Reproductive Parameters of Indian Threadfin *Alectis indicus* in Andaman Sea, Thailand

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ABSTRACT

Information on reproductive biology is essential for both fisheries management and aquaculture. In this study, samples of *Alectis indicus* (90 females and 97 males; size ranges: 1.2–7.8 kg, 47.0–99.9 cm for females and 1.6–7.3 kg, 52.3–100.0 cm for males) were acquired from a local fish supplier in Trang Province on the coast of the Andaman Sea, Thailand, between November 2020 and October 2021. The results revealed that the sex ratio of sampled *A. indicus* was not different from 1:1; size at first maturation was 69.7 cm for males and 67.7 for females; gonadosomatic index (GSI) ranged from 0.03 to 1.20% in males and from 0.27 to 2.91% in females; percentage of post-vitellogenic oocytes (%PVO) ranged from 0 to 34.45%; and GSI showed positive moderate correlation with %PVO ($r = 0.497$, $p = 0.0001$). Based on GSI and %PVO, female *A. indicus* presumably spawned year-round with two peaks, in July and November-December, whereas the peak of male GSI value occurred in July. Female GSI and %PVO that marked the spawning peaks were 1.24–1.63% and 16.19–18.98%, respectively, while male GSI at the spawning peak was 0.79%. The information obtained not only benefits understanding of reproductive biology of *A. indicus* in the Andaman Sea but is also useful for efforts at captive breeding of this species.

Keywords: Condition factor, Gonadosomatic index, Size at first maturation, Spawning season

INTRODUCTION

The genus *Alectis*, a member of the family Carangidae, comprises three species, two of which are distributed in the tropics (*A. indicus* [Rüppell, 1830] and *A. ciliaris* [Bloch, 1787]), while *A. alexandrina* (Geoffroy Saint-Hilaire, 1817) is found in subtropical seas (Froese and Pauly, 2019). With maximum published body length and body weight of 165 cm and 25 kg, respectively (Froese and Pauly, 2019), they are among the largest carangids. Although they are of minor importance in terms of global fisheries production, juvenile-stage *A. indicus* and *A. ciliaris* are recognized as attractive aquarium fishes, while the adults are well accepted as food fish. In addition, like some other members of the family Carangidae, *Alectis* spp. are important for recreational fisheries (Katsuragawa and Matsuura, 1992).

In recent years, aquaculture of carangid fishes has received much interest. Development of new culture species is underway following the long-term experience with popularly cultured carangid species like yellowtail (*Seriola quinqueradiata*) and ovate pompano (*Trachinotus ovatus*) (Na-Nakorn *et al*., 2023). To develop aquaculture of a species, knowledge of its reproductive biology (e.g., spawning

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season, sex ratio, developmental stages of gonads) is an initial step towards breeding success. Among parameters studied, gonadosomatic index (GSI)-the percentage of gonad weight relative to body weight-has been widely used to identify spawning season. However, GSI alone may not precisely determine the spawning season because the time lag between oocyte maturation and spawning is unknown (Kainge *et al*., 2007). In addition, there was at least one observation in *Seriola lalandi* where partially and fully spermiated testes did not differ significantly in GSI value, nor did ovaries at final maturation stage and those at ovulated stage (Poortenaar *et al*., 2001). This has necessitated a parallel study on gonad development based on histology of gonads. Reproductive biology has been reported for several carangid species (e.g., *Trachurus mediterraneus*, Viette *et al*., 1997; *S. lalandi*, Poortenaar *et al*., 2001; *Carangoides bajad* and *Gnathanodon speciosus*, Grandcourt *et al*., 2004; *Trachinotus marginatus*, Lemos *et al*., 2011; *Scomberoides lysan*, Thulasitha and Sivashanthini, 2013), but this information is lacking for *Alectis* spp. Therefore, the current study was conducted to estimate spawning seasons of *A. indicus* in Thailand by monitoring year-round GSI and gonadal development of *A. indicus*. In addition, sex ratio and other related information such as Fulton's condition factor and size at 50% maturity were also determined. The knowledge gained from this study can benefit fisheries management and development of captive breeding of this species in the future.

MATERIALS AND METHODS

The protocols used in this study have been approved by Kasetsart University's Institutional Animal Care and Use Committee (ID ACKU65-FIS-015).

