



## Reproductive attributes of the spot-tail shark, *Carcharhinus sorrah* collected from westernmost waters of Aceh, Indonesia

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### ABSTRACT

The spot-tail shark, *Carcharhinus sorrah* is a species of requiem shark found primarily in warm coastal waters of the Indo-Pacific region. This study aims to assess the length at first maturity and length distribution. The spot-tail shark, *C. sorrah* collected from key fish landing sites in Aceh Province, Indonesia. Data collection occurred between March 2020 and October 2022 at three fishing ports: Banda Aceh (BA), Aceh Barat (AB), and Aceh Barat Daya (ABD). A One-way Analysis of Variance (ANOVA) was employed to analyze the total length (TL) of male and female fish from these sites. Results indicated an overall sex ratio of female to male fish at 1:1.67 ( $\chi^2 = 45.19$ ,  $p < 0.001$ ), with significant differences observed in sex ratios between BA and ABD ( $\chi^2 = 6.72$ ,  $p = 0.01$ ;  $\chi^2 = 41.14$ ,  $p < 0.001$ ), while AB showed no significant difference ( $\chi^2 = 1.64$ ,  $p = 0.20$ ). Logistic regression analysis revealed variations in the length at which 50% of males and females reached maturity ( $L_{m50}$ ): males from ABD, AB, and BA were 110.65 cm TL, 117.03 cm TL, and 152.65 cm TL, respectively, while females from BA, ABD, and AB were 107.30 cm TL, 113.94 cm TL, and 116.14 cm TL, respectively. Notably, males from ABD and females from BA matured earlier than those from other sites. In terms of length distribution, the average greatest with standard deviation ( $\pm$ SD) length of male *C. sorrah* was  $122.87 \pm 37.87$  cm TL in AB, followed by BA at  $113.80 \pm 13.10$  cm TL and ABD at  $107.86 \pm 18.38$  cm TL. This species is important for both ecological balance and fisheries, emphasizing the need for effective management and conservation efforts.

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### Introduction

The Indo-Pacific region has been known as the home of diverse chondrichthyan fauna such as sharks, rays and chimeras that inclusively contain great numbers of shark species (Kirke *et al.*, 2024). Shark species are considered highly vulnerable fishery resources due to their strong market demand. Due to potential increasing demands for shark flesh for human consumption, sharks are increasingly exploited both by targeted species and as bycatch species and may put high pressure on shark's fishery and threat to their sustainability (Varghese *et al.*, 2016, Nurdin *et al.*, 2023).

Increasing fishing pressure for sharks and other numbers of fish captured incidentally as by catch has

drastically driven the decline of many fish species worldwide (Baje *et al.*, 2018; Kirke *et al.*, 2024). It is now estimated that shark populations declined over 70% in the years between 1970 and 2018 (Oliver *et al.*, 2015; Kirke *et al.*, 2024). Their life historical characteristics such as slow-growing phase, late maturing and low number fecundity are addressed as the main factors to the global decline of sharks (Nurdin *et al.*, 2023, Kirke *et al.*, 2024).

The spot-tail shark, *Carcharhinus sorrah* is widely distributed in the Indian Ocean and the West Pacific Ocean, from the Red Sea along way to the Australian waters (Joung *et al.*, 2022). In Indonesian territory waters, *C. sorrah* has considered as one of the most common species that widely distributed in Sumatera,

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Jawa and Bali waters (Nuridin *et al.*, 2023). They mainly are being targeted by fishermen by using gill nets and long lines from coastal waters to the deep open seas (Sen *et al.*, 2018). Thus, shark fishes are amongst the most important fishery commodities in Indonesia.

However, habitats of each shark species could be varied, depending on their life characteristics (Varghese *et al.*, 2016; Shaaban *et al.*, 2018). For instance, *C. sorrah* is a common coastal pelagic, which is mostly spread in warm tropical and insular shelves water, often appearing in coral reef at a depth of more than 50 meters (Simpfendorfer and Dulvy, 2018). Regional differences in life history characteristics of sharks might reflect to habitat pressures, predators and capacity of each population species (Sen *et al.*, 2018).

