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Biological aspects, exploitation rates, and spawning potential ratio of scalloped hammerhead shark (*Sphyrna lewini* Griffith & Smith, 1834) in Lampung Bay waters, Indonesia

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Abstract. The scalloped hammerhead shark is an endangered species that is listed in CITES Appendix II. Information on the biological aspects, exploitation rate, and spawning potential ratio of scalloped hammerhead sharks are very limited, especially in Lampung Bay waters. These data were important to find solutions and the best management to sustain the scalloped hammerhead sharks in Indonesia, especially in Lampung Bay waters. The aim of this study is to investigate the biological aspects, exploitation rates, and spawning potential ratios of scalloped hammerhead sharks in Lampung water. Scalloped hammerhead shark samples were collected from the catch of bottom gillnet in Kalianda Fish Landing Place, Lampung Province. Enumerators collected biometric data (length and weight) of 332 scalloped hammerhead sharks from July to November 2020. Biological aspects include distribution of length, length-weight (L-W) relationships, length at first capture, and length at first maturity. The utilization rate was calculated using the exploitation rate (E) and the estimated SPR based on length data. The results show that the length of scalloped hammerhead sharks ranged from 37.5 to 173.0 cm FL. Most of the samples fish had not spawned yet or were immature (L_c=47.1 cm FL; L_m=89.4 cm FL). The growth pattern of scalloped hammerhead sharks was allometrically negative. Scalloped hammerhead sharks have natural mortality of 0.18/year, while fishing mortality was 1.08/year. The fishing status of scalloped hammerhead sharks in Lampung Bay was fully exploited (E=0.85), and the stocks were in a recruitment overfishing condition. These findings indicate that effective management is required to ensure the sustainability of scalloped hammerhead sharks in Lampung Bay waters, such as adjusting mesh size, fishing season, and avoiding capture in the nursery area.

Keywords: Biological aspects, exploitation rates, scalloped hammerhead, Lampung Bay waters

1. Introduction

Hammerhead sharks (*Sphyrna* spp.) are critically endangered and vulnerable species, with decreasing populations [1], and are listed in CITES Appendix II [2]. The populations of hammerhead sharks are thought to have decreased due to intensive fishing and trading; including targeting their fins for international demands [3] and [4]. These species are almost universally distributed across a wide range of latitudes, inhabiting coastal warm temperate and tropical coastal and seas [2]. The IOTC reported that, while the exact population status of scalloped hammerhead sharks are unknown, it is suspected that there have been declines in hammerhead shark populations around the world, one of which is in Indian Ocean [5].

In Indonesian, the scalloped hammerhead shark can be found in Indian Ocean, Sunda Strait, Java Sea, South China Sea, Sumatra waters, Kalimantan waters, Sulawesi waters, Maluku waters, and Papua waters [6]. As oceanodromous fish, scalloped hammerhead sharks spend their lives in both oceanic and coastal waters. The pelagic hammerhead shark was mostly caught as bycatch in the tuna fishery but the coastal one became a target in the artisanal fishery [7], [8], and [9]. They are caught frequently in Indonesian waters [10] but with limited data, except particularly in the south of Java and Nusa Tenggara [11] and [12].

In western Indonesian waters, one location that is the habitat of this shark species is Lampung Bay, located in Sunda Strait, between Java Island and Sumatra Island. In this area, the scalloped hammerhead sharks were mostly caught as bycatch by bottom gillnet fishery [13]. Information on the biological aspects, exploitation rate, and spawning potential ratio of scalloped hammerhead sharks are very limited, especially in Lampung Bay waters. These data were important to find solutions and the best management to sustain the scalloped hammerhead sharks in Indonesia, especially in Lampung Bay waters. The aim of this study is to investigate the biological aspects, exploitation rates, and spawning potential ratio of scalloped hammerhead sharks in Lampung Bay waters.

2. Materials and methods

2.1. Sampling methods

Scalloped hammerhead shark samples were collected from the catch of bottom gillnet in Kalianda Fish Landing Place, Lampung Province (Figure 1). Enumerators collected biometric data (length and weight) of 332 hammerhead sharks from July to November 2020 (Figure 2).

