Growth, mortality, and reproductive model of Bombay duck (*Harpodon nehereus,* Hamilton 1822) in Juata Laut waters, North Kalimantan

[1]Gazali Salim, [2]Azis, [3]Abdul M. Prasetia, [4]Agus Indarjo, [2]Rukisah, [5]Meiryani, [1]Lailaturrif'ah, [1]Eka Wulandari, [1]Abdul Jalil, [1]Muhammad A. Fauzi, [6]Tamrin Toha, [7]Sutrisno Anggoro, [8]Julian Ransangan, [9]Mujiyanto Mujiyanto

[1] Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Borneo University, Tarakan, Indonesia; [2] Department of Aquaculture, Faculty of Fisheries and Marine Science, Borneo University, Tarakan, Indonesia; [3] Department of Electrical Engineering, Faculty of Engineering, Borneo University, Tarakan, Indonesia; [4] Department of Marine Science, Faculty of Fisheries and Marine Science, Diponegoro University Semarang, Indonesia; [5] Accounting Department, Faculty of Economics and Communication, Bina Nusantara University, Jakarta, Indonesia; [6] Local Government of Fisheries for Tarakan City, Indonesia; [7] Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Diponegoro University Semarang, Central Java, Indonesia; [8] Borneo Marine Research Institute, University Malaysia Sabah, Malaysia; [9] Research Center for Conservation of Marine and Inland Water Resources, National Innovation Research Agency, Republic of Indonesia. Corresponding author: G. Salim, axza_oke@yahoo.com

Abstract. Bombay-duck (*Harpadon nehereus*) is a valuable commodity in Tarakan City, with significant economic potential, but there has been a decline in its population due to maximum utilization. Therefore, this study aimed to analyze the growth, mortality, and reproduction of *H. nehereus*. The study activities were conducted over a period of 4 months, from June to September 2022 in the Juata Laut areas, North Kalimantan using a descriptive and quantitative approach. Sampling was carried out using a mini-trawl fishing gear in Tarakan Sea, East Kalimantan, and the male fish were found to be more abundant than females. The results showed that the length-weight relationship was negatively allometric, with fat and thin body shapes in males and females, respectively. The growth, mortality, and exploitation rate model of males were found to be higher compared to females. Furthermore, the male and female gonads were dominant at GML I and II, respectively. In terms of first maturity size, the females had a faster growth rate compared to the males, who had a greater gonad maturity index value. Based on the results, proper ecological management can be implemented to sustain the *H. nehereus* population.
Key Words: growth model, mortality, reproductive, traditional fishing.

Introduction. Based on local administration, Juata Laut waters are part of the waterbodies in Tarakan City Regency, North Kalimantan Province, consisting of two main islands, namely Tarakan and Sadau. Furthermore, Tarakan City has an area of approximately 254.18 km^2, of which 98.22% is an island (249.65 km^2) and 1.78% is seawater (4.53 km^2) (The Audit Board of The Republic of Indonesia, Representatives of the North Kalimantan Province 2022). The ocean in this area has been reported to have significant potential for the fishery industry and can provide economic opportunities for the livelihood of the local population. One of the valuable fishery productions in the city is the catch of Bombay-duck (*Harpadon nehereus,* Hamilton 1822), which has a high market price. The local fishermen often use various fishing tools, including "dogol (Indonesian)", "payang (Indonesian)", "traps", and mini-trawl fishing gear (BPS 2021). *H. nehereus* is often caught using a mini-trawl fishing gear, in sea waters. This product is highly valued by local people as a food ingredient and is popular among tourists as a local product, in the form of salted fish (dried fish). It is also commonly sold in several places inside and outside Tarakan City, thereby contributing to the economic growth of the area (Salim et al 2022a). Nugroho et al (2017) reported that *H. nehereus* has immense potential, with the capacity of producing 10 tons of fresh fish per month. The Central Agency of Statistics, Tarakan City Regency (BPS 2021) in line with the Directorate of Regional Potential Development of 2009 stated that West and East Kalimantan produced ±44 and ±149 tons of fisheries, respectively. This suggests that the potential for fisheries capture in all Kalimantan regions is estimated to be 807 tons annually. Based on previous reports, there has been a recent increase in fisheries production due to the increased use of mini-trawl fishing equipment. *H. nehereus* has been reported to be one of the species with the highest catch rate and a high market price compared to others. However, it is important to utilize its economic potential while maintaining sustainable practices. One of the ways to achieve this is by controlling *H. nehereus* population to ensure sustainability.

Based on interviews with fishermen in the Juata Sea area of Tarakan City, there has been a decrease in catches due to an increase in the use of mini-trawl fishing gear. Consequently, fishermen had to venture into the Nunukan waters, Nunukan Regency, East Kalimantan. Despite the decrease in *H. nehereus* catch in Juata Laut waters, it has been noted that catching was only carried out during low tide, twice a month, with an interval of five days. This increased fishing effort caused degradation in the size and population of the species, as indicated by a decrease in catch from 10-15 baskets to 2-3 baskets. Setiawan (2022) stated that continuous exploitation of *H. nehereus* without paying attention to ecological conditions can alter its endemicity. To address this issue, Indarjo et al (2022) suggested that a domestication model can be implemented to conserve the species, but data on growth, mortality, size at first maturity, and reproduction are also important in the conservation efforts. Therefore, this study aimed to analyze the growth, mortality, and reproduction of *H. nehereus* in the Juata Laut area, Tarakan City.

Material and Method

Description of the study. This study was carried out over a period of 4 months, from June to September 2022. Furthermore, sampling was performed 4 times each month, for a total of 17 times, to collect data on the growth, mortality, and reproduction of *H. nehereus*. The study stations were determined using the purposive sampling method, based on the catch location of local fishermen in the Juata Laut waters, Tarakan City Regency, North Kalimantan, Republic of Indonesia, as shown in Figure 1.

