Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(5): 2613 – 2633 (2025)
www.ejabf.journals.ekb.eg

Growth, Mortality, and Stock Status of Bigeye Scad *Selar crumenophthalmus* in the Natuna Sea, Indonesia

Moh Fauzi [1]*, Heri Widiyastuti[1], Achmad Zamroni[1], Thomas Hidayat[1], Siti Mardlijah[1], Arief Wujdi[2], Andina Ramadhani Putri Pane[1], Tirtadanu[1], Karsono Wagiyo[1], Tegoeh Noegroho[1]

[1]National Research and Innovation Agency (BRIN), Indonesia. Jalan Raya Nanggewer KM. 42 Cibinong, Bogor, Indonesia

[2]Interdisciplinary Program of Marine and Fisheries Sciences and Convergent Technology, Pukyong National University, Busan, Republic of Korea. 48513

***Corresponding Author: mohf003@brin.go.id**

ARTICLE INFO

Article History:
Received: July 20, 2025
Accepted: Sep. 25, 2025
Online: Oct. 17, 2025

Keywords:
Selar crumenophthalmus,
Length-based stock assessment,
Overfishing,
Spawning potential ratio (SPR),
Natuna Sea,
Fisheries management

ABSTRACT

The bigeye scad (*Selar crumenophthalmus*) is a commercially significant small pelagic species in Indonesia's Fisheries Management Area (FMA) 711, a region facing increasing fishing pressure and declining catch rates. This study provides the first quantitative stock assessment for this species in the Natuna Sea to establish a scientific basis for management. Length-frequency data from 6,511 individuals were collected monthly from March 2019 to November 2021 from commercial purse seine landings and were analyzed using the TropFishR package with the electronic length frequency analysis (ELEFAN) method. The results indicated a fast-growing population with an asymptotic length (L_∞) of 26.18cm and a growth coefficient (K) of 0.87 year^{-1}. However, the stock is under intense pressure, with fishing mortality (F=2.03 year^{-1}) being nearly double the natural mortality (M=1.07 year^{-1}). This has led to an unsustainable exploitation rate (E=0.65) and has depleted the spawning stock biomass to a critical level, with a spawning potential ratio (SPR) of just 19%, below the 20% limit reference point. This study concludes that the bigeye scad stock is experiencing severe growth overfishing and is at high risk of recruitment overfishing, threatening the long-term viability of the fishery. Urgent management interventions are imperative, focusing on reducing fishing mortality through effort controls and increasing the size at first capture via gear modifications to rebuild the spawning stock and to ensure the sustainability of this vital resource.

INTRODUCTION

The Natuna Sea and the South China Sea are regions of concentrated fishing for small pelagic species. The exploitation is consistently conducted by purse seine fleets operating from several fishing ports in Indonesia's Fisheries Management Area 711 (FMA-711), such as Pemangkat, Batam, Karimun, and Palembang **(Hariati *et al.*, 2009;**

Priatna *et al.*, 2024). The utilization rate of pelagic marine resources in the Natuna and South China Sea has generally increased from year to year. This condition has resulted in a 0.20 ton trip^{-1} year^{-1} decrease in the average CPUE (Catch per Unit Effort) from 2007 to 2013. The increasing demand for fish as a food source has led fishermen to increase their fishing efforts (number and capacity) to procure more fish, despite the decline in fish potential **(Wiyono, 2012)**. To exploit pelagic resources in the South China Sea, fishermen in Pemangkat have been augmenting their operational inputs (fuel, voyage duration, rations, and lighting power) and increasing their fishing efforts **(Budiarti *et al.*, 2015)**.

The catch composition indicates that the big eye scad (*Selar crumenophthalmus*) represents a substantial proportion, ranking second in abundance after the Indian scad (*Decapetrus russelli*) **(Safitri & Magdalena, 2018)**. The bigeye scad is categorized as an economically significant commodity, denoting a product with substantial market value, notable macro-production volume, and excellent production capacity **(Syam *et al.*, 2017)**.

The scientific evaluation of fisheries underpins the sustainable use of marine resources from ecological, economic, and social viewpoints. Understanding current fishing pressure and stock biomass in relation to biological reference points aids in developing management strategies for sustainable harvesting. Single-species models are often used for management objectives to determine these reference values **(Hilborn & Walters, 1992; Skern-Mauritzen *et al.*, 2016)**.

In tropical fisheries, the evaluation of fish stocks is mainly performed using length-composition data **(Sparre & Venema, 1998)**. Nonetheless, in some instances, length-based models have shown enhanced performance relative to specific catch-based models. This is attributed to the heightened sensitivity of these models in capturing historical situations and depletion levels (**Pons *et al.*, 2019)**.

Therefore, this research intended to determine the growth characteristics, mortality rates, and fisheries management reference points for the bigeye scad (*Selar crumenophthalmus*) in the waters of the Natuna Sea, Indonesia.

MATERIALS AND METHODS

Study area and data collection

Data on length-frequency for estimating the stock assessment of bigeye scad fishery were collected from commercial purse seine landing sites in Pemangkat Fishing Port, West Kalimantan, Indonesia. Data on the length-frequency of bigeye scad were collected monthly from March 2019 to November 2021 using a random sampling procedure. The fork length of all collected individuals was measured to a precision of 0.1cm and was weighed to an accuracy of one gram. Length frequency data were later pooled into groups of 1cm length intervals.

