Growth and mortality of grey reef shark *Carcharhinus amblyrhynchoides* in Makassar Strait, Indonesia

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Abstract. Small-scale fishers generally carry out shark fishing in Indonesia. Trends in shark fishing are growing, both as the primary target and bycatch. This research aimed to determine the growth, mortality and exploitation rates by age group of grey reef sharks (*Carcharhinus amblyrhynchoides*) caught in the Makassar Strait. The samples were taken from September to June 2020. The results showed an asymptotic length (L_∞) of 407 cm, a growth rate coefficient (K) of 0.16 and a theoretical age (t_0) -0.3967. The fishing mortality (F) value was 0.37 year^{-1}, natural Mortality (M) was 0.26 year^{-1}, and the total mortality (Z) was 0.63 year^{-1}. An exploitation rate of 0.59 indicates that the *C. amblyrhynchoides* has experienced over-exploitation.

Key Words: growth, mortality, exploitation rate, fishing intensity, population decline.

Introduction. Indonesia is one of the most prominent nations in the landing shark process. Between 2005 and 2017, Indonesia was the top global shark catcher with an average 110,737 metric ton year^{-1}. Small-scale fishers generally carry out shark fishing in Indonesia. Trends in shark fishing are growing, both as a primary target and as bycatch (Zainudin et al 2017). The Makassar Strait is an area that contributes to shark production. Shark fishing activities are carried out in shallow coastal waters, which is their nursery and feeding ground. The development of the shark trade, which is still continuous and intensive, has made several species vulnerable or declined in Indonesia's population. Most of the shark species are on the red list of the International Union for Conservation of Nature (IUCN). However, the lack of information regarding the catch data, potential, diversity, biology and exploitation rate of sharks in Indonesia is an obstacle to determining the basis for implementing a sustainable shark management (Fahmi 2013). The development of the intensive shark caused species vulnerability and decline in Indonesian waters. One of the near-threatened shark species is the grey reef shark *Carcharhinus amblyrhynchoides* that can be found in Indonesian waters, such as the Makassar Strait.

Almost all parts of the shark's body can be exported and have sale value, which encourages the intensification of the fishing activities, causing sharks over-exploitation and affecting the sustainability of these populations. For instance, Damora & Yuneni (2015) conducted a study at the Banyuwangi, East Java, which found that the exploitation of the Kejen shark was relatively significant.

Low fecundity, long sexual maturity, and slow growth are vulnerability indicators in fish exploitation (Dulvy et al 2014). Restoration of shark resources is needed to prevent these species extinction, considering that sharks are a slow-growth species, as demonstrated by several studies. A study on the shark species *Carcharhinus brevipinna*, *Carcharhinus obscurus* and *Carcharhinus plumbeus* in Australian waters found growth rates below 0.5 year^{-1}. Mako shark *Isurus oxyrinchus* in Mexican waters (Holmes et al 2015), shortfin (Ribot-Carballal et al 2005) and blue shark *Prionace glauca*, in the southern waters of the Atlantic Ocean for (Joung et al 2017), all show the same pattern.

Apart from slow growth, sharks maturation also takes a long time, namely 13.5 years for females and 12.5 years for males (Baremore & Hale 2012).

In some areas, information on the level of the exploitation levels is lacking (Tsai et al 2015). To prevent a decline in the sharks' population due to high fishing intensity, supporting information is needed to manage this species, including population parameters. Therefore, this paper aimed to analyze the growth and mortality aspects of *C. amblyrhynchoides* in the Makassar Strait waters, as input for a sustainable management of the shark fishing in Indonesian waters.

Material and Method

Description of the study sites. This research was conducted from September 2019 to June 2020. The research location was in the Makassar Strait. The fishing ground samples can be seen in Figure 1. The method in this research is descriptive, with observation techniques (direct observation). The observation method is used to obtain an overview of the object under study for growth, mortality, level of exploitation and yield-per-recruit. Sampling is carried out monthly, based on the fishermen's catch using longline and gill net. Fish is then measured in total length so the shark specimens should have a complete body, head, and tail for measurement of the total length. The total length of fish samples was measured from the tip of the upper jaw to the tip of the tail fin using a ruler board (accuracy of 0.1 cm). The results of the length measurement are then tabulated so that length frequency data are obtained for each length interval. Length measurement data were used to estimate growth and mortality. The number of measured sample specimens was 718 individuals.

