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Biology and fisheries aspects of Western Longnose Spurdog, *Squalus edmundsi* from the Eastern Indian Ocean, Indonesia

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Abstract. *Fahmi, Sentosa AR. 2017. Biology and fisheries aspects of Western Longnose Spurdog,* Squalus edmundsi *from the Eastern Indian Ocean, Indonesia. Biodiversitas 18: 1714-1722.* A research has been done to determine some biological aspects of Western Longnose Spurdog (*Squalus edmundsi*) from the Eastern Indian Ocean Fishing Region in Indonesia (WPP 573). A total of 1797 samples were recorded from bottom longline fisheries at Tanjung Luar, Lombok from July 2015 to November 2016 by a trained enumerator. The study revealed that Selat Alas and the south west of Sumbawa waters are the most fished areas in the region for this species, with the peak fishing season may occur from January to March. The average catch rate of *S. edmundsi* was about 8 individuals per boat. The size of sharks varied from 470 mm to 1150 m total length (TL), with average size was 723.6±111.5 mm. Size distributions and sex ratio between females and males were significantly different, indicating a sexual dimorphism. This study revealed a fact that there was no seasonal pattern in the reproductive cycle of *S. edmundsi* in this region, which means the parturition may occur throughout the year. Analysis on its population status showed that this species was very susceptible to overfishing. This condition should be responded by the government through management actions for its fishery.

Keywords: *Squalus edmundsi*, Squalidae, biology, Indian Ocean

INTRODUCTION

Eastern Indian Ocean Fishing region (WPP573) is one of the most important fishing regions in Indonesia. It covers about a half of Indonesian's Indian Ocean area from south of Java to south of East Nusa Tenggara waters. This area is also considered as one of the most exploited waters in Indonesia, due to many fishing methods are involved, from traditional to industrial fisheries (Blaber et al. 2009; Fahmi and Dharmadi 2013a).

This area is also the most favorite spot for shark fishery, with the average shark catch more than 10,000 tons annually until 2007, but then there was a rapid decline in the following years to around 4,000 tons (Fahmi and Dharmadi 2013a). Deepwater shark fishery plays an important role at several fish landings in the region due to the high demand of shark liver oil in both domestic and international markets in which deepwater sharks such as squalids and centrophorids are target species (Fahmi and Dharmadi 2013a). There are several fishing methods to catch deepwater sharks, but the most common one is bottom longlining, which operates in the depth from 50 to more than 400 m (Dharmadi and Fahmi 2007; Fahmi and Dharmadi 2013a).

Dogfish shark or spurdog shark (Family Squalidae) is one of the most commonly caught in deepwater shark fishery in Indonesia (Fahmi and Dharmadi 2013a). At least five species of squalids are known to occur in this area, i.e. *Squalus edmundsi* White, Last and Stevens 2007, *S. hemipinnis* White, Last and Yearsley 2007, *S. montalbani* Whitley 1931, *S. nasutus* Last, Marshall and White, 2007, and *Cirrhigaleus barbifer* Tanaka, 1912 (White et al. 2006; Last et al. 2007; White et al. 2007). The Western Longnose Spurdog, *Squalus edmundsi,* is known as one of the most common squaloids in the deepwater shark longline fisheries operating in the eastern Indian Ocean fishing region, together with the Indonesian short snout spurdog, *Squalus hemipinnis* (Dharmadi and Fahmi 2007; White and Dharmadi 2010). This species is a member of the "*Mitsukurii*" group of the Family Squalidae, which is characterized by relatively large size, having a dark caudal bar through the base of lower caudal fin lobe, low dorsal fin spines, and first dorsal fin spine is shorter than the second (Last et al. 2007; White et al. 2007; Last and Stevens 2009). *Squalus edmundsi* was previously known as *Squalus* sp. C in previous kinds of literature (Last and Stevens 1994; White et al. 2006). This species is usually caught at a depth between 200 and 850 m and well distributed in the East Indian Ocean from Indonesia to Western Australia (White et al. 2007; Last and Stevens 2009).

The conservation status of this species in the IUCN red list for threatened species is categorized as Near Threatened (White 2009). Nevertheless, biological information of *S. edmundsi* is still very few. This article aims to provide updated information on the biology of this species including its fishery.

MATERIALS AND METHODS

A daily survey had been conducted to record shark catch landings at Tanjung Luar, East Lombok District, West Nusa Tenggara Province, Indonesia from July 2015 to November 2016 (Figure 1). Information on the total catch, species name, sex, and length of the shark's species was gathered through direct observation at landing site by a trained enumerator, while a number of boats operated, boat name and number of days' trip were recorded through interviews and using landing port data. Shark species were identified following identification guides by White et al. (2006) and Fahmi and Dharmadi (2013b). The total length for each shark was measured to the closest cm. Females and males were differentiated by the presence of claspers organ on males.