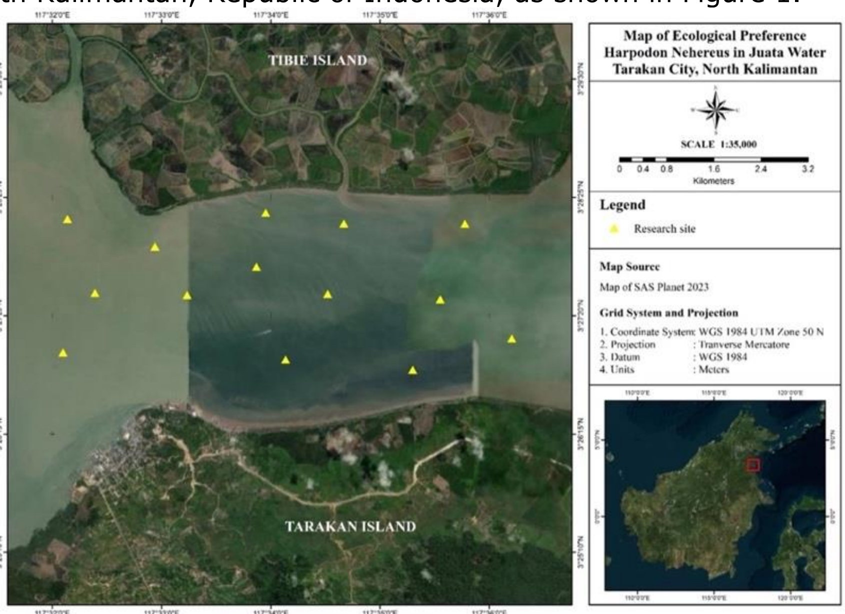


Figure 1. Map of research stations.

Research methods. The method used descriptive quantitative methods. Data was collected through direct field surveys by following mini-trawl fishermen with GPS to map (3^0 57,356' East Latitude, 117^0 56,325' Southern Latitude). Data collection for *H. nehereus* was carried out by purposive random sampling, with primary data in total length, total weight, sex, gonad weight, gonad length, and the number of eggs.

Data analysis. Analysis of nomei fish data on growth variables using the Von Bertalanffy model formula, the allometric model and the condition index model using data in the form of total length, total weight and sex (Salim et al 2022b; Indarjo et al 2023). Mortality data processing variables use the model formula of natural mortality, catch mortality, total mortality and exploitation rate using advanced data from the Von Bertalanffy model (Salim et al 2022b; Indarjo et al 2023). Reproduction data processing variable uses the following formulas: the Gonad Maturity Level (GML), Gonad Maturity Index (GMI), the First Maturity Size (FMS) using sex data, visualization observations, gonadal weight, total weight, total length (Firdaus et al 2013b).
a) Fish population. The population of *H. nehereus* was analyzed using an absolute growth approach using the Von Bertalanffy Equations (Sparre et al 1999):

$$Lt = L\infty\ (1 - e^{-k\ (t - to)})$$

Where:
Lt - expected length of fish at age t (cm);
L∞ - asymptotic average length (at infinite; in cm);
K - growth rate coefficient (per day);
to - estimated theoretical age of fish at zero length;
e - constant (= 2.71828).

b) Age structure. The age structure analysis uses the mode class shift method with the Von Bertalanffy model as described in Sparre et al (1999), namely:

$$(\Delta L/\Delta t) = (L_2 - L_1) / (t_2 - t_1) \text{ and } L_{(t)} = (L_2 + L_1) /2.$$

Where:
(ΔL/Δt) - relative growth;
ΔL - fish length;
Δt - time period;
L(t) - the average length mode.

By plotting the values of $L_{(t)}$ and (ΔL/Δt), a regression linear formula is obtained:

$$y = a + bx$$

Where:
a - $((\Sigma y/n) - (b\ (\Sigma x/n)))$;
b - $(n\Sigma(xy) - (\Sigma x) * (\Sigma y)) / (n\Sigma x^2 - (\Sigma x)^2)$;
n - total samples;
x - value $L_{(t)}$;
y - value (ΔL/Δt).

The average value of the length mode of the method was used to calculate the asymptotic length (L∞) and the growth coefficient (K):

$$K = - b$$
$$L_\infty = - a / b$$

To determine the value of the theoretical age t_0 (the theoretical time at zero fish length) the Pauly (1984) model was used:

$$\text{Log}\ (-t_0) = 0.3922 - 0.2752\ \text{Log}\ (L_\infty) - 1.0382\ \text{Log}\ k$$

To derive the relative age at various lengths from the Von Bertalanffy model the following equations were used, according to Gulland (1976):

$$-\ln (1-Lt/L_\infty) = - K (t_0) + K (t)$$
$$t = t_0 - \ln * (1 - (Lt / L_\infty)$$

c) Allometry. The length-weight relationship correlation was analyzed to determine the growth pattern, by entering length and weight data converted into logarithmic form and then processing using SPSS 16.0 software with linear regression method (Sarwono 2006). The length-weight relationship model used the following Effendie (1979) formulae:

$$Y= a X^b \quad \text{or} \quad \text{Log } Y = \text{Log } a + b \text{ Log } X \quad \text{or} \quad W = a L^b$$

d) Condition factor. To value of KTI (Condition Factor) for an isometric growth is was determined by using the following formula (Effendie 1979):

$$K_{(TI)} = 10^5 \text{ x } \frac{W}{L}$$

Where:
$K_{(TI)}$ - condition factor;
W - apparent weight of fish (g);
L - fish length (mm).

The value the formula is taken so that K(TI) approaches the value of 1.

According to Weatherley (1972), the condition factor of fish with allometric growth properties can be determined by the following method:

$$Kn = \frac{W}{\hat{W}}$$

Where:
Kn - condition factor;
W - total fish weight (g) / total weight measurement (g);
$\hat{W}$ - estimated fish weight (g) / ideal weight estimate (g);
$\hat{W}$ - a L^b ($\hat{W}$ is derived from the length-weight regression equation).

