Biology aspect and parameter population the scalloped hammerhead (Sphyrna lewini Griffith & Smith, 1834) caught from coastal fisheries in the eastern Indian Ocean

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Abstract. The scalloped hammerhead, Sphyrna lewini, have a circumglobally distribution in tropical and warm-temperate waters. Generally, in Indian ocean this species is a bycatch of the tuna longline, however, in Tanjung Luar, this species is a target species. The life history from this species is still limited. The study aimed to assess the biology aspect and growth of the scalloped hammerhead in the period February 2013 to December 2016. The result showed that 2449 individuals were caught with size between 43-395 cm TL (average 198.03 cm) for females and males ranged between 47-340 cm TL (average 161.61 cmTL). The sex ratio that was dominated by female sharks was 2.69: 1. The clasper length and total length relationship were positive with a linear regression equation of CL = 0.0902*TL-4.4402 (R2=0.6837). It showed that the length of the claspers increases proportionally with the length of the body. Application of age at length data for produced von Bertalanffy growth model parameter estimates of female L∞ = 397 cm TL, K = 0.27 year⁻¹, and for male S. lewini was L∞ = 381 cm TL, K = 0.17/ year. The total mortality rate (Z) the scalloped hammerhead was 1.15/ years, natural mortality (M) is 037/ years and the fishing mortality (F) was 0.78/ years with exploitation rate (E) = 0.68

1. Introduction
The scalloped hammerhead, Sphyrna lewini, have a circumglobally distribution in tropical and warm-temperate waters. This species is a member of family Sphyrnidae and type of shark is often caught in Indonesian waters [1], especially in the Indian Ocean region south of Java and Nusa Tenggara [2]. The hammerhead shark originally a bycatch on tuna fisheries but in artisanal fisheries in some areas are sometimes targeted for catch [3, 4, 5]. [5] reported that the catch of S. lewini from longline fishery based in Tanjung Luaras much as 18% of the total catch. The S. lewini population is thought to have experienced pressure due to fishing and trafficking intensive, especially for the fins [6][7]. Although status the exact population is not known, however, presumably there has been a decline in the population of S. lewini in all over the world, one of that is in the Indian Ocean waters ([4]). In general, sharks are very vulnerable to overfishing pressure [8, 9] because this species has the cycle long life, growth and development slow sexual maturity as well low fecundity [10, 11,12, 13]. Hence, monitoring to the status of the scalloped hammerhead population other elasmobranchii need to be done in order to be able applied a fisheries management effort sustainable.

Current data and information needs related to S. lewini quite important considering its conservation status according to the International Union's Red List for the conservation of Nature and Natural Resources (Red List IUCN) is rare (Endangered). According to Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora it has included in Appendix II [5, 14, 15], even in Indonesia itself the scalloped hammerhead shark is a species which is prohibited from
2. Materials and Method

2.1. Field work
The study was conducted in Tanjung Luar, West Nusa Tenggara, part of Eastern Indian Ocean (Figure 1). Sampling was done monthly between February 2013 to December 2016. The total length (TL) was measured from the most anterior part of the cephalopodic head to the farthest tip of the caudal fin. A total of 2449 specimens of the scalloped hammerhead *Sphyrna lewini* were measured during the study period. Sex determination of *Sphyrna lewini* was based on the presence of the clasper in the male.

![Figure 1. Map of sampling site](image)

2.2. Data Analysis
To determine the sex ratio of *Sphyrna lewini* found in this study, we used the formula according to [18]:

\[ NK = \frac{NJ_B}{N} \times 100\% \]

where \( NK \) = sex ratio; \( NJ_B \) = number of female or male of *S. lewini* and \( N \) = total number of *Sphyrna lewini* observed.

Sex ratio between females and males was also analyzed using Chi-Square test to determine the significant difference from the expected ratio 1:1 [19].
The growth of the scalloped hammerhead is estimated according to the von Bertalanffy Growth Function (VBGF) based on the value of growth parameters including length asymptotic ($L_\infty$, unit cm), growth (k, unit year $^{-1}$), and theoretical age, which is the age when the fish reach size 0 ($t_0$, unit year).

