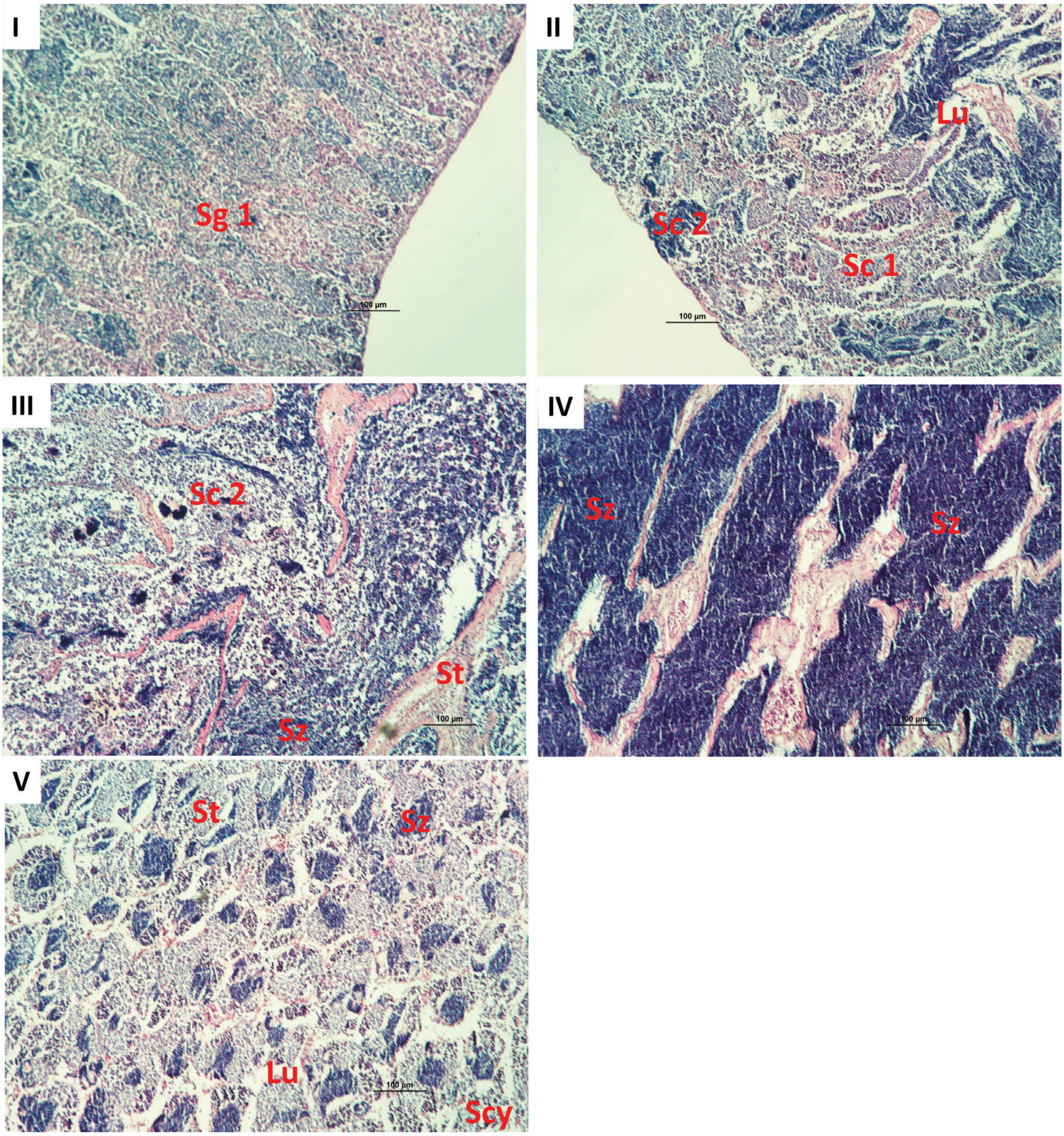


**Figure 2.** Microphotographs (10 × magnifications) of histological slides for five gonadal maturity stages in male yellowfin snapper, *Lutjanus xanthopinnis*, from eastern South China Sea(Malaysia). (**I**) Immature phase containing spermatogonia (stage I). (**II**) Developing/regenerating phase (stage II); (**III**) Spawning capable phase. (**IV**) Actively spawning phase containing very high numbers of spermatozoa (stage IV). (**V**) Regressing phase (stage V). Abbreviations: Sg1 = primary spermatogonia; Sc1 = primary spermatocyte; Sc2 =secondary spermatocyte; St = spermatid; Sz = spermatozoa, Lu = lumen; Scy = spermatocyst.

