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Reproductive biology of mackerel scad (*Decapterus macarellus* Cuvier, 1833) in The North Halmahera waters

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ABSTRACT

Studying the biological reproduction of fish is important for determining the spawning season and providing several management options to protect the fisheries. The study conducted length and biology reproduction sampling of Mackerel scad (*Decapterus macarellus*) caught by mini purse seine landed in Tobelo coastal fishing port during 2015–2016. The total sample consisted of 1228 individuals, 526 males and 671 females with size distributions ranging from 12.50 to 29.90 cmFL. Results showed that there were 432 immature and 94 mature male fish and 582 immature and 89 mature female fish. The growth pattern for male fish is negative allometric (b<3) while for females is isometric (b=3). The highest GSI value for male was recorded during May and November, while for females it was in May and October. Based on this result, the spawning season of mackerel scad in the North Halmahera waters is predicted to occur in March-May and August-October, by the first and second transition seasons. The study found that the length at first maturity (Lm) was 24.90 cmFL for male fish and 26.41 cmFL for female fish, the Lm bigger than Length at first capture (Lc) of 21.93 cmFL. This means the fish was caught before mature gonads and had a chance to spawn.

Introduction

Decapterus macarellus, or mackerel scad, plays a pivotal role in Indonesia's economy as an important economic fish. This oceanic species, thriving in high salinity, is a key member of the small pelagic fish category. Belonging to the stenohaline group, it sustains itself by feeding on plankton. Mackerel scad, with its habitat ranging from 0–400 m and commonly found at 40-200 m (Fishbase, 2024) and distributed in Indonesian waters.

Indonesia ranks second in the world after China in capture fisheries production (FAO, 2022). In the North Halmahera waters, mackerel scad is commonly caught by fishermen as bait for catching tuna. However, due to the abundant catch, it has also become a consumption. The utilization of mackerel scad resources in the North Halmahera waters is carried out by artisanal fishery using mini purse seines with a one-day operation system.

Indonesia has 11 fishery management areas (FMA) and the Halmahera Sea is included in FMA-715. A total of 11 small pelagic fish are recorded in Indonesia's national fisheries system in FMA-715, and the dominant species include those in the mackerels and scads groups (MMAF, 2016a). The small pelagic fish stock in FMA-715 was fully-exploited in 2011 (MMAF, 2011), over-exploited in 2016 (MMAF, 2016b), and fully-exploited in 2022 (MMAF, 2022).

Excessive utilization can lead to the collapse of fishery efforts; therefore, fisheries management is necessary. Fisheries management requires basic information, including biological aspects (Zamroni *et al.*, 2019; Costa *et al.*, 2020; Widiyastuti *et al.*, 2020;

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Bintoro *et al.*, 2020; Patawari *et al.*, 2022; Tenriware *et al.*, 2023; Munandar *et al.*, 2024; Retnoningtyas *et al.*, 2024). The size of fish at gonad maturity is crucial in reproductive strategy and exploitation (Stearns, 1992). High-pressure swings can reduce the size of fish at gonad maturity (Pollock, 1995) and cause increased mortality (Jørgensen *et al.*, 2007).

This study delves into the reproductive biology of mackerel scad in the North Halmahera waters. It covers crusial aspects such as size distribution, growth patterns, sex ratio, gonad maturity levels, gonadosomatic index, length at first capture, and length at first maturity. The research results, once obtained, are expected to significantly contribute to sustainable management of mackerel scad.

Materials and Methods

Location and time of research

Fish samples were collected at Tobelo coastal fishing port (Figure 1), from April 2015 to September 2016 (samples were unavailable in June 2015, December 2015, and February 2016). The sample was obtained using a mini purse-seine. A sampling of fish was carried out every month using the random sampling method. The samples measured fork length (FL) using measuring paper (cm), body weight (W), and gonad weight (Wg) using a digital scale (grams). The fish samples were dissected to observe their gonads. Environmental characteristics used data obtained from Aqua MODIS satellite L3 (sea surface temperature (SST) and chlorophyll-a (SSC)).

