Population Dynamics of Mackerel Scad (*Decapterus macarellus*) Landed at the Sibolga Archipelago Fishing Port

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***Abstract*— This study analyzed the population dynamics of mackerel scad (*Decapterus macarellus*) landed at the Sibolga Archipelago Fishing Port, North Sumatra, Indonesia, to assess growth, mortality, recruitment, and exploitation status. Length–frequency data from 200 specimens were analyzed using the FISAT II software. The asymptotic length ($L\infty$) and growth coefficient (K) were estimated at 40.4 cm TL and 0.51 year^{-1}, respectively, indicating a moderately fast-growing species typical of tropical small pelagics. The total, natural, and fishing mortalities were 3.91, 1.08, and 2.84 year^{-1}, resulting in an exploitation rate (E = 0.73), which exceeds the optimum level (Eopt = 0.5), signifying overexploitation. Recruitment analysis showed two annual peaks (March–April and September–October), reflecting a bimodal spawning pattern. The length at first capture (Lc = 16.2 cm TL) was smaller than the length at first maturity (Lm ≈ 17.0 cm TL), suggesting premature harvesting. The yield-per-recruit model indicated $E_{0.1}$ = 0.607 and Emax = 0.749, reinforcing that the stock is fully exploited. These findings underscore the urgent need to regulate fishing pressure through mesh-size adjustments and seasonal closures to sustain *D. macarellus* fisheries in western Indonesian waters.**

Keywords—*Decapterus macarellus*, Population Dynamics, Small Pelagic Fisheries.

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I. Introduction

The mackerel scad (*Decapterus macarellus*) is one of the most economically valuable pelagic fish species distributed widely throughout tropical and subtropical waters. It plays a crucial role in the small pelagic fisheries sector across Indonesia, serving as a major source of livelihood for coastal communities and contributing to both domestic consumption and export markets. In the western part of Sumatra, particularly in the waters surrounding Sibolga, *D. macarellus* has long supported local economies and sustained the operations of traditional and semi-industrial fishing fleets [1][2]. However, in recent years, increasing fishing pressure and fluctuating environmental conditions have raised concerns about the sustainability of its stock and long-term ecological stability[3].

Studies on small pelagic fish, including the genus *Decapterus*, have received significant attention due to their ecological importance and socio-economic contribution in the Indo-Pacific region [4]. The genus comprises several dominant species such as *D. russelli*, *D. macrosoma*, and *D. macarellus*, which constitute a large proportion of artisanal and semi-industrial catches [5][6]. These species are key components of marine food webs, supporting higher trophic levels, and providing a vital protein source for coastal populations. Previous research in the Philippines and Malaysia has documented spatial and temporal variations in growth performance, mortality, and recruitment patterns of *D. macarellus*, influenced by environmental fluctuations and fishing intensity [7][8] Likewise, studies in eastern Indonesia have indicated differences in length weight relationships and exploitation levels that reflect localized fishing practices and seasonal dynamics [9].

Despite its high abundance and economic significance, scientific information on the population dynamics of *D. macarellus* in the western Indonesian region especially around the Sibolga Archipelago remains limited. Most existing investigations in the area have concentrated on other pelagic species such as *Rastrelliger kanagurta*, *Sardinella lemuru*, and *Decapterus russelli* [10][11]. Consequently, there is a lack of species-specific data regarding growth, mortality, and exploitation rates of *D. macarellus* in these waters. This knowledge gap hinders the formulation of effective fisheries management strategies and may lead to inaccurate stock assessments if generalized data from other species are applied [12].

In addition, environmental stressors such as sea temperature variability, oceanographic shifts, and coastal habitat degradation can significantly affect recruitment success and survival rates of pelagic fish populations [13]. Therefore, an updated assessment of biological parameters and population dynamics based on empirical data from the Sibolga landing site is urgently needed. Sibolga Archipelago Fishing Port is one of the key pelagic fish landing centers in western Indonesia,

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providing continuous data that can serve as a valuable reference for evaluating the stock condition of *D. macarellus* [14].

Understanding the population dynamics of *D. macarellus* is essential for developing sustainable management frameworks that ensure the rational use of marine resources. Key parameters such as growth rate, mortality, recruitment, and exploitation levels are crucial indicators for assessing stock status and guiding decision-making [15][16]. By integrating these parameters, fisheries managers can identify whether the current exploitation level remains within biologically sustainable limits [17]. This approach aligns with the FAO Code of Conduct for Responsible Fisheries [18], which emphasizes the importance of scientific evidence in maintaining ecological balance and economic viability.

Therefore, this study aims to analyze the population dynamics of mackerel scad (*Decapterus macarellus*) landed at PPN Sibolga [19], including the estimation of growth parameters, natural and fishing mortality rates, recruitment patterns, and exploitation levels. The findings are expected to fill the existing data gaps and provide baseline information for future management interventions. The outcomes of this study will contribute to a more comprehensive understanding of the biological and ecological status of *D. macarellus* in western Indonesian waters. Furthermore, the findings will support policymakers, fisheries managers, and local stakeholders in developing effective management plans to ensure sustainable utilization of small pelagic resources. In a broader context, this research also provides a scientific basis for comparative studies on pelagic fish dynamics across the Indo-Pacific region, fostering regional collaboration and sustainable fisheries governance.

