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Biological aspects of the Halmahera Walking Shark (*Hemiscylium halmahera*) as Data and Support Protection Regulations Endemic Species on Equatorial Latitudes in Halmahera Sea, North Maluku, Indonesia

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ABSTRACT

The Halmahera Walking Shark (*Hemiscyllium halmahera*) is a species of marine fish endemic to the Halmahera Islands. This species is distributed in the Halmahera sea in general. This species is also found in the archipelago. The archipelago in the Halmahera Sea that is part of the equatorial region is Tawabi Island. Tawabi Island is a small island located on the equator. This research aimed to obtain data on the population structure of the *H. halmahera* on the small island of Tawabi on equator. *H. halmahera* samples were captured in coral reef, seagrass and mangrove ecosystem areas. Morphometric data were taken, such as the total length and the body weight of the fish using a ruler. Marine environment quality such as salinity, temperature, pH and dissolved oxygen were taken using standard operational procedures with Horiba equipment. The population structure analyzed was cohort, class frequency, and condition factors. The results of the study found cohorts of fish, namely adult and old ages. The juvenile age group was not found in the age group. The class interval formed two age groups that supported the results of the cohort analysis. *H. halmahera* body shape was plump. The plumpness of the fish indicates that the habitat is supportive and food sources are abundant. Marine environmental conditions were found to be normal, thereby supporting the ecological sustainability of the *H. halmahera* species. The population structure of the *H. halmahera* on the small island of Tawabi at equatorial latitudes is described as having different subpopulations.

INTRODUCTION

Tawabi Island, located in the Kayoa Islands of the Halmahera archipelago, is a small, flat coral island situated directly on the equator. This unique geographical position influences the surrounding marine climate and environmental conditions. Factors such as temperature, salinity, dissolved oxygen, pH, and shallow sea topography—particularly

the high solar intensity due to the sun being directly overhead—contribute to a distinct marine environment compared to regions located outside the equatorial zone. The consistently high sea surface temperatures in these shallow waters are thought to impact the structure and dynamics of marine populations. Population dynamics such as growth patterns, trophic relationships, and reproductive strategies are influenced by these environmental factors, leading to variations in population structures as organisms adapt to their surroundings.

Tawabi Island's morphology is characterized as a flat coral island, a typological category that includes other island forms such as salluvium and atoll islands **(Bengen & Retraubun, 2006; Bengen *et al.*, 2012)**. Observations have identified coral rocks on the mainland of Kayoa Island, suggesting that the island was formed as a result of tectonic activity. This geological history is similar to that of Lombok Island, which experienced subsidence during the Middle Miocene era, as evidenced by the presence of coral reef units developing atop older volcanic formations **(Astjario & Astawa, 2005)**.

Such abnormal or extreme aquatic habitat conditions may lead to increased local adaptability among marine organisms. These adaptations can manifest through morphological, physiological, and genetic modifications, ultimately influencing body shape and other phenotypic characteristics.

One species that exemplifies such adaptation is the Halmahera Walking Shark (*Hemiscyllium halmahera*), a benthic and territorial species found in the waters around Tawabi Island. First described by **Allen *et al.* (2013)**, this shark is endemic to the Halmahera region. Notably, *H. halmahera* uses its pectoral fins to "walk" along the seabed **(Allen *et al.*, 2013; Allen *et al.*, 2016; Jutan *et al.*, 2018; Akbar *et al.*, 2019; Jutan *et al.*, 2019; Madduppa *et al.*, 2020)**. These sharks are solitary and engage in limited local migration, making periodic population assessments necessary to monitor their ecological status.

The presence of *H. halmahera* across different aquatic habitats reflects both morphological and genetic responses to environmental variation, which may lead to differences in body size and other traits. Environmental factors are known to influence genetic expression and may even lead to changes at the DNA level, thereby affecting phenotypic characteristics **(Allen *et al.*, 2013; Akbar *et al.*, 2019; Madduppa *et al.*, 2020)**.

