Reproduction of Indian mackerel (*Rastrelliger kanagurta*) in North Maluku waters

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Abstract. The understanding of the reproduction of a fish species is an important prerequisite for providing scientific advice for sustainable fisheries management. This study aims to analyze the reproductive parameters of Indian mackerel caught in North Maluku waters. Data analysis used a population parameter approach, using 3,000 mackerels which were caught with a mini purse seine. The parameters analyzed were the length-weight relationship, growth parameters, and gonadal maturity level and fecundity. The results obtained showed that the growth of male and female mackerel in North Maluku waters had a negative allometric pattern, which means that the increase in body length is faster than the increase in weight. The male mackerel reached a maximum length of 335.91 mm at the age of 40 months or 3.4 years, while the female mackerel reached a maximum length of 356.88 mm at the age of 47 months or 3.9 years. The maturity levels of mackerel found consisted of gonadal maturity level I to gonadal maturity level V. Mackerel was found to be dominated by gonadal immature individuals. Highest numbers of male and female mackerel with gonadal maturity were found in May with the respective percentages of 56.78% and 58.19%. Mackerel spawning occurred several times in a season with the peak spawning season found in June and July. The fecundity of female mackerel found in North Maluku waters was 26,764-81,563 eggs.
Key Words: fecundity, gonadal maturity level, growth pattern, local fishery, small pelagic fish.

Introduction. Indian mackerel (*Rastrelliger kanagurta*) is a small pelagic fish that has potential economic value and is commonly found throughout Indonesian waters (Sarasati 2017). North Maluku is one of Indonesian regions that have a large potential for mackerel resources. Mackerel in the North Maluku region is known as "kombong". This type of fish is usually caught using mini purse seines, gill nets, and hand lines (Abubakar et al 2019).

The fishing business of Indian mackerel in North Maluku waters is carried out freely in intensive and in various ways. Thus, there is a tendency for over-exploitation to meet an ever-increasing demand for mackerel in North Maluku. The high level of mackerel fishing requires good management efforts to make it a sustainable (Ibrahim et al 2017).

The increased demand for fish certainly has a positive impact on fisheries development. However, the higher demand for a resource will be followed by the higher exploitation pressure. If not wisely managed, it is feared that intensive use of fish resources will push the fishing business to the brink of collapse and the occurrence of various conflicts among fishers groups. To support the sustainable management of fish resources, adequate data and information are needed regarding the biological aspects of the fish being managed, such as mackerel.

One of the biological aspects needed for managing fish resources sustainably is reproductive biology. According to Putera & Setyobudiandi (2019), an understanding of the reproductive biology of a fish species is an important prerequisite for providing scientific advice for its sustainable management. To obtain this data and information, it is necessary to study in detail the reproductive biology aspects of mackerel. Based on previous descriptions, the purpose of this study was to analyze several reproductive parameters of male mackerel caught in North Maluku waters.

Material and Method

Research location and time. This study was carried out in Ternate City, North Maluku Province, Indonesia. Fish samples were collected at Ternate Fishing Port while data processing and analysis were conducted at Fishery Bio-ecology Laboratory of Fishery and Marine Science Faculty, Khairun University. The study was undertaken for six months, from January to June 2022.

Data collection. Reproduction analysis of Indian mackerel in North Maluku waters was carried out using fish population parameters approach and used Indian mackerel caught by a mini purse seine as study samples. The samples were taken randomly from mini purse seine boats that landed fish at Ternate Fishing Port. A number of 125 sample fish were collected every week from January to June 2022. At the end, in 24 weeks of research period, the total number of sample fish collected in this study was 3,000 individuals.

The total length of all sample fish was measured using a fish measuring board with an accuracy of 1.0 mm while the fish body weight was measured using a scale with an accuracy of 0.1 gram. Other tools used during the research were surgical instruments, glass preparations, Petri dishes, measuring cups, pipettes, microscopes, micrometers, and calculators. Chemical material used in the study was 40% formaldehyde solution.

Sample fish were grouped based on length, sex, and gonad maturity level (GML), and measurements were separately taken for each sex. Total data of fish sample was used for analysis of length-weight relationships, growth parameters, and GML. While for fecundity analysis, we only used data of female fish that had GML IV.

Analysis of length-weight relationship. Length-weight relationship analysis was carried out separately between male and female sample fish. The calculation of the length-weight relationship refers to the formula introduced by Effendie (2002) in Nasution et al (2015), namely:

$$W = a L^b$$

where: W = body weight (gram), L = total length (cm), a and b = constants.

Both a and b values were obtained by changing the above formula into additive form through a logarithmic transformation so that a simple linear regression equation was formed as follows:

$$\text{Log } W = \text{Log } a + b \text{ Log } L$$

To see whether the linear regression model can be used as an estimator of the relationship between body weight and total length, the model was statistically tested by analysis of variance (Table 1).