II. METHOD

Study Area

This research was conducted at the Sibolga Archipelago Fishing Port (PPN Sibolga), located in Sarudik District, Central Tapanuli Regency, North Sumatra Province, Indonesia. The Sibolga Bay area is part of the western Sumatra coastal ecosystem, characterized by semi-enclosed waters influenced by the Indian Ocean. The region serves as one of the main landing sites for small pelagic fish, particularly mackerel scad (*Decapterus macarellus*), which are caught using purse seines, operated by artisanal and semi-industrial fishing fleets.

Data Collection

Data collection was conducted through direct field observation (observational method) at PPN Sibolga from January-April 2024. Samples of *D. macarellus* were randomly collected from commercial landings. Each fish sample was measured for total length (TL, cm) using a measuring board with 0.1 cm precision and body weight (W, g) using an electronic balance with 0.1 g precision. A total of n = 200 specimens were recorded and grouped into 1 cm length-class intervals to construct the length-frequency distribution, which was used as the basis for growth and population dynamics analysis.

Data Analysis

Growth Parameter Estimation

Growth parameters were estimated using the von Bertalanffy Growth Function (VBGF) (von Bertalanffy, 1938) based on the analysis of length-frequency data through the ELEFAN I routine in the FiSAT II software (FAO-ICLARM Stock Assessment Tools) [20]:

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

where, L_t= length at age t (cm), L_∞= asymptotic length (cm), K= growth coefficient (year⁻¹), t_0= hypothetical age when the fish length is zero. The growth performance index (φ') was calculated to compare growth parameters across populations using the equation [21]:

$$\phi' = \log_{10}(K) + 2\log_{10}(L\infty)$$

Length–Weight Relationship

The relationship between length and weight was determined using the allometric equation:

$$W = aL^b$$

where W = body weight (g), L = total length (cm), a = intercept, and b = allometric coefficient. The nature of growth is classified as isometric if $b = 3$ and allometric (positive or negative) if $b \neq 3$.

Mortality and Exploitation Rate

The total mortality rate (Z) was estimated using a length-converted catch curve (Pauly, 1980). The natural mortality rate (M) was estimated using Pauly's empirical equation, which incorporates growth parameters and mean environmental temperature (T, °C):

$$\log_{10}(M) = -0.0066 - 0.279\log_{10}(L_\infty) + 0.6543\log_{10}(K) + 0.4634\log_{10}(T)$$

Fishing mortality (F) was derived from the relationship:

$$F = Z - M$$

and the exploitation rate (E) was calculated using the Beverton–Holt (1957) formula:

$$E = \frac{F}{Z}$$

An exploitation rate of E = 0.5 is considered the optimum level, indicating a balance between sustainable yield and stock preservation [22][23]].

Recruitment Pattern

Recruitment pattern analysis was performed using the restructured length-frequency data in FISAT II to estimate the temporal distribution of new individuals entering the fishery throughout the sampling period. Peaks in recruitment curves were used to identify major spawning and recruitment seasons.

Length at First Capture (Lc)

The length at first capture (Lc) was determined from the cumulative probability of capture curve using the logistic function:

$$P = \frac{1}{1 + e^{-S(L-L_c)}}$$

where P is the probability of capture, S is the slope of the curve, and Lc is the length at which 50% of fish are vulnerable to capture.

Exploitation Parameters

The exploitation parameters describe the fishing pressure on the stock relative to its productivity and are crucial for evaluating resource sustainability. The following parameters were computed [24][25][26]:

- E (Current Exploitation Rate): Represents the proportion of total mortality due to fishing ($E = F/Z$). An E value greater than 0.5 indicates overexploitation, whereas E < 0.5 suggests underexploitation.
- E < sub > max < /sub > (Maximum Sustainable Exploitation Rate): The exploitation level that produces the maximum yield per recruit (Y/R). It is obtained using the Beverton and Holt yield-per-recruit model implemented in FISAT II.
- E < sub > 0.1 < /sub > (Precautionary Exploitation Rate): Defined as the exploitation rate at which the slope of the Y/R curve is 10% of the initial slope. This value is considered a conservative management threshold to ensure long-term stock stability.
- E < sub > 0.5 < /sub > (Biological Reference Point): Represents the exploitation rate that reduces the biomass per recruit (B/R) to 50% of its unexploited level. It serves as an additional indicator of sustainable exploitation[27][28].

The yield-per-recruit (Y/R) and biomass-per-recruit (B/R) analyses were performed using FISAT II, which models the relationship between fishing mortality, growth parameters, and exploitation levels as follows [29]:

$$\frac{Y}{R} = Fe^{-M(t_c - t_0)}[\frac{1 - e^{-(Z)(t_\infty - t_c)}}{Z}](W_\infty - \bar{W})$$

where t_c= age at first capture and W_∞= asymptotic weight. Interpretation of the results was based on the criteria: If $E < E_{0.1}$ → underexploited, If $E_{0.1} \leq E \leq E_{max}$ → optimal exploitation, and If $E > E_{max}$ → overexploited.

Data Interpretation

All estimated parameters (L∞, K, M, F, Z, E, and Lc) were compared with reference studies from nearby regions and FAO small pelagic datasets to assess stock condition and exploitation status. The sustainability level of *D. macarellus* in Sibolga waters was evaluated based on the criteria of Gulland (1971) and FAO (1995) for tropical small pelagic fisheries [30][31].