Fish samples

A total of 90 female (4–12 fish·month^{-1}) and 97 male (3–17 fish·month^{-1}) *Alectis indicus* were purchased from a local collector in Amphur Muang, Trang Province, on the coast of the Andaman Sea in Thailand, between November 2020 and October 2021. The size of females ranged between 47.0 and 99.9 cm in total length (mean = 74.27±10.14 cm) and between 1.2 and 7.8 kg (mean = 3.70±1.29 kg); males ranged between 52.3 and 100 cm (mean = 72.01±10.95 cm) and between 1.6 and 7.3 kg (mean = 3.46±13.62 kg). It should be noted that *A. indicus* is mainly caught by angling; as such, the supply of specimens was irregular and in small quantity. The collector kept the specimens in a freezer (-10 °C) and the samples were transferred twice monthly (in the second and fourth week) to a biology laboratory of the Faculty of Science and Fisheries Technology, Rajamangala University of Technology Srivijaya, Trang Campus, where the investigations were performed. Individual specimens were identified based on guidelines from Fishbase (Froese and Pauly, 2019). Then they were measured to the nearest millimeter and weighed to the nearest gram before their abdomens were opened and the gonads were removed, weighed, and fixed in neutral buffered formalin for further histological study. Gonadosomatic index was calculated as a percentage of gonad weight to body weight. Fulton's condition factor (K) was calculated using the formula $K=100\times\frac{W}{L^3}$, where W = body weight in grams and L = total length in centimeters. It should be noted that sex cannot be differentiated using external morphology in this species, and thus, histology of gonads was used to identify sex.

Size at 50% maturity

For the estimation of size at 50% maturity ($L_{50\%}$) of the population, the data on total length were arranged in 5-cm length classes. $L_{50\%}$ was calculated using a logistic equation:

$$P_L=\frac{1}{1+e^{(a+b\times L)}}$$

where P_L = proportion of mature individuals; L = total length (cm); a, b = constants to be iteratively estimated with a nonlinear least-squares procedure.

To estimate the coefficients a and b, natural logarithm was taken as follows:

$$\ln\left(\frac{1}{P_L}-1\right)=a+bL$$

Finally, length at 50% maturity ($L_{50\%}$) was estimated using the formula: $L_{50\%} = \frac{a}{b}$. In addition, lengths at 25% ($L_{25\%}$) and 75% ($L_{75\%}$) maturity were estimated by $L_{25\%} = \frac{(a\text{-}\ln 3)}{b}$ and $L_{75\%} = \frac{(a+\ln 3)}{b}$, respectively.

Macroscopic stages of gonads

Morphology of gonads was examined and classified into five (females) or four (males) stages according to Thulasitha and Sivashanthini (2013).

Histological study

Histological study was performed following standard procedure (Humason, 1962). In brief, samples of gonad tissue (10×10×10 mm) were taken from anterior, middle and posterior parts of the ovaries. Then the sample tissue was separately dehydrated using an ascending ethanol series and subsequently cleared with xylene, infiltrated with paraffin wax, and embedded into the block. Cross-sections of 3–5 µm thickness were mounted onto slides and stained with hematoxylin and eosin (H & E). Each slide was then observed under a compound microscope. The oocyte development stages were identified based on Uribe *et al*. (2012).

Percentage of vitellogenic, post-vitellogenic, and atretic oocytes

Ovarian histology was observed using a compound microscope under 10×40 magnification. The oocytes (and oogonia) appearing in each field were identified by developmental stage and enumerated. Then a percentage for each oocyte stage was calculated. Notably, we could not obtain good histological slides of testes; therefore, no histology data were analyzed for males.

Statistical analysis

The data on individual GSI, and percentages of vitellogenic, post-vitellogenic and atretic oocytes were compared between months using one-way analysis of variance followed by mean comparison based on Duncan's multiple range test. Data expressed as percentages were arcsine-transformed prior to the analyses. In addition, the relationship between GSI and % vitellogenic or post-vitellogenic oocytes was analyzed using Pearson's correlation. Yates's corrected version of Pearson's chi-squared statistics (Fowler *et al*., 1998) was performed on the overall sex ratio to test for departure from a 1:1 ratio using the following formula:

$$\chi^2 = \sum_{i=1}^{N} \frac{(|O_i - E_i| - 0.5)^2}{E_i}$$

where O_i = an observed frequency; E_i = an expected (theoretical) frequency, asserted by the null hypothesis; and N = number of distinct events.

RESULTS

Descriptive statistics and sex ratio

Among 187 individuals collected, 97 were male and 90 were female. Sex ratio did not significantly deviate from 1:1 (1:1.05 female:male; Chi-square value = 0.192; df = 1; p = 0.6608).

Macroscopic characters of ovaries

Ovaries appeared in pairs, with oval shape; their size and morphology varied with developmental stage. However, among the five previously described stages of ovaries (Thulasitha and Sivashanthini, 2013), only three stages were found among the 90 females investigated in this study (Figure 1). Stage I (immature: small, threadlike ovaries) and stage V (resting/spent: flaccid ovaries with large internal lumens) ovaries were not found. The morphology of each ovarian stage is described in Table 1.

Macroscopic characters of testis

Testes appeared as paired, sac-like organs; their morphology varied with developmental stage. All four stages of testes according to Thulasitha and Sivashanthini (2013) were observed (n = 97) (Figure 2) and their descriptions are shown in Table 2.

Table 1. Stages of ovaries of female *Alectis indicus* observed in this study.