Some previous investigations into the reproductive biology of *C. sorrah* have been conducted. Report from Joung *et al.* (2022) described that the maximum size of *C. sorrah* were greater than 160 cm, size at maturity were 106 cm and 110-118 cm for males and females, respectively. Kirke *et al.* (2024) reported that mating season lasts from February to March and the age at maturity was 2-3 years. In spite of the aforementioned works, biological information particularly on length at first maturity and length distribution pattern of *C. sorrah* in the westernmost Indonesia is still lacking and poorly understood.

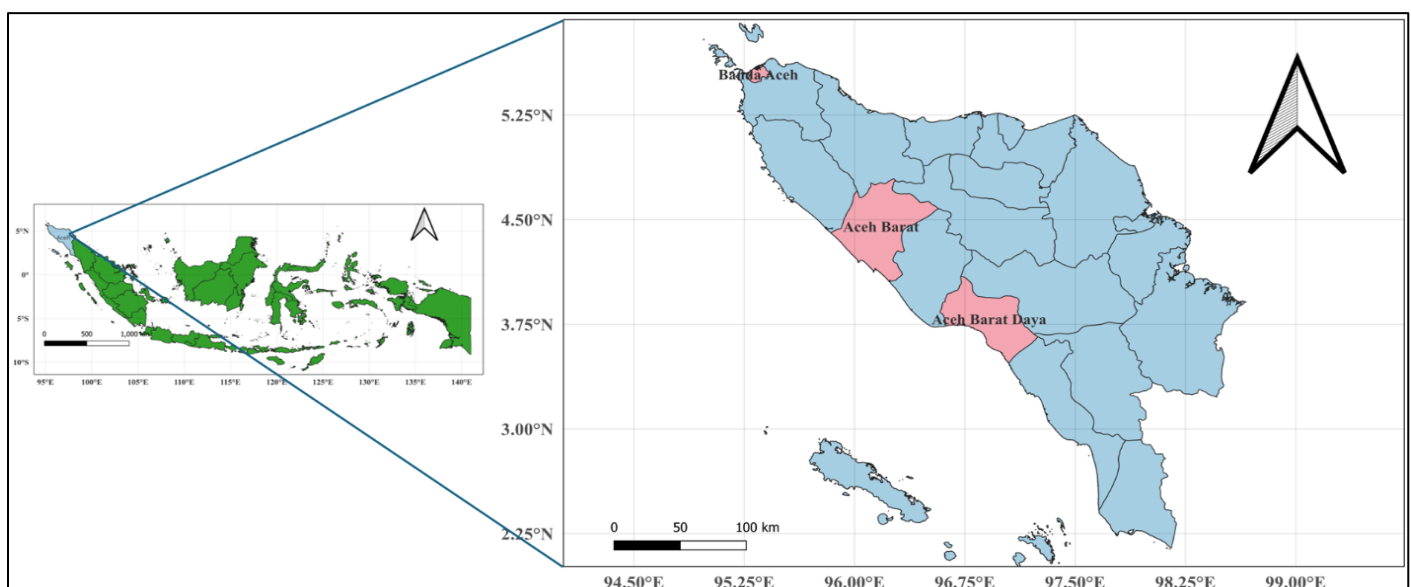
Understanding the life history and biology reproduction of *C. sorrah* is fundamental to their conservation and successful management of fisheries in its region, in which could be used as qualitative and

quantitative assessment of the population size (Taylor *et al.*, 2016; Raicisi *et al.*, 2017). Information on reproductive biology of shark species also subject to commercial harvest for stock assessment management (Kirke *et al.*, 2024). Studies on the maturity of sharks are important in their management, since the attainment of sexual maturity has a vital impact on their distribution, life behavior and ecology of sharks (Varghese *et al.*, 2016). For this matter, if the correlation amongst length and sexual maturity are well documented, length at first maturity and length distribution can be used in reproductive cycle of fish. (Simpfendorfer and Dulvy, 2018). Therefore, fundamental data on the life history characteristics of sharks needs to be addressed in order to conduct the appropriate shark fisheries management. Hence, this present investigation aims to assess the length distribution, sex ratio and length at first maturity of *C. sorrah* collected from fish landing site in some important fish landing ports in Aceh province.