Estimation of the $L_\infty$ and k parameters was performed by means of the Electronic Length Frequency Analysis (ELEFAN) analysis with the TropfishR package [20] on the R-Statistics Program software version 3.6.3 [21]. Fish growth can be modelled with the VBGF non-linear regression curve so that the length of the fish at a certain age (longevity or $L_t$ (cm)) can be estimated the equations reported by [22] is described as:

$$L_t = L_\infty (1-e^{-k(t-t_0)})$$

The parameters for the growth functions are as follows: $L_t$ is the length at age $t$ (in years); $L_\infty$ is the species maximum (in mm); $t_0$ is the mean theoretical age when length is equal to zero (years); and $k$ is the growth coefficient.

The theoretical age at birth ($t_0$) was calculated using the empirical formula [22]

$$\log (-t_0) = -0.392 - 0.275 \log L_\infty - 1.038 \log K$$

The total mortality coefficient ($Z$) was estimated by linearizing length-converted catch curve analysis $Z$ was calculated by:

$$Z = M + F$$

Natural mortality of the stock was estimated using [24]:

$$\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$$

Where, $M =$ natural mortality and $T$ ($^\circ$C) = annual mean water temperature. The fishing mortality ($F$), describing the rate of mortality due to fishing activities, was estimated from the relationship.

Exploitation rate ($E$) was measured by the formula:

$$E = F/Z$$

3.** Result and Discussion**

3.1. Length Frequency Distribution

Total 2449 individuals of *S. lewini* was found in this study during 2013-2016 (Figure 2). This figure showed the abundance of *S. lewini* was dominated by female during study with length distribution ranged from 43-395 cm TL (average 198.03 cm) for females and males ranged between 47-340 cm TL (average 161.61 cmTL).
Figure 2. Length distribution of *Sphyra lewini* caught from eastern Indian ocean

3.2. Estimation of Growth Parameter (*L*<sub>∞</sub>, *K*, *t*<sub>0</sub>)
Estimated growth parameters of the scalloped hammerhead performed in conditions by gender segregation. Growth forms a nonlinear regression curve with the equation *L*<sub>t</sub>=381 (1-e-0.17(t+0.4688)) for
male and \(L_t = 397 \left(1 - e^{-0.27(t+0.3039)} \right)\) for female (Figure 3 and Figure 4). Von Bertalanffy Growth Curve can reconstruct on a monthly length frequency distribution monthly length frequency distribution showed a shift in the fish size mode from month to month that indicates population growth.

The growth parameter of the scallop hammerhead in this study was similar with several landing place such as South Nusa Tenggara, Java Sea and Borneo (Table 1).
Table 1. Growth parameters of the scalloped hammerhead at several landing place

| No | Sex  | $L_{\infty}$(cm) | K (year) | Location                               | References |
|----|------|------------------|----------|----------------------------------------|------------|
| 1  | Male | 381              | 0.17     | Eastern Indian Ocean                   | Present study |
|    | Female | 397           | 0.27     |                                        |            |
| 2  | Male | 399              | 0.29     | South Nusa Tenggara                    | [25]       |
|    | Female | 399           | 0.24     |                                        |            |
| 3  | Male | 339              | 0.29     | Java Sea and Borneo                    | [17]       |
|    | Female | 289.3       |          |                                        |            |
| 4  | Male | 259.8            | 0.15     | South Java, Bali and Lombok            | [3]        |
|    | Female | 389.6       | 0.16     |                                        |            |
| 5  | Male | 266              | 0.05     | Brazillian coast                       | [26]       |
|    | Female | 300          | 0.05     |                                        |            |
| 6  | Combine | 330.5       | 0.077    | Eastern Australia                      | [27]       |
| 7  | Male | 278.4            | 0.13     | Western North Atlantic and Gulf of Mexico | [28]     |
|    | Female | 302.1       | 0.09     |                                        |            |
| 8  | Male | 334.4            | 0.13     | Pacific Mexican coast                  | [29]       |
|    | Female | 319.7       | 0.16     |                                        |            |
| 9  | Male | 320.6            | 0.22     | Taiwan, China                          | [30]       |
|    | Female | 319.7       | 0.25     |                                        |            |
| 10 | Combine | 329          | 0.073    | Northwestern gulf of Mexico           | [31]       |