Length frequency of both sexes was compared and tested using two-samples Kolmogorov-Smirnov test (Motta et al. 2005) to see whether any differences in their size distributions. Sex ratio between females and males was also analyzed using Chi-Square test to determine the significant difference from the expected ratio 1: 1 (Gay 1996).

Length-weight relationship was calculated using the standard power equation $W=aL^b$ and ln transformation was applied to plot the linear regressions. Analysis of Covariance (ANCOVA) was used to test the difference of length-weight relationships between female and male. The maturity stages of females were not analyzed as specimens were not dissected. Maturity stages of males were classified based on the condition of the claspers. The non-calcified and not fully-calcified claspers were categorized as immature, while the full-calcified claspers were categorized as mature (White and Dharmadi 2010). Length at first maturity of male *S. edmundsi* was estimated using Spearman-Karber method (Udupa 1986).

The catch rate (R) of *S. edmundsi* from the bottom longline fishery operating from Tanjung Luar, Lombok was calculated using formula following Hoenig et al. (1997):

$$R = \frac{\sum_{j=1}^{n} Cj}{\sum_{j=1}^{n} Lj}$$

Where, Cj = number of catch per boat; Lj= number of the day at operation per boat; and n = number of boats.

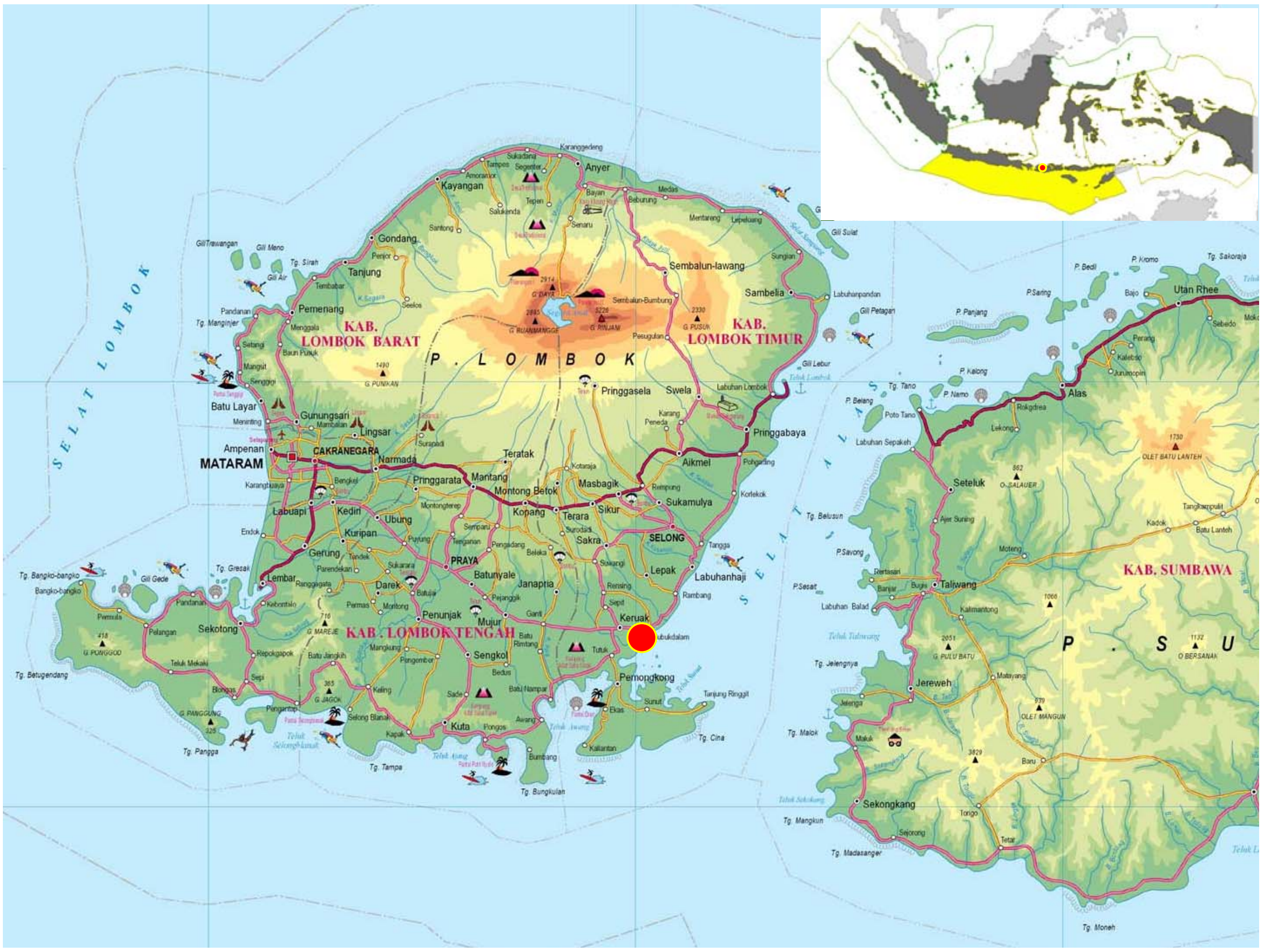

Figure 1. Study site at Tanjung Luar (●), Lombok Island, in Eastern Indian Ocean Fishing region (WPP573; yellow highlighted)