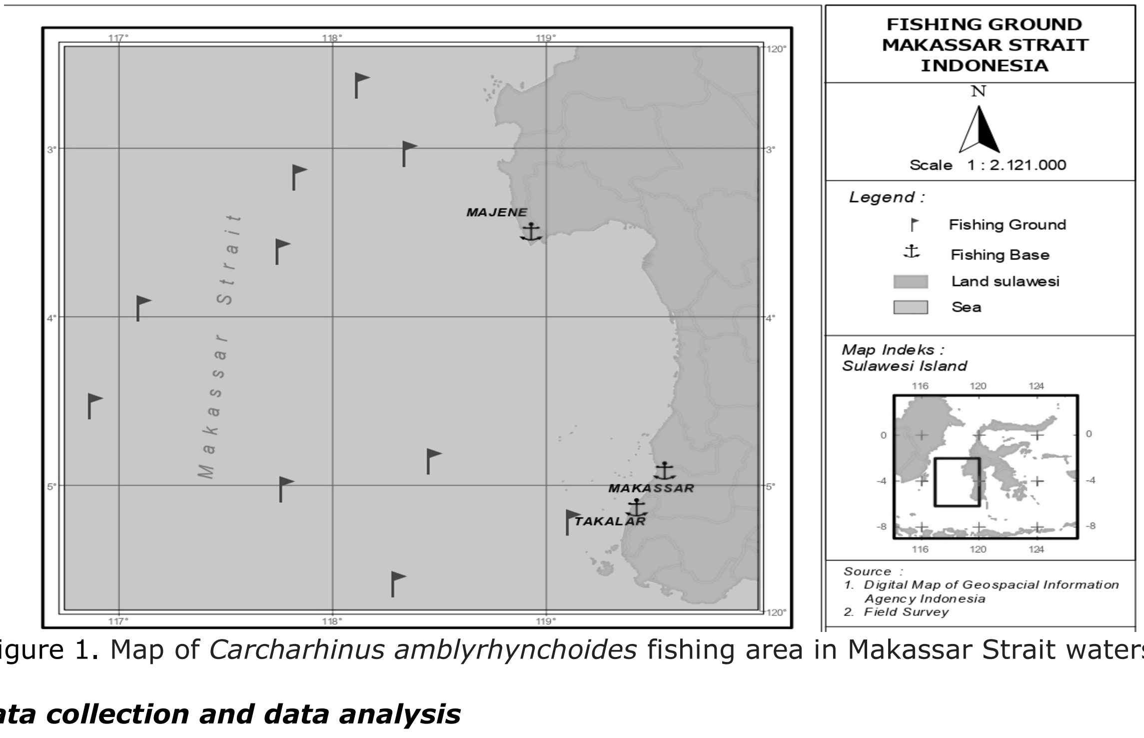

Figure 1. Map of *Carcharhinus amblyrhynchoides* fishing area in Makassar Strait waters.

Data collection and data analysis

Growth. Estimation of growth parameters using the Von Bertalanffy's growth formula:

$$Lt = L_\infty (l-e^{-K(t-to)})$$

Where:
Lt - total length of fish on the age of t (cm);
L_∞ - asymptotic length (cm);
K - growth curvature;
t_0 - the theoretical age when length equals zero (years);
t - age (years).

Growth parameters (K and L_∞) were estimated using the ELEFAN I method, which was accommodated in the FiSAT II software (Gayanilo et al 2003). Furthermore, for the determination of t_0 the Pauly (1980) empirical formula was used:

$$\text{Log}(-t_0) = -0.3922 - 0.2752 (\text{Log } L_\infty) - 1.038 (\text{Log } K)$$

Where:
L_∞ - asymptotic length (cm);
K - growth curvature;
t_0 - the theoretical age when length equals zero (years).

Mortality.
1. Natural mortality. Natural mortality was estimated using the Pauly (1980) empirical formula:

$$\text{Ln } M = -0.0066 - 0.279 \text{ Ln } L_\infty + 0.6543 \text{ Ln } K + 0.4634 \text{ Ln } T$$

Where:
M - natural mortality rate (years);
L_∞ - asymptotic length (cm);
K - growth curvature;
T - water temperature (℃).

2. Total mortality. Total mortality was estimated by the equation proposed by Beverton and Holt equation (Sparre 1998):

$$Z = K\left(\frac{L\infty - \bar{L}}{\bar{L} - L'}\right)$$

Where:
Z-total mortality rate (year);
K-growth curvature;
L_∞-asymptotic length (cm);
L-length average (cm);
L'-the lower limit of the length class (cm).

3. Catch mortality. The mortality due to the exploitation, the catch mortality (F), can be obtained after determining the total mortality (Z) and the natural mortality (M), from the equation:

$$F = Z - M$$

All of these methods are accommodated in the FiSAT II software.