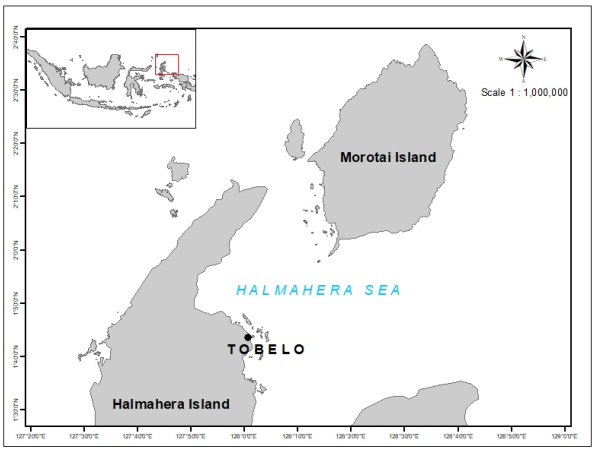


Figure 1. The map of study area

Data analysis

Size distribution and growth pattern

The frequency of fish number analyzed tabulates the size distribution. Length-weight relationship data are analyzed based on Effendi (1997), the formula of allometric growth model is as follows:

$$W = aL^b$$

Information:

W = Weight (gram)
a = intercept
L = total length (cm)
b = slope

Allometric or isometric relationships were analyzed by T-test. If the value of b ≠ 3 or allometric and if the value of b = 3 or isometric.

Sex ratio and gonadosomatic index

The sex ratio was analyzed by comparing the total number of males and females (Effendie, 1997).

$$\text{Sex ratio} = M/F$$

Information:

M = number of males
F = number of females.

Furthermore, to find out the balance of male and female was analyzed by the Chi-square test (Steel and Torrie, 1993).

The gonadosomatic index as a proxy for reproductive activity (Flores *et al.*, 2019) calculated using the formula:

$$GSI = GW/BW$$

Information:

GSI = gonado somatic index
GW = gonad wight
BW = body weight

Length at first captured (Lc) and length at first maturity (Lm)

The length at first captured was analyzed using a relationship between fork length (x-axis) and the number of individual fish (y-axis) to obtain a sigmoidal curve. The length at first captures is the length at 50% of the population caught, and calculated using Sparre and Venema (1999) formula:

$$SLest = \frac{1}{1 + \exp(S1 - S2 * L)}$$

$$Ln\left[\frac{1}{SL} - 1\right] = S1 - S2 * L \ldots$$

$$L_{50\%} = \frac{S1}{S2}$$

Information:

SLest = logistic curve
S1 = a
S2 = b
S1 and S2 = constant

The length at first maturity was analyzed using the Spearman-Karber method (Udupa, 1986) with the formula:

$$M = (Xk + X/2) - (X\sum pi)$$

Information:

M = log length at first maturity
Xk = log of length class median at 100% matured fish
X = increment of the log of length class median
pi = number of matured fish and each length class ratio (number of matured fish at class I/number of fish samples at class i).

Furthermore using a 95% confidence interval is the equation:

$$\text{antilog}\ (M \pm 1.96 \sum (x^2(pi-qi/ni-1)))$$

Information:

qi = 1-pi
ni = number of fish samples at class i

Results

Size distribution and growth pattern

The total sample obtained was 1228 individual mackerel scad. There are 526 males (432 immature and 94 mature), 671 females (582 immature and 89 mature), and 31 unidentified (immature). The size distribution of the study ranged from 12.50 to 29.90 cmFL (Figure 2).

The 24-25 cmFL interval classhas the highest number of fish. The immature male fish size ranged from 15 to 29 cmFL (40.56-285 g), while the mature male ranged from 18.30 to 29.90 cmFL (73.80-315.50 g). The immature female fish size ranged from 12.50 to 28 cmFL (24.26-274 g), while the mature female ranged from 20.90 to 28.50 cmFL (124.10-310.30 cmFL), and the unidentified fish size ranged from 13.50 to 26.90 cmFL (27-237 g) (Table 1).