The condition index criteria according to Salim et al (2020) are as follows:
1. The range the of condition index values is from 0.1 to 1.51 for a skinny body shape,
2. The condition index values range from 0.1 to 0.49 for a thin body,
3. The condition index value is 1 for a proportional body shape,
4. The condition index values range from 1.01 to 1.50 for a fat body shape,
5. The condition index values are >1.50 for an obese body shape.

e) Gonad Maturity Level (GML). Table 1 shows the method used in classifying the level of gonadal maturity. The classification was based on fieldwork observation and included an analysis of gonad progression and spawning seasons. Furthermore, the analysis was carried out using a descriptive-analytical quantitative approach, which involved calculating the change percentage of the number of fish at a certain maturity level and the maturity index for each month (Achmad et al 2019). The indices of gonad maturity were obtained by calculating the ratio of the weight of the gonad and fish bodies, multiplied by 100% (Andrade et al 2003; Austin et al 2008; Achmad et al 2019).

Table 1

Gonad maturity stages of male *Harpadon nehereus*

Stage	*Image of male gonads*	*Gonad maturity levels**
I		Gonad maturity Stage I in males was clear white, with a shape like a thread.
II		Gonad maturity Stage II in males was milky brown with slightly visible blood cells.
III		Gonad maturity Stage III in males was slightly reddish brown with visible blood cells.
IV		Gonad maturity Stage IV in males was slightly pale brown.
V	-	-

*Tan & Tan (1974); Gosh et al (2009); Dopeikar et al (2015).

Table 2

Gonad maturity stages of female *Harpadon nehereus*

Stage	*Image of female gonads*	*Gonad maturity levels**
I		Gonad maturity Stage I in females was like a clear white thread and was difficult to determine in some cases.
II		Gonad maturity Stage II in females was milky white and slightly reddish. Blood cells in fish began to appear.
III		Gonad maturity Stage III in females was reddish brown in color, the blood cells were clearly visible, and the eggs were rather dense.
IV		Gonad maturity Stage IV in the females was bright red in color with visible blood cells and the eggs were very dense.
V	-	Gonad maturity Stage V in female nomei fish (*H. nehereus*) had started to turn white and the eggs were very dense.

*Tan & Tan (1974); Gosh et al (2009); Dopeikar et al (2015).

f) Gonad Maturity Index (GMI). To analyze data regarding the gonadal maturity index (GMI), Effendie (1979) suggested using the following formula:

$$GMI\ (\%) = \frac{B_g}{B_t}$$

Where:
GMI - gonadal maturity index (%);
Bg - gonadal weight in (g);
Bt - body weight in (g).

g) The First Maturity Size (FMS). The size of first maturity (Lm) was calculated using Spearman-Karber formula (Udupa 1986):

$$Log\ Lm = X_k + d/2 - (d * \Sigma p_i)$$

Where:
d = xi +1- xi, for i = 1, 2, …., k-1
$p_i = r_i / n_i$; $q_i = 1 - p_i$
i - the middle-value logarithm of the I-th length classes.
X_k - the mean logarithm of the most gonad-matured length class.
n_i - fish number in the extended class I
r_i - gonadal mature fish number in length class I

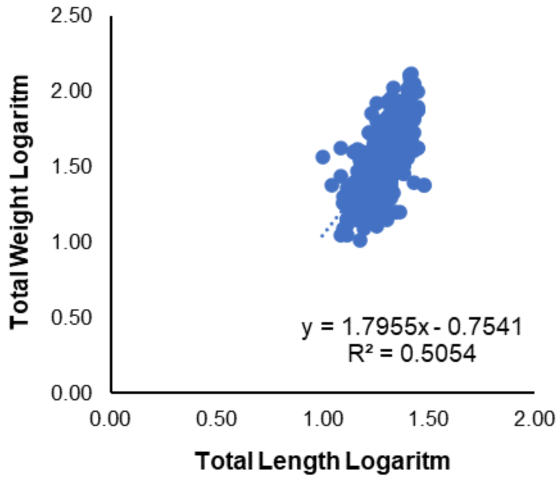
The value of the Lm range is calculated with a significance level of 5% using the formula:

$$Antilog\ \{Log\ Lm \pm 1{,}96\ \sqrt{d^2\ [pi \times qi / (ni-1)]}\}$$

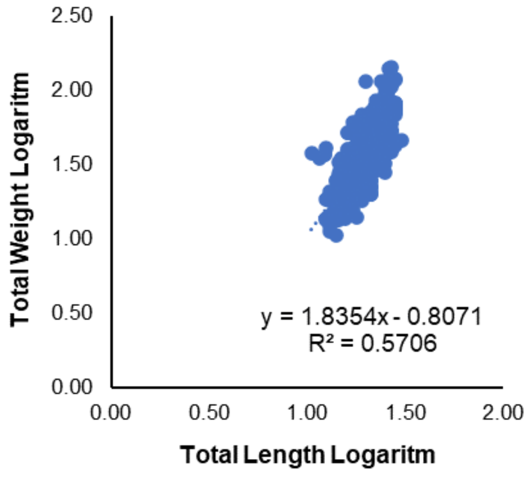
Results

Length-weight correlation. The length-weight correlation results were analyzed based on a total of 2,533 male and 1,627 female individuals. The analysis was carried out from June to September 2022 and the results are presented in Figure 2.

In fisheries biology, the length-weight correlation was a crucial factor in the management of fisheries resources, particularly in the selection of fishing tools to catch fish of the required size. It also provided information on the allometric or isometric growth conditions of a species in a population unit. As shown in Figure 2, the "b" value of the equation for the length and weight of the male species was 1.7955, while a value of 1.8354 was obtained for females. This indicated that the growth of males and females had a negative allometric pattern. The results showed that the condition of *H. nehereus* was affected by various factors, including density, gonad maturity, feed, sex, and age.



(a) Male



(b) Female

Figure 2. Length-weight relationship of *Harpadon nehereus*.

Condition index. The condition index described the size of the fishery, expressed by length and weight data. It also showed an excellent condition in terms of physical capacity to survive and reproduce.