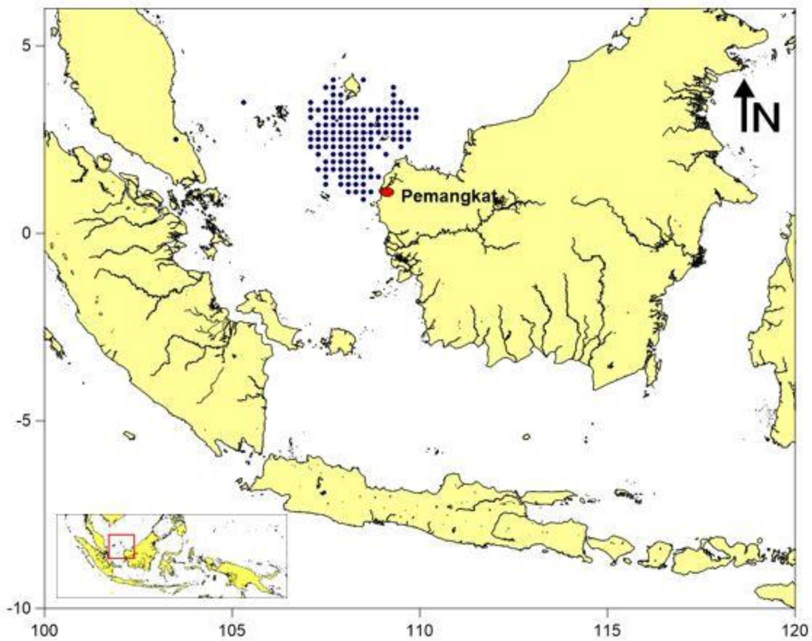

Fig. 1. The fishing grounds of purse seine vessels that are stationed at the Pemangkat Fishing Port in West Kalimantan, Indonesia

Data analysis

Length frequency distribution

LFQ data collected over three years were employed to evaluate the biological stock characteristics of *S. crumenophthalmus* in this study. The "lfqModify()" and "lfqRestructure()" functions were employed to convert the LFQ data into monthly captures, which were then divided into 15 length classes **(Taylor & Mildenberger, 2017)**.

Selectivity length

Selectivity length (SL_{50}) was determined using a logistic curve for trawl net selectivity **(Sparre & Venema, 1998)**:

$$S_L = \frac{1}{1+\exp\,(a-b^{*}L)} \quad (1)$$

Where, SL denotes the selectivity of the fishing gear, a and b represent constants, L signifies the length of the fish, and the value of Lc is derived from the ratio a/b.

Estimation of growth parameter

Numerous methodologies have been established for analyzing length-frequency data from fisheries with data deficiencies, including population characteristics and stock status. Specific methodologies are integrated into the R statistical computing software and are created in the TropFishR package. This software comprises both conventional and contemporary versions of the electronic length frequency analysis, which is used for estimating growth parameters and incorporates novel optimisation approaches. In this study, we used contemporary techniques through the ELEFAN GA and SA approaches contained in the TropFish R package version 1.6.6 **(Taylor & Mildenberger, 2017)**.

The TropfishR package offers two ELEFAN optimization approaches: simulated annealing (ELEFAN S.A) and a generic algorithm (ELEFAN G.A). Both were utilized, and the approach with the best scoring fit (Rn max) was selected for further analysis. These two models will estimate Linfinity and K from length frequency data by restructuring the data and fitting the growth curve through it. The Powell-Wetherall method **(Wetherall *et al.*, 1987)** was used to provide an initial estimate of the asymptotic length (L_∞); the technique requires a catch vector per length class representative of the length distribution in yearly catches, instead of the catch matrix **(Taylor & Mildenberger, 2017)**. With this initial estimate of L_∞ as the seeded value, the ELEFAN procedure was used to fit the seasonally oscillating von Bertalanffy growth function (soVBGF) from the length–frequency data. Growth was modeled in this study according to the soVBGF **(Somers, 1988)**, and a separate non-linear fitting of the soVBGF to length-at-age data was produced using the same procedure as described by **Taylor and Mildenberger (2017)**. It is essential to note that the newly implemented ELEFAN methods (ELEFAN S.A. and ELEFAN G.A.) enable the optimization of the soVBGF7 **(Taylor & Mildenberger, 2017)**. The growth performance index Ø′ (phi-prime) was calculated based on the growth parameter test, following the equation of **Pauly and Munro (1984)**. The theoretical lifespan (t0) was determined using the empirical equation **(Pauly, 1984)**:

$$\text{Log}\,(-t_0) = -0.392 - 0.275 \log\, L_\infty - 1.038 \log\, k \quad (2)$$

Upon acquiring growth parameters (L_∞, K, and t_0), their values are included in the von Bertalanffy growth function (VBGF) **(Bertalanffy, 1938)**:

$$Lt = L_\infty (1 - \mathrm{e}^{-\mathrm{K}(\mathrm{t}-\mathrm{t}_0)} \quad (3)$$

Where, Lt represents the length at age t (cm); L_∞ denotes the asymptotic length (cm); K signifies the growth coefficient (year^{-1}); t is the passage time (i.e., age; years); t_0 indicates the hypothetical fish age at zero length (years).

The K parameter estimates the longevity (lifespan) or maximum age (t_{max}) of short mackerel species utilizing Pauly's formula **(Pauly, 1984)** as follows:

$$t_{max} = 3/\mathrm{K} \quad (4)$$

Natural mortality, fishing mortality rate, and exploitation rate

Natural mortality was assessed utilizing the length-based updated Pauly estimator as advised by **Then *et al.* (2015)**

$$M = 4.118\, K^{0.73}\, L_\infty{}^{-0.33} \quad (5)$$

The linearized length-converted catch curve method was employed to estimate the instantaneous total mortality rate (Z) **(Pauly, 1990)**

$$\log\left(\frac{N_i}{d\,t_i}\right) = a + b_t \quad (6)$$

The calculation of fishing mortality (F) is derived by deducting natural mortality (M) from total mortality (Z):

$$F = Z - M \qquad (7)$$

The correlation between fishing mortality (F) and natural mortality (M) was employed to calculate the exploitation rate (E) of the stock, as delineated by **Pauly (1983)**, in the subsequent manner:

$$E = F/Z \qquad (8)$$

Stock size estimation and yield per recruit

Variation in the fishing mortality (F) value was also identified for each length class by applying a virtual population analysis (VPA) using the VPA function within the TropfishR package. Jones's length-based virtual population analysis (*VPA*) was used to estimate stock size **(Jones, 1984)**. The model of **Thompson and Bell (1934)** was used for estimating the relative yield per recruit (*YPR*) and reference points. The Thompson and Bell model was used to provide biological reference levels, which are needed to deduce input control measures, including reducing fishing effort. The fishing mortality required to estimate the yield and biomass trajectories in the study was obtained by varying the parameter F in the Thompson and Bell model. The YPR model requires information about the parameters of the length-weight relationship (a) and (b), and the optional maturity parameters (Lmat and Wmat) allow for the estimation of the spawning potential ratio (SPR). In this study, these values pertain to the work of **Fauzi *et al.* (2018)**, who previously researched the same species and locations.