**Table 2.** Sex ratio of *Lutjanus xanthopinnis* by size groups with associated Chi-square ($\chi^2$) values from eastern South China Sea, Malaysia.

| Size range [cm] | Total (*N*) | Male (*N*) | Female (*N*) | Male [%] | Female [%] | Sex ratio (M:F) | $\chi^2$ |
|---|---|---|---|---|---|---|---|
| 14–16 | 12 | 3 | 9 | 25 | 75 | 1:3 | 3.00 |
| 16–18 | 171 | 101 | 70 | 59.06 | 40.94 | 1:0.69 | $5.62^{S}$ |
| 18–20 | 221 | 115 | 106 | 52.04 | 47.96 | 1:0.92 | 0.37 |
| 20–22 | 117 | 63 | 54 | 53.84 | 46.16 | 1:0.85 | 0.69 |
| 22–24 | 29 | 24 | 5 | 82.76 | 17.24 | 1:0.21 | $12.45^{S}$ |
| 24–26 | 17 | 15 | 2 | 88.24 | 11.76 | 1:0.14 | $9.94^{S}$ |
| 26–28 | 5 | 5 | 0 | 100.00 | 0.00 | — | $5.00^{S}$ |
| Total | 572 | 326 | 246 | 57.00 | 43.00 | 1:0.75 | $11.18^{S}$ |

$^{S}$ = significant difference at a level of 5%.