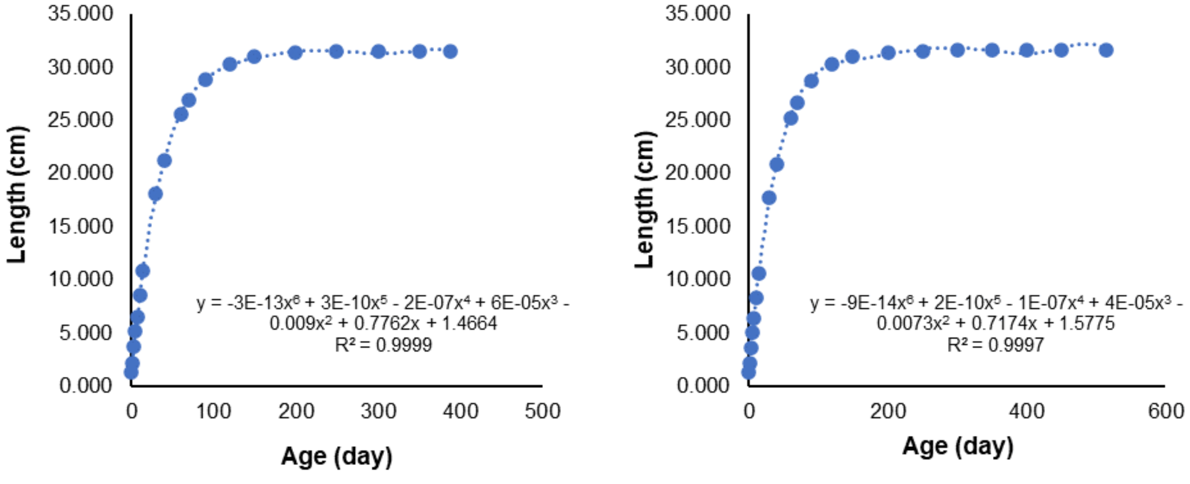
Table 3

Criteria condition index of *Harpadon nehereus*

No.	*Criteria condition index**	*Body shape*	*Male*	*Female*	*Percentage (%)*	
					Male	*Female*
1.	0	There isn't any	0	0	0.0	0.0
2.	0.1 to 0.49	Very thin	13	4	0.5	0.2
3.	0.50 to 0.99	Thin	1189	788	46.9	48.4
4.	1	Proportional	44	35	1.7	2.2
5.	1.01 to 1.50	Fat	1217	746	48.0	45.9
6.	>1.51	Very Fat	70	54	2.8	3.3

*The value of the Criteria Condition Index follows King (1995); Andrade et al (2003); Achmad et al (2019); Salim et al (2021, 2022a); Indaarjo et al (2021, 2022, 2023).

Model von Bertalanffy. The age structure of *H. nehereus* can be described using the Von Bertalanffy model with a polynomial orthogonal equation type. Furthermore, Figure 3 shows the relationship between age and the total length, which were represented by the x-axis and y-axis, respectively. The male orthogonal polynomial equation of type 6 was described by the equation $Y=-3e\text{-}13x^6+3e\text{-}10x^5-2e\text{-}07x^4+6e\text{-}05x^3-0.009x^2+0.7762x+1.4664$ with $R^2=0.99$ and correlation (r) value of 0.9999. Meanwhile, the female orthogonal polynomial equation type 6 was described as $Y=-9e\text{-}14x^6+2e\text{-}10x^5-1e\text{-}07x^4+4e\text{-}05x^3-0.007x^2+0.7174x+1.5775$ with $R^2=0.99$ and the correlation value (r) of 0.99. Based on these results, the correlation value between the two variables was extreme. The male growth pattern showed a significant change in the growth speed after 120 days, once it reached the size of 30.3 cm.



(a) Male | (b) Female

Figure 3. Model of Von Bertalanffy between males and females.

Gonad maturity level and gonad maturity index. Gonad Maturity Level (GML) referred to the developmental stage before and after the fish spawned, and the observation was carried out morphologically. The time taken for fish to first mature their gonads was related to growth and influential environmental factors affecting them, specifically food availability.

Table 4

Gonad maturity level between males and females

Stage	*Sample (Individuals)*		*Percentage (%)*	
	Male	*Female*	*Male*	*Female*
I	2295	1331	90.6	81.8
II	150	185	5.9	11.4
III	64	62	2.5	3.8
IV	24	49	0.9	3.0
V	-	-	-	-

H. nehereus in the Juata Laut waters of Tarakan City exhibited varying GML, which indicated the levels of gonad maturity at each sampling time, as shown in Table 4. The variations in GML obtained at each sampling time suggested that these fish spawn throughout the year. Due to the year-round spawning, the GML composition consisted of various groups with unequal percentages. A high rate of considerable gonad maturity indicated the peak of spawning.

Quantitative changes occurring in the gonads can be determined based on the GMI, which was the ratio between the weight of the gonads and the body. Furthermore, the mean index for males ranged from 2.3 to 14, while for females, it was 2.1 to 14.2. Based on observations, the value of the GMI for females was relatively more significant compared to males, as shown in Table 5.

Table 5

Calculation of Gonad Maturity Index (GMI) *Harpadon nehereus from* June to September 2022

Stage	*Body-weight (g)*		*Gonad-weight (cm)*		*Percentage of GMI (%)*	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
I	10.3-131.4	10.6-123.8	0.1-0.3	0.1-0.3	0.08-3.88	0.09-3.23
II	22.3-106.2	19.85-86.6	0.4-1.0	0.4-0.9	0.47-3.00	0.57-2.89
III	10.3-120.4	23.3-105.9	1.0-2.0	1.0-1.8	1.00-7.90	1.04-6.01
IV	12.8-127.3	16.0-142.6	1.7-4.48	1.6-12.5	1.6-12.7	2.41-44.78
V	-	-	-	-	-	-

The calculation results showed that the first maturity size (FMS) of the male species was of 16.8 cm length, with a maximum length of 16.9 cm. Furthermore, the gonads matured for the first time at 17.1 cm with a total length of 17.2 cm, as shown in Table 6.