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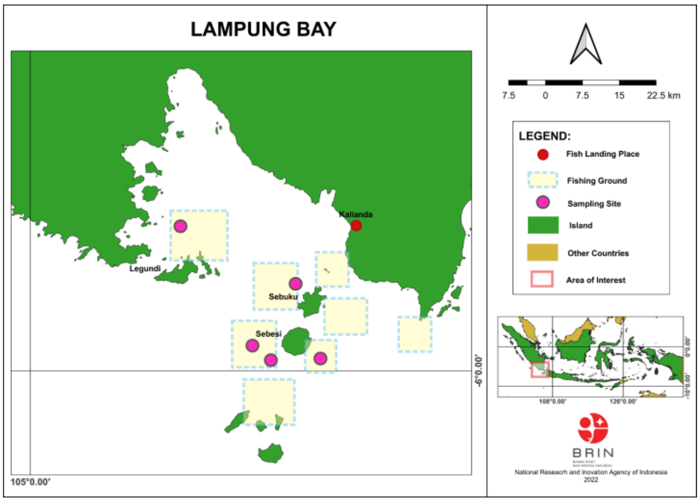

Figure 1. Sampling location and fishing locations of bottom gillnet fishery in Lampung Bay waters

Figure 2. Measurement of length and weight of hammerhead sharks by an enumerator in Kalianda Fish Landing Place

2.2. Data analysis

Biological aspects

The length distribution of scalloped hammerhead sharks is obtained by tabulating the length data on the frequency distribution table for the length. The equation used to analyse the length-weight (L-W) relationship was [14]:

$$W = aL^b \quad (1)$$

where W is total weight (g), L is fork length (cm FL), a is a constant, and b is a growth coefficient. To calculate the interval of 95% confidence the value of b we used the formula in [15]. The length at first capture (L_c) is obtained from a/b.

The equation used to analyse the selectivity of fishing gear was [15]:

$$S_{CL} = \frac{1}{1+exp\,(a-b*CL)} \quad (2)$$

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where S_{CL} is fishing gear selectivity, *a* and *b* are constants, and *CL* is the fish length.

The equation used to analyze the length at first maturity (L_m) was [16]:

$$\text{Log}_{10}L_m = 0.8979 * \log_{10}L_\infty - 0.0782 \quad (3)$$

where L_m is the length at first maturity, and L_∞ is the length of asymptotic.

Mortalities and exploitation rates

The following formula was used to calculate the natural mortality (*M*) [17]:

$$M = \frac{\beta K}{e^{K(C_1.t_{max}-t_0)}-1} \quad (4)$$

where *M* is the natural mortality, β is a coefficient of growth from L-W relationships, K is the growth rate, C_i is 0.30 for the pelagic fisheries, t_{max} is the maximum age and t_0 is the theoretical age of the fish when it has zero length.

To calculate the total mortality (*Z*), we used the equation of the linearized length converted catch curve [15]:

$$ln\frac{C(L1,L2)}{\Delta t(L1,L2)} = C - Zt\left(\frac{L1+L2}{2}\right) \quad (5)$$

where *Z* is the total mortality, *C* is length class frequency, *L*1 represents size at age *t*, *L*2 represents size at age $t+\Delta t$, and Δt is period needed for an average to grow from *L*1 to *L*2.

The formulas that were used to determine the exploitation rate (E) and fishing mortality (*F*) were [15]:

$$F = Z - M \text{ and } E = \frac{F}{Z} \quad (6)$$

Spawning Potential Ratio (SPR)

The spawning stock biomass per recruit (SSBR) was calculated based on susceptibility and maturity in each group of age and it was calculated by the total of SSBR from young until the oldest of the group age [18] and [19]. The fishing mortality was calculated at 40% (F40%) SSBR. The length-based SPR analysis was used to determine F40% [20]. The SPR was the ratio of SSBR in the exploited stock ($SSBR_{exploited}$) to the SSBR if there is no fishing ($SSBR_{F=0}$) [18]:

$$SPR = \frac{SSBR_{exploited}}{SSBR_{F=0}} \quad (7)$$

All data were analysed using Microsoft Excel.

3. Results

The length of 332 scalloped hammerhead sharks caught by bottom gillnet in Lampung Bay waters ranged 37.5 – 173.0 cm FL with more fish in size 55 cm FL and up (Figure 3). From the weight-length relationship (Figure 4), we found that the constant *b* was 2,7826. This indicates that the growth pattern of scalloped hammerhead sharks in Lampung Bay was negative allometric, meaning the fish tends to be slimmer with increasing length. Most of the samples fish had not spawned yet or were immature. The L_c was 47.1 cm FL (Figure 5) and L_m was 89.4 cm FL.