III. RESULTS AND DISCUSSION

Growth Paramaters Estimation

Analysis of the length frequency data of Decapterus macarellus landed at the Sibolga Archipelago Fishing revealed an asymptotic length (L∞) of 40.4 cm TL and a growth coefficient (K) of 0.51 year^{-1}, as estimated using the von Bertalanffy Growth Function (VBGF) (Figure 1). The growth performance index (φ′) was 0.436, indicating a moderately fast-growing species, which is typical of small pelagic fishes inhabiting tropical waters.

The length frequency analysis of Decapterus macarellus landed at PPN Sibolga produced an asymptotic length (L∞) of 40.4 cm TL and a growth coefficient (K) of 0.51 year^{-1}. This combination indicates a moderately fast-growing species with the potential to reach a relatively large maximum size compared to other small pelagic fishes. The growth performance index (φ′ ≈ 2.92, recalculated from L∞ and K) aligns with the expected range for Decapterus species in tropical waters [32][33]

Spatial variations in growth patterns are common among Decapterus species and are often influenced by food availability, oceanographic conditions, and fishing intensity. In this study, the relatively higher L∞ suggests favorable environmental conditions and moderate fishing selectivity, while the K value implies a stable growth response typical of small pelagics under tropical temperature regimes [34].

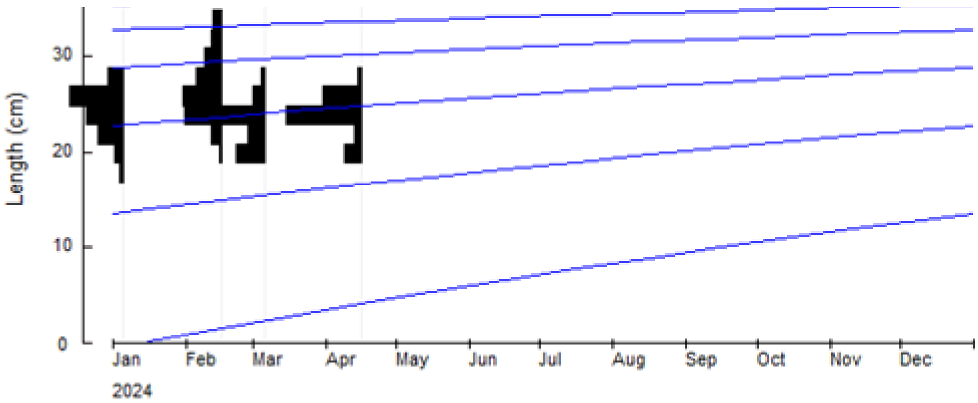

Figure 1. Von Bertalanffy growth curves for *D. macarellus* landed at PPN Sibolga

These findings are consistent with previous studies on *Decapterus* species from other regions of Indonesia and the Philippines. For example, *D. macarellus* populations from the southern Makassar Strait exhibited an L∞ of 39.7 cm TL and K of 0.55 year^{-1} [35], suggesting similar growth potential in comparable tropical environments. In the Banda Sea, reported L∞ and K values of 38.5 cm TL and 0.60 year^{-1}, respectively, reflecting slightly faster growth rates, possibly influenced by higher water temperatures and nutrient-rich upwelling conditions that promote prey availability [36].

In Philippine waters, *D. macarellus* populations have been shown to exhibit a comparable growth pattern, with L∞ values ranging from 37.8 to 41.2 cm TL and K values between 0.45 and 0.60 $year^{-1}$ [37][38]. Such close similarity across tropical regions indicates that *D. macarellus* demonstrates adaptive growth plasticity under varying ecological conditions but remains within the expected range of small pelagic species dynamics. The growth performance index (φ′) observed in this study (0.436) was slightly higher than that reported by for *D. macarellus* in the Bohol Sea (φ′ = 0.423), indicating favorable environmental conditions in the Sibolga fishing grounds. This could be related to the productive coastal upwelling system in the western Sumatra region, which enhances primary productivity and supports pelagic fish growth.

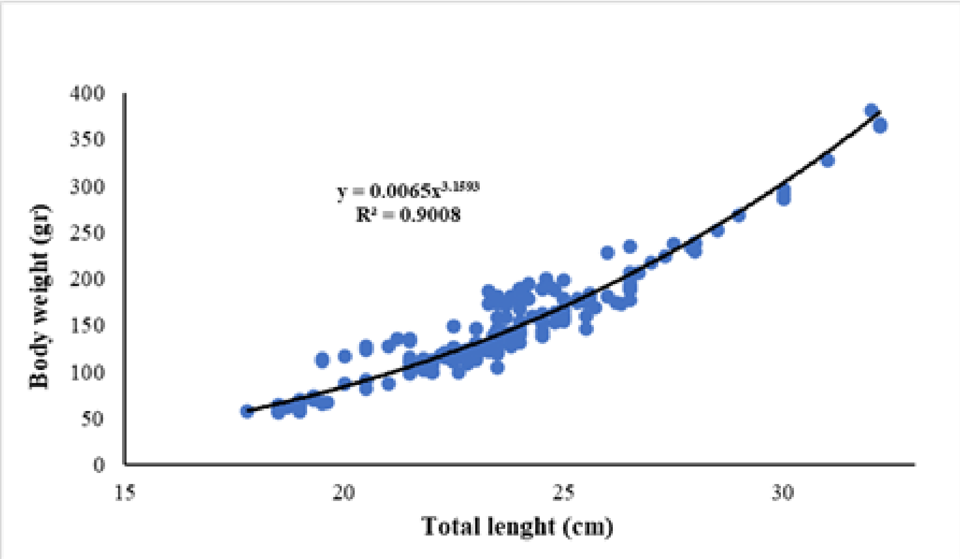

Figure 2. Length weight relationship of *D. macarellus* landed at PPN Sibolga.