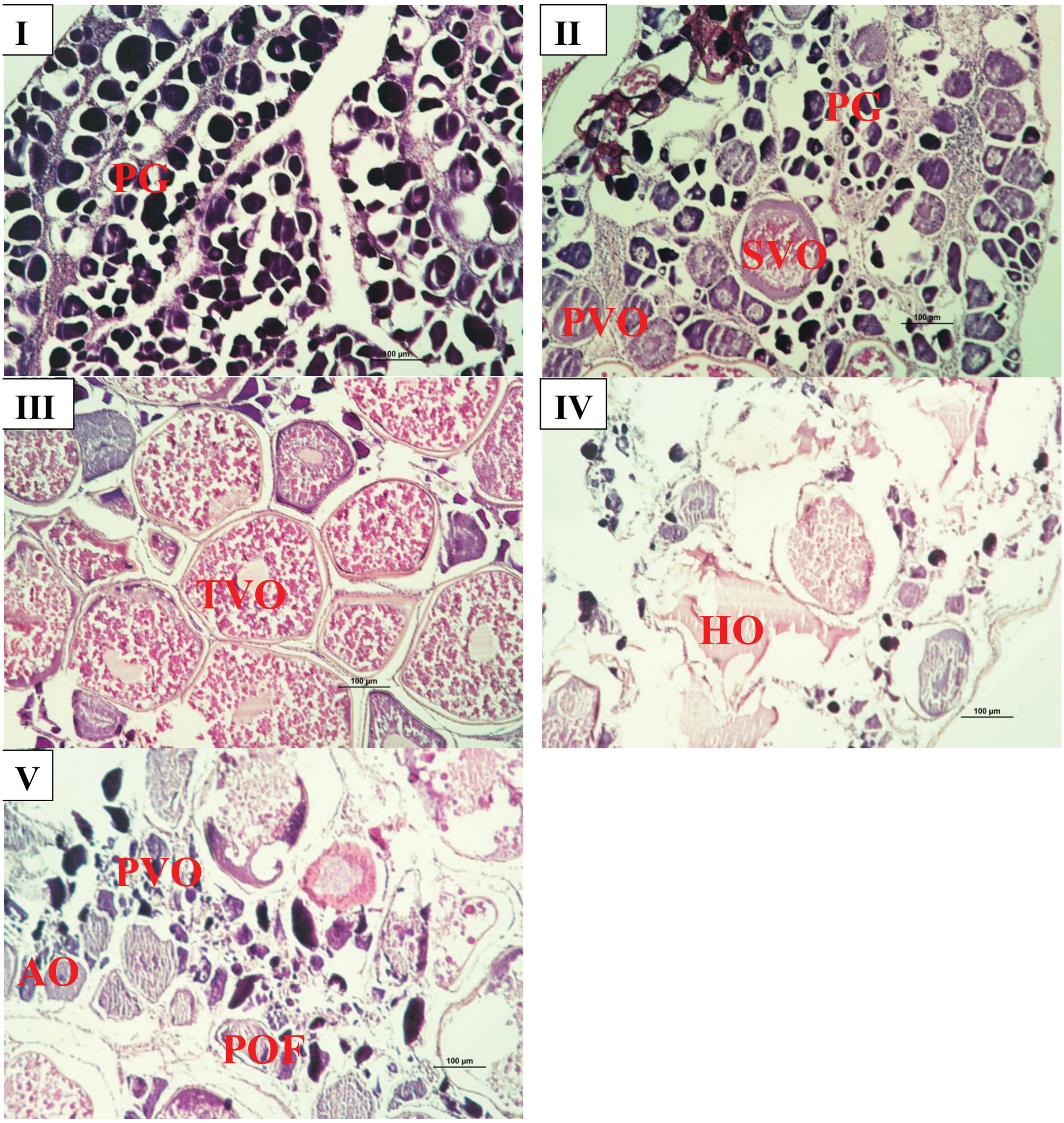


**Figure 3.** Microphotographs (10 × magnifications) of histological slides for five gonadal maturity stages in female yellowfin snapper, *Lutjanus xanthopinnis*, from eastern South China Sea(Malaysia). (**I**) Immature phase (stage I). (**II**) Developing/regenerating phase (stage II); (**III**) Spawning capable phase. (**IV**) Actively spawning phase (stage IV). (**V**) Regressing phase (stage V). Abbreviations: PG = primary growth of oocytes; PVO = primary vitellogenic oocytes; SVO = secondary vitellogenic oocytes; TVO = tertiary vitellogenic oocytes; HO = hydrated oocytes; AO = atretic oocyte; POF = post-ovulatory follicle.

**Length at maturity.** Mature male individuals ranged from 16.1 to 26.8 cm (20.64 ± 2.52 cm) in total length while females—15.8 to 25.2 cm (19.03 ± 1.68 cm). Straight-line analysis revealed that female *L. xanthopinnis* in Terengganu waters reached earlier length at first maturity than males. The calculated length at 50% sexual maturity ($L_{50}$) of *L. xanthopinnis* was 20.56 cm ($N$ = 132) for males (Fig. 6A) and 14.53 cm ($N$ = 162) for females (Fig. 6B). The association of mature proportion and total had provided a coefficient of determination ($R^2$) of 0.737 for females and 0.888 for males.

**Batch fecundity.** For batch fecundity, 67 mature female gonads were evaluated, TL varied from 16 to 25.2 cm (19.4 ± 1.96 cm), the $W_B$ ranged from 64.5 to 279.36 g (118.5 ± 41.48 g), and the $W_G$ ranged from 1.6 to 11.1 g (3.98 ± 2.3 g). The overall quantity of mature oocytes in ovaries ranged from 16 405 to 94 357 oocytes (35 904 ± 19 121 oocytes). In the presently reported study, the fecundity of fish exhibited a positive correlation with gonad weight compared to the length and weight of the fish (Fig. 7). The strongest correlation was found when fecundity was compared with $W_G$ ($R^2$ = 0.966).