Maturity stage	Macroscopic characters of ovaries
II (maturing)	Ovaries small, opaque with a few small blood vessels, no visible ova (Figure 1a).
III (mature)	Ovaries with size larger than stage II and thin ovarian wall, more blood capillaries visible on ovarian surface, small ova visible with pale yellow color (Figure 1b).
IV (spawning)	Swelling ovaries occupying > 1/3 of body cavity, ovarian wall very thin and supplied with numerous blood capillaries, large ova visible (Figure 1c).

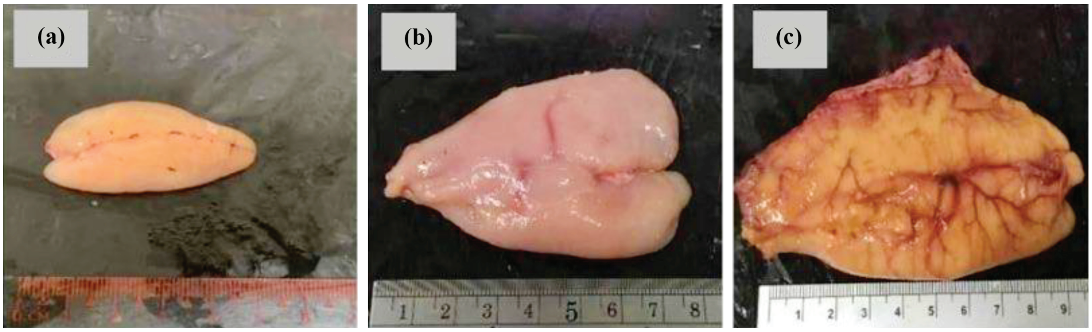


Figure 1. Morphology of *Alectis indicus* ovaries: (a) stage II, maturing ovaries; (b) stage III, mature ovaries; (c) stage IV, spawning ovaries.

Table 2. Stages of testes of male *Alectis indicus* observed in this study.

Maturity stage	Macroscopic characters of ovaries
I (immature)	Small, threadlike and opaque, reddish brown in color (Figure 2a).
II (maturing)	Threadlike but larger than stage I, whitish in color with some brown portions (Figure 2b).
III (mature)	Apparent increase in size over stage II, whitish with thick testis wall, swelling and filled with milt with slightly lobulate appearance (Figure 2c).
IV (spawning)	Larger than stage III, whitish with fully lobulate appearance, testis wall very thin (Figure 2d).

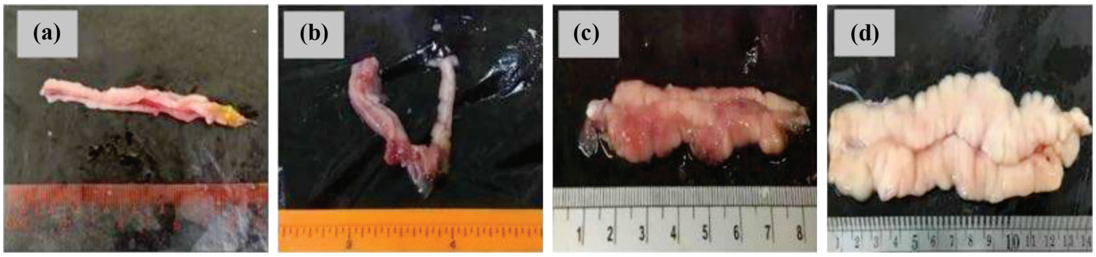
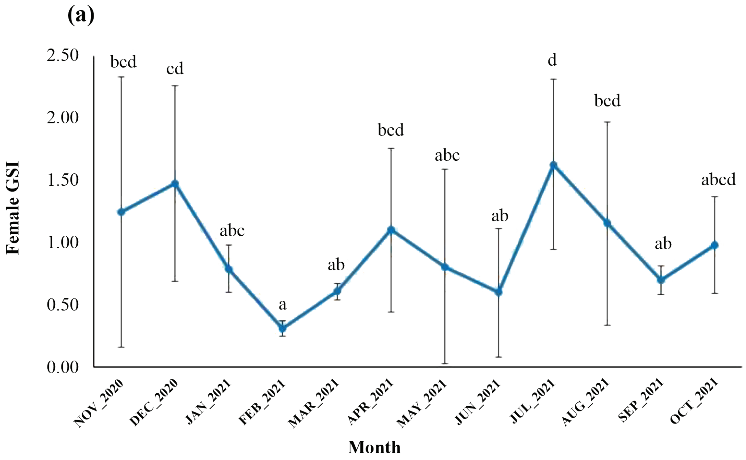


Figure 2. Morphology of *Alectis indicus* testes: (a) stage I, immature testis; (b) stage II, maturing testis; (c) stage III, mature testis; (d) stage IV, spawning testis.

Gonadosomatic index (GSI)

Mean GSI of females varied considerably among months (Figure 3a) and ranged from 0.30± 0.03% (February 2021) to 1.63±0.68% (July 2021), with the overall mean across months of 1.00±0.77%. Most months (9 of 12 months) were not significantly different in GSI. However, GSI was remarkably high in November and December and again in July, whereas the lowest GSI values were observed between January and March. A frequency distribution of female GSI by sampling month (data not shown) showed that individuals with GSI above the mean were found in every month except for February, March and September.