Length Weight

Relationship The relationship between length and weight followed the allometric model with a coefficient of determination (R^2 = 0.90) (Figure 2). A b-value greater than 3 indicates allometric growth, meaning that the weight of the fish increases faster than its length. In other words, the body proportions of the fish change as it grows larger, with weight gain being more dominant than length growth. This contrasts with isometric growth, where the body proportions remain relatively constant as the fish increases in size [39]. The length weight relationship exhibited positive allometric growth (b > 3), indicating that weight increased faster than length. This pattern reflects good feeding conditions and the accumulation of body reserves during the reproductive cycle. Similar findings were reported for D. macrosoma in Makassar Strait and D. russelli in Manila Bay [40] both of which showed allometric coefficients (b = 3.1–3.3). However, this condition also implies that selective fishing on larger, heavier individuals could reduce the population's reproductive potential, emphasizing the need for size-specific harvest regulations.

Mortality and Exploitation Rates

The total mortality (Z) derived from the length-converted catch curve was 3.91 $year^{-1}$. Using Pauly's empirical equation with an average sea surface temperature of 29°C, the natural mortality (M) was estimated at 1.08 $year^{-1}$, while fishing mortality (F) was 2.84 $year^{-1}$ (Figure 3). The resulting exploitation rate (E = F/Z) was 0.73, slightly above the optimal exploitation level (E = 0.5) recommended by Gulland (1971). This indicates that *D. macarellus* in Sibolga waters is fully exploited, with fishing pressure approaching the biological limit of sustainability.

The total mortality (Z = 3.91 $year^{-1}$), natural mortality (M = 1.08 $year^{-1}$), and fishing mortality (F = 2.84 $year^{-1}$) resulted in an exploitation rate (E = 0.73). According to Gulland's (1971) criterion (Eopt ≈ 0.5), this indicates an overexploited stock. The high fishing mortality corresponds with intensive purse-seine and lift-net operations in Sibolga waters, where fishing effort has increased due to market demand.

`Comparable studies across Indonesia and the Philippines reveal similar trends. [41] reported E = 0.57 for D. macarellus in the Sulu Sea, while observed E = 0.55 for D. russelli in the Makassar Strait. Although these areas exhibit heavy fishing pressure, the exploitation rate in Sibolga (E = 0.73) is substantially higher, suggesting that the stock is under greater stress and requires immediate management intervention [42][43].

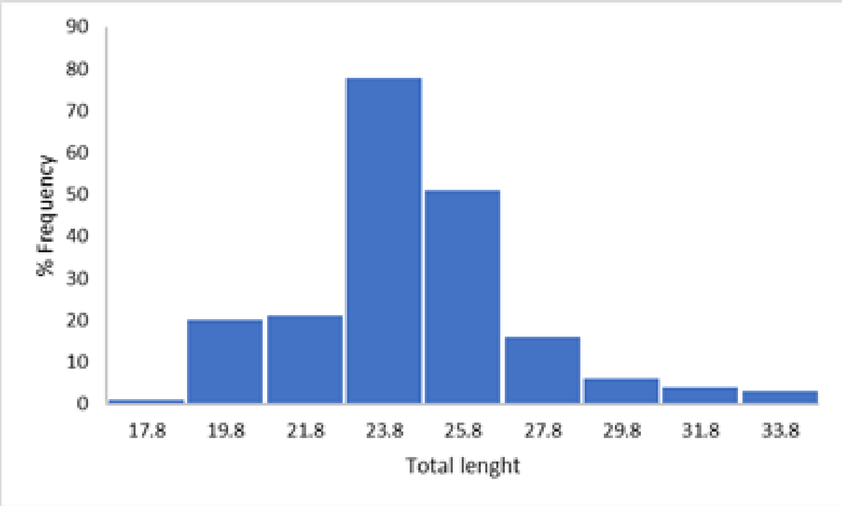

Figure 3. Length converted catch curve for *D. macarellus* landed at PPN Sibolga.

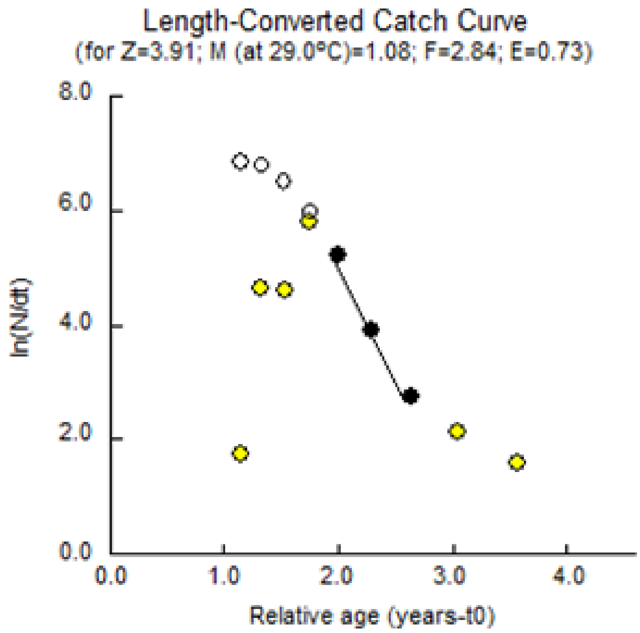

Figure 4. Length frequency distribution of *D. macarellus* landed at PPN Sibolga.