Previous studies have investigated aspects such as distribution, morphometrics, dietary composition, genetics, and tonic immobility of *H. halmahera* at various sites across North Maluku **(Allen *et al.*, 2013; Allen *et al.*, 2016; Jutan *et al.*, 2017; Jutan *et al.*, 2018; Akbar *et al.*, 2019; Mukharror *et al.*, 2019; Madduppa *et al.*, 2020; Mu'min *et al.*, 2021; Wahab *et al.*, 2022; Ichsan *et al.*, 2023; Akbar *et al.*, 2023)**. However, none of these studies have examined the population structure of *H. halmahera* on a small island that lies directly on the equator.

Previous research has focused on regions such as Kao Bay, Weda Bay, Ternate Island, Mare Island, Lelei Island, Maitara Island, Tidore Island, and Morotai Island—locations that do not cross the equator **(Jutan *et al.*, 2017; Akbar *et al.*, 2019; Madduppa *et al.*, 2020; Mu'min *et al.*, 2021; Wahab *et al.*, 2022)**. The distinct environmental characteristics of equatorial aquatic habitats like those around Tawabi Island highlight the importance of understanding population structures under such conditions. Habitat characteristics are critical as they provide food sources and essential ecological services for marine organisms, making environmental conditions a key determinant of population dynamics and ecological adaptation.

MATERIALS AND METHODS

1. Study area

Tawabi Island, located in the southern part of the Halmahera archipelago in Indonesia (Fig. 1), possesses significant fisheries potential due to its diverse coastal ecosystems, including mangroves, seagrass meadows, and coral reefs (Fig. 2). While coral reefs are the primary habitat of Hemiscyllium halmahera (Fig. 4), the presence of adjacent ecosystems such as mangroves and seagrass beds likely contributes to the broader ecological distribution and life cycle support of this species (Fig. 2).

The island is inhabited by a community of predominantly small-scale fishers who rely on traditional fishing methods, including nets and handlines, to exploit the abundant demersal fish populations in the surrounding waters. The region's high fisheries potential was further confirmed through field research conducted between April 2021 and March 2023 in the waters surrounding Tawabi Island (0°00′08.83″ N, 127°42′39.21″ E), as indicated in Fig. (1).

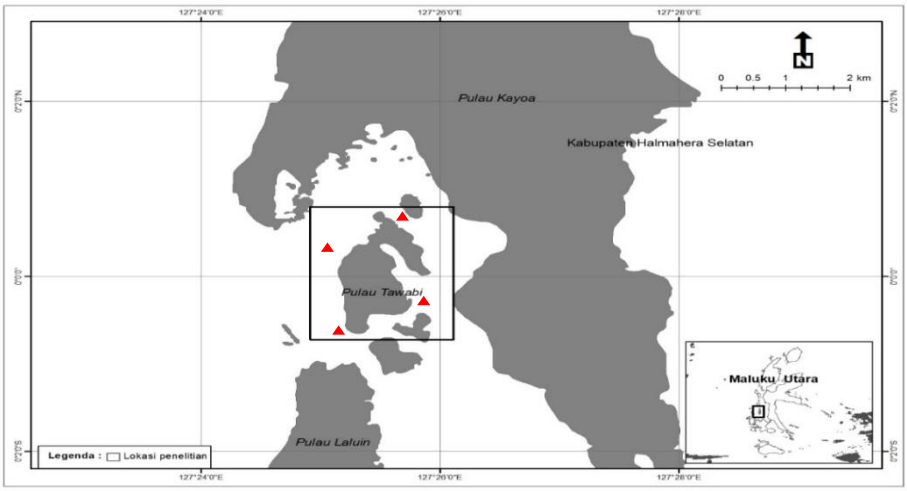

Fig. 1. Research site of *H. halmahera* in Tawabi, Kayoa Island

2. Sampling

Specimens of *Hemiscyllium halmahera* were collected from various habitats around Tawabi Island at sea depths of 1–2 meters in seagrass and mangrove ecosystems using basic diving equipment, and at depths of 3–15 meters in coral reef areas using SCUBA diving techniques. The target sample size was 30 individuals **(Akbar *et al.*, 2023)**. Additional specimens were also obtained from local fishers as part of by-catch during small-scale fishing operations.