Table 6

First maturity size of *Harpadon nehereus* from June to September 2022 period

Sex	*First maturity size*	
	Lower limit	*Upper limit*
Male	16.8	16.9
Female	17.1	17.2

Discussion. The presence of different types of water influenced the behavior of fisheries, causing them to spend more energy while carrying out their activities of foraging for food compared to other fish living in calm waters (Indarjo et al 2021,2022). The results showed that the growth and weight of males, females, and combined fish can be explained by a negative allometric relationship, where length growth was faster than weight. The "b" value for males and females was $b<3$, which was consistent with Ibrahim et al (2017) and Indarjo et al (2023) that when $b=3$, the weight gain was balanced with the length (isometric). Meanwhile, if the value of $b<3$, then the growth in size was faster compared to the weight increase (negative allometric). The results also showed that a 'b' value >3 indicated the presence of a faster length increase compared to the weight gain (positive allometric). The length-weight relationship of *H. nehereus* from June to September was examined, and the correlation coefficient ("r" value) for females was calculated. The calculation results showed the presence of a strong relationship. A value of r close to 1, indicates a substantial length-to-weight connection (Windarti 2020), while a weak association is shown by a small. According to Mulfizar (2012), fish living in fast-flowing waters have a lower b value, while those in calm currents have a significantly higher value.

The condition index was a valuable tool for evaluating the significance of various fish spawning areas as well as the spawning season. Table 3 shows that the range of *H. nehereus* male condition factors during the study was from 0.1 to >1.51. Furthermore, the lowest index criteria for males were very thin body shape, while the highest with fat body shape. The lowest condition index criteria for females were very thin body shape, while the highest with a thin body shape.

The length-weight relationship of the samples was influenced by the availability of natural food and by the environmental conditions supporting growth. Variations in the length and weight caused differences in the condition index and affected the condition of the fish that were spawning. These findings are consistent with Aisyah et al (2017) that spawning was one of the causes of changes in the fish condition index. Commercial condition factor values have been reported to be essential in determining the quality and quantity of fish meat available for consumption (Wujdi et al 2012).

The model von Bertalanffy suggested that males reached an asymptotic growth of 29.9 cm at an age of 299 days, with an average growth rate of 0.0348 cm per day. Furthermore, this model can be applied to estimate the age of the fish in the range of 27 to 30 days old. In the Juata Laut waters of Tarakan City, the male fish typically reached a gonadal size of 16.8 to 16.9 cm at the first maturity size, which is important in maintaining population sustainability. Based on the model analysis, the transition from the gonad maturity to a slower growth rate occurred at the size of 27 cm or at the age of 65 days. The age range from day 65 to day 299 suggested a repetitive pattern of the weight growth and of the gonad maturity, while the growth in total length from 27 cm to 29.9 cm took a relatively long period. The Von Bertalanffy model also explained that the asymptotic size of females was 27.2 cm at an age of 396 days, with an average growth rate of 0.03 cm per day. The application of this model can estimate the age of female fish in the range of 37 to 38 days old.

The age structure was an essential component of fisheries biology. Furthermore, the fish age, length, and weight relationships can provide information on the age at first maturity, the lifespan, growth, mortality, and reproduction (Firdaus et al 2013a; Salim et al 2022b). The number of fish in each class at any given time depended on the recruitment occurring each year, and most of the lost species were due to human exploitation or natural causes. The analysis of the Petersen model, which was the basis for Von Bertalanffy's growth, showed that the length scale of both male and female species had shifted to the right (Figure 3). This indicated an increase in the population of the species around the study area. Furthermore, old fish continued to grow, but the rate decreased due to the lack of food, which was absorbed for body maintenance, movement, reproduction, or for avoiding predators (Firdaus et al 2013a).

Based on the genital maturity level (GML), the majority of the samples obtained were categorized as GML I (90.6%). This suggested that in the study areas fish were primarily focused on discovering food, and energy obtained was likely used for growth. *H. nehereus* were found to have reached the first stage of gonad development while still experiencing a reasonably fast growth period. At this stage, the energy in their body was divided between the growth of length and gonad, which was essential for maintaining stability and avoiding predators, including fishermen. Furthermore, for most fish, mortality was caused by natural factors, such as predators or competition for food, which can lead to cannibalism within the population. *H. nehereus* is cannibalistic species, as evidenced by several catches, where small fish were found in the mouth and stomach of larger species. Based on the age and total length, females tended to reach the height of their first maturity size (FMS) faster compared to males. This was because females required gonad growth (for reproduction) to maintain population sustainability.

The GML showed that the majority of the samples were obtained in the areas, which were mostly used for foraging. The Von Bertalanffy growth curve revealed that the fish reached their first stage of gonad development while still experiencing a reasonably fast growth period. Furthermore, the energy obtained was used for the growth of gonads and body length. Based on the results, the dominant cause of death was natural factors, and females tended to have a higher mortality rate compared to males, leading to population degradation. The catch mortality and exploitation rate revealed that females were caught at lower rates compared to males. Effendie (1979) reported that *H. nehereus* experienced rapid growth in size at the beginning of their life but slowed down as they reached the maximum length. Restiangsih et al (2016) also stated that various factors, such as habitat, food availability, age, fishing gear, and environmental conditions can impact the size of fish in different waters. According to Kasmi et al (2017) & Kantun et al (2018), high and low GMI were caused by environmental factors, which were directly related to food availability as an energy source for somatic development and reproduction. An increase in the GMI value was one of the indicators of the spawning season, and this is consistent with Arrafi et al (2016). According to the criteria of Pauly (1984), the Juata Laut waters exceeded the specified sustainable limit during the study. Although the maximum total sustainable use of 50%was exceeded by only a small percentage, Kurniawati et al (2016) stated that this was a warning in the management of *H. nehereus* resources, specifically in the Juata Laut waters of Tarakan City. Siby et al (2009) stated that the first maturity size (FMS) can be characterized periodically in order to predict population pressure. According to Kamal et al (2020), the presence of different FMS was a fish reproductive strategy to restore population balance, due to changing conditions, abiotic factors, and overfishing. Dahlan et al (2015) reported that the size and age of the first maturity gonads differed across various species. Several factors can affect the FMS, including sex, diversity, age, size, and physiological characteristics.