GSI of male fish was much lower than that of females, ranging from 0.07±0.03% in February 2021 to 0.79±0.38% in July 2021 (overall mean = 0.31±0.30%), but showed a similar trend to female GSI (Figure 3). Notably, male GSI showed the same peak as female GSI in July, while GSI in November and December (which had peaks for female GSI) was significantly lower than the July value. Male individuals with GSI above the mean appeared in seven sampling months, but not in December, January, February, June and September.



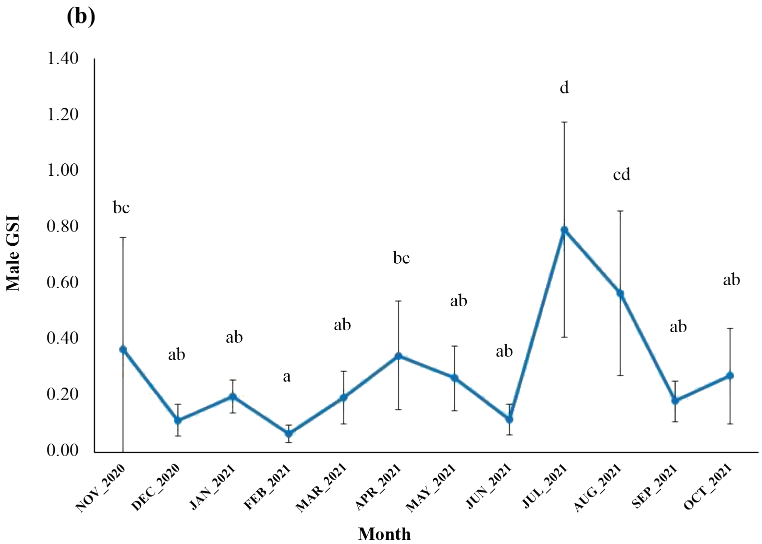


Figure 3. Gonadosomatic indices of *Alectis indicus* collected from Trang Province, Thailand (Andaman Sea) during November 2020 and October 2021: (a) female GSI; (b) male GSI.

Gonad histology

Only the histology of ovaries was clear enough for analysis in this study. Histology of testes gave poor results, and as such it is not described here. Five oocyte stages were identified as described below.

Stage I, young cells: Oogonia and oocytes packed in ovigerous folds were small and nucleus lacked nucleolus.

Stage II, previtellogenic stage: This stage was marked with the presence of nucleolus in nucleus visible until cortical alveoli (yolk vesicles) appeared as milky-white round particles dispersed within cytoplasm; oil droplets appeared around yolk vesicle as transparent round droplets (Figure 4a).

Stage III, vitellogenic stage (VG): This stage was marked with presence of yolk granules which appeared as bright-pink substance accumulated in cytoplasm, germinal vesicle was at cell center; follicular layers were visible (Figure 4b).

Stage IV, post-vitellogenic stage (PVO): This stage was indicated by cytoplasm filled with yolk granules, with germinal vesicle positioned between center and cell periphery, at cell periphery, or not visible (Figure 4c).

Stage V, atretic stage: Oocytes had irregular cell shape; follicular layers enlarged (Figure 4d).

Percentages of oocyte stages

Figure 5 depicts the average proportion of oocytes in pre-, post-vitellogenic and atretic stages by month. The percentage of vitellogenic oocytes, which mark the onset of oocyte maturation, did not change much throughout the year, with small peaks in July and August (Figure 5a). Meanwhile, the percentage of post-vitellogenic oocytes (PVO), an indicator of oocyte maturation, was highest in November, July and October (16.20±11.59%–8.98±11.44%) (Figure 5b). It should be noted that PVO were observed in every month except January and February, and that high variation was apparent in each month, with a minimum value of 0% and maximum of > 30% PVO. The profile of VO and PVO suggested that spawning of this species may occur year round with the highest peaks in July and August, and the additional peak suggested by %PVO in October to November. Atretic oocytes were observed throughout the year, and the proportions were fairly high from October until January (Figure 5c). In relation to the morphology of ovaries, no PVO were found in stage II (maturing) ovaries, while >0 to <10% PVO were observed in each of the stage III (mature) ovaries and ≥10% PVO in each of the stage IV (spawning) ovaries.