In order to determine the population structure of this species in Eastern Indian Ocean fishing region, the length-based frequency data was used to estimate the growth curve that "best" fits a set of length-frequency data in the growth parameters. The growth parameters were estimated using Von Bertalanffy model and natural mortality was estimated using Pauly's empirical equation from the regression line which extrapolated from the length-converted catch curve. Relative yield per recruit (Y′/R) was estimated using Beverton and Holt model that was modified by Pauly and Soriano (1986) and plotted with the exploitation level to estimate the maximum exploitation level (E_{max}). All analyses were performed using FISAT II software package (Gayanilo et al. 2005).

RESULTS AND DISCUSSION

Size distribution

A total of 1797 individuals of Western Longnose Spurdog, *Squalus edmundsi* were recorded from the deepwater longline fishery during the study period, with 997 of them were measured and weighed. The sharks were caught at size between 470 and 1150 mm Total length (TL) with average size at 723.6±111.5 mm TL and mode length was at 680 mm TL. According to their sex, length frequency for females was 470-1150 mm (n=802) and 490-990 mm for males (n=192). The mean and modal length of females were 746.67±107.81 and 700 mm, while males were 626.87±67.80 and 570 mm TL, respectively. The size class 670-719 mm was a predominance of females, while males were predominant at size class 620-669 mm (Figure 2 and 3). The maximum size of *Squalus edmundsi* in this study was higher than those stated in White et al. (2007) and Last and Stevens (2009).

The t-test showed a significant difference in the average of total length between females and males (t-test, $p<0.01$). While the Kolmogorov-Smirnov test (KS) for significant differences in the size distributions indicated that females and males were taken from populations with different distribution ($p< 0.05$). This result clearly showed that males are generally smaller in size comparing to females. The monthly averages of the total length of *S. edmundsi* also show that the size of females was always greater than males. The average total length of females varied from 694-834 mm TL, while males were from 583-702 mm TL. (Figure 4).

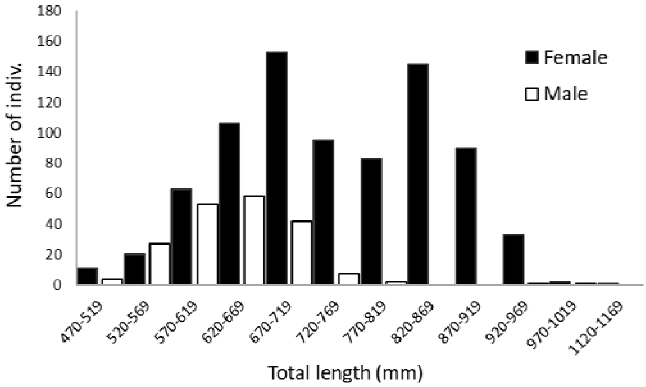

Figure 2. Length frequency of females and males of *Squalus edmundsi* from Tanjung Luar landing site from July 2015 to November 2016

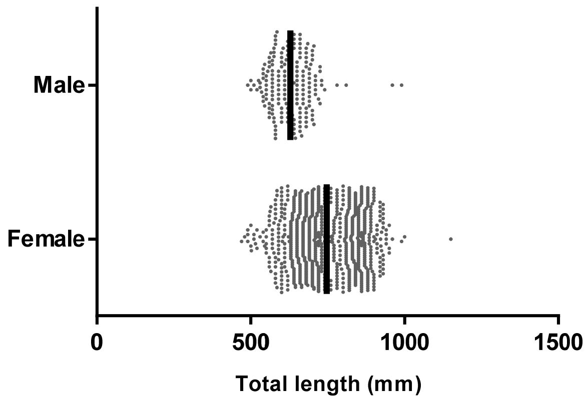

Figure 3. Scatter plot graph shows the size distribution of females and males of *Squalus edmundsi* from Tanjung Luar landing site. Black lines indicate the mean size