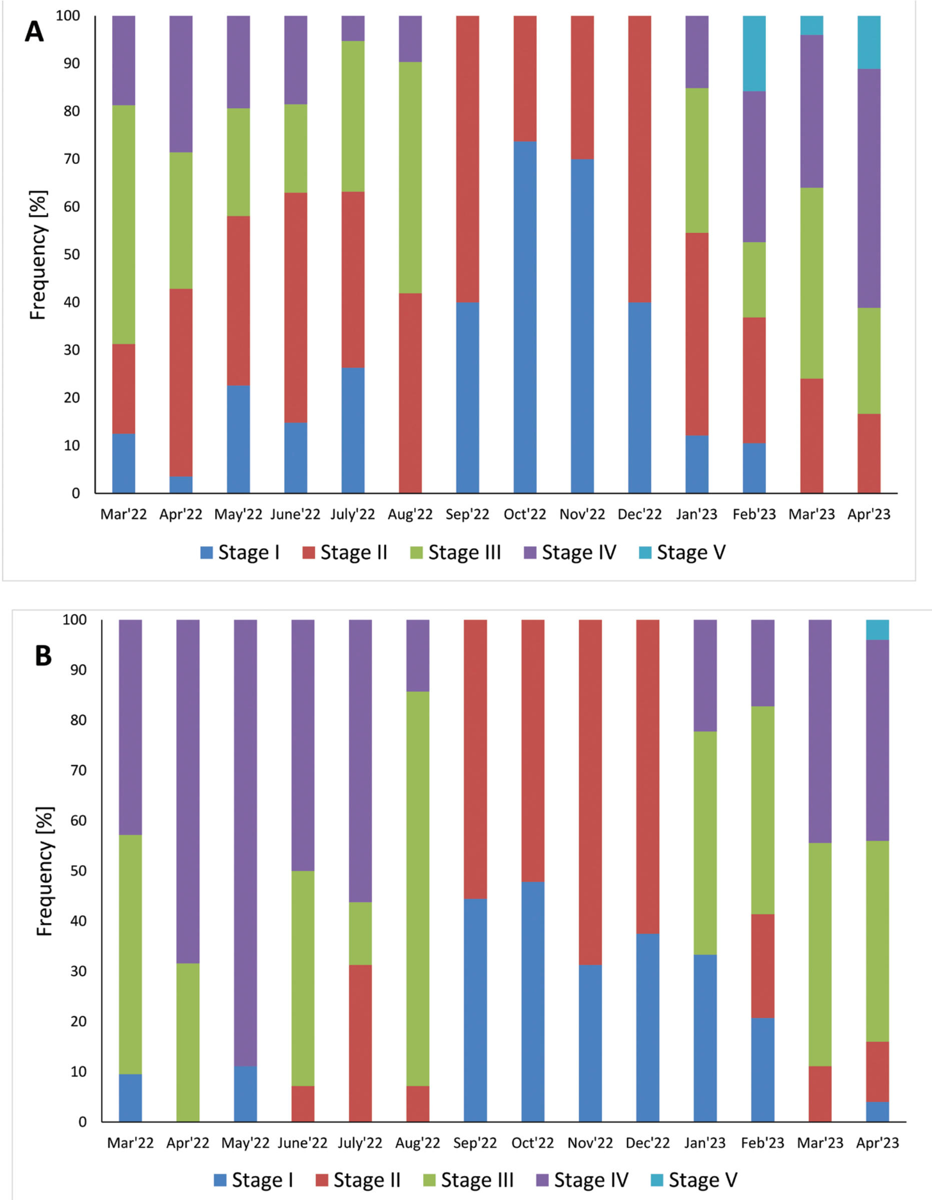


**Figure 4.** Monthly fluctuations in gonadal developmental stages for males (**A**) and females (**B**) of *Lutjanus xanthopinnis.*

## Discussion

The lack of precise fishery and biological data required for fisheries management is common in developing countries. The presently reported study provides first-hand information on the reproductive biology of *Lutjanus xanthopinnis* on the east coast of Peninsular Malaysia. The highest total length of *L. xanthopinnis* was measured in Terengganu waters, Malaysia at 26.8 cm which is considerably longer than the length that Velamala et al. (2020) reported from the Visakhapatnam Coast, India. The higher maximum length observed in this study may be caused by different environmental variables associated with differences in geography (Smoliński and Berg 2022). The presently reported study found that the monthly recorded and size-based sex ratio of *L. xanthopinnis* population was biased towards males and differed from the expected ratio of 1:1. Many researchers have made similar findings about various *Lutjanus* species (Fry et al. 2009; Pradeep 2016; Araki and Tachihara 2021) corroborating the results of the presently reported study. The sex ratio deviates from the expected 1:1 for several reasons, including population adaption, sexual behavior, availability of food, and environmental variables (Brykov et al. 2008; Vandeputte et al. 2012).