Correlation between GSI and other parameters

GSI and %PVO were moderately correlated (r = 0.497, p = 0.0001), while no correlations were observed between GSI and % vitellogenic or atretic

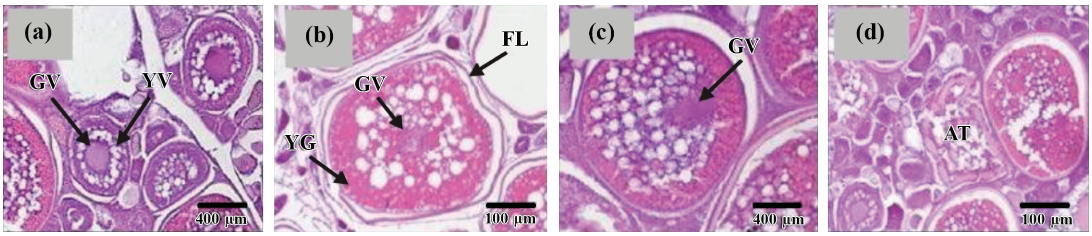


Figure 4. Histomicrographs of *Alectis indicus* oocytes collected from Trang Province, Thailand (Andaman Sea) during November 2020 and October 2021: (a) oocytes in previtellogenic stage marked with large germinal vesicle (GV) and yolk vesicles (YV) around GV; (b) an oocyte in vitellogenic stage marked with relatively small, central GV, bright pinkish yolk granule (YG) at oocyte periphery and distinct follicular layer (FL); (c) a post-vitellogenic oocyte marked with a migrating GV towards oocyte periphery; (d) an atretic oocyte (AT) appearing among other oocytes of various stages.

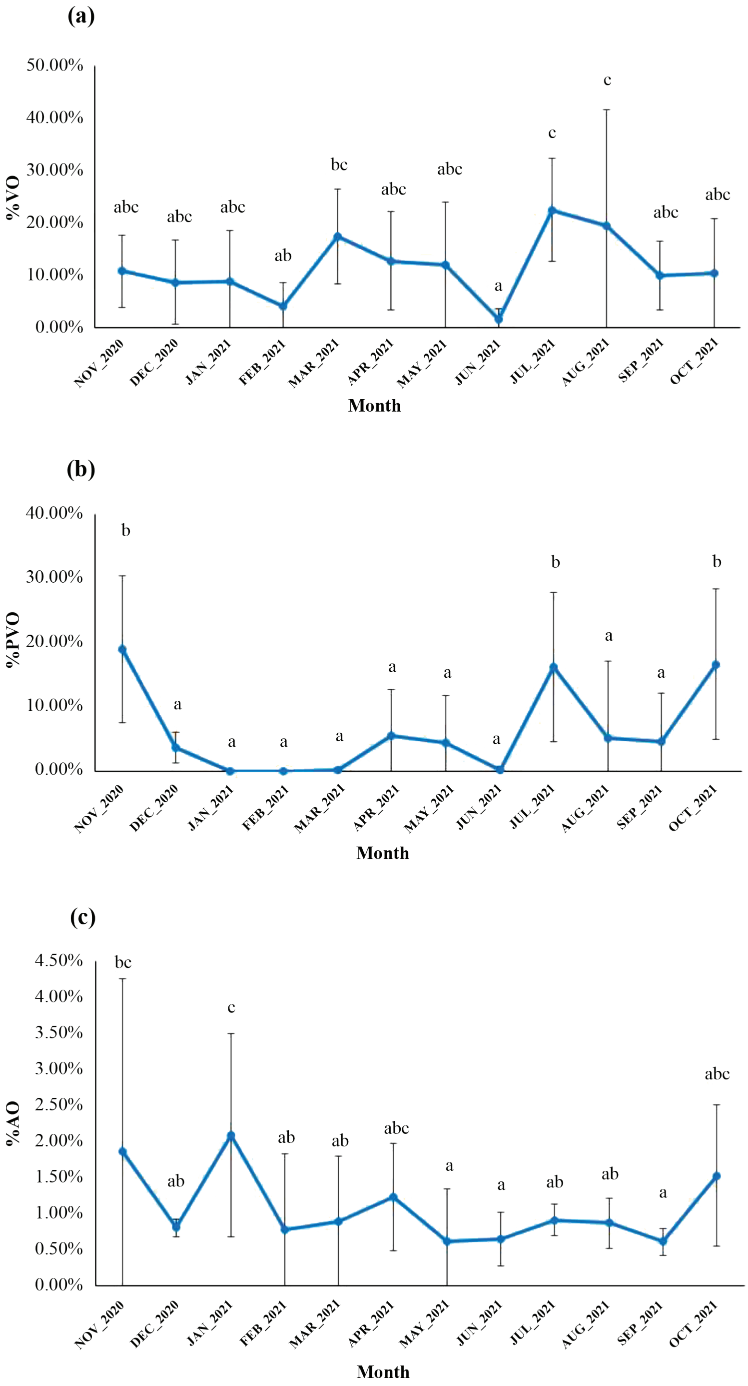


Figure 5. Percentage of oocytes in different stages of *Alectis indicus* collected from Trang Province, Thailand (Andaman Sea) during November 2020 and October 2021: (a) vitellogenic oocytes (VO); (b) post-vitellogenic oocytes (PVO); (c) atretic oocytes (AO).

oocytes (r = 0.117 and 0.106, respectively; p = 0.274–0.318). The correlation between GSI and body weight was not significant (r = 0.13, p = 0.23), nor between GSI and length (r = 0.11, p = 0.33).