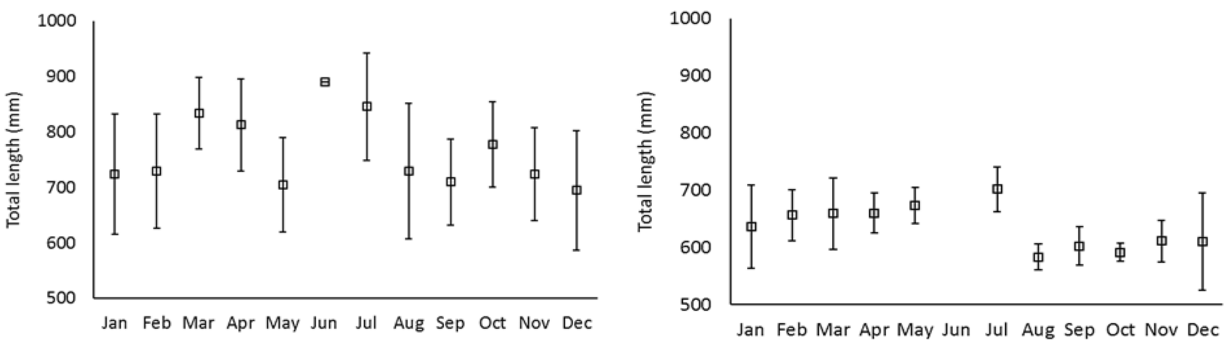

Figure 4. Monthly mean total length of females (left) and males (right) *Squalus edmundsi* from Tanjung Luar landing site. Error bars show standard of deviations

The greater size of females compared to males showed a clearly sexual dimorphism. The fact that females are generally larger than males also occurred on other *Squalus* species such as *S. acanthias* Linnaeus 1758 and *S. megalops* (Macleay 1881) (e.g. Hanchet 1988; Watson and Smale 1998), and also for most sharks (Compagno 1984; White et al. 2006).

Sex ratio

The total number of females *S. edmundsi* captured during the study period was much higher than males, reaching up to four times. A total of 802 females were recorded during the study comparing to 195 males. Overall sex ratio between males and females of *S. edmundsi* in this fishing region was 1: 4.11. This ratio indicated that there was a significant difference from the ratio 1: 1 (χ^2 = 369.56; P<0.05). In general, the monthly sex ratio between males and females were also significantly different throughout the year (Figure 5), except for those in July 2015 when the sex ratios were equal (χ^2 = 0 and 1; P>0.05).

The imbalance proportion between females and males throughout the year indicates that there are segregation patterns in the population of *S. edmundsi* in the Eastern Indian Ocean fishing region. This study revealed the segregation is not only by sex but also by body size or age (between young and adults, see Figure 8). Many authors noted that segregation patterns in elasmobranchs occur not only between females and males but also between size class and reproductive stages (Nammack et al. 1985; Rago et al. 1996; Ellis and Shackley 1997). The disparity in the sex ratio, which more females than males, commonly happen on several deepwater shark species, such as *Squalus megalops* (Macleay 1881), *S. acanthias* Linnaeus 1758, *Deania calcea* (Lowe 1839), *Etmopterus granulosus* (Günther 1880), *E. spinax* (Linnaeus 1758), *Mustelus antarcticus* Günther 1870, and other squalids (see Vince 1991; Lenanton et al. 1990: Wetherbee 1996; Graham 2005; Hazin et al. 2006; Gennari and Scacco 2007; Moura et al. 2014; Irvine et al. 2012).

The imbalanced sex ratio may give implication to the decrease of reproduction outputs. However, there is no evidence of this situation can lead to lower recruitment due to lack of information on the reproductive behavior of this species. The differences in the sex ratio are thought to be related to breeding behavior and are likely to result in unisexual aggregations in certain areas at different times of the year (Compagno 1984; Ellis and Shackley 1997). Several factors related to the sexual and size segregation patterns of a deepwater shark have been identified for particular species, and reproductive strategy could be the main reason (Main et al. 1996; Sims et al. 2005; Cabello et al., 2007). Main et al. (1996) suggested that females occupied an area where the food source is available. While Sims et al. (2005) suggested that males tend to swim more actively to seek females, while females may just stay in a hiding place such as sea canyons. These segregation patterns, therefore, should be put into consideration of the management plan of this species. Hanchet (1988) found that females *Squalus acanthias* in New Zealand waters move to shallower waters at about 50 m depth during their gestation period and swim back to deeper water (200-300m) where parturition, mating, and ovulation take place. This migrating behavior of females *S. acanthias* into shallower waters has also been identified in other areas such in British waters and the southern Black Sea (Compagno 1984; Avsar 2001). On the other hand, Graham (2005) found that the mature females of *S. megalops* tend to aggregate at the deeper water than the mature males.

The bias in sampling method was also suggested by several authors, especially for the sample collected by commercial fishers (Lenanton et al. 1990; Ellis and Shackley 1997; Watson and Smale 1998). Sharks may be taken only from particular areas where may not represent the entire range of the species distribution. The abundance of females in the catch in particular period of time may also indicate the seasonal variation in the reproduction cycle of several species such as the lesser spotted dogfish *Scyliorhinus canicula* (Linnaeus 1758) and the gummy shark *Mustelus antarcticus* (see Lenanton et al. 1990; Ellis and Shackley 1997).