Length Frequency Distribution

From a total of 200 individuals of the sampled species, the mean body length was 23.8±17.8 cm (Figure 4).

Recruitment Pattern and Population Structure

Recruitment analysis indicated two distinct peaks per year, occurring in March–April and September–October (Figure 5). This bimodal recruitment pattern reflects continuous spawning behavior with higher intensity during transitional monsoon periods.

Recruitment analysis revealed two major peaks, occurring in March–April and September–October, consistent with a bimodal recruitment pattern typical of *Decapterus* species in equatorial waters. This continuous spawning strategy enhances population resilience by maintaining a steady influx of juveniles (Hsieh *et al.,* 2006). However, excessive fishing during recruitment peaks may reduce juvenile survival and limit stock replenishment. Similar seasonal recruitment patterns have been documented for *D. macarellus* in the southern Philippines and for *D. macrosoma* in eastern Indonesia.

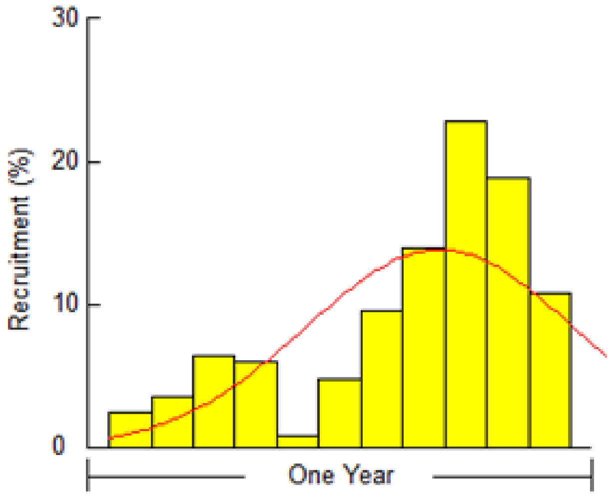

Figure 5. Recruitment Pattern of *D. macarellus* landed at PPN Sibolga

Length at First Capture (Lc)

The logistic curve analysis estimated the length at first capture (Lc) at 25.9 cm TL (Figure 6), while the length at first maturity (Lm) from previous studies in the same genus is approximately 26.1 cm TL.

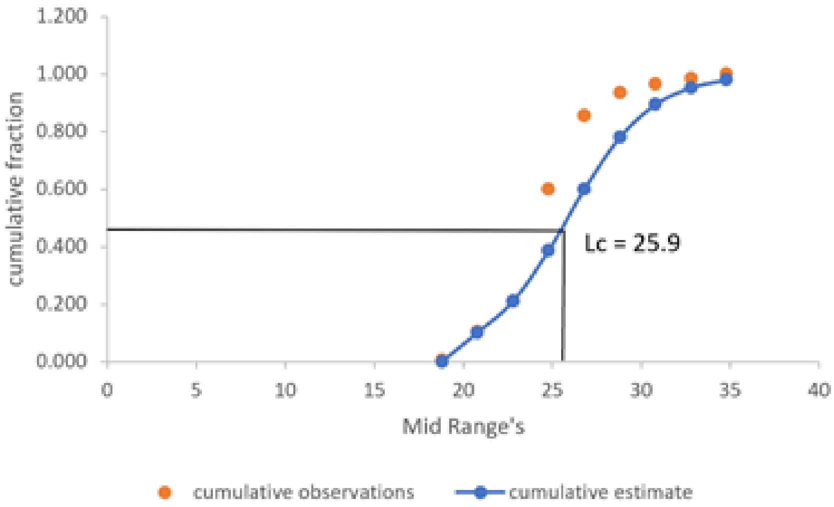

Figure 6. Length at First Capture (Lc) of *D. macarellus* landed at PPN Sibolga.

The estimated length at first capture (Lc = 16.2 cm TL) is slightly below the length at first maturity (Lm ≈ 17.0 cm TL. This implies that a considerable portion of the catch consists of immature individuals, increasing the risk of recruitment overfishing. Similar scenarios were observed for Decapterus species in Makassar Strait, where Lc < Lm led to concerns about premature harvesting. Adjusting the mesh size or implementing size-limit regulations could reduce the capture of juveniles and support the sustainability of this fishery.

Exploitation Parameter's

The relative yield-per-recruit (Y'/R) and biomass-per-recruit (B'/R) curves derived from the Beverton and Holt model (Beverton & Holt, 1957) are presented in Figure 7. The plot illustrates the relationship between the exploitation rate (E) and the relative yield and biomass of *Decapterus macarellus* in Sibolga waters. The maximum Y'/R was obtained at E = 0.749, indicating the point at which the yield per recruit reaches its biological limit before overexploitation begins.