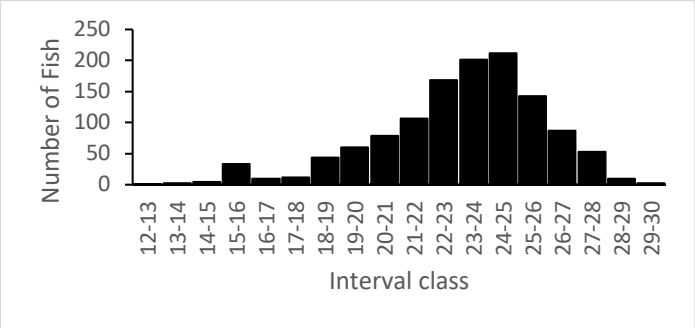
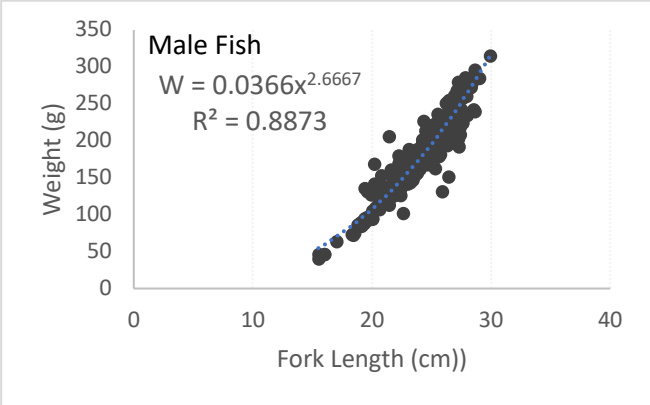


Figure 2. Size distribution of mackerel scad in the North Halmahera waters

Growth patterns of mackerel scad in the North Halmahera waters are shown in Figure 3. The growth pattern of male s negative allometric (b < 3) or length increment larger than weight increment. Based on those statements, the value of b for male fish is 2.67 and the growth pattern of female fish is isometric (b = 3), or length and weight increment is the same (Figure 3). The determination coefficients (R^2) for male and female are 0.89 for male and 0.93 for female.

Male



Female

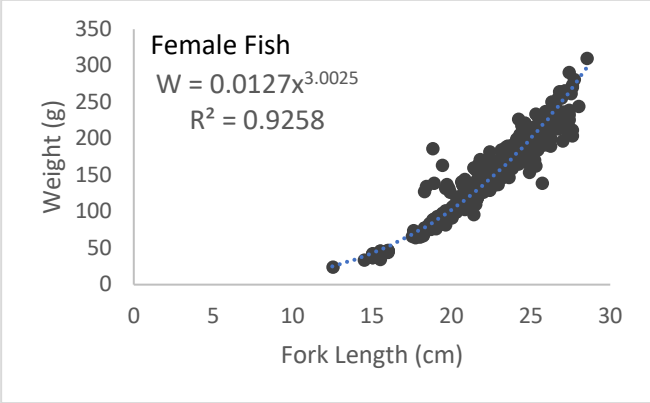


Figure 3. Growth pattern of male and female fish in the North Halmahera waters.

Sex ratio and gonado somatic index

The sex ratio of mackerel scad was 1:1.275 (Male:Female). The different number of male and female fish made the different sex ratio for each month (Figure 4). The female fish dominated in this study, except in June, August, and October when male fish dominated. The sex ratio based on interval class showed the male fish dominated in the high interval class (Figure 5).

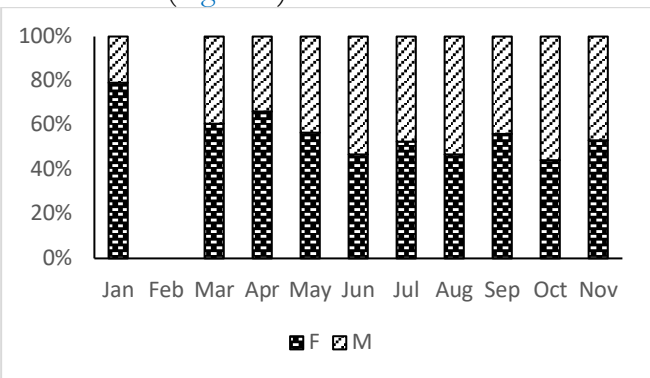


Figure 4. Monthly sex ratio of mackerel scad in the North Halmahera waters.

Table 1. Length (cm) and weight (g) of immature and mature of mackerel scad in the North Halmahera waters.