Table 1

Analysis of variance (at levels of confidence of 95% and 99%)

Source of variation	*Degrees of freedom*	*Sum of squares*	*Mean square*	*F*
Between	k-1	*SSB*	$MSB = \frac{SSB}{dfB}$	$\frac{MSB}{MSW}$
Within (error)	n-k	*SSW*	$MSW = \frac{SSW}{dfW}$	
Total	n-1	SST		

Carlender rule (Effendie 2002 in Kasmi et al 2017) was applied to test value of b to 3, with below calculations:

$$\sum d^2\, y.x = \sum \frac{(\sum xy)^2}{\sum x^2}$$

$$S^2yx = \frac{\sum d^2 y.x}{n-1};\ S^2b = \frac{S^2y.x}{\sum x^2};\ Sb = \sqrt{S^2}b;\ t\ calc = \frac{3-b}{Sb}$$

Interpretation of calculated b values was undertaken following Ricker (1975) in Kasmi et al (2017), where: if the value of $b < 3$ or $b > 3$, then the fish growth pattern follows an allometric growth pattern; and if $b = 3$, it is called an isometric growth pattern.

Analysis of growth parameters*.* To estimate the growth of Indian mackerel, we first determined the length frequency of the fish. Furthermore, the age group of fish was determined using the Tanaka method. This method uses total length frequencies data of fish groups as the basis for determining their cohort groups. Thus, by using Tanaka method, we can determine cohort group average length. At the end, the average length value was plotted against the age to find the growth curve for each cohort.

Estimation of the value of the fish growth coefficient (K) and the fish infinity length (L_∞) was obtained based on the Ford-Walford method (Sparre & Venema 1998). This was done by using regression analysis for the fish length at age t (Lt) with the fish length at age t+1 (Lt+1) to get K = -Ln.b and L = a/(1-b). Then, we used empirical formula (Pauly 1983 in Mosse & Hutubessy 1996) to calculate the value of t_o, as described by Tangke (2014):

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

Once the values of K, L and t_o were calculated, a growth model and long-life relationship for North Maluku mackerel could be determined by inserting the values of these growth parameters into the von Bertalanffy growth model, as follows:

$$Lt = L_\infty(1 - e^{-K(t-t_0)})$$

where: Lt = fish length at age t, L_∞ = infinity length, *e* = natural logarithm constant, K = growth coefficient, t = time, and t_o = initial time of measurement.

Analysis of gonad maturity level*.* The maturity level of the gonads was determined with microscope by examining gonadal maturity characteristics described by Effendie (1979) in Fauzi et al (2020) (Table 2). Observation of the GML was conducted separately between male and female sampled fish.

Table 2

Classification and characteristics of fish gonad maturity level (GML)

GML	*Female*	*Male*
I	- ovaries like threads; - long to the front of the body; - clear color; - slippery surface.	- size like short; - ends in the body cavity; - clear color.
II	- bigger size; - the color is dark yellowish; - eggs are not clearly visible.	- larger testes; - milky white; - the shape is clearer than GML I.
III	- the ovaries are yellow; - the eggs are visible to the eye.	- serrated surface of the testes; - the color is getting whiter; - preserved testes break easily.
IV	- larger ovaries; - yellow eggs; - eggs are easy to separate; - the oil from the eggs is not visible; - the eggs fill 1/2 - 2/3 of the body cavity.	- like GML III; - testes are clearly visible; - testes getting stiffer; - the body cavity is filled with the testes; - the color is milky white.
V	- presses intestine; - wrinkled of ovaries; - the walls are thick; - there are leftover eggs on the discharge section.	- testes on the back deflated; - discharge section is not empty.

Furthermore, determination the gonadosomatic index (GSI) was carried out by using formula given by Ningrum et al (2015):

$$GSI = \frac{GW}{BW} \times 100$$

where: GW = gonadal weight (g), and BW = body weight (g)

Analysis of fecundity. The fecundity analysis was conducted on all female sample fish having eggs at GML-IV. The ovary samples were preserved in Gilson's solution, then the number of eggs was counted by means of a combination of gravimetric, volumetric, and arithmetic methods (Effendie 2002). The combined method was as follows: after all the ovaries were weighed, 5 parts of the egg sample were taken randomly to be observed, and then the entire gonad sample was weighed. The next step was to calculate the volume of sample gonads by diluting the sample gonads in 10 or 15 cc of Gilson's solution and then take 1 cc of the diluted gonad and count its eggs total number. The calculation of fecundity was based on Murua et al (2003) formula, as follows:

$$F = \left(\frac{G}{Q}\right) x\, N$$

where: F = fecundity (grain), G = weight of the gonad (g), Q = weight of the gonad sample (g), and N = number of eggs per gonad sample (grain).

Results and Discussion

Length-weight relationship. The results of the length-weight relationship analysis of sample fish produced a growth model Log W = -4.166 + 2.665 Log L and R^2 = 0.904 (for male fish) and Log W = -4.932 + 2.990 Log L and R^2 = 0.837 (for female fish), analysis data summary presented in Table 3.