## Materials and Methods

### Data collection

Data collection was carried out Between March 2020 until October 2022 at three sites of fishing ports *viz.*, Banda Aceh (BA), Aceh Barat (AB) and Aceh Barat Daya (ABD) in Aceh provinces (Figure 1). Moreover, measurement of the total length, sex of *C. sorrah* was conducted by enumerators who had been fully trained before the process of data collection started. In this case, only samples derived from samples from bottom long line fishing gear were collected and only recorded daily during landing time on 0600 to 1200, except on Friday.



**Figure 1.** Maps of sampling site at westernmost parts of Aceh, Indonesia

**Table 1.** Size attributes of *C. sorrah* collected from westernmost parts of Aceh, Indonesia

| Site            | N   | Min-Max        | TL±SD        | 95% CI          |
|-----------------|-----|----------------|--------------|-----------------|
| Banda Aceh      |     |                |              |                 |
| Male            | 25  | 90.15 – 143.24 | 113.8±13.1   | 108.39 - 119.21 |
| Female          | 47  | 73.12 – 165.74 | 107±25.53    | 99.5 - 114.5    |
| Aceh Barat      |     |                |              |                 |
| Male            | 70  | 75.45 – 234.36 | 122.87±37.87 | 113.84 - 131.9  |
| Female          | 86  | 73.56 – 235.42 | 118.47±36.65 | 110.61 - 126.32 |
| Aceh Barat Daya |     |                |              |                 |
| Male            | 177 | 74.45 – 155.14 | 107.86±18.38 | 105.13 - 110.59 |
| Female          | 320 | 74.4 – 155.24  | 110.16±14.01 | 108.62 - 111.7  |
| Overall         | 725 | 73.12 – 235.42 | 111.73±23.11 | 110.05 - 113.42 |

Note: N=number, Min=minimum, Max=maximum, TL=total length, SD=standard deviation, CI=confident interval

### Sex ratio

Sex ratio of *C. sorrah* collected from those three sites was calculated by the formula of total number of male sharks divided by female sharks. The chi-square ( $\chi^2$ ) was later on used to examine the difference of fish sex ratio (Sokal and Rohlf, 1981).

### Length at first maturity ( $L_{m50}$ )

To estimate length of fish maturity ( $L_{m50}$ ), frequency distribution and proportion of both male and female *C. sorrah* were binned into the 10 cm length class, then analyzed by the following logistic function (Williams et al., 2006):

$$P_{lm} = (1 + \exp^{-\ln 19 (M - M_{50}) / (M_{95} - M_{50})})^{-1}$$

where  $P_{lm}$  is the of proportion of mature fish in each 10 cm length class  $M$ ,  $M_{50}$  and  $M_{95}$  are the length at which 50% and 95% of population are mature, respectively.

### Statistical analysis

A One-way Analysis of Variance (ANOVA) test was performed to testify the means of total length (TL) of males and females *C. sorrah* collected from those three fishing ports. Prior to analysis, all of the raw data were first log transformed (log+1) to reduce non-normality residues. All data analyses were calculated using Paleontological Statistics (PAST) software version 4.03 (Hammer et al., 2001).

## Results

### Size attributes

Based on the examined samples, the smallest and the largest sharks collected were 73 and 235 cm in TL, respectively. The primary of fish total length ranged between 107-116 cm TL, accounting for 24.78% of all samples collected from the entire period (Table 1, Figure 2). Sex of fish could be assigned into three different sites based on data collection. The average TL with standard deviation

(±SD) of males and female from BA, AB and ABD were 113.8 cm TL ± 13.1 and 107.00 cm TL ± 25.53, 122.87 cm TL ± 37.87 and 118.47 cm TL ± 36.65, and 107.86 cm TL ± 18.38 and 110.16 cm TL ± 14.01, respectively.