Length-weight relationship

A total of 971 individuals of *S. edmundsi* were used to generate the length-weight relationship curve for combining sexes. The weight of this species ranged from 400 and 4800 g for females and from 400 to 2200 g for males. The relationships between total length (TL) and total weight (W) were expressed by the formulas: W=0.00000017 $TL^{3.81}$ (r^2=0.85; n=971) for combining sexes; W=0.00000018 $TL^{3.85}$ (r^2=0.83; n=781) for females; and W=0.000000018 $TL^{3.95}$ (r^2=0.76; n=190). The ANCOVA test failed to detect significant differences in the slopes between regressions of the ln transformed TL and W for both females and males (F=3.6; p>0.05) (Figure 6). These relationships may indicate that the sampled sharks in this study were from one age group or in the same condition factor.

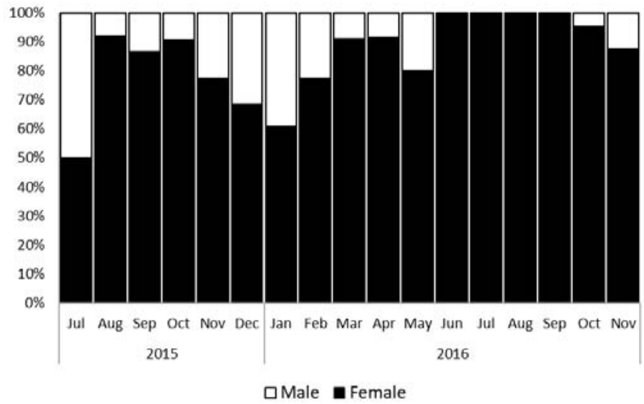

Figure 5. The sex ratio between males and females of *Squalus edmundsi* from the Eastern Indian Ocean fishing region at several occasions from July 2015 to November 2016.

The length-weight relationship analysis is essential to determine the fish condition in its environment (Safran 1992). The variations in length-weight relationship may indicate different sample size, unequal size distribution between males and females or age groups, and also ontogenetic differences (Stevens and Wiley 1986). The presence of high proportion of sampled pregnant females in the data set may lead to the variation in length-weight relationship between the sexes, as the weight of pregnant females is considerably heavier than non-pregnant ones (Motta et al. 2005).

Length at maturity

A total of 196 males were examined to determine the maturity level of males *S. edmundsi*. During the study period, about 75% of sampled males were categorized as mature, with the rests were immature. The smallest size of mature male recorded in this study was at 520 mm TL and the largest immature male was identified at 640 mm TL (Figure 7). The size at first maturity (L_{50}) of male *S. edmundsi* estimated using Spearman-Karber method was at 597.6 mm TL, with 95% confidence limits of class between 556.8 and 641.4 mm TL, respectively.

The size at first maturity of males in this study is similar to White et al. (2006) but higher than those are stated in Last and Stevens (2009) and White and Dharmadi (2010). While the smallest size of mature male recorded in this study was slightly shorter than stated in White et al. (2007). The size distribution and monthly mean total length of *S. edmundsi* showed that this species was mainly caught in the mature stage. The averages of the total length of both sexes were greater than the estimation size at first maturity. It means the sharks were caught from a population which consists of more than 50% mature animals.

The monthly catch proportion between immature and mature male sharks also showed an unfairness (Figure 8). Mature males dominated the catch for most of the year except from August to October. However, due to the low number of sample collected during the study, it is difficult to state that the seasonal reproduction cycle occurs on the male *S. edmundsi*. The occurrence of mature individuals in significant proportion in each month data indicated that there is no seasonal reproduction cycle for this species. Nevertheless, there is no information on the maturity stages of females that may lead to uncertainty whether the fishing areas of *S. edmundsi* are utilized as mating or breeding zones. The occurrence of mature individuals in relatively large numbers throughout the year indicated a non-seasonality of the reproductive cycle, which means that parturition occur throughout the year. A similar pattern is also shown by its sister species, the shortnose spiny dogfish (*Squalus mahia,* previously identified as *S. megalops*) from the Agulhas Bank, South Africa, that (Watson and Smale 1998; Viana et al. 2017).

Watson and Smale (1998) suggested that the absent of juveniles and young sharks in the sampling result was affected by the gear selectivity, such as using the trawl net with large mesh size. However, Graham (2005) and Rochowsky et al. (2015) found evidences that the gear selectivity was not one of key factors of the exclusion juveniles and young sharks from the catch.

Catch and efforts

According to interviews and landing port data, the fishing area of the deepwater longline fishery operating from Tanjung Luar is from the south of Lombok to the Sawu Sea with the number of days of operation varied from one to 20 days. Based on the catch data, *S. edmundsi* were caught at a larger number from Alas Strait and the south west of Sumbawa waters rather than any other fishing areas.