Table 3

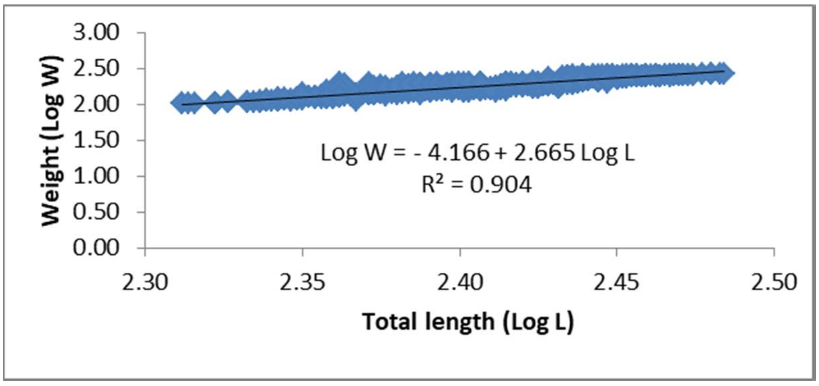
Regression analysis results of fish body length and weight

Parameter	*Male fish*	*Female fish*
Number of samples (n)	1100	1900
Ranges L (mm)	205-305	210-310
Intercept (a)	-4.166	-4.932
Slope (b)	2.665	2.990
Multiple R	0.951	0.915
R square (R^2)	0.904	0.837

The value of R is an indicator of a closeness of the relationship between fish body length gain and weight gain. The value of the regression coefficient (b) obtained showed the growth balance between the length and weight of the fish. From the resulted growth model equation, we had b = 2.66 for male fish and b = 2.99 for female fish. Thus, the b values for both male and female fish were less than 3 (b < 3). This value indicated that the growth of mackerel in North Maluku had a negative allometric pattern, which meant that the increase in fish body length was faster or more dominant than the increase in body weight.

According to Effendie (2002), the value of b is in the range of 2.4-3.5, if it is outside this range then the body shape of the fish is outside the normal shape models. The results obtained in this study is similar to research conducted by FPLHI in 2004 that found mackerel fish populations in Jakarta Bay to have a value of b = 2.87 (negative allometric pattern) (Nasution et al 2015). However, a different result was found by Mosse & Hutubessy (1996) for mackerel populations in Ambon Island (Eastern Indonesia) and in Pelabuhan Ratu (Java, Western Indonesia) with a value of b = 3.26 which showed that mackerel in both areas had a positive allometric growth pattern (meaning that the fish body weight grew faster than growth in length). Positive allometric growth patterns were also found by Abdurahiman et al (2004), Abdussamad et al (2006), Sivadas et al (2006), and Rahman & Hafzath (2012) in the Kuantan waters (Malaysia), Calicut (India), Karnataka (India), and Kakinada (India), where mackerel fish populations had the b values of 3.38, 3.08, 3.2, and 3.3, respectively. According to Effendi (1997) in Nasution et al (2015), differences in fish growth patterns are influenced by several factors, including differences in environmental conditions and food availability. The model of the long-weight relationship between male and female mackerel found in North Maluku is presented in Figure 1.

(a) Male fish



(b) Female fish

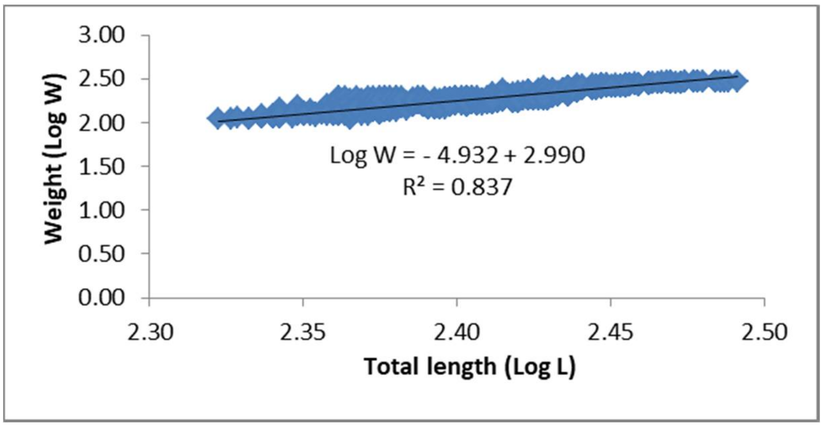


Figure 1. Length-weight relationship between male fish (a) and female fish (b) during the study period of January-June 2022.

Growth parameters. The analysis results of the body length frequency on all sample fish produced 3 age groups. The results of the growth line analysis based on the Tanaka method followed by the analysis of the Ford-Walford plot method yielded the value of the Von Bartalanffy growth parameter estimator for the North Maluku mackerel as presented in Table 4.

Table 4

Estimated value of fish growth parameters

Fish sex	*Growth parameters*		
	L_∞ (L inf)	*K (month)*	*t_0*
Male	335.91	0.38	-0.21
Female	356.88	0.33	-0.25

Thus, the growth equation for each Indian mackerel was obtained as follows:

$$Lt = 335.91\ [1-e^{-0.38\ (t\ +\ 0.21)}] \text{ for male fish}$$
$$Lt = 356.88\ [1-e^{-0.33\ (t\ +\ 0.25)}] \text{ for female fish}$$

The estimated value of growth parameters obtained indicated the relationship between growth pattern and maximum age of male and female mackerel populations in North Maluku waters, which can be presented in a growth curve as in Figure 2.