For length distribution, the average (±SD) of greatest length of males *C. sorrah* was found in the AB (122.87 cm TL ± 37.87), followed by BA (113.80 cm TL ± 13.10) and ABD (107.86 cm TL ± 18.38), respectively. For females *C. sorrah*, greatest length was in AB (118.47 cm TL ± 36.65), followed by ABD (110.16 cm TL ± 14.01) and BA (107.00 cm TL ± 25.53), respectively (Table 1). From One-way ANOVA test results, there were either significant differences observed on the average length for males ( $F = 9.40$ ,  $p < 0.001$ ) and females ( $F = 6.19$ ,  $p = 0.002$ ) of fish between sites. Furthermore, Tukey's post-hoc indicated that length of males *C. sorrah* collected from AB had significant different from ABD ( $p < 0.001$ ) and significant difference also detected from BA with AB ( $p = 0.009$ ) and AB with ABD ( $p = 0.004$ ), respectively.

### Sex Ratio

The overall sex ratio between female and male fish was 1:1.67 ( $\chi^2 = 45.19$ ,  $p < 0.001$ ). Moreover, sex ratio according to localities show significant different in BA and ABD ( $\chi^2 = 6.72$ ,  $p = 0.01$  and  $\chi^2 = 41.14$ ,  $p < 0.001$ ), except for AB ( $\chi^2 = 1.64$ ,  $p = 0.20$ ) (Table 2). It is clearly exhibiting a significant number of male predominance in all sites.

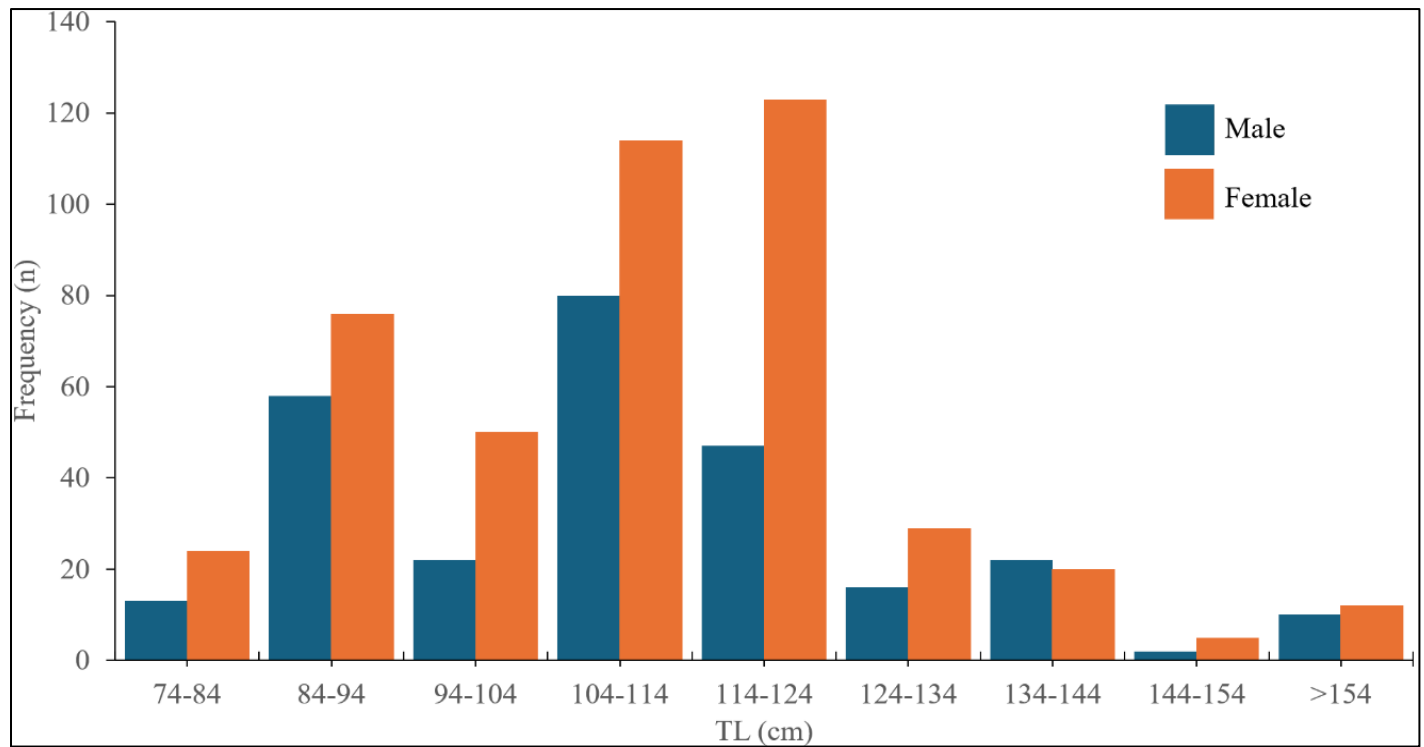
### Length at first maturity ( $L_{m50}$ )