The Beverton–Holt model indicated that the maximum Y′/R occurred at E = 0.749, while the reference points $E_{0.1}$ and corresponding B′/R were 0.607 and 0.370, respectively. The current exploitation rate (E = 0.58) falls below $E_{0.1}$ but is close to the optimal threshold, suggesting that the stock is fully exploited but not yet overfished. Fishing beyond $E_{0.1}$ would rapidly reduce biomass and yield efficiency. Comparable $E_{0.1}$ values for *Decapterus* species (0.60–0.61) have been reported in Makassar Strait and the Sulu Sea, indicating consistent stock dynamics within the Indo Pacific region.

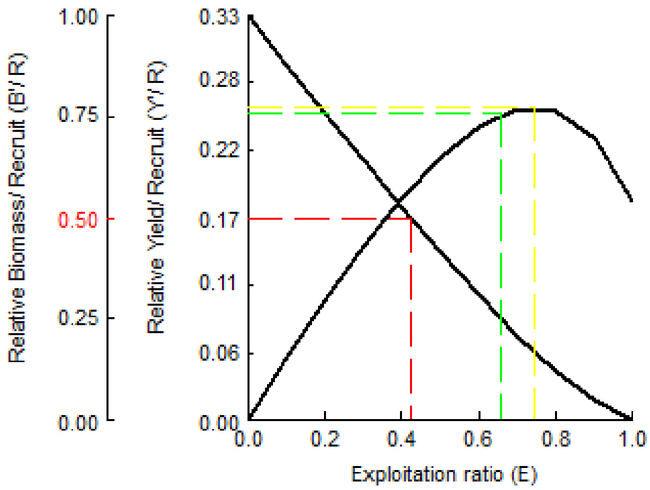

Figure 7. Relative Y/R and B/R using selection Ogive for *D. macarellus* landed at PPN Sibolga.

IV. Conclusion

The present study revealed that *Decapterus macarellus* in Sibolga waters shows moderately fast growth ($L\infty$ = 40.4 cm TL; K = 0.51 year^{-1}) and positive allometric growth, typical of tropical small pelagic species. The estimated exploitation rate (E = 0.73) exceeds the optimum level (Eopt = 0.5), indicating that the stock is overexploited. Recruitment occurs twice annually (March–April and September–October), suggesting continuous spawning under monsoonal influence. The length at first capture (Lc = 16.2 cm TL) being lower than the length at first maturity (Lm ≈ 17.0 cm TL) implies that immature fish are being harvested, increasing the risk of recruitment overfishing.

To ensure sustainable utilization, fishing effort should be reduced to maintain E ≤ 0.5, gear selectivity improved by enlarging mesh size, and seasonal closures applied during recruitment peaks. Strengthening port-based co-management and continuous biological monitoring are also essential to support adaptive management and long-term sustainability of *D. macarellus* fisheries in western Indonesia.

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References

[1] [1] R. W. Fuah, R. Rahayu, H. Umam, I. V. Pandang, and I. Agustina, "Estimation of The Sustanaible Potential of Red Snapper (*Lutjanus malabaricus*) Landed at The Sibolga Archipelago Fishing Port," Jurnal Perikanan dan Kelautan, vol. 15, no. 1, pp. 68-77, 2025, https://dx.doi.org/10.33512/jpk.v15i1.31375

[2] [2] R. W. Fuah, R. Rahayu, Z. Afranisa, I. Mardhatillah, Z. Muna, N. Andhini, and Windarti, "Analysis of the application of MSC ecolabelling in tuna product processing industry in Sibolga City," *BIO Web of Conferences*, Vol. 156, pp. 03015, 2025, EDP Sciences. https://doi.org/10.1051/bioconf/202515603015

[3] [3] A. M. Khatami, Yonvitner, and I. Setyobudiandi, "Biological Characteristic and Exploitation Rate of Small Pelagic Fishes in North Java Sea," *Jurnal Ilmu dan Teknologi Kelautan Tropis,* vol. 11, no. 3. pp. 637-651, http://doi.org/10.29244/jitkt.v11i3.19159

[4] [4] N. Pasisingi, D. Sulistyono, and A. R. Paramata, "Growth and Mortality Rate of Scad (*Decapterus macrosoma*, Bleeker 1851) Landedat Inengo Fish Landing Base, Bone Bolango, Gorontalo. Biota: Biologi dan Pendidikan Biologi, vol. 14, no. 2, pp. 74-86. https://doi.org/10.20414/jb.v14i2.362

[5] [5] D. Pauly, and P. Martosubroto, "Baselines of Philippine and Indonesian coastal fisheries.," ICLARM Studies and Reviews 22, 182 pp, 1996.

[6] [6] R. Froese, and D. Pauly, (Editors), "FishBase 2023 version. 2023' *(www.fishbase.org)*.

[7] [7] F. D. Silooy, A. Tupamahu, O. T. S. Ongkers, and Haruna, "Population Dynamics of Mackerel Scad (*Decapterus macarellus*) in the Banda Sea," International Journal of Environment, Agriculture and Biotechnology (IJEAB), vol. 4, no. 4, pp. 1199-1204. 2019. https://doi.org/10.22161/ijeab.4446

[8] [8] D. Panda, S. K. Chakraborty, A. K. Jaiswar, A. P. Sharma, B. C. Jha, B. T. Sawant, S. K. Bhagabati, and K. Kumar, 2012. Fishery and population dynamics of two species of carangids, *Decapterus russelli* (Ruppell, 1830) and *Megalaspis cordyla* (Linnaeus, 1758) from Mumbai waters. Indian Journal Fish, vol. 59, no. 4, pp. 53-60, 2012.