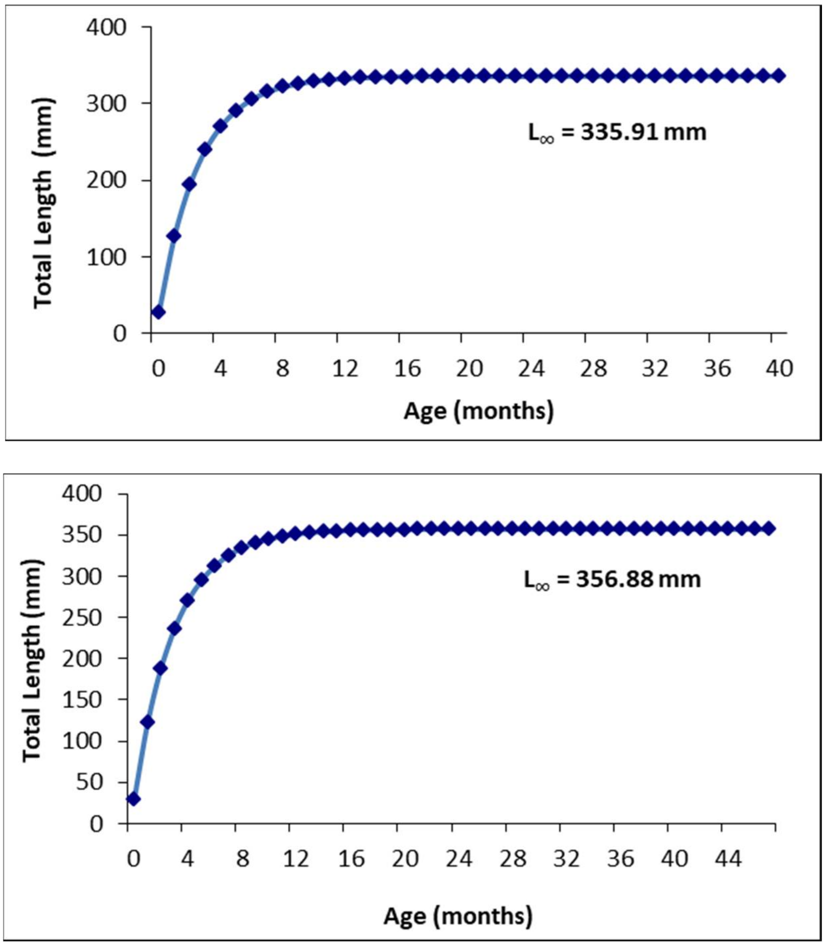


Figure 2. Length growth curve of male (top) and female (bottom) mackerel fish found in North Maluku waters in January-June 2022.

From Figure 2 it can be seen that male mackerel reached a maximum length of 335.91 mm at the age of 40 months or 3.4 years, while female mackerel reached a maximum length of 356.88 mm at the age of 47 months or 3.9 years. In other words, at the age of 40 months or 3.4 years for male mackerel and 47 months or 3.9 years for female mackerel, there was no more growth or increase in the fish body length. A similar result was found by Jayabalan et al (2014), who stated that the life span of mackerel on the Sohar Coast, Oman, was approximately 4 years. Similarly, research conducted by Nasution et al (2015) suggested that mackerel took about 48 months to reach its maximum length.

According to Rehman et al (2019), differences in growth parameters can be caused by differences in the length of sampling period, season, size of fish samples analyzed, and fishing areas. Likewise, according to Effendie (2002), the growth of fish is heavily influenced by environmental factors including the type of food, the food availability, the size of fish population, the oceanographic conditions (temperature, oxygen, etc.), and the internal factors of the fish population (such as age, heredity, and genetics).

Differences in growth parameter values found in this study were more influenced by the composition of the sample fish than the methods used. If a sample had more young fish, then the growth coefficient would be high. Conversely, if there were more old fish in a sample, the growth coefficient would tend to be low. The habit of mackerel to form schools of fish of the same size makes it difficult to obtain a representative sample of the overall length composition of the fish population in a sea region (Widodo 1988).

Gonad maturity level (GML). Examination of the GML on 1,100 male sample fish and 1,900 female sample fish found five levels of gonadal maturity, namely GML I (immature), GML II (maturing), GML III (mature), GML IV (ripe), and GML V (spent). The percentage of GML for male and female mackerel based on the month of observation is presented in Table 5. The data in Table 5 shows that male and female mackerel caught are dominated by fish that have not yet matured, namely 54.11% for male fish and 53.89% for female fish. Meanwhile, mackerel with mature gonads was 45.89% for male fish and 46.11% for female fish. Such a composition of the fish population, if it occurs for a long time, can have a negative impact on the survival of the mackerel resources in North Maluku waters.