Mahmoud (2009) reported that sex cells can be collected in both solitary and cluster form without a membrane. Oocytes at the alveoli cortical stage were reported to be deposits of trophic compounds, while those at the vitellogenin stage were characterized by an improvement in quantity and yolk vesicle. These improvements were indicated by an increase in protein granules and fat acquisitions. Skoblina (2010) stated that the oocyte hydration process was characterized by the formation of yolk globule proteins influenced by proteolytic lysosomal enzymes due to germinal vesicle breakdown. This finding is consistent with Dorostghoal et al (2009): the stage was indicated by the presence of yolk globules, which filled the entire cytoplasm, while the nucleus moved towards the animal pole. Achmad et al (2019) and Brulé et al (2016) also stated that the development of spermatocytes was found at the stage of maturity of fish gonads, classified as the *gonochorism* type. Therefore, the fish size at first gonadal maturity was not consistently similar (Effendie 1979). Gonad development was influenced by two factors, including environmental and hormonal factors (Ghosh et al 2009). Vidyastari et al (2020) reported that spawning usually occurred after the peaks of maturity, leading to a decrease in GML in the subsequent stages.

Conclusions. The length-weight correlation between males and females of *H. nehereus* had negative allometric growth characteristics. The body shape of the males was dominantly fat, while the females were thin. Furthermore, the Von Bertalanffy model's results showed that asymptotic growth in males was higher, suggesting that they experienced more mortality and exploitation compared to the females. In terms of geographical location, the fish were predominantly found in GML I. The index of gonad maturity in males was considerably higher compared to females, indicating that they had a faster maturation rate.

Acknowledgements. The researchers would like to thank the Ministry of Education and Culture, the Republic of Indonesia. Also, we would like to thank the Borneo Tarakan University and The Institute for Research and Community Service (LPPM UBT in

Indonesian) for funding the Research by the Second Stage of Higher Education Applied Research Scheme in 2022.

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

References

Achmad D. S., Ali S. A. A., Indar Y. N., 2019 The gonad maturity development and spawning season of orange-spotted grouper (*Epinephelus coioides*) at Kwandang Bay, Gorontalo Province, Indonesia. AACL Bioflux 12(2):642-649.

Aisyah S., Bakti D., Desrita, 2017 [The growth pattern and condition factor of Lemeduk fish (*Barbodes schwanenfeldii*) in Belumai River Deli Serdang, North Sumatera Province]. Acta Aquatica 4(1): 8-12. [In Indonesian].

Andrade A. B., Machado L. F., Hostim-Silva M., Barreiros J. P., 2003 Reproductive biology of the Dusky grouper *Epinephelus marginatus* Lowe, 1834. Brazillian Archives of Biology and Technology 463:373-381.

Arrafi M., Ambak A., Rumeaida P., Muchlisin Z. A., 2016 Biology of Indian mackerel, *Rastrelliger kanagurta* (Cuvier,1817) in the western waters of Aceh. Iranian Journal of Fisheries Sciences 15(3):957-972.

Austin E., Lucey S., Stormer D., Juanes F., 2008 Michael King: Review of ‟Fisheries Biology, assessment, and management. Reviews in Fish Biology and Fisheries 18:451-452.

Brulé T., Caballero-Arango D., Renan X., Colas-Marrufo T., 2016 Confirmation of functional hermaphroditism in six grouper species Epinephelidae: Epinephelinae from the Gulf of Mexico. Cybium 401:83-92.

Dahlan M. A., Omar S. B. A., Tresnati J., Umar M. T., Nur M., 2015 [Sex ratio and first gonadal maturity size of Mackerel fish (*Decaptrerus macrosomo* Bleeker, 1841) from the waters of Bone Strait, South Sulawesi]. Torani: Journal of Fisheries and Marine Science 25(1):25-29. [In Indonesian].

Dopeikar H., Keivany Y., Shadkhast H., 2015 Reproductive biology and gonad histology of Kura Barbel, *Barbus lacerta* (Cyprinidae), in Bibi-Sayyedan River, Tigris Basin. North-Western Journal of Zoology 11:141402.

Dorostghoal M., Peyghan R., Papan F., Khalili L., 2009 Macroscopic and microscopic studies of annual ovarian maturation cycle of Shirbot *Barbus grypus* in Karoon River of Iran. Iranian Journal of Veterinary Research 10(2):172-179.

Effendie M. I., 1979 [Fisheries biological methods]. Yayasan Dwi Sri Press, Bogor, 111 p. [In Indonesian].

Firdaus M., Salim G., 2018 Study population of mudskipper (*Periophthalmus barbarus*) in Bekantan and Mangrove Conservation Area, Tarakan City, North Kalimantan. Borneo Saintek of University of Borneo Tarakan Journal 1(3):68–78.

Firdaus M., Salim G., Cahyadi J., Weliyadi E., Bintoro G., 2020 Model and nature of growth of red snapper fish (*Lutjanus argentimaculatus* (Forsskål, 1775) fishing catch of bottom fish pots in Bunyu waters, North Kalimantan. AACL Bioflux 13(3):1410-1421.

Firdaus M., Salim G., Maradhy E., Abidani I. M., Syahrun, 2013a [Growth and structural analysis of Nomei fish (*Harpodon nehereus*) in Juata Laut waters, Tarakan City]. Jurnal Akuatika 4(2):159-173. [In Indonesian].

Firdaus M., Salim G., Maradhy E., Abdiani I. M., 2013b [Biotechnical management of nomei fish (*Harpodon nehereus*) population in Tarakan City Waters (Sustainable Management Study)]. Final Report of Competing Grant Research. Universitas Borneo Tarakan, 50 p. [In Indonesian].

Ghosh S., Pillai N. G. K., Dhokia H. K., 2009 Fishery and population dynamics of *Harpadon nehereus* (Ham) off Saurashtra Coast. Indian Journal of Fish 56(1):13-19.