[9] [9] S. Herwaty, A. Mallawa, Najamuddin, and M. Zainuddin, "Population Dynamic of Mackerel Scad (*Decapterus macarellus* Cuvier, 1833) in the Timor Sea," Jurnal Kelautan Tropis Juni, vol. 27, no. 2, pp. 333-344, 2024. https://doi.org/10.14710/jkt.v27i2.21918

[10] [10] L. P. S. S. Putri, Karnan, and D. Santoso, "Analysis of Morphometric Characteristics of Indian Mackerel (*Rastrelliger kanagurta* Cuvier, 1816) Landed at the Fish Landing Base Tanjung Luar, East Lombok," Jurnal Biologi Tropis, vol. 24, no. 3, pp. 170–180, 2024. http://doi.org/10.29303/jbt.v24i3.7376

[11] [11] I. N. Y. Parawangsa, and P. A. Tampubolon, "Some biological aspects of Indian mackerel (*Rastelliger kanagurta* Cuvier, 1816) in Bali Strait waters," Omni-Akuatika, vol. 19, no. 2, pp. 137-146, 2023. https://doi.org/10.20884/1.oa.2023.19.2.1073

[12] [12] R. J. H. Beverton, and S. J. Holt, "*On the dynamics of exploited fish populations,"* Fisheries Investigations Series II, Vol. 19, Ministry of Agriculture, London, 1957.

[13] [13] W. W. L. Cheung, R. Watson, and D. Pauly, "Signature of ocean warming in global fisheries catch," Nature, vol. 497, pp. 365–368., 2019. https://doi.org/10.1038/nature12156

[14] [14] J. A. Pattikawa, O. T. S. Ongkers, J. M. S. Tetelepta, P.

[15] Uneputty, and A. Amirudin, "Some biological aspects of mackerel scad (*Decapterus macarellus*) in Ambon Island waters, Indonesia,' International Journal of Fisheries and Aquatic Studies, vol. 6, no. 4, pp. 171-175, 2018.

[16] [15] P. G. B. Neto, F. M. Dutra, E. L. C. Ballester, and L. Portz, "Growth and Survival of Silver Catfish, *R. quelen*, Larvae Fed Enriched Live Food and Artificial Diet," Revista Brasileira de Ciência Veterinária, vol. 20, no. 4, pp. 216-221, 2013. https://doi.org/10.4322/rbcv.2014.011

[17] [16] M. King, '*Fisheries biology, assessment and management.* 2nd ed," Blackwell Publishing, Oxford, 2007.

[18] [17] G. R. Allen, and M. V. Erdmann, "*Reef fishes of the East Indies"*. Vol. I–III, Tropical Reef Research, Perth, Australia, 2012.

[19] [18] FAO, "*Code of Conduct for Responsible Fisheries,"* Food and Agriculture Organization of the United Nations, Rome, 1995.

[20] [19] R. Rahayu, and R. W. Fuah, "Analysis of Perception and Compliance of Sibolga Purse Seine Fishermen Based on Licensed Fishing Ground," Journal of Fish Health, vol. 5, no. 3, pp. 442-456, 2025. https://doi.org/10.29303/jfh.v5i3.7867

[21] [20] P. Sparre, and S. C. Venema, "*Introduction to tropical fish stock assessment,"* FAO Fisheries Technical Paper No. 306/Rev.2, Rome, 1998.

[22] [21] D. Pauly, "On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks," Journal du Conseil, vol. 39, no. 2, pp. 175–192, 1980. https://doi.org/10.1093/icesjms/39.2.175

[23] [22] J. A. Gulland, "*The fish resources of the ocean,"* FAO Fisheries Technical Paper No. 97, Rome, 1971.

[24] [23] M. Haddon, "*Modelling and quantitative methods in fisheries,"* 2nd ed. CRC Press, Boca Raton, 2011.

[25] [24] P. A. Henderson, and R. M. Seaby, "*Population analysis system II for windows,"* Pisces Conservation Ltd., UK, 2005.

[26] [25] G. Bianchi, "*Field guide to the commercial marine and brackish-water species of Tanzania,"* FAO Fisheries Identification Sheets, 1985.

[27] [26] W. E. Ricker, "*Computation and interpretation of biological statistics of fish populations,"* Bulletin of the Fisheries Research Board of Canada, 191, 382 pp, 1975.