Captured individuals were carefully caught by hand and immediately placed into cooler boxes filled with seawater to ensure their survival during transport **(Akbar *et al.*, 2023)**. Once secured, each specimen was measured for a set of morphometric parameters including total length (TL), standard length (SL), head height (HH), head length (HL), head width (HW), body circumference (BC), pectoral fin length (PF), anal fin length (AF), dorsal fin length (DF), and caudal peduncle length (CPL). All measurements were taken in centimeters. Body weight was recorded using a digital scale with an accuracy of 0.01 **grams (Allen *et al.*, 2013; Akbar *et al.*, 2019; Madduppa *et al.*, 2020; Akbar *et al.*, 2023)** (Fig. 3).

Wet body weight (the total weight of the live, unprocessed fish) was recorded across multiple size classes to evaluate growth and condition **(Mallawa *et al.*, 2017; Aisyah *et al.*, 2018)**. As a nocturnal species, *H. halmahera* is most active during nighttime in shallow, flat areas of coral reefs and seagrass beds. Individuals display a brown coloration with distinctive stripes and spots, as illustrated in Fig. (4).

Following data collection, all live specimens were returned to their natural habitat to minimize ecological disturbance and support conservation efforts.

Fig. 2. Description of the habitat of the *H. halmahera* and the distribution of coastal ecosystems in Tawabi, Kayoa Island. *Source*: photo by Firdaut Ismail in Tawabi, Kayoa Island, March 2023

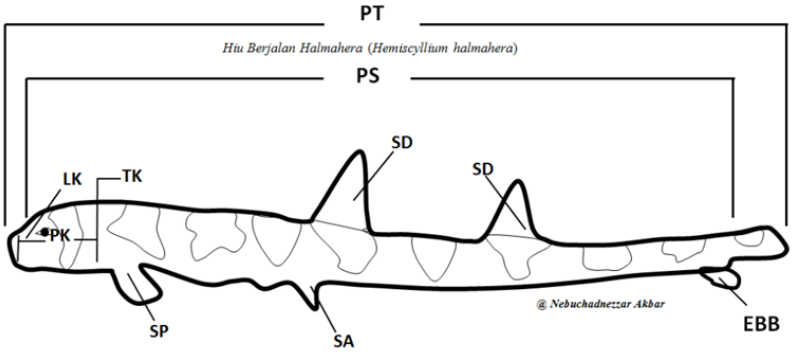

Fig. 3. Morphometric measurements of the *H. halmahera*

The sampling of *Hemiscyllium halmahera* was conducted both during the day and at night to account for the species' diel behavioral patterns. During daylight hours, individuals were typically observed resting in mangrove ecosystems, often within the root systems, or in coral reef habitats where they were found lying motionless with their heads and bodies positioned on coral structures. This behavior reflects the species' cryptic and sedentary nature during non-active periods.

Based on previous studies, juvenile individuals ranged from 15 to 22cm in total length, adults ranged from 31 to 44cm, and reproductively mature individuals measured between 45 and 100cm **(Allen *et al.*, 2013; Bennet *et al.*, 2015; Jutan *et al.*, 2017; Akbar *et al.*, 2019)**.

Environmental parameters—salinity (ppt), sea surface temperature (°C), dissolved oxygen (DO, g/mL), and pH—were measured in situ using a Horiba multiparameter water quality probe **(Patty *et al.*, 2019)**. The instrument was submerged in the water column to a depth of 1 to 3 meters and left in place for a few minutes to allow for accurate readings. The values for each water quality variable were then recorded directly from the device **(Patty *et al.*, 2019)**.