Results

First length distribution. Based on the results of the study, the number of sharks caught in the Makassar Strait was 827. The collected specimens are then separated by population groups. Based on the separation analysis, six groups of fish sizes were obtained, by intervals spread over a length ranging from 27.5 to 227.5 cm. The results of the separation of fish groups are presented in Figure 1.

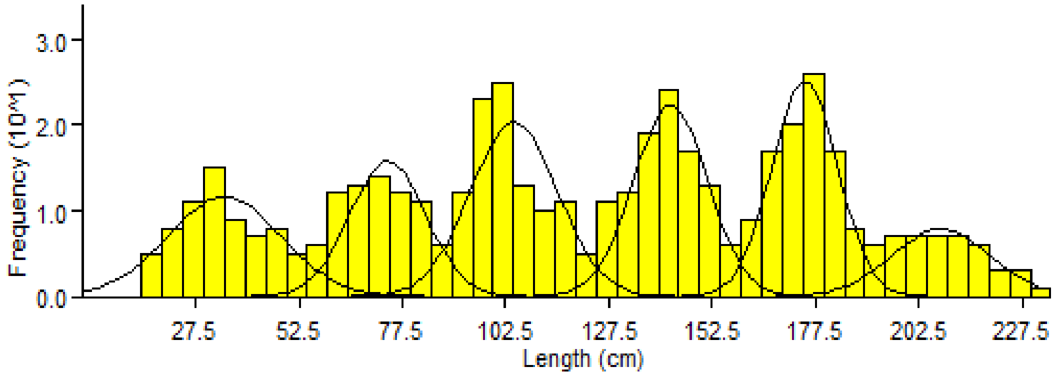

Figure 1. First length distrubution of *Carcharhinus amblyrhynchoides.*

Growth. Based on the use of the direct-fit of L / F data method (ELEFAN 1) through the FISAT II software (FAO-ICLARM Fish Stock Assessment Tools), the *C. amblyrhynchoides* asymptotic length (L_∞) growth parameter was determined: 407 cm (the theoretical growth limit in spite of age increase) and a growth rate coefficient of 0.16 was obtained. The result of asymptotic length L_∞ growth of *C. amblyrhynchoides* can be seen in Figure 2 and Von Bertalanffy's growth formula for *C. amblyrhynchoides* can be seen in Figure 3.