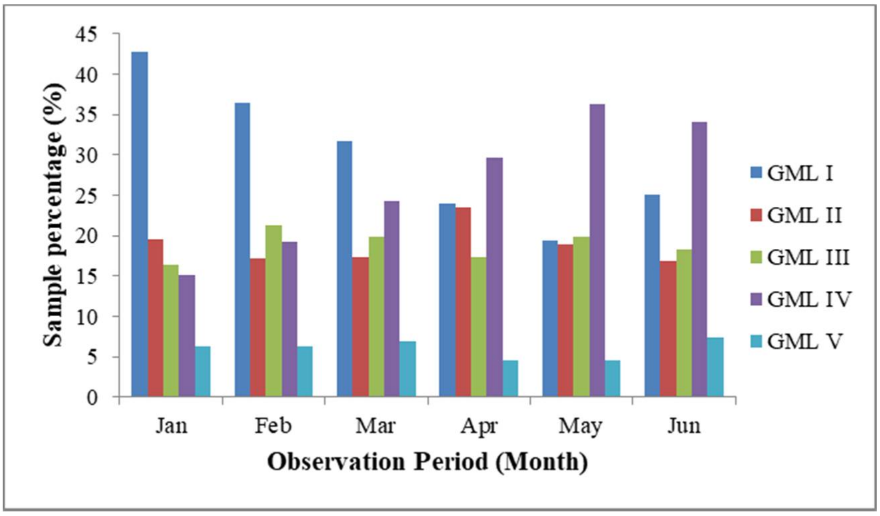
Table 5

Percentage of gonadal maturity levels for male Indian mackerel (a) and female Indian mackerel (b) in North Maluku waters, January-June 2022

Observation period (month)	*Immature gonads*		*Mature gonads*		*Number of samples (fish)*
	Sum (fish)	*Percent (%)*	*Sum (fish)*	*Percent (%)*	
Male fish					
January	109	68.55	50	31.45	159
February	115	59.59	78	40.41	193
March	90	55.90	71	44.10	161
April	93	52.54	84	47.46	177
May	86	43.22	113	56.78	199
June	102	48.46	109	51.54	211
Total	595	54.11	505	45.89	1100
Female fish					
January	232	68.44	107	31.56	339
February	176	57.14	132	42.86	308
March	186	54.87	153	45.13	339
April	166	51.88	154	48.13	320
May	125	41.81	174	58.19	299
June	139	47.12	156	52.88	295
Total	1024	53.89	876	46.11	1900

Male and female mackerel with mature gonads (GML III and IV) were found throughout the study period. The highest numbers of male and female mackerel with gonadal maturity were both found in May, namely 56.78% and 58.19% respectively. This is different from the results of Saputri's study (2017) who found that number of gonadal mature fish (GML III and IV) was found more in August and September. Kasmi et al (2017) also found different results, namely the highest number of mackerel with mature gonads was found from July to September. According to Lalèyè et al (2006), differences in the development of gonad maturity can be caused by population genetics, differences in growth rates, water quality, differences in geographic areas or conditions, and fishing pressure. This opinion is also supported by Reynolds et al (2001), De Graaf et al (2003), and Oktaviani et al (2014). Another factor was proposed by Brojo & Sari (2002) who stated that the non-uniformity of gonadal development in a fish species can also be caused by differences in spawning time between groups of fish. Fluctuations in the level of gonadal maturity for each sex of mackerel based on the months of observation are presented in Figure 3.

(a) Male fish



(b) Female fish

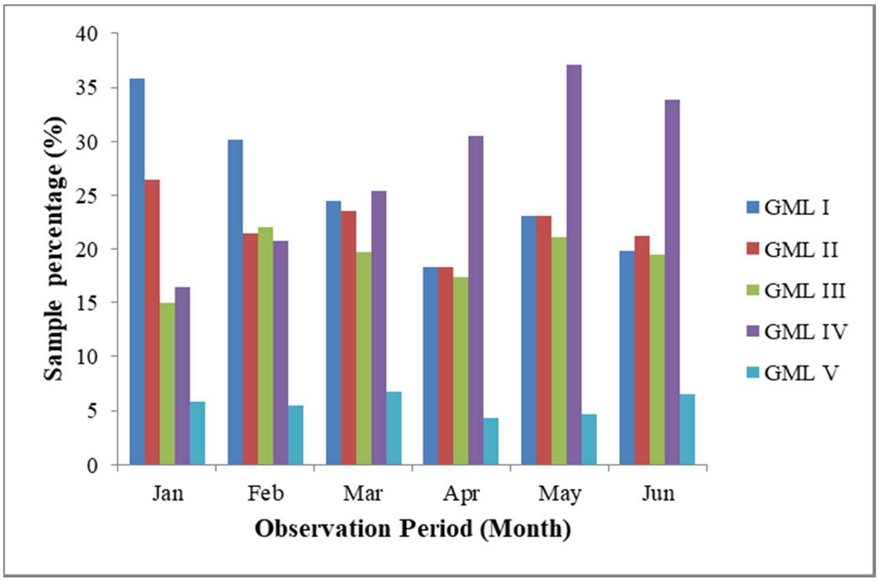


Figure 3. Fluctuations in the level of gonad maturity of male fish (a) and female fish (b) during the study period of January-June 2022.