Ibrahim P. S., Setyobudiandi I., Sulistiono S., 2017 [Length-weight relationship and condition factors of yellow mackerel (*Selaroides leptolepis*) in Sunda Strait waters]. Jurnal Ilmu dan Teknologi Kelautan Tropis 9(2):577-584. [In Indonesian].

Indarjo A., Salim G., Maryanto T. I., Ngungut, Linting L. A., Firdaus M., Rozi, Rukisah, 2023 Growth patterns and mortality of lobster *Panulirus ornatus* from the catch of bottom gill net fishers in the western waters of Tarakan Island. HAYATI Journal of Biosciences 30(3):532-542.
Indarjo A., Salim G., Nugraeni C. D., Anggoro S., Maryanto T. I., Prakoso L. Y., Pramono B., Azis, Meiryani, Ransangan J., Khasani I., 2022 Preliminary study on the domestication of giant freshwater prawn, *Macrobrachium rosenbergii* (De Man, 1879) from North Kalimantan, Indonesia. AACL Bioflux 15(6):3121-3130.
Indarjo A., Salim G., Nugraeni C. D., Zein M., Ransangan J., Prakoso L. Y., Suhirwan Anggoro S., 2021 Length-weight relationship, sex ratio, mortality and growth condition of natural stock of *Macrobrachium rosenbergii* from the estuarine systems of North Kalimantan, Indonesia. Biodiversitas 22:846-857.
Kamal M. M., Ernawati Y., Dewi N. N., 2020 Length at first maturity, spawning time, and reproductive output in the females of Hamilton's anchovy (*Thryssa hamiltonii* Gray, 1835). Jurnal Biologi Tropis 20(1):1-6.
Kantun W., Kasmi M., Syamsul H., Asti S., 2018 Reproductive biology of Indian mackerel *Rastreliger kanagurta* (Cuvier, 1816) in Makassar coastal waters, South Sulawesi, Indonesia. AACL Bioflux 11(4):1183-1192.
Kasmi M., Kantun W., Syamsul H., 2017 [Reproductive biology of Indian mackerel, *Rastreliger kanagurta* (Cuvier, 1816) in Takalar Coastal Waters, South Sulawesi]. Jurnal Iktiologi Indonesia 17(3):259-271. [In Indonesian].
Kurniawati K., Ghofar A., Sapuutra S. W., Nugraha B., 2016 [Growth and mortality bigeye tuna (*Thunnus obesus*) in Indian Ocean were landed in Benoa Harbour, Denpasar, Bali]. Journal of Maquares: Management of Aquatic Resources 5(4):371-380. [In Indonesian].
Mahmoud H. H., 2009 Gonadal maturation and histological observation of *Epinephelus areolatus* and *Lethrinus nebulosus* in Halaieb/Shalatien Area "Red Sea", Egypt. Global Veterinaria 3(5):414-423.
Mulfizar M., Zainal A., Muchlisin M., Dewiyanti I., 2012 [Length-weight relationship and condition factors of three fishes found in Gigieng estuary of Aceh Besar, Aceh Province]. Depik 1(1):1-9. [In Indonesian].
Nugroho E. D., Vlorensius V., Salurapa A., 2017 [Spawning preference and habitat of Nomei fish (*Harpodon nehereus*) in Juata Laut Tarakan waters as a conservation effort]. Jurnal Ilmiah Biologi 5(1):55-60. [In Indonesian].
Pauly D., 1984 Fish population dynamics in tropical waters: A manual for use with programmable calculators. ICLARM Studies and Review, 325 p.
Restiangsih Y. H., Noegroho T., Wagiyo K., 2016 [Biological aspects of Indo-Pacific King MackereL (*Scomberomorus guttatus*) in Cilacap and adjacent waters]. BAWAL 8(3):191-198. [In Indonesian].
Salim G., 2013 [Condition index value of *Siganus javus* based on fishermen's catch in Juata Waters, Tarakan City]. Jurnal Harpodon Borneo 6(1):37-42. [In Indonesian].
Salim G., 2015 [Analysis of allometric growth and condition index of Caesio Cunning captured by Fishermen of Tarakan City]. Jurnal Harpodon Borneo 8(1):35-42. [In Indonesian].
Salim G., Handayani K. R., Anggoro S., Indarjo A., Syakti A. D., Ibrahim A. J., Ransangan J., Prakoso L. Y., 2020 Morphometric analysis of *Harpodon nehereus, Harpiosquilla raphidea*, and *Scylla serrata* in the coastal waters of Tarakan, North Kalimantan, Indonesia. Biodiversitas 21:4829-4838.
Salim G., Handayani K. R., Indarjo A., Ransangan J., Rizky R., Prakoso L. Y., Pham Y. T. H., 2021 [Characteristic of population growth and mortality of windu shrimp (*Penaeus monodon*) in Juata waters Tarakan City, Indonesia]. Jurnal Ilmiah Perikanan dan Kelautan 13(1):114-120. [In Indonesian].
Salim G., Hendrikus, Indarjo A., Prakoso L. Y., Haryono M. G., Irawan A., Ransangan J., 2022a Characteristics of model growth and mortality of white shrimp (*Penaeus merguiensis* de Man 1888) in the estuary of Bengara, Regency Bulungan. IOP Conference Series Earth Environmental Science 1083:012083.

Salim G., Rukisah R., Azis A., Firdaus, M., Toha T., Awaludin A., Prasetia A. M., Nugraeni C. D., Al-Hafizh M. F., Rahmatsyah R., Ipa H., Muslikah V., Safira R., Sastri S. S., Jati T. S., Jalil A., Fauzi M. A., Rif'ah L., Wulandari E., 2022b [Processing of Nomei fish (*Harpodon nehereus*) into Nugget in Juata Laut Area, Tarakan City]. JOMPA ABDI: Jurnal Pengabdian Masyarakat 1(3):126-136. [In Indonesian].

Sarwono J., 2006 [Quantitative and qualitative research methods]. Graha Ilmu Press, Yogyakarta, 286 p. [In Indonesian].