3. Data analysis

After taking all of the Halmahera walking shark's measurements, the data were imported into Microsoft Excel.

Fig. 4. Morphological appearance of the endemic fish species *H. halmahera* in the Halmahera Islands. *Source*: photo by **a)** Nebuchadnezzar Akbar and **b)** Abdurrachman Baksir in North Maluku Sea, March 2023

4. Cohorts

Cohort analysis of Hemiscyllium halmahera was conducted based on the total length and body weight data collected from the sampled individuals. Morphometric data were processed and analyzed using FISAT II (FAO-ICLARM Stock Assessment Tool) software **(Utami *et al.*, 2018; Akbar *et al.*, 2023)**.

The length-frequency distribution was established using total length measurements of the specimens. The analysis followed the method proposed by Bhattacharya (1967), which involves grouping the data into appropriate length classes, determining the class interval and width, and calculating the frequency for each class. This approach enabled the identification of cohorts within the population, providing insight into the population structure and growth dynamics of H. halmahera **(Utami *et al.*, 2018)**.

5. Length frequency distribution

Length frequency distribution data were obtained using Microsoft Excel **(Sturges, 1926 in Lempoy *et al.*, 2020)**. The condition factor was obtained based on length and weight of the sample **(Ibrahim *et al.*, 2017)**. The Sturges rule in Microsoft Excel was used to obtain long frequency distribution data **(Sturges, 1926 in Lempoy *et al.*, 2020)**.

6. Condition factor (Kf)

The condition factor of *Hemiscyllium halmahera* was calculated based on the relationship between total length and body weight of each individual **(Ibrahim *et al.*, 2017)**. This metric provides an indication of the overall health and well-being of the fish.

Criteria for interpreting condition factor values were based on the classification provided by **Effendie (1997)**, as summarized in Table (1). In cases where the growth pattern was determined to be isometric—meaning the fish's body proportions remain

consistent as it grows—the condition factor was calculated using the standard length-weight relationship formula as described by **Effendie (2002)**:

$$K = \frac{10^5 W}{L^3}$$

Condition factor calculation formula and allometric growth pattern : $K = \frac{W}{aL^b}$

Description: K = condition factor, W = fish weight (gr) and L = total length (cm)

Tabel 1. Criteria and the range of values for the fish condition factor

No.	Criteria	Value ranges
1	Plump (*Fusiform*)	1-3
2	Flat (*Compressed*)	2-4

RESULTS

1. Cohort

Samples of *Hemiscyllium halmahera* were collected from four regions around Tawabi Island: South Tawabi (12 individuals), North Tawabi (12 individuals), East Tawabi (3 individuals), and West Tawabi (3 individuals). A total of 30 individuals were analyzed.

Cohort analysis revealed the presence of two distinct age groups within the sampled population. As shown in Fig. (5), the histogram of length-frequency data displayed two prominent peaks, indicating the existence of two separate generations. These findings suggest active recruitment and population turnover in the area, which may reflect environmental influences or reproductive timing.

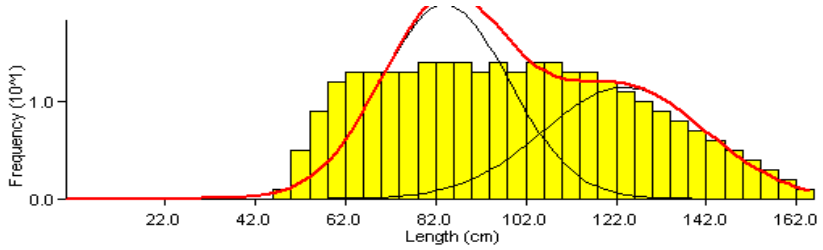

Fig. 5. Frequency of length indicates two cohorts (adult and old age) in the *H.halmahera* population in Tawabi, Kayoa Island, Indonesia