The distribution of GML based on the time of observation of each sample fish indicates a consistent spawning pattern in mackerel populations in North Maluku. This is illustrated by the percentage of fish having mature gonad (GML III and IV). Figure 4 explains that an increase in the number of mature female mackerel is always followed by an increase in the number of male mackerel. Based on this, it can be assumed that mackerel in North Maluku waters can spawn several times in one season with the peak spawning season in June and July, which is some time after the highest gonadal maturity percentage, was reached in May. As stated by Arrafi et al (2016) that an increase in the gonadal maturity index (GMI) value of fish is an indicator of the spawning season, namely based on the GMI value every month, the peak spawning of female and male mackerel occurs after achieving the highest GMI values. This research results were the same as those obtained by Katiandagho & Marasabessy (2017) who suggested that the peak of mackerel spawning occurred in April-June. Likewise, a study by Kasmi et al (2017) showed that mackerel experienced gonadal maturity throughout the year with the peak occurring in July-August. Furthermore, Nugroho & Murdlijah (2006) explained that mackerel spawned for the first time at the age of two years which then took place periodically with two peaks per year occurring in March and October.

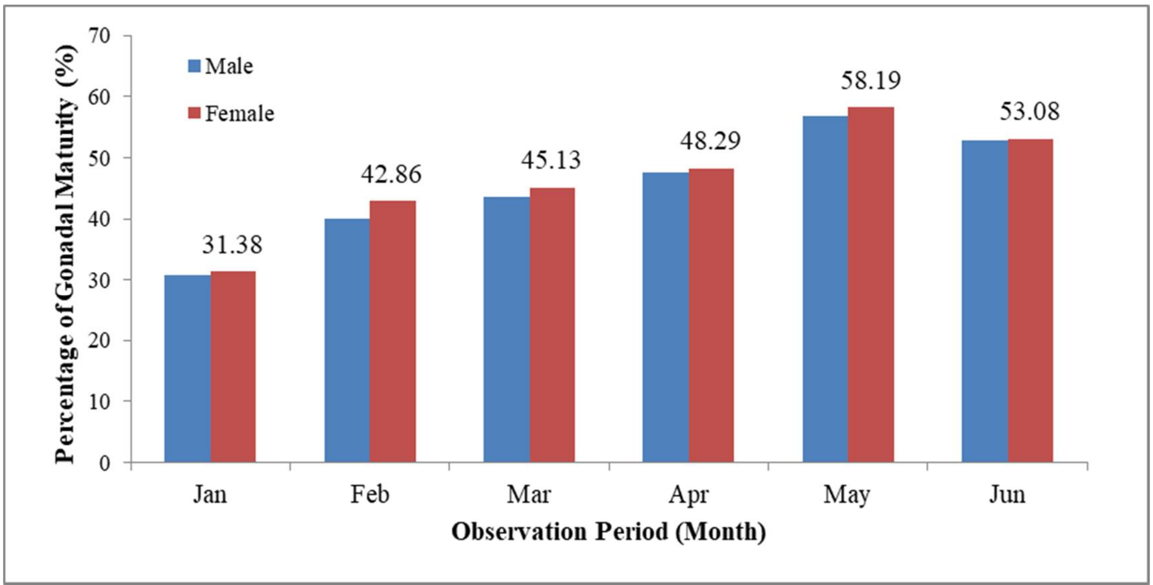


Figure 4. Number of male and female fish with mature gonads during the study period of January-June 2022.

Fecundity. The results of observations on 514 female mackerel gonads with GML IV obtained fecundity values in the range of 26,764-81,563 eggs. The existing variations in the number of eggs at various lengths of mackerel indicated the possibility of egg production occurring for each class of fish length (Table 6). The fecundity obtained in this study has a different range from the results of Harianti's study (2013) that found female mackerel individuals produced eggs in the range of 2,314-96,924 eggs with an average number of 24,075 eggs. Meanwhile, the results of a study by Zaki et al (2016) on the Mahout coast, Arabian Sea, found the fecundity value of mackerel in the range of 64,024-151,844 eggs. The difference in the number of mackerel eggs can be caused by differences in the length and diameter of the eggs, as proposed by a study result of Burhanuddin & Djamali (1977) in Najamuddin (2004). Other contributing factors to differences in mackerel fecundity are environmental factors, genetics, food availability, and are also related to fish age and fish reproductive potential (Effendie 2002).

Table 6

Variation of fecundity in body length of mackerel fish in North Maluku waters in period of January-June 2022

The median length of fish (mm)	*Gonadal maturation frequency (GML IV)*	*Fecundity (eggs fish^{-1}) interval*	*Average*
214	0	0	0
223	0	0	0
232	0	0	0
241	82	26,764-32,640	29,702
250	104	26,800-34,740	30,770
259	69	27,140-33,640	30,390
268	96	30,216-37,541	33,879
277	77	58,180-71,685	64,933
286	57	66,342-77,213	71,778
295	22	75,286-77,464	76,375
304	6	74,257-79,421	76,839
313	1	81,563	81,563

The results of the regression analysis showed that there was a strong relationship between the fish total length and the number of eggs with a correlation coefficient (r = 0.96), also had a very strong mutual influence with the coefficient of determination (r2 = 0.93); with the regression equation F = -208402 + 947.8331 L (where F is fecundity [number of eggs] and L is the total length of fish in mm). The regression results indicated that the total body length had an effect of up to 96% on the total fecundity. In other words, the longer a fish, the more eggs it will have. The similar result was also found by Makmur & Prasetyo (2006) on snakehead (*Channa striata*) fish populations in South Kalimantan.