Year	Month	Immature			Mature		
		n	Length	Weight	n	Length	Weight
Male							
2015	Apr	59	22.24 (18.40-26.10)	144.05 (73.00-234.00)			
2015	May	23	25.63 (23.60-27.40)	197.47 (161.00-232.00)			
2015	Jul	29	24.96 (23.60-27.20)	202.58 (172.00-234.00)			
2015	Aug	24	22.55 (19.40-25.80)	167.91 (126.00-227.00)			
2015	Sep	25	23.21 (20.10-26.60)	169.84 (130.00-234.00)			
2015	Oct	32	24.92 (19.60-28.50)	181.18 (127.00-243.00)	2	27.60 (27.20-28.00)	220.00 (205.00-235.00)
2015	Nov	28	23.39 (21.20-27.60)	171.21 (102.00-274.00)	1	22.60 (NA)	152.00 (NA)
2016	Jan	9	17.06 (15.00-20.00)	63.74 (40.56-95.62)			
2016	Mar	13	25.42 (24.00-27.50)	207.47 (176.10-255.60)	7	26.97 (25.20-28.40)	241.54 (205.10-279.60)
2016	Apr	28	24.93 (22.50-27.60)	196.06 (150.50-258.20)	11	26.06 (24.20-29.90)	221.91 (180.30-315.50)
2016	May	19	23.59 (22.30-25.70)	167.83 (142.60-212.30)	14	25.22 (23.10-26.90)	208.47 (167.80-261.50)
2016	Jun	31	24.12 (22.40-26.10)	174.18 (137.60-222.50)	11	25.43 (23.30-28.60)	214.82 (162.30-296.40)
2016	Jul	34	22.03 (20.00-25.40)	136.47 (101.30-207.00)	1	22.80 (NA)	167.60 (NA)
2016	Aug	72	23.03 (20.60-29.00)	163.36 (107.00-285.00)	29	24.97 (18.30-28.60)	205.37 (73.80-286.00)
2016	Sep	6	24.28 (21.50-25.50)	176.08 (123.50-213.70)	18	24.52 (21.50-28.30)	184.76 (124.20-272.70)
Female							
2015	Apr	142	20.63 (17.60-27.60)	115.77 (65.00-274.00)			
2015	May	41	25.10 (22.60-27.40)	190.09 (145.50-236.00)			
2015	Jul	33	25.06 (23.50-27.40)	206.21 (182.00-239.00)			
2015	Aug	33	22.67 (18.30-26.40)	171.39 (128.00-251.00)			
2015	Sep	37	24.02 (19.60-27.00)	183.13 (127.00-237.00)			
2015	Oct	26	24.82 (20.60-28.00)	185.65 (137.00-245.00)	1	27.40 (NA)	233.00 (NA)
2015	Nov	31	23.01 (18.80-25.70)	162.38 (123.00-211.00)	2	25.75 (24.40-27.10)	201.00 (187.00-215.00)
2016	Jan	34	16.09 (12.50-20.00)	50.25 (24.26-98.70)			
2016	Mar	21	24.93 (19.90-26.50)	203 (98.50-246.70)	10	26.43 (25.00-28.50)	246.61 (196.00-310.30)
2016	Apr	36	24.27 (22.70-25.80)	184.31 (153.60-225.90)	14	24.54 (23.70-25.40)	195.76 (172.20-214.50)
2016	May	17	23.48 (22.30-24.90)	166.62 (140.90-199.30)	15	24.76 (22.60-27.50)	200.65 (148.60-261.80)
2016	Jun	27	23.86 (22.50-26.40)	171.81 (137.40-243.50)	10	24.13 (23.20-24.80)	179.94 (158.00-202.50)
2016	Jul	37	21.81 (20.00 24.60)	132.91 (96.70-182.90)	1	20.90 (NA)	128.40 (NA)
2016	Aug	46	22.19 (18.00-26.60)	145.78 (65.90-242.00)	31	23.93 (21.50-27.60)	185.52 (124.10-271.00)
2016	Sep	21	23.03 (21.60-25.80)	153.15 (118.30-218.20)	5	24.36 (22.90-26.50)	186.28 (149.50-236.30)
Unidentified							
2015	May	1	26.90 (NA)	237.00 (NA)			
2015	Aug	1	24.10 (NA)	177.00 (NA)			
2016	Mar	8	17.13 (15.00-19.00)	62.76 (30.00-84.00)			
2016	Aug	21	15.72 (13.50-17.90)	48.48 (27.00-77.00)			