Fulton's condition factor (Kn)

The value of Kn was not significantly different between males (0.90±0.11) and females (0.88±0.11) (F = 1.496; p = 0.223). Kn of males and females showed similar trends (Figure 6), whereby the values were highest in November and then dropped until April; surged again during May to September but with a slight drop in August. It should be noted that the Kn value for males and females was less than 1 throughout the year, with some exception.

Size at 50% maturity

Size at 50% maturity, which is defined as the size at which 50% of individuals in a population are mature, was 67.70 cm (a = 7.53, b = 0.11, r^2 = 0.91) for females and 69.70 cm (a = 9.46, b = 0.13, r^2 = 0.97) for males. Meanwhile, $L_{25\%}$ and $L_{75\%}$ for females were 58.6 and 78.4 cm, respectively, and they were 64.3 and 81.2 cm for males.

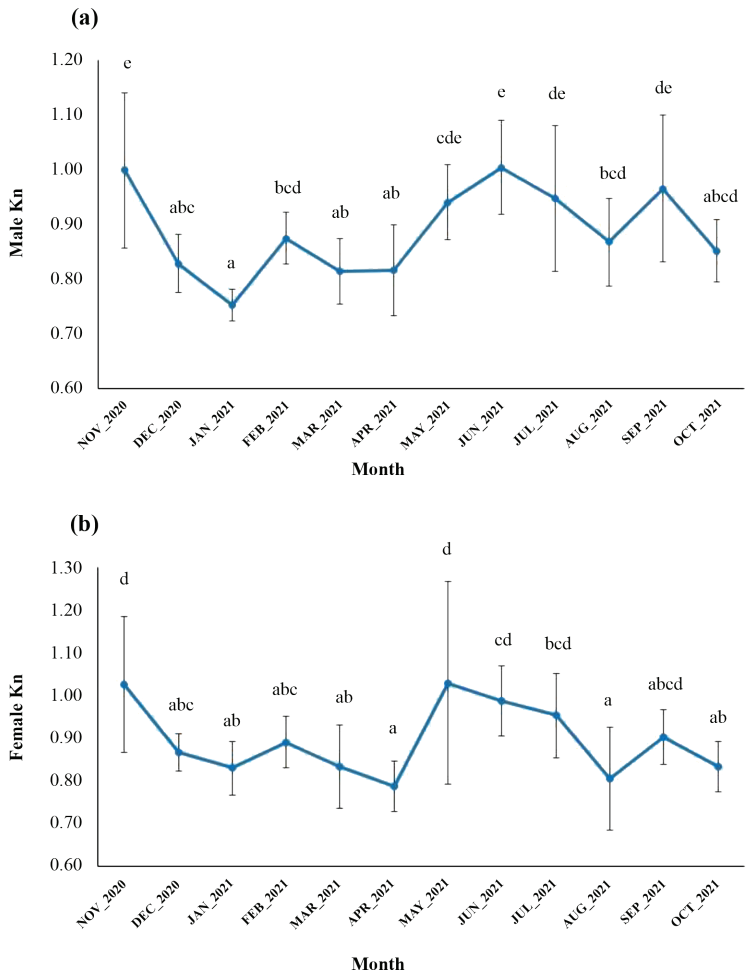


Figure 6.. Fulton's condition factor (Kn) of *Alectis indicus* collected from Trang Province, Thailand (Andaman Sea) during November 2020 and October 2021: (a) males; (b) females.

DISCUSSION

Sex ratio

Sex ratios for fishes in the genus *Alectis* have not been reported before. *Alectis indicus* in this study possessed a sex ratio of 1:1, which was in line with many other carangids, and especially *Selene dorsalis* (Arra *et al*., 2018), the closest relative of *Alectis* spp. in terms of evolution based on morphometrics (Gushiken, 1988; Reed *et al*., 2001), and also *Caragoides malabaricus* (Venkataramani and Natarajan, 1984), which is evolutionarily closest to *A. indicus* based on sequences of mitogenomes (Li *et al*., 2020). To our knowledge, a majority of the carangids have been reported with equal sex ratio, for example, *Ca. bajad* and *G. speciosu*s (Grandcourt *et al*., 2004); *Sc. lysan* (Thulasitha and Sivashanthini, 2013); and *Carangoides coeruleopinnatus* (Fadzli *et al*., 2022). Unequal sex ratios were found in some carangids; for example, male-dominated populations were reported for *Atule mate* (Clarke, 1996) and *Scomberoides commersonnianus* (Qamar *et al*., 2020), while *C. ignobilis* from the Northwestern Hawaiian Islands (1:1.39, M:F) and *C. melampygus* (1:1.148, M:F) were female-dominated (Sudekum *et al*., 1991).