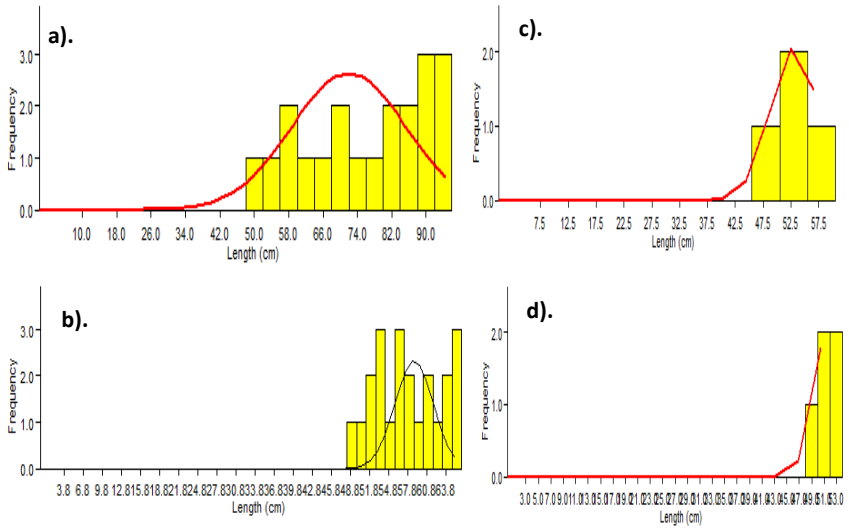

Fig. 6. Cohorts distributions on Tawabi Island **a)** North Tawabi Island **b)** South Tawabi Island, **c)** East Tawabi Island, and **d)** West Tawabi Island

Spatial analysis of *Hemiscyllium halmahera* cohorts around Tawabi Island indicated no significant variation in age group distribution across sampling locations (Fig. 6). In North Tawabi (North Kayoa), 12 individuals were collected, all of which belonged to the adult age category, forming a single age group with total lengths ranging from 51 to 65 cm and body weights between 320 and 510g. Similarly, in South Tawabi, 12 individuals were found within the adult size range of 50 to 65cm and weights of 390 to 500g, also forming one distinct age group.

In East Tawabi, three individuals were recorded, all within the adult category, measuring 48 to 50 cm in length and weighing between 310 and 380g. West Tawabi also yielded three individuals in the adult category, with lengths ranging from 49 to 51cm and weights from 300 to 330g, comprising a single cohort.

Despite the presence of two age groups in the overall population, individual sample locations typically showed only one cohort, likely due to the limited number of individuals in certain areas. This reflects an uneven spatial distribution, potentially influenced by environmental factors or habitat preference.

The cohort analysis revealed two main age groups within the population. The first cohort, consisting of 22 individuals, had a mean total length of 84.06 ± 14.28cm. The second cohort included 8 individuals with a mean total length of 123.83 ± 18.08cm (Table

2). These findings suggest the coexistence of two distinct generations within the *H. halmahera* population around Tawabi Island.

Table 2. Average cohort of the *H. halmahera* on Tawabi Island

Groups	Avarage ± standard deviation	Populations	Index separation
1	84.06 ± 14.28	22	n.a.
2	123.83 ± 18.08	8	2.15

2. Interval class

Length class intervals were determined based on the total length measurements of *Hemiscyllium halmahera* individuals and the frequency of specimens within each class. The intervals were established using the minimum and maximum observed lengths, allowing for the construction of a histogram to visualize the size distribution of the population.

The highest frequency was observed in the 48–51cm class interval, which included 12 individuals (Fig. 7). The 56–60cm interval contained 6 individuals, while the 54–57cm and 60–62cm intervals each included 2 individuals. These results indicate that the population of *H. halmahera* on Tawabi Island, Kayoa, is predominantly composed of medium- to large-sized individuals (Fig. 7).