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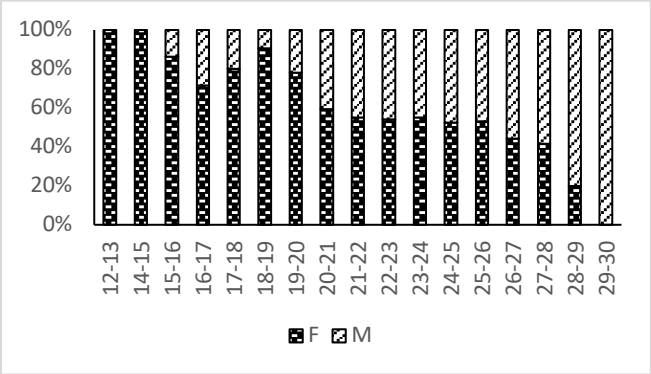

Figure 5. Interval class sex ratio of mackerel scad in the North Halmahera waters.

The number of mature mackerel scad male and female was less than of immature ones (Figure 6), the immature fish were dominant throughout the study period. The most mature fish were discovered in March and September for male fish and in March and August for female fish.

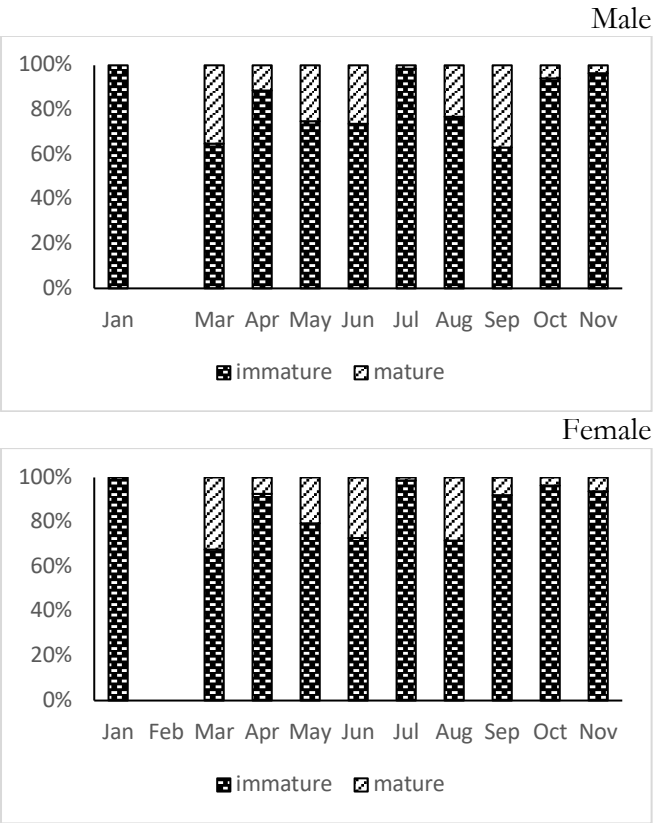

Figure 6. Temporal fluctuation in the proportion of immature and mature male and female gonads of mackerel scad in the North Halmahera waters.

The GSI value can be used to estimate the spawning season. The GSI value of mackerel scad in North Halmahera waters fluctuated for each month and presented in Figure 7. The highest GSI value for male fish was recorded in May and November, while female fish recorded in May and October. The spawning season of mackerel scad in North Halmahera waters is indicated during March-May and August-October or transition season I and transition season II.

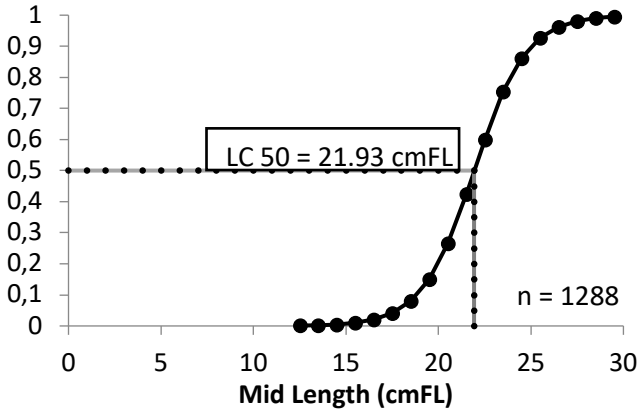

Figure 8. Length at first capture of mackerel scad in the North Halmahera waters.

Length at first captured (Lc) and length at first maturity (Lm)

The size prediction of fish caught is used to analyze length at first capture (Lc). The study found that Lc was 21.93 cmFL (Figure 8).