The fish spawning season is regulated by an association of the GSI and the pattern of the gonadal development stages, which provides a trustworthy indicator of reproductive activity (Rizzo and Bazzoli 2020). The spawning season was estimated to be protracted from January to August, with a peak period in March and April based on GSI and gonad development stages (Figs. 4, 5). According to Yaakob and Chau (2005), Malaysia's northeast monsoon season continues from November to February. Spawning begins towards the end of the rainy season (January) and continues until mid-summer (August). The majority of tropical lutjanids are serial spawners with prolonged spawning seasons

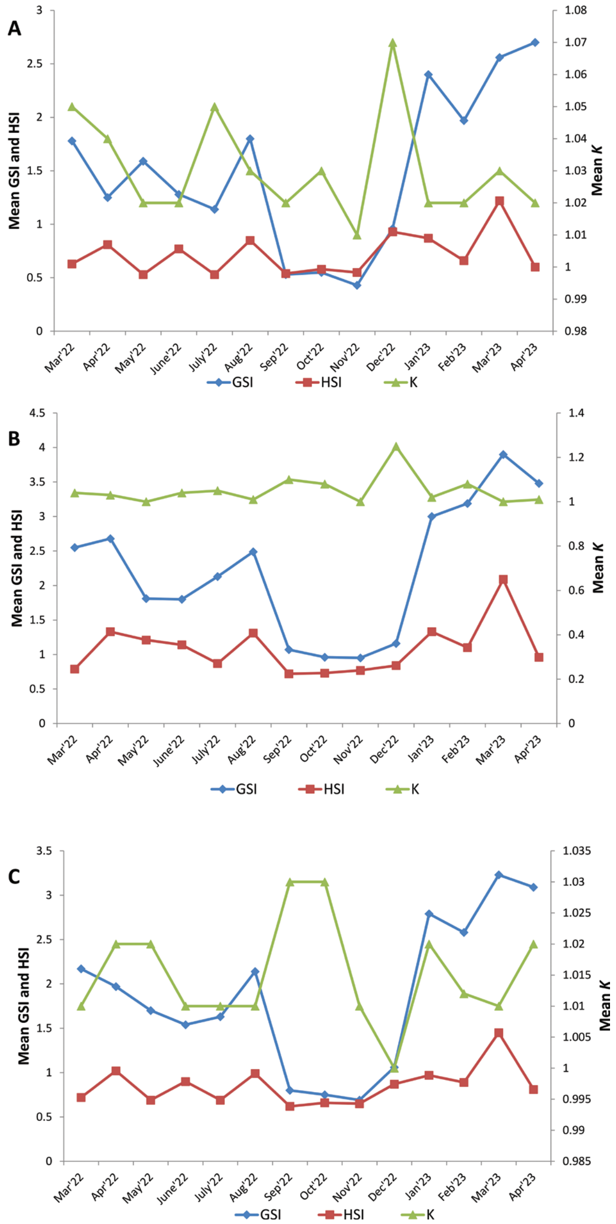


**Figure 5.** Monthly variations of gonadosomatic index (GSI), hepatosomatic index (HSI) and condition factor ($K$) of males (**A**), females (**B**), and combined sexes (**C**) of *Lutjanus xanthopinnis* collected at Pulau Kambing Fish Landing Port (Terengganu, Malaysia) eastern South China Sea.

(Kritzer 2004; Shimose and Tachihara 2005; Marriott et al. 2007). Similar findings about the spawning season for *Lutjanus* species were observed in earlier studies conducted in different regions: May to September for *L. quinquelineatus* (see Araki and Tachihara 2021), April to August for *Lutjanus fulviflamma* (Forsskål, 1775) (see Shimose and Nanami 2015), June to September for *Lutjanus fulvus* (Forster, 1801) (see Shimose and Nanami 2014), May to October for *Lutjanus gibbus* (Forsskål, 1775) (see Nanami et al. 2010a), June to October for *Lutjanus decussatus* (Cuvier, 1828) (see Nanami et al. 2010b). While the timing of the spawning season varied, it was observed to be prolonged and coincided with the period of warmest water temperature, which is compatible with the findings of the presently reported study.