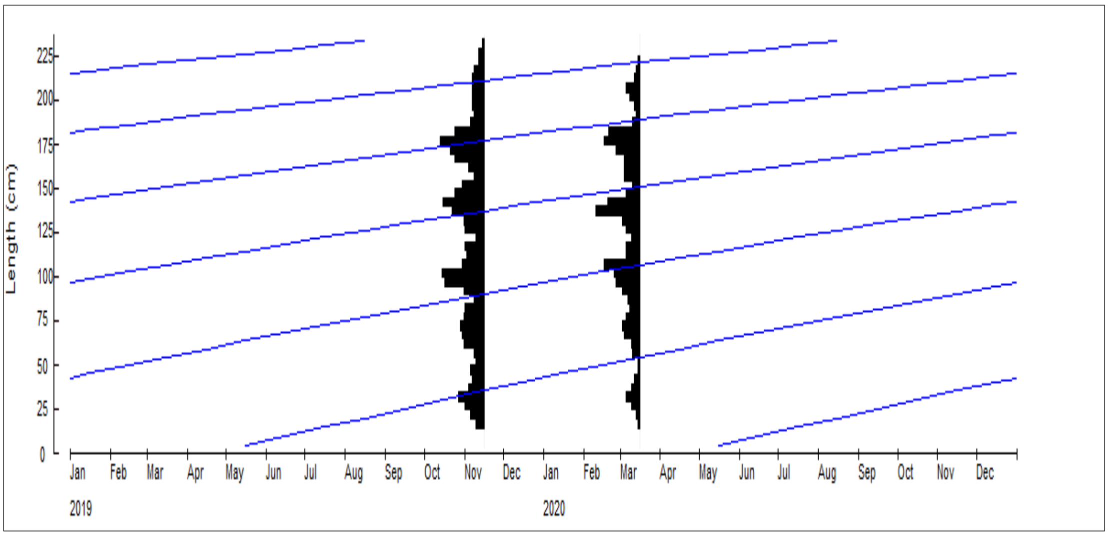

Figure 2. Growth of *Carcharhinus amblyrhynchoides.*

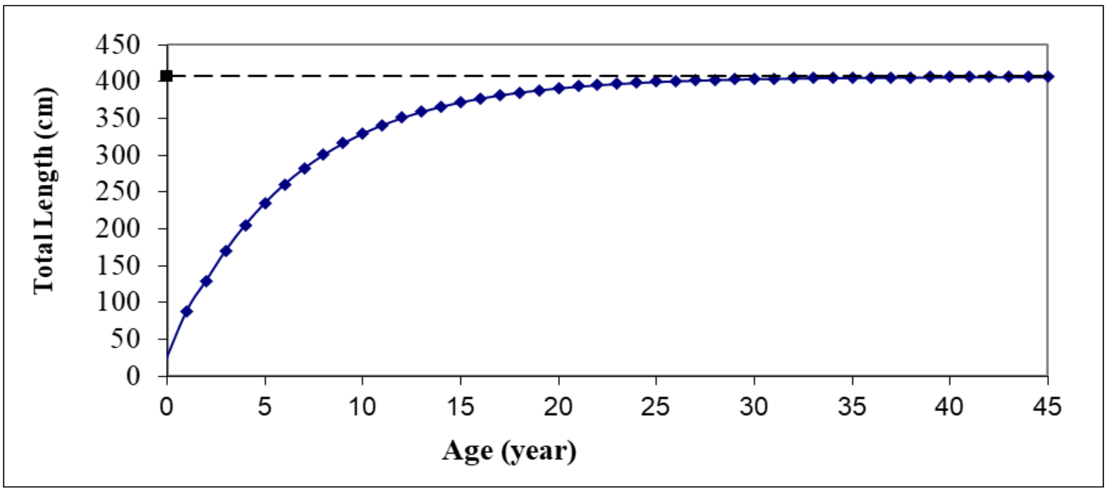

Figure 3. Von Bertalanffy curve for *Carcharhinus amblyrhynchoides.*

The analysis results using For Walford (Sparre & Venema 1999) obtained the value of each growth parameter shown in Table 1.

Table 1
Growth parameter value (L_∞, K, and t_0) of *Carcharhinus amblyrhynchoides* in Makassar Strait

Growth parameter	*Value*
Asymptotic length (cm)	407
Growth curvature	0.16
Theoretical age (year)	-0.52

Mortality. The fishing mortality (F) value was 0.37 year^{-1}, natural mortality was 0.26 year^{-1}, and the total mortality was 0.63 year^{-1}. From these results, it can be seen that the mortality rate due to fishing is greater than the natural mortality rate. Based on the natural mortality and mortality due to fishing catch (F), the exploitation rate (E) can be determined using formula E = F / Z. The rate of exploitation is an index that describes the level of stock utilization in water. Sparre & Venema (1999) state that the value of E=0.50 indicates the maximum level of stock utilization and E>0.50 indicates that the stock has been overexploited. The utilization rate of the *C. amblyrhynchoides* stock in the Makassar Strait indicates overfishing: E=0.59.

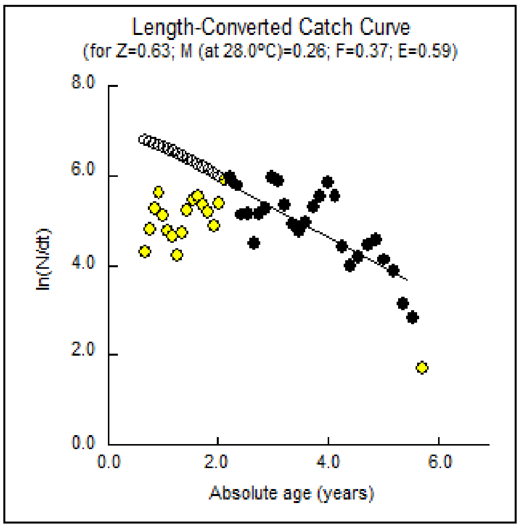

Figure 4. *Carcharhinus amblyrhynchoides* mortality.

Discussion

First length distribution. The results showed that smaller sharks were caught. It is happening because the fishing gear probably used the gill net with 2.4 and 5 inches mesh size. During the fishing process, most young sharks are caught by entangling them in the gill net. According to Suryagalih (2012), a fish with a body slightly more significant than the mesh fish will be caught by the gill net and if the fish is much larger than the mesh, it will get caught by entanglement. A gillnet is a rectangular fishing gear that catches many aquatic species, including the king mackerel, baronang, red snapper, yellowtail, pompano, crab, grumpy fish, sharks, and many others. Sharks are a bycatch of the gillnet fishing gear used by fishermen in the Makassar Strait waters (Damora et al 2018). Young sharks get also caught because the gill net's fishing ground overlaps with the playing and foraging area of *C. amblyrhynchoides* (shallow waters around the coastal area). Fahmi (2013) observed that small (juvenile) sharks get caught in shallow waters, while large sharks are a bycatch of the tuna fisheries.