Gonadosomatic index (GSI)

Previous studies on spawning seasons of fish have relied on several types of information, such as presence of gravid females, presence of eggs and/or larvae in natural waters, GSI and development stage of oocytes (reviewed by Honebrink, 2000; Kainge *et al*., 2007; Singh *et al*., 2011; Jansen *et al*., 2015). However, among these, GSI has been the most commonly used parameter which has been reported as highly correlated with vitellogenin gene expression in 2 fish species (*Notopterus notopterus* and *Anematichthys armatus*; Panprommin *et al*., 2015). GSI of most fishes was higher in females than males (e.g., Brewer *et al*., 1994; Grandcourt *et al*., 2004; Al-Rasady *et al*., 2012; Qamar *et al*., 2020), with some exceptions (e.g., equal GSI in male and female *Tr. mediterraneus*; Demirel and Yüksek, 2013). Our results showed that *A. indicus* was similar to most other species, whereby female GSI was greater than that of males. The value of GSI also varied with species, and thus the GSI value indicating spawning season varied considerably. For example, GSI in peak months of the presumed spawning season of *A. indicus* in the present study was 1.63±0.68% (range = 0.75%–2.82%) for females and 0.79±0.38% (range = 0.24–1.20%) in males. Similar values were reported for *S. dorsalis* (Arra *et al*., 2018) and *Ca. coeruleopinnatus* (Fadzli *et al*., 2022). Higher GSI values during spawning season were reported for some carangids, e.g., *Tr. mediterraneus* (2.0–6.0% for both males and females; Demirel and Yüksek, 2013), *Ca. bajad* (~2.5 for males and >1.5–2 for females) and *G. speciosus* (>3 for males, >2.5 for females; Grandcourt *et al*., 2004). Notably, GSI of spawning females could be as high as ≥10%, as observed in *Caranx bucculentus* (Brewer *et al*., 1994).

Correlation between GSI and %PVO

Although the profile of %PVO across months was slightly different from female GSI, the %PVO was consistent with GSI in that the lowest values of both parameters were observed in February, while %PVO in July (with highest GSI) was among the highest. The relationship between GSI and %PVO was confirmed by a significant correlation between these parameters, and thus supported the use of GSI, which is much easier to measure than %PVO in predicting spawning of *A. indicus*.

Spawning season

The spawning season of *Alectis* spp. has never been systematically studied before except for a report on natural spawning in the Philippines (von Westernhagen, 1974) which occurred in December-January and in June. The other related information was from a report on *A. ciliaris* in India, where a season (March to May, with a possible peak in April) was suggested based on the greatest number of larvae collected (National Bioresource Development Board, 2016). Like other members of the family Carangidae, which have a fairly long spawning season and where spawning occurs repeatedly and periodically (reviewed by Honebrink, 2000), *A. indicus* also appeared to spawn year-round based on the scattering of relatively high GSI individuals and presence of PVO throughout the year. This may be supported by the minimal variability of climate in the Andaman Sea, especially water temperature (e.g., 28–29 ºC in September to February and 29–30 ºC in April to August) (Isa *et al*., 2020). Johannes (1978) suggested that this spawning strategy may be a characteristic of tropical marine fishes in response to year-round food abundance and constant high temperatures.

The peaks of the spawning season (for females) of *A. indicus* revealed in this study coincided with the monsoon seasons, whereby the major peak (July) occurred during the southwest monsoon (June–July) and a minor peak (November) occurred at the beginning of the northeast monsoon (November–February) (Yaakob and Chua, 2005). The proposed spawning season in the present study aligns with the natural spawning evidence reported in the Philippines (in the Bohol Strait), whereby two major spawning events were observed in December-January and in June (von Westernhagen, 1974). Similar spawning periods were reported for species of other carangid and non-carangid fishes. For example, year-round spawning with peaks in monsoon seasons was observed in skipjack tuna (*Katsuwonus pelamis*, Family Thunnidae) in the western Indian Ocean (Grande *et al*., 2014), while male and female *Selene dorsalis* (continental shelf of Côte d'Ivoire) spawned in August (with a second peak in January for males and February for females) (Arra *et al*., 2018). Spawning of fishes during the monsoon may be in response to enhanced productivity of the ocean during that period (Wiggert *et al*., 2006; Arra *et al*., 2018). In contrast, the spawning peak of coastal trevally, *Ca. coeruleopinnatus* inhabiting an area (Terenganu, Malaysia) near this study, occurred at the end of the northwest monsoon (February–April), and this was tentatively attributed to increased temperature (Fadzli *et al*., 2022). Such difference may indicate different triggering factors for gonad development and spawning in different species.

Notably, male *A. indicus* showed only one GSI peak, while two peaks were observed for females. Although concurrent GSI peaks of males and females likely indicates a spawning season, this phenomenon was also reported in at least one other carangid species, *Ca. bajad* (Grandcourt *et al*., 2004). It is also possible that the small sample sizes of male fish used in the current study (n = 5 and 3 in November and December, respectively) may account for the absence of a male GSI peak in November–December due to sampling error.