RESULTS

Length-frequency distribution

Fig. (2) presents the fork length data of bigeye scad *S. crumenophthalmus* during the sampling period. Throughout the study period, 6,511 samples of bigeye scad were measured. The length range was 11 to 24.6cm FL, with a mean length of 17.9 ± 2.08 cm FL. Fifteen length classes, each with 1cm intervals, were established, with the mode located in the 18cm length class. The selectivity of purse seine gear for bigeye scad (SL_{50}) was 17cm, which is smaller than the length at first maturity (L_{mat}) of 20cm.

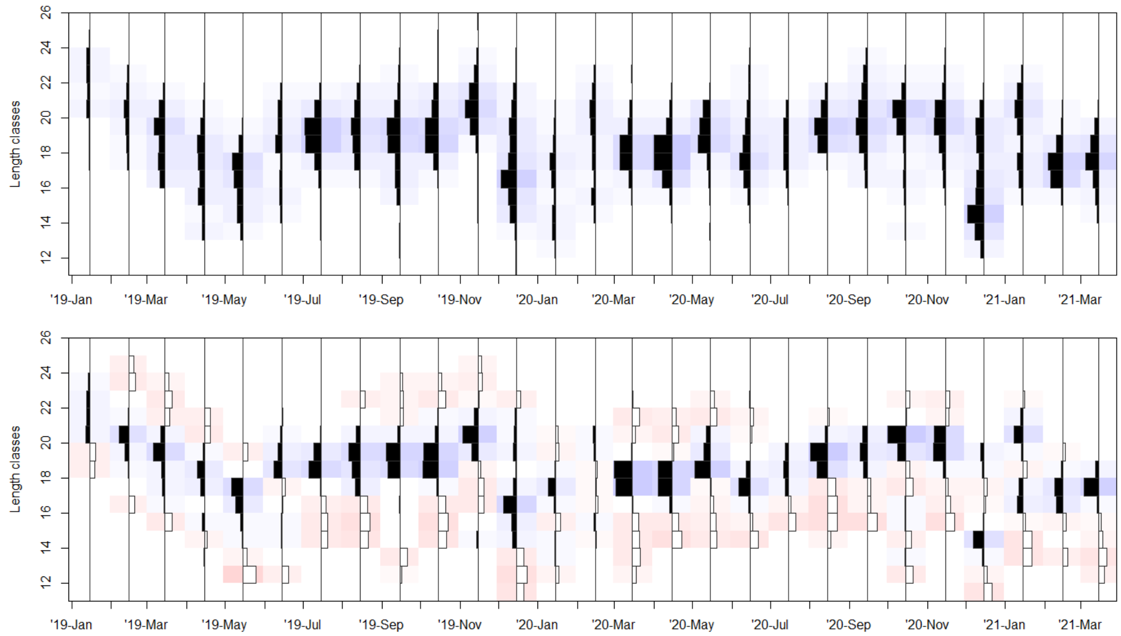

Fig. 2. Fork length frequency data of *Selar crumenophthalmus* depicted in captures from 2019 to 2021 (a) and restructured data (b), utilizing a moving average (MA) of 7 over the sampling period for the calculation of biological stock parameters. Positive (black, identified as peaks in the computation of the goodness-of-fit indicator Rn) and negative (white, identified as troughs) Scored bins are represented by the orientation of the histogram

Growth parameters

Table (1) presents the population parameters (L_∞, K, tanchor, C, Φ, ts, and maximum Rn value) of *Selar crumenophthalmus* collected between 2019 and 2021. Two methods were employed to estimate these parameters: ELEFAN S.A. and ELEFAN G.A. Among these approaches, ELEFAN S.A. appears to be the most effective. For the subsequent analysis, the data utilized were those from the ELEFAN S.A. method, which indicates an asymptotic length of 26.18 cm and an annual growth rate of 0.87, based on the Rn value. The values of t anchor, C, Φ, and ts were recorded at 0.99, 0.93, 2.78 $year^{-1}$, and 0.97, respectively.

Table 1. Comparison of growth parameter estimates for *Selar crumenophthalmus* using various methods

Methods	L_∞ (cm)	K ($year^{-1}$)	t_anchor	C	Φ ($year^{-1}$)	ts	Rn
ELEFAN S.A.	26.18	0.87	0.99	0.93	2.78	0.97	0.52
ELEFAN G.A.	27.17	0.78	0.28	0.94	2.88	0.08	0.32

Fig. (3a) illustrates the growth trajectories across the size modalities of the ELEFAN S.A. growth estimation technique. This line depicts the theoretical trajectory of average fish growth over time. Three age cohorts of bigeye scad inhabit the Natuna Sea. Utilizing the optimal method in growth analysis, ELEFAN S.A. (red line) identified the youngest cohort within the length class of approximately 14cm in December, representing a continuation of the young fish cohort that emerged in October (two months prior). The juvenile fish exhibit elevated growth rates until they attain a length of 18cm, after which their growth rate decelerates until they attain their asymptotic length of 26.18cm FL. Rn represents the goodness-of-fit metric. It assesses the extent to which the growth curve (red line) aligns with the peaks of the histogram. An elevated Rn value (approaching 1) signifies a superior alignment between the calculated curve and the observed data. The value of 0.52 indicates that the growth model developed by ELEFAN S.A. exhibits a reasonably good match to the length frequency data of bigeye scad. Nilai t0 is obtained from the **Pauly (1984)** equation of -0,24 so that the von Bertalanfy function is $Lt = 26.18(1 - \mathrm{e}^{-0.87(\mathrm{t}-(-0.24)}$ (Fig. 3b)