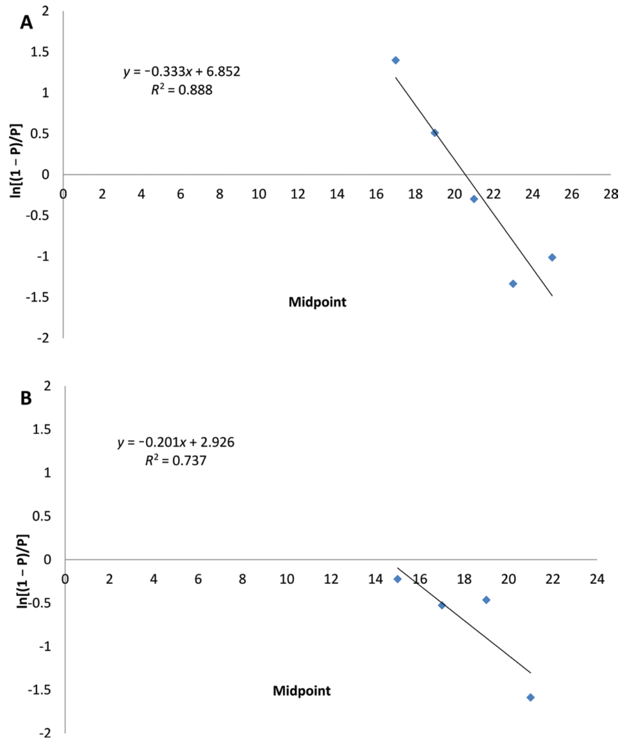


**Figure 6.** Proportions of mature males (**A**) ($n$ = 132) and females (**B**) ($n$ = 162) of *Lutjanus xanthopinnis* by fitting to a straight line of $\ln[(1 - R_M) \times R_M]$ against the midpoint of each size class. The fish were collected at Pulau Kambing Fish Landing Port (Terengganu, Malaysia) eastern South China Sea. $R_M$ = mature individuals rate.

Variations in $K$ and HSI were used to evaluate the patterns of energy use in fish during the reproductive phase. In the presently reported study, the mean condition factor ($K$) was higher than 1 in both sexes, indicating they are physiologically stable. According to Jisr et al. (2018), if a fish species has a $K$ value equal to or very close to 1, we consider that species to have a general fitness level. Muchlisin et al. (2017) claim that when $K$ is 1, there is still a balance between prey and predators, the waterways are in good condition, and fish can flourish. In general, condition factors are typically influenced by several biotic and abiotic factors, such as food availability, water quality, age, size, sex, and stage of gonad development (Kuriakose 2014). The condition factor and its strong opposite relation with GSI show that muscle weight decreases during reproduction due to the mobilization of muscle energy to aid gonad development. These findings were supported by Fadzli et al. (2022), where decreasing condition factors imply rapid growth of gonads. However, the pattern of HSI showed associations with the monthly progression of GSI, indicating that liver lipid storage is not necessary for fish reproduction.

Understanding the length at maturity will help determine the size that should be fished for sustainable fisheries (Thulasitha and Sivashanthini 2013). The calculated length at 50% sexual maturity ($L_{50}$) of *L. xanthopinnis* was 20.56 cm for males and 14.53 for females (Fig. 6). These length values were higher than those reported for *L. quinquelineatus* from Okinawa, Japan by Araki and Tachihara (2021) and smaller than those reported for