Setiawan W., 2022 [Climate change and overfishing drain of global fish stock]. https://nationalgeographic.grid.id/read/133463720/perubahan-iklim-dan-penangkapan-berlebihan-menguras-stok-ikan-global?page=all. [In Indonesian].

Siby L. S., Rahardjo M. F., Sjafei D. S., 2009 [Reproductive biology of red rainbowfish (*Glossolepis incisus* Weber 1907) in Sentani Lake]. Jurnal Iktiologi Indonesia 9(1):49-61. [In Indonesian].

Skoblina M. N., 2010 Hydration of oocytes in teleost fishes. Russian Journal of Developmental Biology 41(1):1-12.

Sparre P., Venema Sc., 1999 [Introduction to tropical fish stock assessment]. FAO Fisheries Technical Paper 306(1):376. [In Indonesian].

Tan S., Tan K., 1974 Biology of the tropical grouper, *Epinephelus tauvina* Forskal. I. A. Preliminary study on hermaphroditism in *E. tauvina*. Singapore Journal of Primary Industries 2(2):123-133.

Udupa K. S., 1986 Statistical method of estimating the size at first maturity in fishes. Fishbyte 4(2):8-10.

Vidyastari O., Watiniasih N. L., Pebriani D. A. A., 2020 [The reproductive biology of Scad Fish (*Decapterus* sp.) at Nusantara Fisheries Harbour in Pengambengan Jembrana, Bali]. Advances in Tropical Biodiversity and Environmental Sciences 4(1):26-29. [In Indonesian].

Weatherley A. H., 1972 Growth and ecology of the fish population. Academic Press, London, 293 p.

Windarti W., 2020 [Basic fishery biology skills]. Oceanum Press, Pekanbaru, Riau, 153 p. [In Indonesian].

Wujdi A., Suwarso S., Wudianto W., 2012 [Length-weight relationship, condition factors and size structure of Bali Sardinella (*Sardinella lemuru* Bleeker, 1853) in Bali strait waters]. Jurnal Penelitian Perikanan Indonesia 4(2):83-89. [In Indonesian].

*** BPS, Central Agency of Statistics, Tarakan City Regency, 2021 [Annual report Tarakan City 2019-2021]. https://tarakankota.bps.go.id/ [In Indonesian].

*** The Audit Board of The Republic of Indonesia, Representatives of North Kalimantan Province, 2022 [Annual Report]. https://www.bpk.go.id/en [In Indonesian].

Received: 7 March 2023. Accepted: 26 June 2023. Published online: 11 July 2023.
Authors:
Gazali Salim, Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Borneo University, Amal Lama No. 1 Tarakan, North Kalimantan 77123, Indonesia, e-mail: axza_oke@yahoo.com
Azis, Department of Aquaculture, Faculty of Fisheries and Marine Science, Borneo University. Amal Lama No. 1 Tarakan Tarakan, North Kalimantan 77123, Indonesia, e-mail: azis.borneo@gmail.com
Abdul Muis Prasetia, Department of Electrical engineering, Faculty of Engineering, Borneo University, Amal Lama No. 1 Tarakan Tarakan, North Kalimantan 77123, Indonesia, e-mail: prasetia.electric@gmail.com
Agus Indarjo, Department of Marine Science, Faculty of Fisheries and Marine Science, Diponegoro University Semarang, Prof. Soedarto, SH Tembalang Semarang, Central Java 50275, Indonesia, e-mail: indarjoa@yahoo.com
Rukisah, Department of Fisheries Aquaculture, Borneo University, Amal Lama No. 1 Tarakan Tarakan, North Kalimantan 77123, Indonesia, e-mail: kichafishery@gmail.com
Meiryani, Accounting Department, Faculty of Economics and Communication, Bina Nusantara University, Kebon Jeruk Raya No. 27, Kebon Jeruk Jakarta Barat 11530, Indonesia, e-mail: meiryani@binus.edu
Lailaturrif'ah, Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Borneo University, Amal Lama No. 1 Tarakan Tarakan, North Kalimantan 77123, Indonesia, e-mail: lailaturrifah77@gmail.com
Eka Wulandari, Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Borneo University, Amal Lama No. 1 Tarakan Tarakan, North Kalimantan 77123, Indonesia, e-mail: wulandarieka018@gmail.com
Abdul Jalil, Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Borneo University, Amal Lama No. 1 Tarakan Tarakan, North Kalimantan 77123, Indonesia, e-mail: jalil93emroglo@gmail.com
Muhammad Akmal Fauzi, Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Borneo University, Amal Lama No. 1 Tarakan Tarakan, North Kalimantan 77123, Indonesia, e-mail: Ziimall900@gmail.com
Tamrin Toha, Lokal Government of Fisheries for Tarakan City, Jendral Sudirman No. 76 Gedung Gadis II lantai 4 dan 5 Tarakan, 77112, Indonesia, e-mail: marine_borneo@yahoo.com
Sutrisno Anggoro, Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, Diponegoro University Semarang, Prof. Soedarto, SH Tembalang Semarang, Central Java 50275, Indonesia, e-mail: Sutrisnoanggoro52@gmail.com
Julian Ransangan, Borneo Marine Research Institute, University Malaysia Sabah, Locked Bag 2073, Kota Kinabalu Sabah 88999, Malaysia, e-mail: liandra@ums.edu.my
Mujiyanto Mujiyanto, Research Center for Conservation of Marine and Inland Water Resources, National Innovation Research Agency, Republic of Indonesia, Jalan Raya Jakarta-Bogor KM 48 Cibinong, 16911, Indonesia, e-mail: muji019@brin.go.id

How to cite this article:
Salim G., Azis, Prasetia A. M., Indarjo A., Rukisah, Meiryani, Lailaturrif'ah, Wulandari E., Jalil A., Fauzi M. A., Toha T., Anggoro S., Ransangan J., Mujiyanto M., 2023 Growth, mortality, and reproductive model of Bombay duck (*Harpodon nehereus*, Hamilton 1822) in Juata Laut waters, North Kalimantan. AACL Bioflux 16(4):1864-1877.