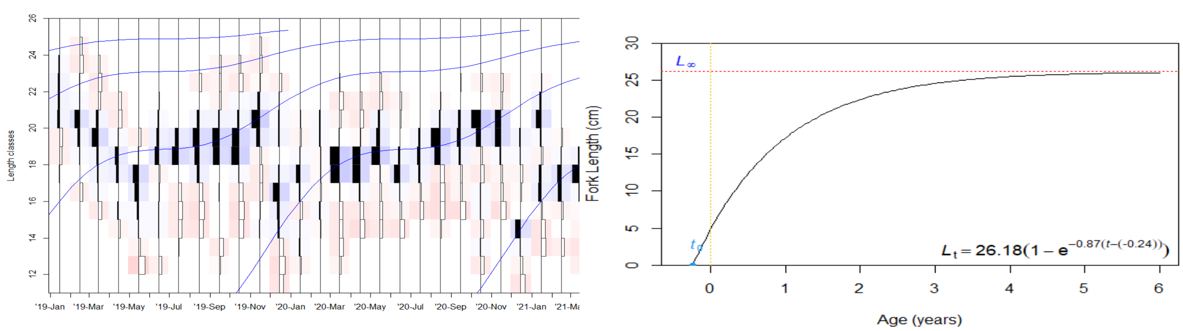

Fig. 3. Growth curves (blue lines) of *Selar crumenophthalmus*, which inhabits the Natuna Sea, are depicted in the length-frequency histogram obtained through the bootstrapped ELEFAN with SA analysis superimposed (a). Growth curve of von Bertalanffy bigeye sa (*S. crumenophthalmus*) reconstructed from the equation $Lt = 26.18(1 - \mathrm{e}^{-0.87(\mathrm{t}-(-0.24)}$. The red line indicates Linf, and the yellow line indicates the value of t0.

Mortality and exploitation rates

Total mortality (Z) was 3.10/a, derived from a linearized length-converted catch curve utilizing TropFishR (Fig. 4a). The methodology established by **Then *et al.* (2015)** was employed to calculate the instantaneous natural mortality rate (M), which is 1.07/a. The fishing mortality rate was determined to be 2.03 by subtracting M from Z. The present exploitation rate (Ecurr) was computed as. 0.65.

Stock size estimation and yield-per-recruit

The stock size value was estimated by inputting parameters, including the values of a and b from the length-weight relationship of bigeye scad in Natuna waters, along with the values of Lmat and Wmat from the previous study **(Fauzi *et al.*, 2018)**. Fig. (4b) illustrates the logistic-shaped fishing pattern across length classes, shown by the red line in the cohort analysis plot. The small group, which included 70% of the overall population, had the highest population of fish (survivors). These fish were young, measuring between 11.5 and 15.5cm in length. The overall population gradually declines as the group's size increases. Larger fish have a better chance of being captured, even if these juveniles are more likely to die naturally (about 10%). Fish were previously caught in every length class; however, 77% of the fish caught were extremely fiercely caught, specifically in sizes 17.5 to 21.5. At length, class 19.5, the apex was reached.

(a) (b)

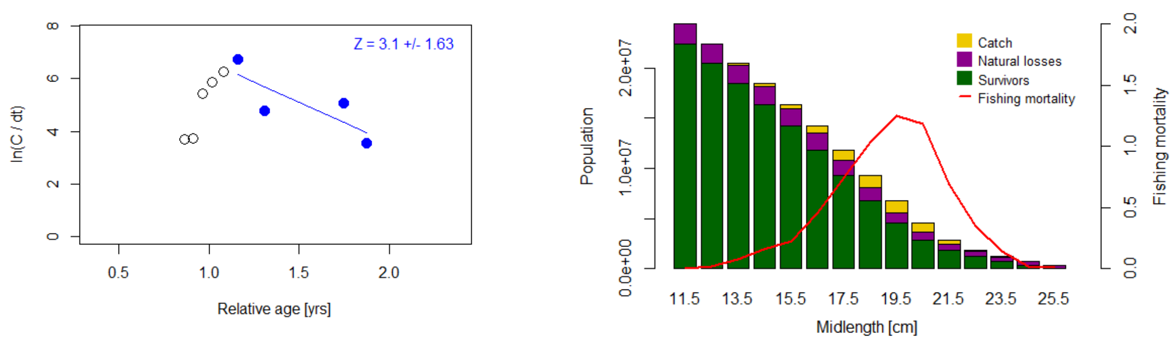

Fig. 4. Length-converted catch curve of *S. crumenophthalmus* (shown by solid dots, which were utilised in the calculation using least squares linear regression) (a), Jones' cohort study of the bigeye scad fishery, detailing fishing mortality rates by length classes and the resultant reconstructed population structure (survivors, natural losses, and catch) quantified each length class (b)

The biological reference values of fishing mortality and exploitation derived from the model are shown in Table (2).

Table 2. Biological reference points of *S. crumenophthalmus* inhabiting the Natuna Sea and the impact of variations in fishing mortality

Level of Fishing Mortality	Parameters				
	F	E	YPR	BPR	SPR
$F_{0.1}$	2.69	0.87	45804.56	NA	0.11
$F_{0.4}$	1.12	0.36	31762.68	69971.3	0.4
$F_{0.5}$	1.53	0.49	37487.22	59907.5	0.29
F_{max}	5	1.61	49472.56	30181.4	0.02
$F_{current}$	2.03	0.65	42141.87	51020.7	0.19

Fig. (5) illustrates the graphical outputs of the model about the yield and biomass curve per recruit in relation to fishing mortality and Lc. The present fishing mortality rate (curr.F = 2.03) remains under the desired reference point $F_{0.1}$ (2.69) and far lower than the F_{max} threshold (5.0)