[28] [27] T. Sakai, "*Fishes of Japan,"* Tokai University Press, Tokyo, 1999

[29] [28] D. Christybapita, M. Divyagnaneswari, and R. D. Michael, "Oral administration of *Eclipta alba* leaf extract enhances non-specific immune responses and disease resistance in tilapia," Fish & Shellfish Immunology, vol. 23, no. 4, pp. 840–852, 2007 https://doi.org/10.1016/j.fsi.2007.03.010

[30] [29] P. Abaunza, L. Gordo, C. Karlou-Riga, A. Murta, A. T. G. W. Eltink, M. T. G. Santamar´ıa, C. Zimmermann, C. Hammer, P. Lucio, S. A. Iversen, J. Molloy, and E. Gallo, 'Growth and reproduction of horse mackerel, *Trachurus trachurus* (carangidae)," Reviews in Fish Biology and Fisheries, vol. 13, pp. 27–61, 2003. https://doi.org/10.1023/A:1026334532390

[31] [30] B. W. Coad, "Review of the Freshwater Catfishes of Iran (Order Siluriformes)," Iranian Journal of Ichthyology, vol. 1, no. 4, pp. 218–257, 2015. https://doi.org/10.22034/iji.v1i4.6

[32] [31] C. W. Petersen, and R. R. Warner, "Sexual patterns in the labroid fishes," Copeia, vol. 2, pp. 357–368, 2002.

[33] [32[H. R. Esmaeili, H. Mehraban, K. Abbasi, Y. Keivany, and B. W. Coad, "Review and updated checklist of freshwater fishes of Iran: Taxonomy, distribution and conservation status," Iran Journal Ichthyol, vol. 4, no. 1, pp. 1-114, 2017. https://doi.org/10.7508/iji.2017

[34] [33] E. J. Tapotubun, M. Riyanto, R. I. Wahju, W. Trilaksani, U. Uju, and S. M. Picaulima, "Hubungan Panjang-Berat, Pola Pertumbuhan, Faktor Kondisi Ikan Layang (Decapterus Russelli) Di Kepulauan Kei, Maluku, Indonesia, BAWAL, vol. 17, no. 1, pp. 15-21, 2025. http://dx.doi.org/10.15578/bawal.17.1.2025.15%20-%2021

[35] [34] A. E. Punt, A. D. M. Smith, and G. Cui, "Review of progress in the introduction of management strategy evaluation (MSE) approaches in Australia's South East Fishery," Marine and Freshwater Research, vol. 52, no. 4, pp. 719-726, 2021 https://doi.org/10.1071/MF99187

[36] [35] J. Rehulka, "Influence of astaxanthin on growth rate condition and blood indices of rainbow trout *Oncorhynchus mykiss*," *Aquaculture*, vol. 190, pp. 27–47. 2000. https://doi.org/10.1016/S0044-8486(00)00383-5

[37] [36] S. J. Brandl, and D. R. Bellwood, "Pair-Formation in Coral Reef Fishes: An Ecological Perspective," Oceanography and Marine Biology, vol. 52, pp. 1-80, 2007. https://doi.org/10.1201/b17143-2?urlappend=%3Futm_source%3Dresearchgate

[38] [37] R. J. Magwa, E. R. E. Gelis, S. Heltria, F. Ramdhani, L. H. Yunita, Y. Wulanda, S. Fatchiyyah, and S. Hadi, "Morphometric Analysis of *Decapterus russelli* in Transitional Season 1 Landed at Kaliadem and Muara Angke Fish Market, Jakarta," Jurnal Pengelolaan Perikanan Tropis, vol. 07, no. 01, pp. 63-69, 2023. https://doi.org/10.29244/jppt.v7i1.43981

[39] [38] H. Honda, and K. Kikuchi, "Nitrogen budget of polychaete *Perinereis nuntia vallata* fed on faeces of Japanese flounder," Fisheries Science, vol. 68, pp. 1304–1308, 2002. https://doi.org/10.1046/j.1444-2906.2002.00568.x

[40] [39] C. H. Hsieh, C. S. Reiss, J. R. Hunter, J.R., Beddington, R. M. May, and G. Sugihara, "Fishing elevates variability in the abundance of exploited species," Nature, vol. 443, pp. 859–862, 2006. https://doi.org/10.1038/nature05232

[41] [40] S. Ohshimo, M. Yoda, N. Itasaka, and N. Morinaga, N., "Age, growth and reproductive characteristics of round scad *Decapterus maruadsi* in the waters off west Kyushu, the East China Sea,' Fisheries Science, vol. 72, no. 4, pp. 855-859, 2006. https://doi.org/10.1111/j.1444-2906.2006.01227.x

[42] [41] P. Purwanto, E. C. Franklin, S. R. Mardiani, and A. White, "Stock Assessment and Overexploitation Risk of Small Pelagic Fish in Fisheries Management Area 715 of Indonesia," Asian Fisheries Science, vol. 35, no. 1, pp. 76–89, 2022. https://doi.org/10.33997/j.afs.2022.35.1.007

[43] [42] M. A. Peck, I. A. Catalán, S. Garrido, and R. R. Rykaczewski, "Small pelagic fish: new frontiers in ecological research," Marine Ecology Progress Series, vol. 741, pp. 1-6, 2024. https://doi.org/10.3354/meps14648

[44] [43] J. Lloret, E. Faliex, G. E. Shulman, J. A. Raga, P. Sasal, M/ Muñoz, M. Casadevall, A. E. Ahuir-Baraja, F. E. Montero, A. Repullés-Albelda, M. Cardinale, H. J. Rätz, S. Vila, and D. Ferrer, "Fish Health and Fisheries, Implications for Stock Assessment and Management: The Mediterranean Example. Reviews in Fisheries Science, vol. 20, no. 3, pp. 165-180, 2012. https://doi.org/10.1080/10641262.2012.695817?urlappend=%3Futm_source%3Dresearchgate