Result from logistic regression on the proportion of mature males and females suggested variation of  $L_{m50}$  from three different regions. The  $L_{m50}$  of males collected from ABD, AB and BA were estimated at 110.65 cm TL, 117.03 cm TL and 152.65 cm TL, respectively (Figure 3a).

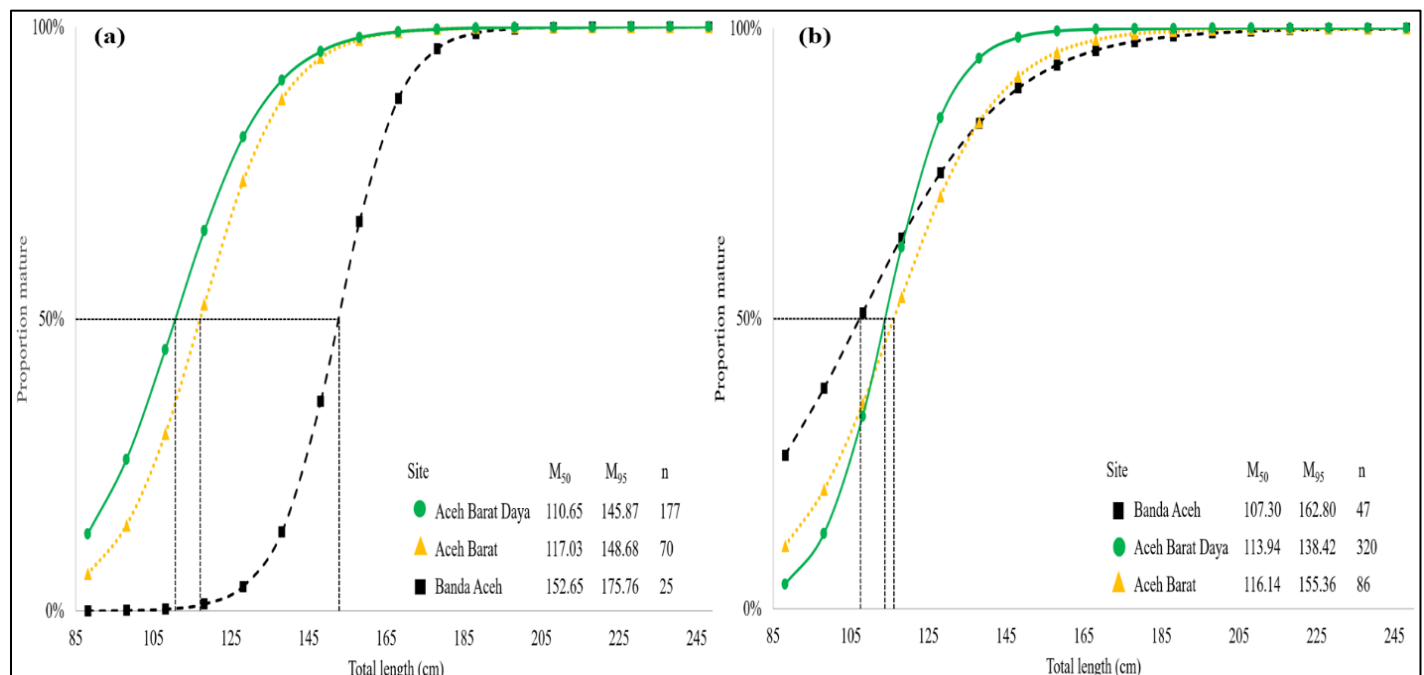
**Table 2.** Sex ratio of *C. sorrah* collected from westernmost parts of Aceh, Indonesia