Conclusions. The growth of male and female mackerel in the North Maluku region follows a negative allometric growth pattern, which means that the increase in body length is faster or more dominant than the increase in body weight. The male mackerel reaches a maximum length of 335.91 mm at the age of 40 months or 3.4 years, while the female mackerel reaches a maximum length of 356.88 mm at the age of 47 months or 3.9 years. The level of gonad maturity of mackerel found during the study period varied from GML I to GML V where fish with immature gonad were more than fish with gonadal ripe fish. The highest numbers of mature male and female mackerel fish were found in May with respective percentages of 56.78% and 58.19%. Mackerel spawning occurs several times a season with peak spawning occurred in June and July. The fecundity of female mackerel in North Maluku waters ranged from 26,764 to 81,563 eggs. This study has produced basic data and information regarding reproduction and growth pattern of Indian mackerel in North Maluku seas. This data could provide good scientific basis for local fishery authorities to develop a more systematic and long-term monitoring for the province Indian mackerel stocks, to achieve its sustainable fishery.

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Conflict of interest. The authors declare that there is no conflict of interest.

References

Abdurahiman K. P., Harishnayak T., Zacharia P. U., Mohamed K. S., 2004 Length-weight relationship of commercially important marine fishes and shellfishes of the southern coast of Karnataka, India. Naga 27(1-2):9-14.

Abdussamad E. M, Kasim H. M, Achayya P., 2006 Fishery and population characteristics of Indian mackerel, *Rastrelliger kanagurta* (Cuvier) at Kakinada. Indian Journal of Fisheries 53(1):77-83.

Abubakar S., Subur R., Tahir I., 2019 [Estimation of the size at first maturity of mackerel (*Rastrelliger* sp) in the waters of Sidangoli Dehe Village, South Jailolo District, West Halmahera Regency]. Jurnal Biologi Tropis 19(1):42-51. [in Indonesian]

Arrafi M., Ambak M. A., Rumeaida M. 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.

Brojo M., Sari R. P., 2002 [Reproductive biology of fivelined threadfin bream (*Nemipterus tambuloides* Blkr.) what landed in place of fish auction Labuan, Pandeglang]. Jurnal Iktiologi Indonesia 2(1):9-13. [in Indonesian]

De Graaf M., Machiels M., Wudneh T., Sibbing F. A., 2003 Length at maturity and gillnet selectivity of Lake Tana’s *Barbus* species (Ethiopia): implications for management and conservation. Aquatic Ecosystem Health & Management 6(3):325-336.

Effendie M. I. 1979 [Fisheries biological methods]. Dewi Sri Foundation, Bogor, 112 pp. [in Indonesian]

Effendie M. I. 2002 [Fisheries biology]. Nusatama Library Foundation, Yogyakarta, 163 pp. [in Indonesian]