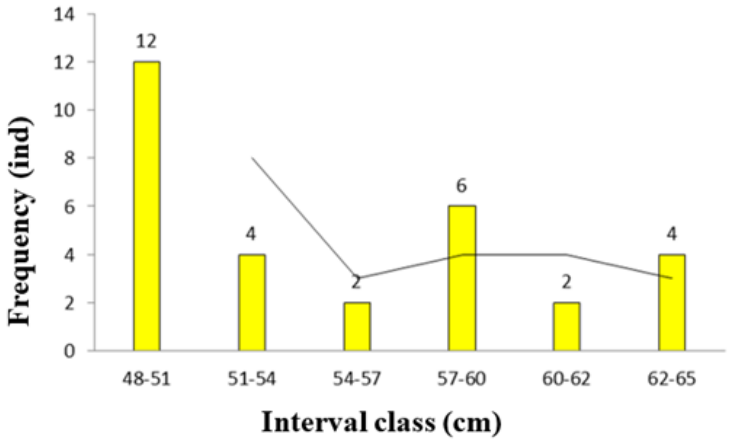

Fig. 6. Interval Class 1, Class 2, Class 3, Class 4, Class 5, Class 6 of *H. halmahera* on Tawabi Island

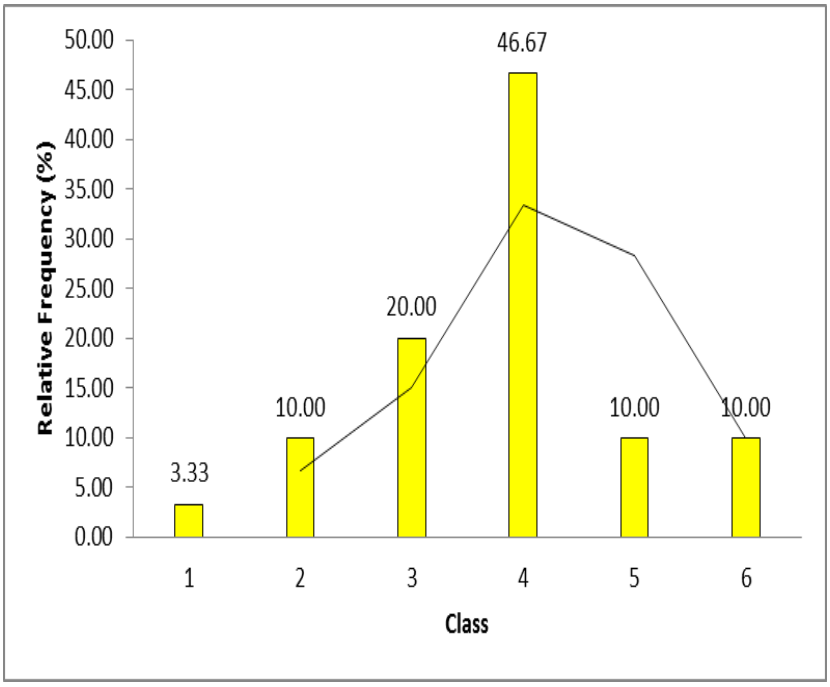

Fig. 5. The Morotai Island relative frequency class of the Halmahera walking shark

3. Condition factor (Kf)

The overall condition factor (FK) values of *Hemiscyllium halmahera* in the waters around Tawabi Island, Kayoa, ranged from 0.0822 to 1.1029, with a mean value of 1.003 (Table 3). This indicates that, overall, the sharks were in good condition relative to their length and weight. When analyzed by location, the condition factor values varied slightly between stations. In South Tawabi Island, values ranged from 0.9121 to 1.0861, with a mean of 1.0011. North Tawabi Island showed a similar range, between 0.9138 and 1.0804, with a mean of 1.0014. East Tawabi Island recorded condition factor values from 0.8681 to 1.1240, with a mean of 1.0120. The highest average FK was observed at West Tawabi Island, where values ranged from 0.8831 to 1.0834, yielding a mean of 1.0133 (Table 3). These results suggest that *H. halmahera* individuals across all sampling sites were generally healthy and well-adapted to their respective environments.