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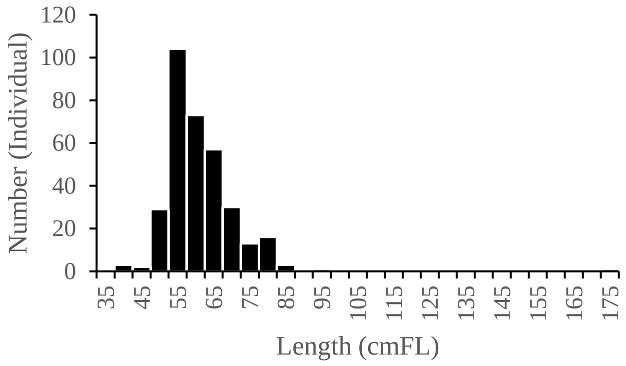

Figure 3. The length distribution of 332 scalloped hammerhead sharks caught by bottom gillnet in Lampung Bay waters

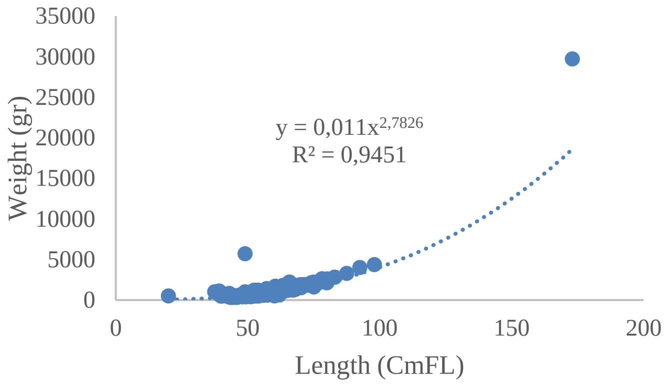

Figure 4. The length-weight (L-W) relationships of 332 scalloped hammerhead sharks caught by bottom gillnet in Lampung Bay waters

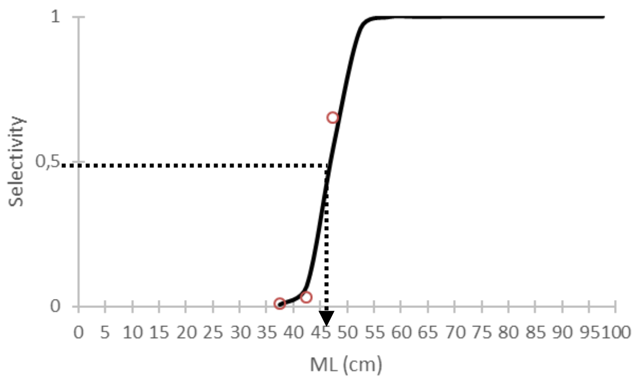

Figure 5. The L_c of scalloped hammerhead sharks caught by bottom gillnet in Lampung Bay waters

The scalloped hammerhead shark natural mortality was 0.18/year, the fishing mortality was 1.08/year, and the total mortality was 1.26/year (Figure 6). The fishing status of scalloped hammerhead sharks in Lampung Bay waters was fully exploited (E=0.85).

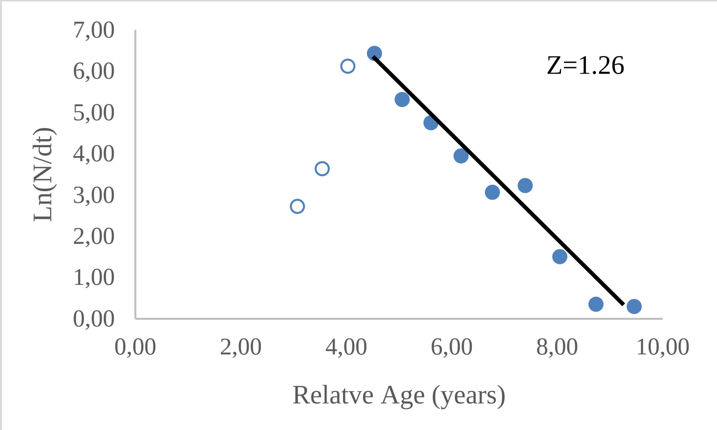

Figure 6. The length converted catch curve for estimating Z of scalloped hammerhead shark in Lampung Bay waters

The SPR was calculated by dividing the SSBR under-exploited conditions by the SSBR under unfished conditions. Because of increased fishing mortality, the SPR has decreased. Currently, the scalloped hammerhead sharks have an SPR 0.16. The scalloped hammerhead shark fishing mortality was 0.35 per year with 40% biomass of SSBR ($F_{40\%}$) (Figure 7).