Fauzi M., Suwarso S., Kembaren D. D., Yahya M. F., 2020 [Reproductive biology and population dynamics of male mackerel (*Rastrelliger kanagurta*, Cuvier 1817) in Aru waters]. BAWAL Widya Riset Perikanan Tangkap 12(3):137-150. [in Indonesian]
Harianti, 2013 [Fecundity and egg diameter of stripped snakehead (*Channa striata* Bloch, 1793) in Tempe Lake, Wajo Regency]. Saintek Perikanan: Indonesian Journal of Fisheries Scienceand Technology 8(2):18-24. [in Indonesian]
Ibrahim P. S., Setyobudiandi I., Sulistiono, 2017 [Length-weight relationship and condition factor yellowstripe scads (*Selaroides leptolepis*) in Sunda strait]. Jurnal Ilmu dan Teknologi Kelautan Tropis 9(2):577-584. [in Indonesian]
Jayabalan N., Zaki S., Al-Kiyumi F., Al-Kharusi L., Al-Habsi S., 2014 Age, growth and stock assessment of the Indian mackerel *Rastrelliger kanagurta* (Cuvier, 1817) along the Sohar coast of Oman. Indian Journal of Fisheries 61(1):1-6.
Kasmi M., Hadi S., Kantun W., 2017 [Reproductive biology of the Indian mackerel, *Rastreliger kanagurta* (Cuvier, 1816) in Takalar coastal waters, South Sulawesi]. Jurnal Iktiologi Indonesia 17(3):259-271. [in Indonesian]
Katiandagho B., Marasabessy F., 2017 [Reproductive potential, spawning pattern, and alternatives management for Indian mackerel (*Rastrelliger kanagurta*) around the east coast of Biak waters]. Agrikan: Jurnal Agribisnis Perikanan 10(2):51-55. [in Indonesian]
Lalèyè P., Chikou A., Gnohossou P., Vandewalle P., Philippart J. C., Teugels G., 2006 Studies on the biology of two species of catfish *Synodontis schall* and *Synodontis nigrita* (Ostariophysi: Mochokidae) from the Ouémé River, Bénin. Belgium Journal of Zoology 136(2):193-201.
Makmur S., Prasetyo D., 2006 [Feeding habits, gonadal maturity level and fecundity of Haruan fish (*Channa striata* Bloch) in the Sambujur River fisheries reserve in the Barito watershed, South Kalimantan]. Jurnal Ilmu-ilmu Perairan dan Perikanan Indonesia 13(1):27-31. [in Indonesian]
Mosse J. W., Hutubessy B. G., 1996 [Age, growth and first maturity of Indian mackerel (*Rastrelliger kanagurta*) from Ambon Island waters and surroundings]. Jurnal Sains dan Teknologi Universitas Patimura 1(1):2-13. [in Indonesian]
Murua H., Kraus G., Saborido-Ray F., Wittames P. R., Thorsen A., Junquera S., 2003 Procedures to estimate fecundity of marine fish species in relation to their reproductive strategy. Journal of Northwest Atlantic Fishery Science 33(5):33-54.
Najamuddin, 2004 [Study of the sustainable utilization of scad (*Decapterus* spp.) resources in the Makassar Strait waters]. Doctoral dissertation, Hasanuddin University Postgraduate Program, Makassar, 263 pp. [in Indonesian]
Nasution M. A., Kamal M. M., Azis K. A., 2015 [Growth, and reproduction of Indian mackerel (*Rastrelliger kanagurta* Cuvier 1817) landed at PPN Pelabuhan Ratu]. Jurnal Perikanan Tropis 2(1):44-54. [in Indonesian]
Ningrum V. P., Ghofar A., Ain C., 2015 [Biological aspects of the blue swimming crab (*Portunus pelagicus*) in Betahwalang waters and around]. Saintek Perikanan: Indonesian Journal of Fisheries Science and Technology 11(1):62-71. [in Indonesian]
Nugroho A., Murdlijah S., 2006 [Relationship between length-weight, sex ratio, and gonadal maturity level of mackerel in the Banda Sea]. Jurnal Penelitian Perikanan Indonesia 12(3):195-200. [in Indonesian]
Oktaviani D., Supriatna J., Erdmann M. V., Abinawanto A., 2014 Maturity stages of Indian mackerel *Rastrelliger kanagurta* (Cuvier, 1817) in Mayalibit Bay, Raja Ampat, West Papua. International Journal of Aquatic Science 5(1):67-76.
Pauly D., 1983 Length-converted catch curves: a powerful tool for fisheries research in the tropics (part 1). Fishbyte 1(2):9-13.
Putera M. L. A., Setyobudiandi I., 2019 [Reproduction of Indian mackerel (*Rastrelliger kanagurta* Cuvier, 1816) relation to sea surface temperature in Sunda strait waters]. Jurnal Pengelolaan Perikanan Tropis 3(1):30-37. [in Indonesian]
Rahman M. M., Hafzath A., 2012 Condition, length-weight relationship, sex ratio and gonadosomatic index of Indian mackerel (*Rastrelliger kanagurta*) captured from Kuantan coastal water. Journal of Biological Sciences 12(8):426-432.

Rehman S., Ayub Z., Siddiqui G., Moazzam M., 2019 Growth, mortality and stock assessment of Indian mackerel, *Rastrelliger kanagurta* (Cuvier, 1816) in the coastal waters of Pakistan, northern Arabian Sea. Russian Journal of Marine Biology 45(1): 67-73.

Reynolds J. D., Jennings S., Dulvy N. K., 2001 Life histories of fishes and population responses to exploitation. In: Conservation of exploited species. Reynolds J. D., Mace G. M., Redford K. H., Robinson J. G. (eds), Cambridge University Press, Cambridge, pp. 148-168.

Ricker W. E., 1975 Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada, Bulletin 191, Ottawa, 382 pp.

Saputri W. E., 2017 [Patterns of growth and reproduction of Indian mackerel (*Rastrelliger kanagurta* Cuvier, 1817) in Sunda Strait waters]. BSc thesis, Bogor Agricultural Institute, 40 pp. [in Indonesian]

Sarasati W., 2017 [Population dynamics and multispecies reproductive biology of mackerel (*Rastrelliger faughni*, *R. kanagurta*, *R. brachysoma*) in Sunda strait waters]. [Thesis]. Bogor Agricultural Institute, 130 pp. [in Indonesian]

Sivadas M., Nair P. N. R., Balasubramanian K. K., Bhaskaran M. M., 2006 Length weight relationship, relative condition, size at first maturity, and sex ratio of Indian mackerel *Rastrelliger kanagurta* from Calicut. Journal of the Marine Biological Association of India 48(2):274-277.

Sparre P., Venema S. C., 1998 Introduction to tropical fish stock assessement. Part 1. Manual. FAO Fisheries Technical Paper No. 306/1 Rev. 2, FAO, Rome, 407 pp.

Tangke U., 2014 [Monitoring of population dynamics parameters of mackerel (*Rastrelliger* sp) in the coastal waters of Ternate Island, North Maluku Province]. Agrikan: Jurnal Agribisnis Perikanan 7(2):8-14. [in Indonesian]

Widodo J., 1988 Population dynamics and management of "ikan layang", scad mackerel, *Decapterus* spp (Pisces: Carangidae) in the Java Sea. PhD dissertation. School of fisheries, University of Washington, Seatle, 150 pp.

Zaki S., Jayabalan N., Al-Kiyumi F., Al-Kharusi L., 2016 Reproductive biology of the Indian mackerel *Rastrelliger kanagurta* (Cuvier, 1816) from the Mahout coast, Sultanate of Oman. Indian Journal of Fisheries 63(2):24-32.

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