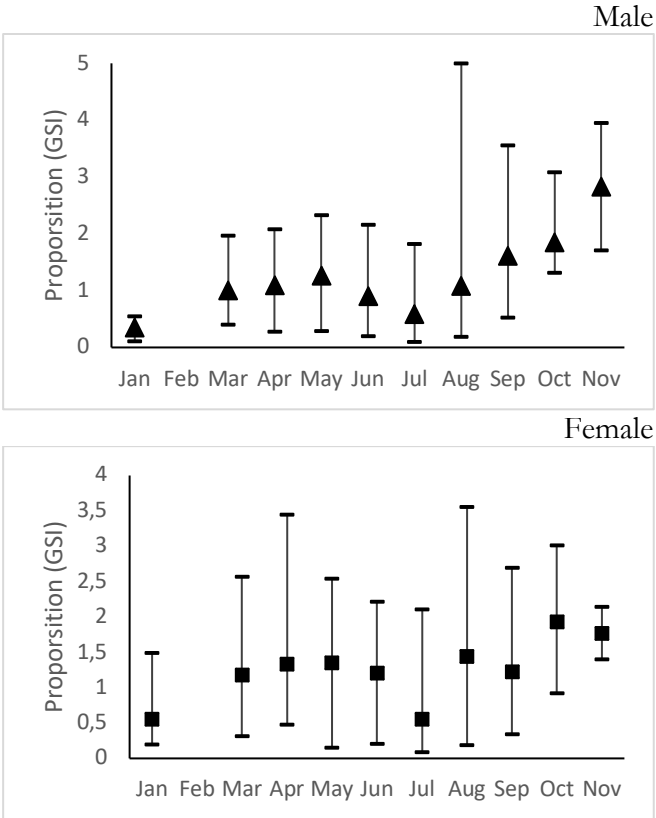

Figure 7. Gonado somatic index of mackerel scad male dan female in the North Halmahera waters.

The length at 95% of maturity (Lm) was 24.90 cmFL for males and 26.41 cmFL for females.

Environmental Conditions

Based on MODIS Aqua satellite data, sea surface temperature (SST) was in the range of 26.28-33.29 °C and the SST average value of 28.52-30.96 °C. The highest average SST occurred in June 2016 (30.96 °C) and the lowest average SST fell in August 2015 (28.52 °C). Meanwhile, the sea surface chlorophyll-a distribution in the North Halmahera waters is around 0.06-1.82 mg/m^3 and the SCC average is around 0.14-0.35 mg/m^3. The highest average SSC occurred in February 2016 (0.35 mg/m^3) and the lowest average SSC in July and October (0.14 mg/m^3). The study of the average SST and SSC value can be further observed in Figure 9.

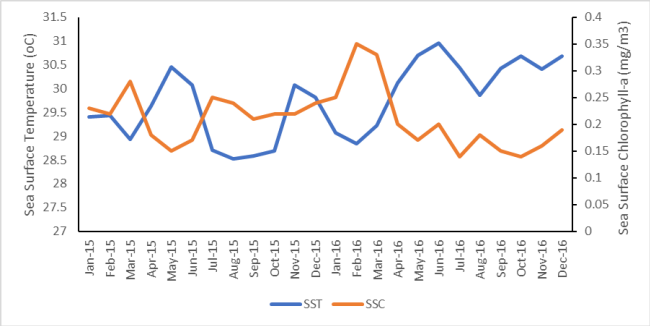

Figure 9. The value of sea surface temperature (SST) and sea surface chlorophyll-a (SSC) in the North Halmahera waters.

Discussion

The size distribution of mackerel scad in the North Halmahera waters was 12.50-29.90 cm FL and it was not very different from other locations in Indonesia. In Ambon waters the size of mackerel scad ranged from 11-24.50 cmFL (Pattikawa *et al.*, 2018), 9.50-31.80 cmFL (Silooy *et al.*, 2019), and 10.50-29.50 cmFL (Widyastuti *et al.*, 2020). Further in the Sulawesi Sea range of 10.25-32.25 cmFL (Zamroni *et al.*, 2019) and 14.25-30.75 cmFL (Baihaqi *et al.*, 2021). Furthermore in Prigi waters range of 16.80-35 cmFL (Bintoro *et al.*, 2020). Moreover the result of Retnoningtas's (2024) study in the Sulawesi Sea reported that the male scads have a size ranging from 14-26.20 cmTL for immature and 19.40-38.20 cmTL for mature; and the female scads have a size range of 13.40-26.80 cmTL for immature and 17.20-32.50 cmTL for mature. The growth pattern of mackerel scad was isometric for females and allometric negative for males. This result is different from Iksan's (2009) study, which found the growth pattern of mackerel scad in the North Maluku waters was allometric negative for males and females. The different factors of size distribution and growth pattern for each location are food availability, eating habits, and environmental conditions to support the growth of fish (Effendie, 1997).