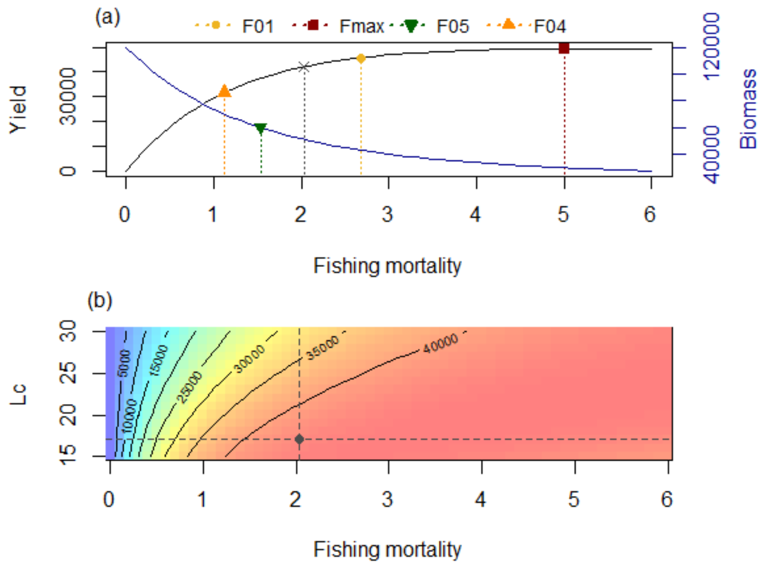

Fig. 5. The Thompson and Bell model of bigeye scad in the Natuna Sea

This model yielded the following results: (a) Yield and biomass curves per recruit. The black dot represents the yield and biomass under current fishing pressure. The fishing mortality for maximum sustainable yield (F_{max}) and fishing mortality to fish the stock at 50% of the virgin biomass ($F_{0.5}$) are represented by the yellow and red dashed lines, correspondingly. (b) examination of the effect of varying exploitation rates and Lc values on the relative yield per recruit

DISCUSSION

This study presents the first comprehensive assessment of the population dynamics of the bigeye scad (*Selar crumenophthalmus*) in the Natuna Sea, which is part of the Fisheries Management Area (FMA) 711 of the Republic of Indonesia. This region is a highly intensive fishing zone for small pelagic species, primarily exploited by the purse seine fleet based in Pemangkat. By employing a length-frequency analysis approach optimized by the ELEFAN simulated annealing (SA) method, this study successfully estimated key population parameters. The main findings indicate that the bigeye scad population in the Natuna Sea has an asymptotic length ($L\infty$) of 26.18cm, a growth coefficient (K) of 0.87 per year, a total mortality (Z) of 3.10 per year, a natural mortality (M) of 1.07 per year, and a fishing mortality (F) of 2.03 per year.

The significance of these findings lies in their ability to directly address the research objectives: to provide a quantitative basis for growth parameters, mortality rates, and management reference points. The establishment of these values is a fundamental step in fisheries science, as it transforms qualitative observations of fishing pressure into measurable quantitative evaluations. The background of this study highlights a trend of increasing fishing effort contrasting with a decline in Catch per Unit Effort (CPUE) in this region, indicating a potential decline in stock health. Without solid population parameters, such claims remain anecdotal. Therefore, the results of this study provide essential diagnostic tools that enable fisheries managers to transition from presumptive management to evidence-based management, which is crucial for the sustainability of the bigeye scad resource in one of Indonesia's most important fisheries granaries.

The bigeye scad samples included in this investigation ranged in length from 11.2 to 24.6cm, which falls within the range reported in earlier research. According to records, bigeye scad range in length from 6.5- 25.5cm in Reunion Island **(Roos *et al.*, 2007)**; 7.7 to 24.25cm in the Maldives Waters **(Adeeb *et al.*, 2014)**; 14.9- 26.4cm in the Celebes Sea **(Chodrijah *et al.*, 2020)** 14.5- 25.5cm in Sibolga, Indonesia **(Fitria *et al.*, 2020)**; and 15– 27cm in Gunungkidul Waters, Indonesia **(Tirtadanu *et al.*, 2025)**. Larger fish specimens have been reported in other regions, such as the northwestern coast of India, where sizes range from 18.6 to 28.5cm **(Panda *et al.*, 2016)**. Additionally, in the waters of the Philippines, sizes range from 27 to 31.6cm **(Dalzell & Penaflor, 1989)**. The SL_{50} value varies similarly. In this investigation, the bigeye scad SL_{50} value was 17.05cm. Prior research in Indonesian seas in Sulawesi revealed a value of 16.75cm **(Adeeb *et al.*, 2014)** and 18.75cm **(Chodrijah *et al.*, 2020)** in Maldivian Waters. The sampling design and fishing gear selectivity have an impact on the variation in the sample range. The estimation of growth, age, and mortality characteristics is significantly impacted by sample size. In general, the estimation findings will be more diverse when the sample size is small. In the meantime, a more accurate and consistent estimate will be obtained with a bigger sample size (>1000 fish) **(Kritzer *et al.*, 2001)**. Furthermore, IUU fishing, fishing pressure, and climate can all alter the length range of the sample and upset the population equilibrium **(Gebremedhin *et al.*, 2021)**.

In tropical and subtropical regions, length-frequency analysis has been extensively employed. The primary benefit of length-frequency (LFQ) data is that only a representative subsample of the total capture is necessary. This means that not all fish in the catch must be measured, as long as the subsample is random and representative of the entire catch **(Kindong *et al.*, 2020)**. ELEFAN S.A. and G.A. are more advanced and reliable than standard search techniques, such as response surface analysis, for deriving growth parameters of the von Bertalanffy growth function (VBGF) from LFQ data **(Pauly, 1980; Mildenberger *et al.*, 2017)**. S.A. searches extensively and narrows down using physics, whereas G.A. employs evolution to refine the solution population. The ELEFAN S.A. algorithm works by finding and connecting the most prominent peaks on the histogram. The best path through these peaks is considered the best-fit growth curve to the data **(Taylor & Mildenberger, 2017)**.

The attained goodness-of-fit value (Rn = 0.52), albeit the highest among the evaluated approaches, ought to be regarded as a genuine representation of the biological intricacy of the tropical fish population, rather than a deficiency in methodology. A primary problem in length-frequency analysis in tropical locations is the recruitment pattern, which often exhibits continuity or prolongation throughout the year, in contrast to the distinct seasonal patterns seen in temperate species. This recruiting technique inherently produces significantly overlapping cohorts in the data, complicating the model's ability to accurately monitor modal advancement **(Sparre & Venema, 1998)**. The ELEFAN method functions by detecting and linking modal peaks; thus, when these peaks are indistinct owing to cohort overlap, the model's capacity to match an ideal growth curve is constrained, hence diminishing the Rn score **(Pauly, 1987)**. The use of contemporary optimization techniques like as simulated annealing (SA) in the TropFishR package recognizes this difficulty, since these approaches are explicitly designed to identify the optimal solution within a complex and "noisy" data environment **(Taylor & Mildenberger, 2017)**. The observed Rn value serves as a sign of an adequate model fit to complicated biological data, and the derived growth parameters are the most objective and reliable estimations achievable.