Table 3. Halmahera walking shark condition factor on Morotai Island

No	Location	Samples	Condition Factor (FK)			Habitat
			Ranges	Evarages	Deviation Standar	
1	South Tawabi Island	12	0.9121-1.0861	1.0011	0.0125	Mangrove, Seagrass, Coral and Bycacth
2	North Tawabi Island	12	0.9138 - 1.0804	1.0014	0.00211	Mangrove, Seagrass, Coral and Bycacth
3	East Tawabi Island	3	0.8681 - 1.1240	1.012	0.011	Seagrass, Coral and Bycacth
4	West Tawabi Island	3	0.8831 - 1.0834	1.0133	0.0045	Coral and Bycacth
	Tawabi Island (General)	30	0.0822-1.1029	1.003	0.009	Mangrove, Seagrass, Coral and Bycacth

4. Environmental parameters

In general, environmental parameter values are still normal based on water quality standards (Decree of the Minister of Environment No. 51 of 2004), thus supporting organisms to occupy aquatic habitats on Tawabi Island, (Table 4). Overall, all results from environmental parameters show stability against seawater. Temperature, salinity, and pH indicate stability and support the existence of life in the sea. The environmental parameters found indicate that the aquatic environment is very supportive of life for the Halmahera walking shark.

Table 4. Aquatic environmental variables based on research location

No	Location	Temperature (°C)	DO (mg/l)	pH	Salinity (‰)
1	Tawabi Island	30-33	7-7.1	7-8.1	33-35

DISCUSSION

The length-frequency analysis of *Hemiscyllium halmahera* in this study indicated two distinct cohorts, representing adult and old-age individuals. Unlike previous studies that identified three cohorts—juvenile, adult, and old age—on Morotai Island **(Akbar *et***

***al.*, 2023)**, the absence of juvenile individuals in Tawabi Island waters suggests a notable population structure difference. Earlier studies by **Jutan *et al.* (2017, 2018)** and **Akbar *et al.* (2019)** reported population characteristics based on observed total length, but without conducting formal cohort analysis. These variations in size distributions support the idea of age-based segregation in fish populations **(Pramurdya *et al.*, 2019; Bahrin *et al.*, 2020)**. Based on existing classification, juvenile sharks measure 15–22cm, adults 31–44cm, and old-age individuals 45–100 cm **(Allen *et al.*, 2013; Bennet *et al.*, 2015; Jutan *et al.*, 2017, 2018; Akbar *et al.*, 2019, 2023)**.

Morphometric data are essential in understanding population dynamics, as they reflect biological processes and environmental influences. Fish length data, in particular, offer insights into life cycles, habitat conditions, and sustainability **(Wudji *et al.*, 2013; Suwarni *et al.*, 2015)**, and can serve as ecological indicators. The dominance of large-bodied individuals in Tawabi Island waters suggests that *H. halmahera* may not use this area as a primary habitat. Instead, the species likely utilizes these waters as a feeding ground, a temporary resting location, or a mating site. The absence of juveniles and young-of-the-year implies that Tawabi Island is not a nursery ground, but rather a transitional habitat utilized during specific biological activities or in response to unfavorable oceanographic conditions elsewhere.

Although *H. halmahera* is known for its limited territorial migration, it is plausible that within a shallow archipelagic environment like Kayoa, the species engages in short-distance spatial movement across nearby islands. This study supports the hypothesis that *H. halmahera* demonstrates habitat selectivity based on life stage, as fish often utilize different habitats throughout their lifecycle **(Tesfay *et al.*, 2019)**.

The two identified cohorts exhibited clear generational separation. The first cohort had a mean length of 84.06 ± 14.28 cm (22 individuals), while the second cohort had a mean length of 123.83 ± 18.08 cm (8 individuals) (Table 2). This size structure is supported by the separation index, where a value greater than 2 indicates distinct age groups **(Sparre & Venema, 1999; Djumanto *et al.*, 2014)**. The absence of overlapping length distributions reinforces the conclusion that the population sampled at Tawabi Island represents two separate age groups.