Size at 50% maturity

The present study revealed size at 50% maturity of *A. indicus* as 67 cm for females and 69 cm for males. This implies that to maintain a spawning stock, *A. indicus* below this size should not be harvested. However, note that the size at 50% maturity varies with geographic location, which may be explained by difference of stocks, temperature (Brusle, 1981; Tormosova, 1983), food availability (Tormosova, 1983) and exploitation pressure (Morales-Nin *et al*., 2002; Engelhard and Heino, 2004). Furthermore, size coverage of the studied sample also can affect this parameter, as suggested by Zorica *et al*. (2011). Their study, which utilized smaller specimens of garfish (*Belone belone*) than in other studies on the same species, estimated a smaller size at 50% maturity. Thus, based on the aforementioned examples, the present study might have overestimated size at 50% maturity of *A. indicus*, and hence necessitates further investigation of this parameter.

Fulton's condition factor (Kn)

Kn has been widely used as an indicator for health of fish, and some studies have revealed its relationship with fish energy reserves (e.g., Herbinger and Friars, 1991; Chellappa *et al*., 1995). However, some findings have contradicted these assumptions, e.g., no relationship between Kn and nutritional values of the fish (Davidson and Marshall, 2010; Mozsár *et al*., 2015).

Difference of Kn values between sexes is common, whereby males generally have higher average Kn than females due to higher energy expended for reproduction by females than males (West, 1990; King, 1995; Fadzli *et al*., 2022). However, this phenomenon was not observed in *A. indicus* in the present study, nor in some other carangid species (e.g., *Carangoides chrysophrys*; Al-Rasady *et al*., 2012) and thus may imply similar energy expenditure for reproduction in males and females. Studies in several carangid fishes revealed constant Kn throughout the year and implied that reproduction of those species depended largely on dietary nutrition prior to the spawning season rather than spending reserve energy for gonadal development (e.g., *Caranx kalla* in Kalita and Jayabalan, 1997; *Ca. chrysophrys* in Al-Rasady *et al*., 2012). On the contrary, we observed significant change of Kn in both male and female *A. indicus* during the year. Although such differences were not supported by statistical tests in most cases, a significant rise of Kn was observed in both sexes in May and June (presumably prior to a spawning peak in July). However, this increase of Kn was not likely due to nutrient accumulation before rapid growth of gonads because the difference was too small (i.e., 0.82 increased to 0.95 [$p<0.05$] in males; 0.79 increased to 0.95 [$p<0.05$] in females). Similar findings were reported for skipjack tuna in the Indian Ocean, where Grande *et al*. (2014) concluded that the increase of Kn from 1.88 to 2.06 was not large enough to indicate energy allocation related to spawning.

Fulton's condition factor (K_n) is the appropriate method for comparing relative heaviness among specimens, meanwhile estimated weight of individuals should be obtained from a length-weight relationship (Froese, 2006). A Kn value of one indicates that the fish are in a good, healthy condition (Froese, 2006; Haberle *et al*., 2023). Kn of *A. indicus* in the present study was less than one throughout the year. This implies low nutritional condition and hence poor growth, which could be attributed to excessive fishing pressure, overcrowding, high competition, limitation of niche foods, environmental change or a combination of these factors (Famoofo and Abdul, 2020; Haberle *et al*., 2023). However, determining the reason for the low observed Kn in *A. indicus* is beyond the capacity of our data.

CONCLUSION

The present study provides novel information on the reproductive biology of *A. indicus* in the Andaman Sea of Thailand. Data from 187 individuals collected between November 2020 and October 2021 revealed that the sex ratio in this population was not different from 1:1; estimated size at 50% maturity was 69.7 cm for males and 67.7 cm for females; GSI ranged from 0.03 to 1.20% in males and from 0.27 to 2.91% in females; %PVO ranged between 0% and 34.45%; and GSI showed positive moderate correlation with %PVO ($r = 0.497$, $p = 0.0001$). Based on GSI and %PVO, female *A. indicus* presumably spawned year-round with two peaks, in July and in November–December, whereas a single male spawning peak was in July. Female GSI and %PVO that marked the spawning peaks were 1.24–1.63% and 16.19–18.98%, respectively, while male GSI at the spawning peak was 0.79%. Fulton's condition factor of males and females was similar (0.88–0.90) and tended to increase prior to the presumed spawning season.

This study is the first effort to understand reproductive biology of this species. Further studies that include wider geographic range and size distribution, larger sample size, as well as other parameters such as fecundity, are required to fully understand this issue. However, the obtained information in the present study can serve as the first basic knowledge of the reproductive biology of the genus *Alectis*, and hence will add to the knowledge for the family Carangidae as a whole. Besides, it provides useful information for further research and development of *A. indicus* aquaculture. For example, the suitable time to collect fingerlings and juvenile or even mature wild broodstock for further breeding experiments can be roughly estimated, and size of mature broodstock is now known. We believe that this work will trigger further research aiming towards captive breeding of this species.

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