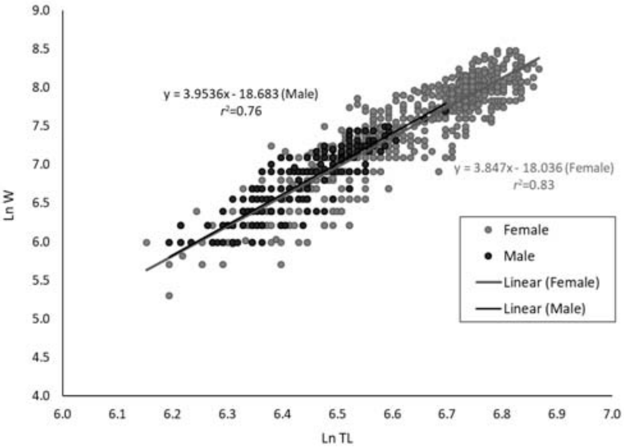

Figure 6. Length-weight relationships between ln transformed TL and ln W of females and males *Squalus edmundsi* in the eastern Indian Ocean fishing region

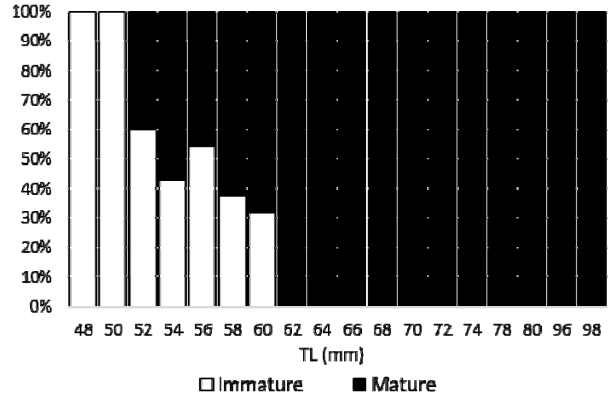

Figure 7. The proportion of immature and mature males of *Squalus edmundsi* based on their length class

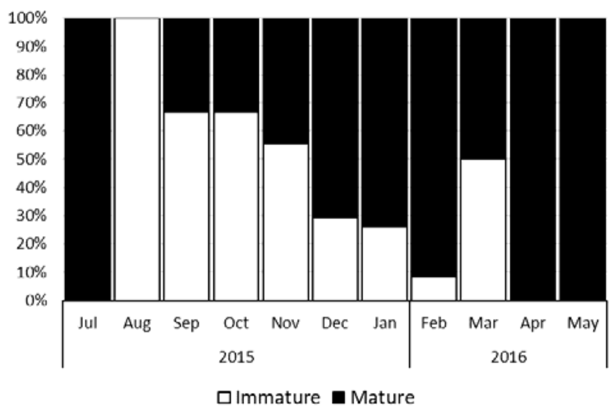

Figure 8. The proportion of immature and mature males of *Squalus edmundsi* at several occasions from July 2015 to May 2016

The numbers of the catch of *S. edmundsi* were fluctuated through time, with the peak season was identified from January to March (Figure 9). During the peak season, the catch reached up to more than 300 individuals per month. In contrast, the lowest catch occurred in June 2016 by only a single individual recorded during this time.

The estimation of daily catch rate of *S. edmundsi* by all fishers operating from Tanjung Luar was 2.66 individuals per boat. According to the number of days at sea, the short time fishing periods (1-2 days) had relatively higher catch rate rather than the longer periods of fishing (Figure 10). As the main fishing gear to target the deepwater sharks, bottom longline plays important role in the number of catch of *S. edmundsi.* The total catch per unit efforts (CPUEs) for catching the species using this single type of fishing gear during the period was 8.46±4.91 ind/boat and 2.95±2.89 ind/day of operation. The monthly CPUE of bottom longliners fluctuated throughout the year. Similar to the total catch, the period between January to March seemed to be the peak season for dogfish fishing, with the CPUE reached a peak in January (Figure 11).

The deepwater shark fishing session seemed different from the pelagic sharks fishing session in the same area. The pelagic shark fishing session mainly occurs from June to October each year, when sharks are usually caught in large numbers comparing to other months. This fishing period is convinced related to the east monsoon season when strong upwelling occurs along the coastline of the Eastern Indian Ocean bringing the high level of primary productivity and the abundance of fishes in the area (Fahmi and Dharmadi 2015). The relatively low productivity of the deepwater fishery in this period may be affected by most fishers from Tanjung Luar focused and attracted more to catch pelagic sharks. It is also shown by the fairly lower number of bottom longline boats operated during the period, leading to the lower CPUEs. On the other hand, a period between January and March seems to be the peak season for the deepwater shark fishery. There are two main reasons that make it happened. First, the west monsoon occurs from November to March, when air masses are flowing from Asia to Australia causing the rainy season in Indonesia. During this period, strong wind, high wave, and heavy rain, commonly happen in the eastern Indian Ocean and adjacent areas (Kurniawan et al. 2011). This situation leads to the difficulty for fishermen, especially who own relatively small fishing boats to go further and make a long trip for fishing. Alternatively, they tend to make a short fishing trip and catch the sharks in the nearby areas such as around Alas Strait, south Lombok, and south-west Sumbawa. As a result, the CPUEs of squalid fishing in the period from January to March was significantly higher than other months.