Length-class interval analysis further revealed uneven size distribution, with the 48–51cm class being the most dominant. Variations in size distribution across classes were associated with the number of individuals in each group, reflecting natural growth patterns and the cohort structure of the population **(Allen *et al.*, 2016; Lestari *et al.*, 2016; Jutan *et al.*, 2018; Sasmita *et al.*, 2018; Dewi *et al.*, 2019; Akbar *et al.*, 2019)**.

The **condition factor (FK)** analysis showed that sharks in Tawabi waters were generally healthy, with FK values ranging from 0.0822 to 1.1029 and an average of 1.003. Among the sub-stations, the highest FK average was observed at North Tawabi Island, and the lowest at East Tawabi Island (Table 3). These results align with findings by **Jutan *et al.* (2018)** and **Akbar *et al.* (2023)**, who reported similarly plump body forms

in sharks from Morotai Island and Kao Bay. The FK reflects the overall "fatness" or body condition of fish, with values between 1 and 3 typically indicating good condition **(Effendie, 2002; Faradonbeh *et al.*, 2015; Ramses *et al.*, 2020; Syuhada *et al.*, 2020)**.

Environmental parameters measured in this study align with data from nearby regions. Previous studies reported water temperatures of 27–34°C, salinity ranging from 28–35‰, and pH levels between 7.0 and 8.5 **(Idrus *et al.*, 2019; Koroy *et al.*, 2019; Katili *et al.*, 2020; Alwi *et al.*, 2021)**. While specific studies on marine conditions directly on the equator are limited **(Julismin, 2013)**, Tawabi Island's position at 0° latitude presents a unique ecological context. Recent work by **Najamuddin (2024)** and **Alhaddad *et al.* (2022)** highlighted the distinct environmental and biological characteristics of equatorial coral islands, noting significant biodiversity and specialized ecosystem dynamics.

Warm temperatures, stable salinity, and adequate pH in Tawabi waters support the physiological needs of *H. halmahera*, a euryhaline and eurythermal species with high adaptability to environmental changes. Studies on its close relative, *Hemiscyllium ocellatum*, have shown resilience to hypoxia and elevated temperatures **(Nilsson & Renshaw, 2004)**, suggesting that *H. halmahera* may exhibit similar tolerance. Coral cover, mangrove species like *Sonneratia* and *Rhizophora*, sandy substrates, and optimal levels of dissolved oxygen further contribute to the species' habitat suitability in this region **(Allen *et al.*, 2016; Jutan *et al.*, 2018; Akbar *et al.*, 2019; Madduppa *et al.*, 2020; Akbar *et al.*, 2023)**.

Despite these favorable conditions, *H. halmahera* faces potential threats from by-catch in capture fisheries, particularly in areas like Tawabi Island where small-scale fishing is prevalent. Overfishing continues to pose a significant threat to marine biodiversity globally **(Miqueleiz *et al.*, 2022)**. Therefore, *in-situ* conservation efforts are essential. Protecting the ecosystems that support *H. halmahera* helps preserve the species while maintaining ecological balance. In-situ conservation involves safeguarding habitats to ensure the continued survival and health of all species within the ecosystem **(Jaisankar *et al.*, 2018)**.

CONCLUSION

This study identified two distinct cohorts within the *Hemiscyllium halmahera* population, indicating the presence of different generations and providing insight into the species' population structure. The analysis of class intervals supported the cohort findings by illustrating the distribution and abundance of individuals within specific size ranges. The sharks examined in this study exhibited a plump body condition, suggesting that the surrounding habitat offers a supportive environment characterized by adequate food availability and protection. Furthermore, the observed marine environmental parameters

were within normal ranges, contributing to ecological stability and comfort for *H. halmahera*. These findings underscore the importance of the Tawabi Island ecosystem in sustaining the species, even if it may function more as a feeding or resting area rather than a primary nursery ground.

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