The ELEFAN SA analysis method yielded an infinite length value of 26.18, accompanied by a growth rate of 0.87. Table (3) presents the parameters related to growth, mortality, and exploitation rates for bigeye scad across different aquatic environments. The most striking observation is that the growth rate of bigeye scad in this study appears to be comparatively lower than that reported in several prior investigations, despite the infinite length range being relatively consistent **(Adeeb *et al.*, 2014; Chodrijah *et al.*, 2020; Mokoagow *et al.*, 2024)**. Several factors, including changes in water conditions, food availability, metabolic rate, fishing pressure, and pollution, can cause variations in L_∞ and K. The sample range within the same species may also be the reason for the variance in growth parameter values **(Sparre & Venema, 1998)**.

Table 3. Bigeye scad growth, mortality, and exploitation rate parameters in a variety of waters

Area	L_∞ (cm)	K	Z	M	F	F/M	ϕ'	E	Sources
Celebes Sea, Indonesia	25.95	1.01	4.28	1.9	2.38	1.25	2.83	0.56	**Chodrijah *et al.*, *(*2020)**
Aceh Waters, Indonesia	19.32	4.6	8.08	3.02	5.06	1.68	3.24	0.63	**Perdana (2019)**
Tomini Bay, Indonesia	26.94	0.55	1.33	0.48	0.85	1.77	2.6	0.64	**Mokoagow *et al.*, (2024)**
Gunungkidul waters, Indonesia	28.2	1.5	6.45	2.17	4.28	1.97	3.08	0.65	**Tirtadanu et al., (2025)**
North-West Coast India	31	1.4	4.62	2.21	2.41	1.09	3.13	0.52	**Panda eta l., (2016)**

Maldives Waters	26.54	1.64	4.01	1.78	2.03	1.14	2.82	0.56	**Adeeb et al., (2014)**
Natuna Sea, Indonesia	26.18	0.87	3.1	1.07	2.03	1.9	2.78	0.65	Present study

An analysis of the criteria outlined in Table (3) across different aquatic environments, including the current research, leads to a uniform conclusion about the life cycle strategy of *Selar crumenophthalmus*. The species often has a substantial growth coefficient (K), with values mostly between 0.87 and 1.64 year^{-1}, with a similarly elevated natural mortality rate (M), frequently above 1.0 year^{-1}. The combination of fast growth (elevated K) and significant natural mortality (elevated M) epitomizes a dynamic, short-lived fish species, sometimes classified as an r-strategist **(Jennings *et al.*, 2001)**. To enable a more rigorous comparison of growth among various stocks, the growth performance index (Φ') was examined **(Pauly & Munro, 1984)**. The results demonstrate that the Φ' values for *Selar crumenophthalmus* show notable consistency across different locations, generally falling between 2.60 and 3.24. The consistency in Φ' provides a unique viewpoint, as this index is regarded as a more stable metric for comparing populations of the same species compared to the highly variable individual parameters of K and $L\infty$ **(Sparre & Venema, 1998)**. Although there is considerable variation in individual K and $L\infty$ values, the intrinsic growth performance of the species is fundamentally conserved. This suggests that these variations are likely plastic responses to differing habitat conditions, including temperature, food availability, and fishing pressure **(Jennings *et al.*, 2001)**. The Φ' analysis indicates that the growth parameters identified in this study ($L\infty$ = 26.18 cm, K = 0.87, Φ' = 2.78) are within a credible range and comparable to other *S. crumenophthalmus* populations across different geographical regions.

The natural mortality rate parameter for bigeye scad in this study was 1.07, and mortality due to fishing was 2.03. This shows that the mortality of bigeye scad due to fishing pressure was much higher than natural mortality, with a ratio of 1.9. The exploitation rate reached a value of 0.65, which exceeded the optimum value of 0.5. The optimal exploitation rate (E_{msy}) is 0.5, and an E value greater than 0.5 indicates over-exploitation or overfishing **(Gulland, 1983)**. When compared to previous studies in various waters (Table 3), it appears that bigeye scad has been overexploited in almost all seas.

Virtual population analysis (VPA) is a method for assessing fish stocks by reconstructing past population sizes and estimating fishing mortality rates. This analysis works retrospectively, using total catch data per age or length group as its primary input. Thus, VPA can provide a detailed picture of fish numbers and catch trends at each stage of the stock's life **(Goodyear, 1993; Sparre & Venema, 1998; Mildenberger *et al.*, 2017)**. It is evident from Fig. (4b) that this fishery has a very high degree of size selectivity. When fish reach a size of 15.5cm, fishing pressure starts to become noticeable, and for fish between 19.5 and 20.5cm, it peaks with a very high exploitation rate (F value > 1.2). Bigeye scad in the Natuna Sea reach their L_{mat} value at a length of 20.2cm FL, according to **Fauzi *et al.* (2018)**. Most of the population collected are fish that are not yet mature, as indicated by the SL_{50} fishing selectivity value of 17.05cm FL. There is a genuine risk of growth overfishing, in which fish are captured before they have reached their full capacity for growth and reproduction, due to the intensive exploitation of this population segment. The sustainability of stocks and future catches is therefore extremely fragile due to severe exploitation at this critical period of the life cycle, and it is contingent upon the success of annual recruitment to restore the population.