Population status

The growth parameters of *S. edmundsi* were calculated based on the class-length frequency data with sex combined, due to the low numbers of individuals recorded in each month. The results of the Von Bertalanffy's growth curve parameters were $L\infty$ =1176mm, k=0.16 year^{-1},t_o= -0.39 year, respectively. The asymptotic length ($L\infty$) value was fairly close to the largest observed shark, which was 1150 mm with the estimated age at 26 years, while the shark is estimated to get its first maturity at 4-5 years old (Figure 12).

Mortality rates in length-based method generated by ELEFAN I routine in FISAT, showed that instantaneous total mortality coefficient (Z) was 0.69 year^{-1}, natural mortality (M) 0.19 year^{-1}, fishing mortality (F) 0.5 year^{-1}, and current exploitation ratio was 0.73year^{-1}. Based on the plot of relative yield per recruit (Y′/R) and exploitation ratio (E), the maximum exploitation level (E_{max}) was estimated to be 0.68 year^{-1} (Figure 13).

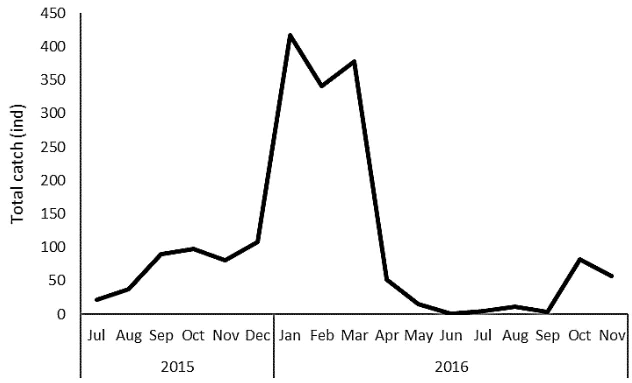

Figure 9. Total catch of the *Squalus edmundsi* at Tanjung Luar landing site from July 2015 to November 2016.

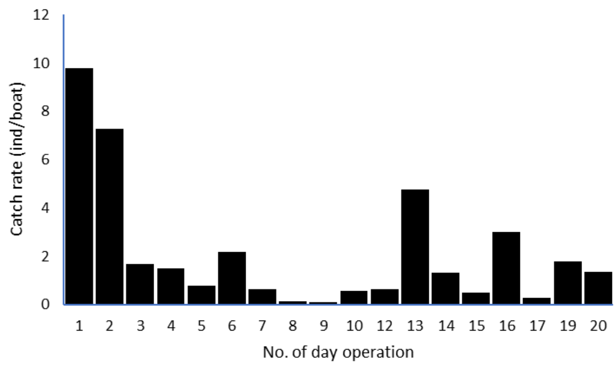

Figure 10. Catch rates of *Squalus edmundsi* based on the number of days operation

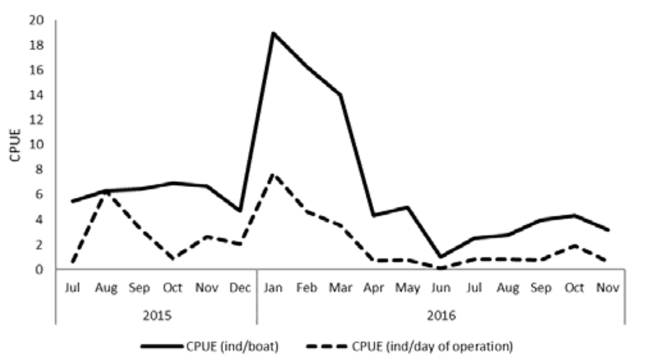

Figure 11. Catch per Unit Effort of *Squalus edmundsi* based on the number of boat and number of days at operation

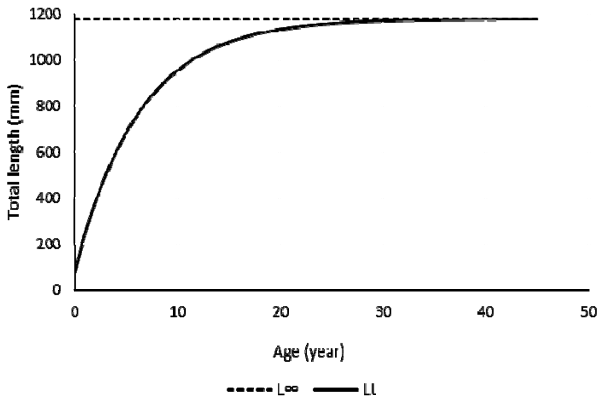

Figure 12. Von Bertalanffy growth curve from length frequency data for *Squalus edmundsi*