| Site            | M   | F   | Sex ratio (M:F) | $\chi^2$ | <i>p</i> value |
|-----------------|-----|-----|-----------------|----------|----------------|
| Banda Aceh      | 25  | 47  | 1:1.88          | 6.72     | <b>0.010*</b>  |
| Aceh Barat      | 70  | 86  | 1:1.23          | 1.64     | 0.200          |
| Aceh Barat Daya | 177 | 320 | 1:1.81          | 41.14    | <b>0.0001*</b> |
| Overall         | 272 | 453 | 1:1.67          | 45.19    | <b>0.0001*</b> |

Note: M=Male, F=Female,  $\chi^2$ = chi-square. \*Bold value indicated highly significant difference ( $p < 0.05$ )



**Figure 2.** Length frequency of *C. sorrah* collected from westernmost parts of Aceh, Indonesia



**Figure 3.** Percentage of mature male (a) and female (b) of size at first maturity ( $L_{m50}$ ) of *C. sorrah* collected from westernmost parts of Aceh, Indonesia

The  $L_{m50}$  of females from BA, ABD and AB were 107.30 cm TL, 113.94 cm TL and 116.14 cm TL, respectively (Figure 3b). By comparison among all study sites, it was stated by the result from logistic regression that the  $L_{m50}$  of males from ABD and females from BA matured earlier than other sites.

## Discussion

The length distribution of *C. sorrah* reveals significant differences between females and males, which can have important implications for their management and conservation. (Hasan et al., 2017; Braccini et al., 2020). Studies have shown that female spot-tail sharks generally grow larger than males. According to research conducted in various regions, females typically reach lengths of up to 2 meters, while males are often smaller, averaging around 1.5 meters (Purushottama et al., 2017; Pacoureaux et al., 2021). This size dimorphism is a common characteristic in many shark species and is often linked to reproductive strategies. (Varghese et al., 2016; Pincinato et al., 2022).

Females of *C. sorrah* tend to exhibit a wider length range, with many individuals recorded at lengths exceeding 1.8 meters. A study in the Gulf of Carpentaria noted that the length frequency for females was significantly skewed towards larger sizes, with a notable proportion of individuals exceeding 1.7 meters (Simpfendorfer and Dulvy, 2018). This larger size is thought to be advantageous for reproduction, as larger females can carry more pups, enhancing reproductive success (Sen et al., 2018; Joung et al., 2022).

In contrast, male of *C. sorrah* exhibit a narrower length range, with most individuals measuring between 1.2 and 1.5 meters. Research from the Andaman Sea found that the majority of males were concentrated in the smaller size classes, with very few exceeding 1.6 meters (Baje et al., 2018). This difference in size distribution may be attributed to factors such as faster growth rates and earlier maturity in males, which often results in a shorter lifespan compared to females (Baje et al., 2018; Nurdin et al., 2023; Kirke et al., 2024).

Males typically grow faster during early life stages, but females surpass them in size as they mature (D'Alberto et al., 2017; Shaaban et al., 2018; Nurdin et al., 2023). Larger females are likely to have better reproductive success due to increased fecundity, while males may focus on reaching maturity earlier to maximize mating opportunities (Chapman et al., 2015; Varghese et al., 2016; Joung et al., 2022). Factors such as prey availability and habitat type can also

impact growth and size distribution, affecting how quickly individuals reach maturity and their maximum size potential (Rahayu et al., 2020; Kirke et al., 2024).