An examination of the biological reference points in Table (2) reveals a significant phenomenon that emphasizes the necessity for management intervention. While the present yield-per-recruit (YPR) at F current = 2.03 has not attained its theoretical maximum (F max = 5), aiming for such a target would be unwise. The use of F max is currently seen as excessively optimistic and lacking in precaution, as it does not take into account the condition of the spawning stock biomass **(Tirtadanu *et al.*, 2023)**. The risks associated with this yield-focused perspective are evident in the stock's present health status. The spawning potential ratio (SPR) stands at 19.1%, which is below the 20% critical threshold commonly recognized as a reference point for recruitment overfishing **(Goodyear, 1993; Coscino *et al.*, 2024)**.

The significance of this SPR threshold can indeed be affected by the life history traits of a species. Selar crumenophthalmus is recognized for its high fecundity, with research conducted in Indonesian waters indicating fecundity values that range from around 148,000 to more than 472,000 eggs per individual **(Chodrijah & Faizah, 2018)**. Theoretically, a high reproductive potential of this nature offers resilience against fishing pressure. The depletion of the spawning stock biomass below this critical threshold, despite the species' high reproductive capacity, underscores the seriousness of the situation created by intense fishing pressure. This indicates that the rate of fishing mortality is surpassing the species' inherent capacity for self-replenishment. Consequently, it is essential to prioritize immediate management actions aimed at substantially decreasing fishing mortality (F). The focus should shift from maximizing yield per recruit (YPR) to a more cautious objective of restoring the spawning stock to safe levels, such as targeting 40% spawning potential ratio (SPR).

The stock dynamics of *S. crumenophthalmus* in the Natuna Sea cannot be separated from its highly dynamic physical environment. As part of the Sunda Shelf, these waters are strongly influenced by the Asian monsoon cycle, which drives significant seasonal changes in current circulation, sea surface temperature (SST), and primary productivity **(Prayogo & Arthana, 2009)**. Previous research in the Natuna Sea has consistently shown that the catch per unit effort (CPUE) for small pelagic fish, including *S. crumenophthalmus*, tends to peak during the Southeast monsoon (May-September) and decline during the Northwest monsoon (November-April) **(Prayogo & Arthana, 2009)**.

The increase in productivity during the Southeast monsoon is closely related to wind-driven oceanographic processes. Stronger southeast winds cause vertical mixing of the water column and can potentially trigger upwelling in certain areas, which brings nutrients from deeper layers to the euphotic zone **(Simanjuntak & Lin, 2022)**. This increased nutrient availability stimulates phytoplankton blooms, which are reflected in higher chlorophyll-a concentrations **(Prayogo & Arthana, 2009)**. As an important link in the pelagic food web, *S. crumenophthalmus*, which feeds on zooplankton, will aggregate in these food-rich areas, thereby increasing their availability to fishing gear and ultimately increasing CPUE. The sampling period in this study, which ran from March 2019 to November 2021, covered several full monsoon cycles; thus, the analyzed length-frequency data have likely captured this seasonal variability, although the growth model used averages it into a single annual seasonal oscillation pattern.

In addition to seasonal variability, fishery dynamics in the Natuna Sea are also influenced by inter-annual climate variability, particularly the El Niño-Southern Oscillation (ENSO) phenomenon. The study period (2019-2021) coincided with a clear ENSO phase transition. Based on the Oceanic Niño Index (ONI), 2019 was characterized by weak El Niño conditions, which then shifted to a neutral phase, followed by a moderate to strong La Niña event that lasted from late 2020 through 2021 **(Australian Government - Bureau of Meteorology, 2025)**.

In the South China Sea region and Indonesian waters, La Niña events are often associated with warmer sea surface temperature anomalies and a potential decrease in chlorophyll-a concentrations due to the weakening of upwelling intensity **(Naimullah *et al.*, 2021)**. These large-scale changes in environmental conditions can significantly affect the distribution, abundance, growth rates, and recruitment success of pelagic fish **(Li *et al.*, 2023)**. Therefore, the population parameters estimated in this study are not a snapshot of a static system but rather an average value obtained from a period of significant climatic fluctuation.

The shift from El Niño/Neutral conditions to a strong La Niña during the study period likely introduced additional variability into the length-frequency data that may not be fully captured by the steady-state assumption of the ELEFAN model. For example, different environmental conditions during the 2020-2021 La Niña could have affected the recruitment success or individual growth rates in that year, which would be reflected as a shift or change in the shape of the length distribution. The ELEFAN model, which applies a single seasonally oscillating growth curve to the entire three-year period, essentially averages these inter-annual effects **(Taylor, 2025)**. The "noise" or model mismatch in certain months, which contributed to the Rn=0.52 value, may be a reflection of this inter-annual environmental forcing. This provides a strong argument for future research that explicitly incorporates environmental covariates (such as SST anomalies or ENSO indices) into growth models to account for climate-driven variability.

Selar crumenophthalmus occupies a central position in the pelagic food web of the Natuna Sea ecosystem. With a trophic level of approximately 3.8, this species functions as a crucial energy link, preying on zooplankton, small shrimp, and other invertebrates, and in turn becoming a primary prey for larger predatory fish (such as tuna and mackerel), marine mammals, and seabirds **(Yang *et al.*, 2025)**. The highly intensive exploitation of a key forage fish species like this, as indicated by the exploitation rate of E=0.65, is a classic symptom of the "fishing down the food web" phenomenon. This phenomenon has been widely documented in the South China Sea, where the depletion of apex predator stocks has shifted fishing pressure to smaller, more abundant species at lower trophic levels **(Szuwalski *et al.*, 2017)**.

The implications of these findings extend beyond the status of a single species. Severe overexploitation of a key forage fish population like *S. crumenophthalmus* poses a significant risk of a trophic cascade. The depletion of this vital energy link could have negative cascading effects on the predator populations above it, including species of high commercial and ecological value. This could disrupt the structure and function of the entire ecosystem. Thus, the findings of this study serve not only as a single-species stock assessment but also as an early warning regarding the broader health of the WPPNRI 711 ecosystem. This directly links the study's results to the principles of the Ecosystem Approach to Fisheries Management (EAFM), which emphasizes the importance of considering ecological interactions and the wider impacts of fishing activities **(Hutubessy & Mosse, 2015)**.