The size of the sharks caught in this study was smaller than the study of Bradley et al (2017) on Palmyra Island (US), where the size was in the range of 60 to 180 cm in length. The research of Espinoza et al (2015) in North Queensland Waters, Australia obtained sharks' size of 51.9-142 cm, with an acoustic method. This variability in size is due to differences in the fishing gear and observation methods. The research of Bradley et al (2017) only reports on one type of fishing gear, namely longline fishing, whereas our current research uses two types of fishing gear: gillnet, and longline.

Growth. Based on the curve above (Figure 2 and Figure 3), theoretically the 45-year-old *C. amblyrhynchoides* shark will have a length of 407 cm, meaning that the shark takes 45 years to reach its asymptotic length. The *C. amblyrhynchoides* growth curve also shows that the shark's growth rate changes over its life span: young fish grow faster than specimens close to L_∞. Baje et al (2018) stated that some large shark species grow and develop very slowly and take six to eighteen years to reach adulthood.

A research performed in the southwestern part of the Pacific show that the *Galeocerdo cuvier* shark has a growth rate coefficient of 0.08 year^{-1} and the maximum length for males is in the range of 72-351 cm and the maximum length for females is in the range of 71-430 cm (Holmes et al 2015). Bradley et al (2017) report that, in Palmyra Island coastal areas, the growth rate coefficient and the asymptotic length of *C. amblyrhynchoides* were of 0.05 year^{-1} and 163.3 cm, respectively. Chodrijah et al (2018) research in West Nusa Tenggara obtained for the Kejen shark *Carcharhinus falciformis* a growth rate coefficient and an asymptotic length of 0.42 year^{-1} and 331.28 cm, respectively. A research carried out by Sen et al (2017) in Gujarat Waters, India, obtained for the *Rhizoprionodon autus* shark a growth rate coefficient and an asymptotic length of 0.32 year^{-1} and 93.8 cm, respectively.

The K value in the present study (Table 1) was greater than of the value reported by Bradley et al (2017), mostly due to the limited sampling period and to the composition of the sample sizes obtained in this study. Branstetter (1987) categorizes K values as follows: 0.05–0.10 year^{-1} for slow-growing species, 0.10–0.20 year^{-1} for medium growing species, and 0.2–0.50 year^{-1} for fast-growing species.

Mortality. The mortality value from *C. amblyrhynchoides* stock in the Makassar Strait consisted of: fishing mortality (F) 0.37 year^{-1}, natural mortality (M) was 0.26 year^{-1}, the total mortality (Z) was 0.63 year^{-1} and exploitation rate (E) was 0.59. A research carried out by Chodrijah et al (2018) in West Nusa Tenggara reported the mortality parameters of the Kejen shark (*Carcharhinus falciformis*) that included the total mortality rate (Z), the natural mortality rate (M) and the mortality rate due to fishing (F) each 2.79 year^{-1}, 0.49 year^{-1}, and 2.30 year^{-1} with exploitation rate (E) is 0.82. Another research carried out by Hidayattuloh (2017) with the same species in Cilacap waters showed the total mortality rate (Z), the natural mortality rate (M) and the mortality rate due to fishing (F) each 2.86 year^{-1}, 1.03 year^{-1}, and 1.83 year^{-1} with exploitation rate (E) of 0.64.

From the information above, all data are different in every location. The variability in the results of the present study is possibly caused by the differences in the environmental conditions of the two waters (Damora et al 2018). Each aquatic environment has its own characteristics in its geographic seasonal and water cycle structure. Therefore, in different habitats, the organisms will develop different body shapes and sizes (Nontji 2002).

The data above have different numbers, but indicate that the fishing mortality is bigger than natural mortality. Besides that, all exploitation rate shows all above 0.5, from which it could be concluded that shark species were over exploited. The mortality rate is the rate of death experienced by sharks during a certain period. Estimating the value of natural mortality creates several difficulties because it can be influenced by the estimation model's choice and by the observation location. Given that the natural mortality rate does not vary too much, the value is usually considered constant from year to year (Pauly et al 1984).

Conclusions. The present study has successfully documented that the growth of *C. amblyrhynchoides* caught in the Makassar Strait is very slow and its catch mortality is higher than its natural mortality, suggesting that *C. amblyrhynchoides* in Makassar Strait is being overexploited.

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Conflict of interest. The authors declare no conflict of interest.

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