Sex ratio is a key aspect of its population dynamics and reproductive biology of fish organisms (Oliver et al., 2015; Braccini et al., 2020). Understanding this ratio is essential for effective fisheries management and conservation strategies (Taylor et al., 2016; Hasan et al., 2017). Research on the sex ratio of *C. sorrah* indicates a generally balanced distribution between males and females

Numerous studies report that the overall sex ratio tends to be approximately 1:1, though fluctuations can occur depending on environmental factors, fishing pressures, and local populations (Kindong et al., 2022). For instance, a study conducted in the northern Arabian Gulf found a sex ratio of *C. sorrah* was about 1.2 males to 1 female, suggesting a slight male-biased ratio in certain regions (Pacoureaux et al., 2021). Conversely, research from the coastal waters of the Andaman Sea reported a near-equilibrium ratio, with 1:1.1 male to female of *C. sorrah* (Pincinato et al., 2022). Such variations highlight the need for localized studies to understand the factors influencing these ratios (Purushottama et al., 2017).

Several factors can influence the sex ratio in *C. sorrah*. Water temperature, salinity, and habitat types can impact growth rates and survival of sexes differently (Rahayu et al., 2020). For instance, warmer temperatures have been associated with higher male mortality in some shark species (Liu et al., 2021). Overfishing can disproportionately affect one sex, particularly if size-selective fishing practices are employed. (Spaet and Berumen, 2015) If larger females, which are often targeted for their reproductive value, are removed from the population, this can skew the sex ratio towards males (Chapman et al., 2015). The reproductive cycle and migratory patterns of *C. sorrah* can also influence the observed sex ratios during specific seasons (Corrigan et al., 2017). For example, breeding migrations may cause temporary imbalances in local populations (Almojil et al., 2018).

The spot-tail shark, *C. sorrah* is a species of requiem shark commonly found in tropical and subtropical waters. Understanding its size and maturity is crucial for effective management and conservation efforts (D'Alberto et al., 2016). *C. sorrah* is recognized for its moderate size, typically reaching lengths of up to 2 meters (approximately 6.6 feet). According to Bradley et al., (2017), adults generally

range from 1.5 to 2 meters, with some individuals reported to exceed this length under optimal conditions. The maximum reported weight of the species can reach around 90 kg (Kirke et al., 2024). Their streamlined body shape and distinctive spot patterns make them easily identifiable in their natural habitat. (Oliver et al., 2015; , Nurdin et al., 2023).

Maturity in *C. sorrah* is influenced by various environmental factors, including food availability and water temperature. (Raeisi et al., 2017, Kirke et al., 2024). Research indicates that females reach sexual maturity at approximately 1.5 meters in length, while males mature at slightly smaller sizes, around 1.2 meters (Varghese et al., 2016; Shaaban et al., 2018; Sen et al., 2018). Maturity is further determined by age, with estimates suggesting that males reach maturity at around 3-4 years, whereas females may take longer, reaching maturity between 4-6 years of age (Simpfendorfer and Dulvy, 2018; Joung et al., 2022).

The reproductive strategy *C. sorrah* is ovoviviparous, meaning that the young develop inside the mother's body and are born alive (Pacoureau et al., 2021; Kindong et al., 2022). Litter sizes can vary significantly, with reports of up to 10 pups per pregnancy (Purushottama et al., 2017 ; Rahayu et al., 2020). The timing of reproduction typically coincides with warmer months, allowing for better survival rates of the young. (Liu et al., 2021).

Understanding the maturity stages of both male and female *C. sorrah* is essential for fisheries management and conservation efforts, particularly in regions where they are exploited (Chapman et al., 2015; Spaet and Berumen, 2015). Ongoing research into their life history traits will aid in developing sustainable practices to ensure the longevity of this species in marine ecosystems (Corrigan et al., 2017; D'Alberto et al., 2016).

## Conclusion

The present study illustrates reproductive attributes of *C. sorrah* in the westernmost waters of Aceh, Indonesia. Female fish predominated the annual stock with the overall sex ratio of male and female was 1:1.67. It was clearly proved by the result from logistic regression that the  $L_{m50}$  of males from ABD and females from BA matured earlier than other sites. This study thus serves crucial scientific information on the reproductive attributes of *C. sorrah* which is vital for the management of fish stock of this species.

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