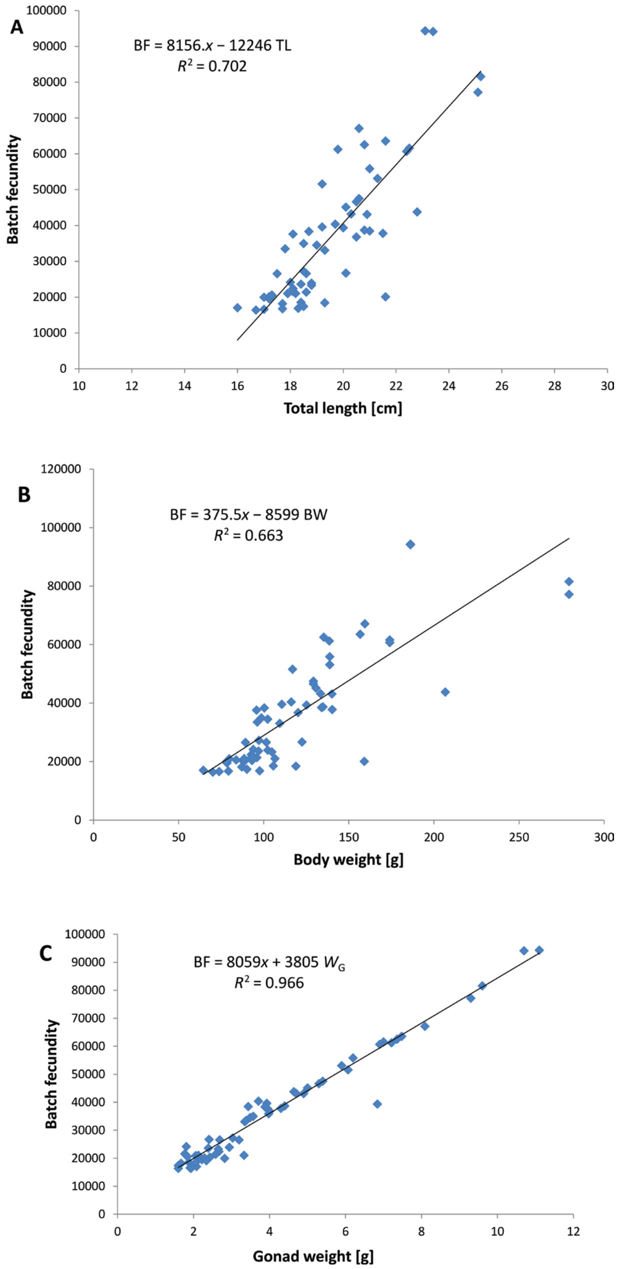


**Figure 7.** Relations between batch fecundity and total length (**A**), relations between batch fecundity and body weight (**B**), and relations between batch fecundity and gonad weight (**C**) of *Lutjanus xanthopinnis* collected at Pulau Kambing Fish Landing Port (Terengganu, Malaysia) eastern South China Sea. BF = batch fecundity, $W_G$ = gonad weight

*L. gibbus* from New Caledonia by Moore (2019). Variations in length maturity may be caused by differences in food available in different geographic locations (Oliveira et al. 2017). Tropical marine fish maturity size increases with distance from the distribution center (Trip et al. 2014). Small-size *Lutjanus* species generally mature earlier than the large snapper (Araki and Tachihara 2021). Moreover, the sample size and composition, sampling interval, and diagnostic criteria all influence the length of maturity estimation (Gaspare and Bryceson 2013). In the presently reported study, the early maturity of females is probably due to excessive fishing pressure.

Fecundity is crucial for developing successful fish species recruitment and regulating the fish population (Fernandes et al. 2022). Our study on *L. xanthopinnis* in Terengganu waters revealed that the fecundity varied from 16 405 to 94 357 oocytes and showed a positive relation with gonad weight compared to the length and weight of the fish. The BF value determined in the presently reported was lower than the value reported by Palla and Sotto (2021) and higher than the value reported by Pradeep (2016). In addition, the relations between BF with TL, $W_B$, and $W_G$ were exponential, which is supported by the findings of Fadzli et al. (2022). Grimes (1987) implied that tropical lutjanids can be very fecund species. The age, the relation of body size, population density, and environmental variability could all contribute to the variation in fecundity (Bradshaw and McMahon 2008).

**Management strategies.** The purpose of fisheries management is to maximize the benefits of the output unit (fish stock) which has been managed. Based on the findings of our study, a few management strategies are suggested here for the sustainable management of *L. xanthopinnis* in Malaysia and elsewhere. For instance, *L. xanthopinnis* in the eastern South China Sea, Malaysia has an $L_{50}$ of 20.56 for males and 14.53 cm for females, meaning 50% of fish at this length are mature. For sustainable management, we recommend catching fish smaller than the $L_{50}$ be strongly prohibited and that fishing not be allowed during the peak spawning seasons. Some researchers revealed that snapper species exhibit aggregating behavior during spawning season (Claro and Lindeman 2003; Malafaia et al. 2021; Motta et al. 2022), focusing on these aggregations at specific times and locations may lead to overexploitation. Consequently, marine protected areas must be established along with other management and conservation measures to ensure the survival of species and ecosystems. There is a need for improved dissemination of stock status information among state and Commonwealth agencies tasked with overseeing the management of particular fisheries targeting this species. This would facilitate the establishment of collaborative management plans that span multiple jurisdictions.

## Conclusion

This study used a multidisciplinary way to understand better the reproductive biology of *Lutjanus xanthopinnis* in the Terengganu waters of the South China Sea, Malaysia, including size structure, sex ratio, gonad maturation stages, gonadosomatic index, spawning season, condition factor, hepatosomatic index, length at first maturity, and fecundity. Knowledge about reproductive biology is essential for sustainable management, especially in rising nations like Malaysia, where managers depend on the maturity length and the reproductive period's start and duration to manage fisheries resources. The presently reported study offers first-hand knowledge of the reproductive biology *L. xanthopinnis*, globally and in Malaysia. These results might be a foundation for managing reef fisheries efficiently and sustainably.

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