The sex ratio of mackerel scad between male and female was 1:1.275, female fish were dominant. According to the study, male fish were more predominant in June, August, and October, while female fish dominated the other months. The male fish dominate at high class intervals, the result similarly in Sulawesi sea (Retnoningtyas *et al.*, 2024). The dominant female fish was also found in Majene waters 0.98:1 (Nur *et al.*, 2017). In different locations in Indonesia found of the male fish was dominant, for instance, in Kendari waters 1.31:1 (Fadila *et al.*, 2016), at Tomini Bay 1.06:1 (Widiyastuti & Zamroni, 2017), in Sulawesi Sea 1.96:1 (Zamroni *et al.*, 2019), in Samudera Hindia (West Sumatera block) 1.2:1 (Widyastuti *et al.*, 2020), in Majene waters 1.81:1 (Tenriware *et al.*, 2023). The equal sex ratio between male and female was found in Sulawesi sea (Retnoningtyas *et al.*, 2024), in Ambon waters (Silooy *et al.*, 2021), and in Prigi waters (Bintoro *et al.*, 2020). The sex ratio is important to know the stability of the fish population in nature and ensure that sustainability can be maintained. The factors influencing the sex ratio are behavioral patterns, mortality, spawning behavior, sexual maturity, and age (Smith *et al.*, 2018).

The mature fish and the GSI can indicate the existence of spawning season. Understanding the fish spawning season is important for sustainable fisheries management. According to the result of fish maturity and GSI, the spawning season of mackerel scad in the North Halmahera waters is indicated during March-May and August-October or during transition season I and transition season II. The spawning season of mackerel scad in Indonesia differed in other locations. For instance, at the eastern of North Sumatera the spawning season occur in January, March, May, and November (Fadhilah *et al.*, 2021), at Tomini Bay in August-November (Widiyastuti & Zamroni, 2017), at the southern waters of Western Java in August-November (Munandar *et al.*, 2024), at Majene waters in April (Tenriware *et al.*, 2023), at Banda Sea in October and December (Silooy *et al.*, 2019). Several factors can influence the differences in spawning season in each location. The environmental conditions are one of the factors, when the spawning season in the North Halmahera waters in transition season I, and the SST value increased and decreased for SSC value. The average SST in the spawning season ranges from 28.94 to 30.70 °C and the average SSC ranges from 0.15 to 0.33 mg/m^3. In transition season II, the average SST in the spawning season ranges from 28.52 to 30.68 °C and the average SSC ranges from 0.14 to 0.24 mg/m^3. According to (Rada

et al., 2019), fish growth is faster in the location of high water temperatures, than in the area of low water temperatures. Moreover, Lagler *et al.*, (1977) states that fish have the ability to adapt to the environment.

The length at first capture (Lc) mackerel scad in the North Halmahera waters is 21.93 cmFL, while the length at mature (Lm) are 24.90 cmFL for male fish and 26.41 cmFL for female fish. The condition indicates that the fish caught before mature gonads (Lc<Lm) and suggests that the mackerel scad in the North Halmahera waters has been unsustainably managed. The dominating catch of smaller fish is a sign of a high exploitation rate, if not handled well in the long term, it will cause overfishing. This result is similar with Purwanto *et al.,* (2022) and Minister of Marine Affairs and Fisheries (2016a) that the stock in Fishery Management Area (FMA) 715 (including Halmahera waters) of mackerel scad are overexploited and good management is required.

Conclusion

The study of reproductive biology of mackerel scad in the North Halmahera waters found that female fish are dominant and most of the fish caught by mini purse seine are in immature size. Most importantly, the spawning season occurred in transition season I and II. The length at first captures bigger than a length at first maturity, which will cause overfishing. This will enable temporary fishing closures to develop sustainable fishing for mackerel scad in the future.

Acknowledgments

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