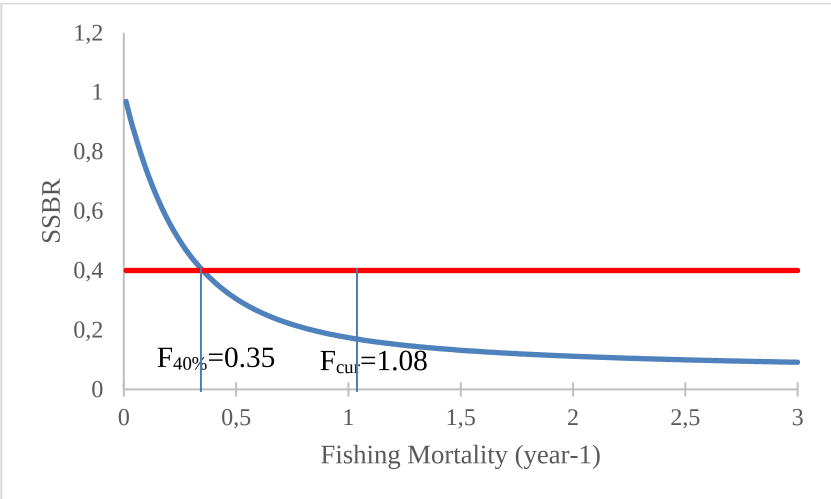

Figure 7. The scalloped hammerhead shark spawning stock biomass as a fishing mortality function in Lampung Bay waters

4. Discussion

The scalloped hammerhead shark in this study was smaller in size than the results of [21] in Tanjung Luar, as well as [7], [10], [12] and [22] in the south of Nusa Tenggara, and also [23] in Banda Aceh waters. The size difference in hammerhead sharks caught is considered to be related to the type of fishing equipment used and the different fishing areas. Scalloped hammerhead sharks are primarily caught using bottom gillnets in Lampung Bay waters while drifting longlines and tuna longlines are used in other areas [12]. Fishing locations in Lampung waters are typically near the coast, whereas fishing locations in other waters are typically further offshore. Shark juveniles and young are typically found in shallow water near the coast [24].

The growth pattern of the scalloped hammerhead sharks caught by bottom gillnet in Lampung Bay waters and landed in Kalianda Fish Landing Place is the same as the resulting study [25] and [26]. The trend of slimmer bodies when growing longer might be caused by the need for more energy to get more food or to hunt larger prey when they become larger and more mature. In general, the growth pattern of this hammerhead shark is influenced by internal such as heredity, age, sex, gonad maturity, growth rate, diet, and health; and external factors such as food, environment, population, type, and geographic habitat [27]. [28] stated that the L-W relationship of fish can be influenced by sex, gonad maturity stage, season, and the level of stomach fullness.

The L_c of scalloped hammerhead sharks in Lampung Bay, 47,1 cm FL, was very small, even smaller than the result [22] which reached 192.26 cm. The size L_c difference between scalloped hammerhead sharks in this study is considered to be related to the type of fishing equipment used. The scalloped hammerhead sharks are primarily caught using bottom gillnets in Lampung Bay waters while the bottom and drifting longlines are used in Tanjung Luar [9]. This L_c was also smaller than the $L_{m,}$ 89,4 cm FL. This means the fish might be caught before their mature size. As a result of not having enough time to reproduce, scalloped hammerhead shark populations will decline. According to [7], the male hammerhead shark in Tanjung Luar reaches adulthood and is ready to reproduce at a size of 165 – 175 cm, while the female is 220 – 230 cm.

Scalloped hammerhead sharks in Lampung Bay waters have natural mortality of 0.18/year, fishing mortality of 1.08/year, and total mortality of 1.26/year, and are fully exploited at 0.85. The exploitation rate of scalloped hammerhead sharks in Lampung Bay waters exceeds the optimum value, so it is necessary to maintain the catch with close monitoring. According to [29], a high exploitation rate can result in overfishing in waters, while [30] states that more fish caught in small sizes indicates that the waters have been degraded.

The proportion of mature size captured was critical in estimating spawning stock biomass [18] and [20]. [31] and [32] proposed a reference point of the best SSBR is 40%. However, the SPR of hammerhead sharks remains below their optimal values, indicating that recruitment is overfished for hammerhead sharks in Lampung Bay waters. According to [14] and [33], if fishing pressure continues to rise, population pressure will lead to recruitment overfishing. [34] stated that recruitment overfishing occurs when the biomass of the spawning stock is depleted to the point where reproduction cannot restock the population. These findings indicate that effective management is required to ensure the sustainability of scalloped hammerhead sharks in Lampung Bay waters, such as adjusting mesh size, fishing season, and avoiding capture in the nursery area.

5. Conclusion

The scalloped hammerhead shark population in Lampung waters which landed in Kalianda Fish Landing Place was dominated by scalloped hammerhead sharks that have not yet spawned with a negative allometric growth pattern. The fishing status of scalloped hammerhead sharks in Lampung Bay waters is fully exploited and the stock is in a recruitment overfishing condition. There is a need for effective management so that scalloped hammerhead sharks in Lampung Bay waters are sustainable.

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