3.3. Length at first capture

Length at first capture ($L_c$) defined as the length which 50% of the fish are retained and 50% cannot be released by fishing gear. The probability length of first at capture for the scalloped hammerhead shark (combine between female and male) in Tanjung Luar was estimated as: $L_c = 192.26$ cm (Figure 5). Length of first at capture for female was estimated as $L_c = 197.66$ cm and for male was $L_c = 164.68$ (Figure 6 and 7)

![Figure 5. Length at first capture ($L_c$) of Sphyrna lewini caught from eastern Indian ocean](image-url)
Figure 6. The length at first capture (Lc) of *Sphyrna lewini* for female caught from eastern Indian ocean

Figure 7. The length at first capture (Lc) of *Sphyrna lewini* for male caught from eastern Indian ocean

3.4. Sex Ratio

A total of 2449 individual’s data of the scalloped hammerhead were 1768 identified as female and 681 were male. The sex ratio between female and male shark in 2013 was 2.43:1. In 2014 was 2.55: 1, 2015 was 2.87 :1 and then 2,66:1 in 2016 (Figure 8)

Figure 8. Sex ratio of *Sphyrna lewini* caught from eastern Indian ocean

The predominance of the scallop hammerhead female was landed in Tanjung Luar is a common phenomenon as is reported in previous research [1, 17, 25]. According to [27] the composition of the size and sex of the scalloped hammerhead being caught will be different in the fishing area. The sex ratio of the scalloped hammerhead caught in southern Nusa Tenggara different from the Java Sea and southern Kalimantan where the catch is dominated by males [17]. The difference in sex ratio on the scalloped hammerhead was influenced by location, oceanography phenomena, and capture methods. Catch by using a long line in the offshore was also thought to affect differences sex ratio because the scallop hammerheads female tends to associated with oceanic waters [32]
3.5. The relationship between clasper length and total length
The relationship between clasper length and total length is positive with a linear regression equation of 
CL = 0.0902*TL-4.4062 (R²=0.6837). It showed that the length of the claspers increases proportionally with the length of the body (Figure 9).

![Figure 9](image_url)

**Figure 9.** The relationship between clasper length and total length of *Sphyrna lewini* caught from eastern Indian ocean

The relationship between clasper length and total length was positive linear. This relationship was supposed to depend on the clasper condition. The more calcium contained on the clasper, the shorter it will be. [33] argued that the relationship between the clasper length and total body length is usually used to determine the size at which the Elasmobranch reach maturity.

3.6. Mortality and exploitation rate
The total mortality rate (Z) the scalloped hammerhead was 1.15/years resulting from the linear curve of the conversion result catch by length or linearization length catch curve (Figure 10). Natural mortality (M) is 0.37/years and the fishing mortality (F) was 0.78/years.
Based on Virtual Population Analysis (VPA) using the length frequency data, the result showed that fishing mortality (F) was maximum/dominant in the size group of 60-80 cm (Figure 11)

Meanwhile, the exploitation rate (E) obtained 0.68. Pauly (1983) [23] stated that exploitation rate will be more than 0.5 for the stocks supposed to over fished. In this study, E value more than 0.5, therefore

Figure 10. Catch curve of *Sphyrna lewini* caught from eastern Indian ocean

Figure 11. Length Structured Virtual Population Analysis of *Sphyrna lewini* caught from eastern Indian ocean
can be said that *Sphyrna lewini* is over exploited along eastern Indian ocean and appropriate management measures have to be taken for maintaining the fishing effort of *S. lewini* in the Indian ocean.

4. Conclusion
The growth of scalloped hammerhead shark can be modeled based on the von Bertalanffy growth curve form the equation $L_t=381 \ (1-e^{-0.17^{(t+0.4688)})}$ for male and $L_t=397 \ (1-e^{-0.27^{(t+0.3039)})}$ for female. The length at first capture $L_c = 192.26$ cm. Exploitation rate $(E) = 0.68$/year indicating that the scalloped hammerhead exploitation is high so it requires strategy formulation effective management to maintain fisheries sustainability.

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