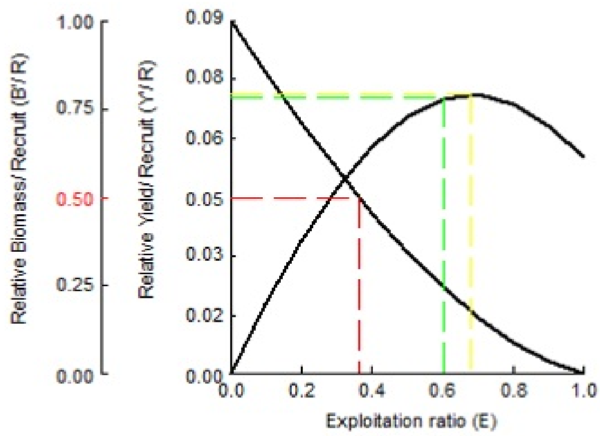

Figure 13. The relationship between relative yield per recruit (Y′/R) and relative biomass per recruit (B′/R) using selective ogive of *Squalus edmundsi*

Understanding the age and growth parameters of sharks is important to determine the population status and to predict the change of populations through time (Cailliet et al. 1986; 2006). The using of the ELEFAN I method to estimate the Von Bertalanffy growth curve based on length-frequency distribution data may underestimate the values of growth coefficient (k) and overestimate the asymptotic length (L∞) due to the difficulty to determine modes when the cohorts are overlap, linearization of the model and assumption of individual variability of growth parameters (Isaac1990; Tsangridis and Filippousis 1991; Sahinler and Can 2003). The bias of k value is still adequate if the coefficient of variation of the parameters L∞ and k not exceed 10% (Isaac 1990).

The underestimation of age parameter can lead to a serious impact on overexploitation of a population or species due to overly optimistic estimates of growth and mortality ratio. Therefore, methods for quantifying aging accuracy and age validation should be implemented (Campana 2001). The most common known method to verify age and growth parameters of sharks is using marginal increment analysis, following by centrum edge analysis and back-calculation method, while size frequency analysis is the least due to the costly and time-consuming (Campana 2001; Cailliet and Goldman, 2004).

Previous studies on estimation of age and growth parameters on squaloids were mostly using dorsal spines (Machado and Figueiredo 2000; Avsar 2001; Clarke et al. 2002a; 2002b; Irvine et al. 2006a; 2006b).The age and growth estimation of *S. edmundsi* in this study was relatively higher than its congeners from other areas. The growth coefficient (k) of *Squalus acanthias* from the Black Sea was estimated 0.17 for both sexes with estimation of maximum age at 13-14 years (Avsar 2001). This species was estimated to get its first maturity at age 12-13 years old based on specimens from Swedish waters (Stenberg 2005). Another congener species, *Squalus mahia*, from South Africa was estimated to have k values 0.033 and 0.089 for females and males, attaining its first maturity at 15 years (females) and 9 years (males) with maximum age at 27 and 18 years, respectively (Watson and Smale 1999).

The closely related species with *S. edmundsi* in "*Mitsukurii*" group, *Squalus mitsukurii*, has variously estimated k-values depending on its area. The estimated k-values for species from central North Pacific Ocean were 0.041 for females and 0.155 for males (Wilson and Seki 1994), while those from Japan were varied from 0.039 to 0.103 for females and from 0.06 to 0.252 for males (Taniuchi and Tachikawa 1999). Females of *S. mitsukurii* were estimated to have their first maturity at a later age compared to males, which were 15 years compared to 4 years in North Pacific, and 9-16 years compared to 5-7 years in Japan (Wilson and Seki 1994; Taniuchi and Tachikawa 1999).

The exploitation rate (E) of *S. edmundsi* in this study was estimated to be higher than its maximum exploitation (E_{max}), which means there is an indication of overfishing on its population in the area. Dogfish sharks and most of the deepwater sharks are living in low productivity environment, having slow growth and high longevity, which makes them highly susceptible to overexploitation and stock depletion, especially if they are targeted (Clarke et al. 2002a; Daley et al. 2002; Irvine et al. 2006a; 2006b). Norse et al. (2012) stated that deep-sea fishes can be sustainably fished at very low catch rates if maintained by respectable fisheries manager.

In conclusion, analyses on the population status of *Squalus edmundsi* showed that this species was susceptible to overfishing, as indicated by the high value of its exploitation rate. The threat on this species population is worsened by none of the fishery-related management to the deep-sea shark fishing in Indonesia. As squaloid shark liver oil has high demands and high prices in the international markets, this product has become a target in the deep-sea fishery. Currently, there is no species-specific catch data of *S. edmundsi* in Indonesian fishery statistics, as they are compiled together with all other squaloid sharks. This condition makes it difficult to assess the conservation status of the species for its fishery management. This study accordingly can be a consideration for the government to start paying attention to the *S. edmundsi* and other deep-sea sharks by implementing a sustainable deep-sea fisheries management.

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