The findings of this study provide a strong scientific basis for the evaluation and reform of the Fisheries Management Plan (RPP) in WPPNRI 711. The overexploited status of the *S. crumenophthalmus* stock indicates that the current management framework has not been sufficiently effective in preventing stock depletion. Based on the primary diagnosis of growth overfishing, management recommendations should be prioritized to address the root cause of fishing inefficiency.

1. **Input and Output Controls to Address Growth Overfishing:** The most urgent and potentially most effective management action is to increase the average size of fish at first capture (Lc). This can be achieved through a combination of several instruments:
    a. **Technical Regulations (Input Control):** Implementing and enforcing regulations on the minimum mesh size for purse seines operating in Fisheries Management Area 711. An increase in mesh size would allow smaller fish to escape, giving them the opportunity to grow larger and spawn at least once before becoming vulnerable to capture.
    b. **Spatial and Temporal Regulations (Output Control):** Identifying and implementing area or seasonal closures. This policy can be designed to protect spawning grounds during peak reproductive seasons or to protect

nursery grounds where juveniles aggregate. This measure would effectively reduce mortality at critical stages in the fish's life cycle.

2. **Effort Control:** Although the current Fcurrent value is below F0.1, the very high exploitation rate (E=0.65) demands a precautionary approach. Any further increase in fishing effort will worsen the stock's condition. Therefore, it is recommended to implement a limitation or moratorium on the addition of purse seine vessels operating from major ports such as Pemangkat **(Fauzi, 2020)**. This effort control will serve as a safeguard to prevent the escalation of fishing pressure in the future.

These recommendations are consistent with the principles of EAFM being promoted in Indonesia **(Hutubessy & Mosse, 2015)**. By focusing on increasing Lc and controlling effort, management will not only improve stock health and long-term catch potential but will also reduce the broader ecological impacts of forage fish stock depletion.

CONCLUSION

This study presents strong evidence that the bigeye scad (*Selar crumenophthalmus*) stock in the Natuna Sea is under intense fishing pressure, resulting in a state of growth overfishing and placing it at high risk of recruitment overfishing. With an unsustainable exploitation rate (E = 0.65) and a spawning stock biomass depleted to a critical level (SPR = 19%), proactive and precautionary management interventions are urgently required to reduce fishing mortality and rebuild the stock.

However, the implementation of these necessary technical measures—such as reducing fishing effort or modifying fishing gear—must carefully consider the socio-economic implications for the fishing communities that depend on this resource. Reducing fishing pressure, while essential for stock recovery, may lead to short-term economic hardship for fishers, and the success of any new regulation hinges on their acceptance and compliance. Therefore, these technical recommendations should be integrated within a broader Ecosystem Approach to Fisheries Management (EAFM) framework that explicitly includes a human dimension. Future implementation should involve participatory approaches, including stakeholder consultations with local fishing communities in FMA 711 to develop acceptable and equitable solutions, an aspect underscored by socio-economic research in the region. By balancing the biological imperative to rebuild the stock with the socio-economic needs of the community, management can work toward the dual goals of a healthy marine ecosystem and a sustainable, long-term fishery that supports coastal livelihoods.

REFERENCES

Adeeb, S.; Fadzly, N. and Sah, A.S.R.M. (2014). Population dynamics of bigeye scad, *Selar crumenophthalmus* in Bangaa Faru, Maldives. *Journal of Marine Biology & Oceanography*, *3*(3), 133. https://doi.org/10.4172/2324-8661.1000133

Australian Government - Bureau of Meteorology. (2025). *Southern Hemisphere Monitoring (Australia)*. http://www.bom.gov.au/climate/enso/?ninoIndex=nino3.4&index=rnino34&period=weekly

Bertalanffy, L. von. (1938). A quantitative theory of organic growth (Inquiries on growth Laws. II). *Human Biology*, *10*(2), 181–213.

Budiarti, T.W.; Wiyono, E.S. and Zulbainarni, N. (2015). Produksi optimal pukat cincin di Pelabuhan Perikanan Nusantara Pemangkat, Kalimantan Barat. *Jurnal Penelitian Perikanan Indonesia*, *21*(1), 37–44. https://doi.org/10.15578/jppi.21.1.2015.37-44

Chodrijah, U. and Faizah, R. (2018). Biologi reproduksi selar bentong (*Selar crumenophthalmus* Bloch, 1793) in Kwandang Waters-Gorontalo Utara. *BAWAL Widya Riset Perikanan Tangkap*, *10*(3), 169–177.

Chodrijah, U.; Faizah, R. and Tirtadanu. (2020). Population dynamic of big eye scad (*Selar crumenophthalmus* Bloch, 1793) in Kwandang Waters-Sulawesi Sea. *E3S Web of Conferences*, *153*, 01005. https://doi.org/10.1051/e3sconf/202015301005

Coscino, C.L.; Bellquist, L.; Harford, W.J. and Semmens, B.X. (2024). Influence of life history characteristics on data-limited stock status assertions and minimum size limit evaluations using Length-Based Spawning Potential Ratio (LBSPR). *Fisheries Research*, *276*, 107036. https://doi.org/10.1016/j.fishres.2024.107036

Dalzell, P. and Penaflor, G. (1989). The fisheries biology of the bigeye scad, *Selar crumenophthalmus* (Bloch) in the Philippines. *Asian Fisheries Science*, *3*(1), 115–131. https://doi.org/10.33997/j.afs.1989.3.1.008

Fauzi, H.A. (2020). Fisheries Management Area Research: Andon Fishers' Economic Contribution to Resource Management in FMA 711. *Conservation Strategy Fund*. https://www.conservation-strategy.org/news/fisheries-management-area-research-andon-fishers-economic-contribution-resource-management-fma

Fauzi, M.; Setyobudiandi, I. and Suman, A. (2018). Biologi reproduksi ikan selar bentong (*Selar crumenophthalmus* Bloch, 1793) di perairan Natuna, Laut Cina Selatan. *BAWAL Widya Riset Perikanan Tangkap*, *10*(2), 105–117. https://doi.org/10.15578/bawal.10.2.2018.105-117

Fitria, D.M.; Sibuea, U.S. and Ghazali, T.M. (2020). Aspek pertumbuhan ikan selar bentong (*Selar crumenophthalmus*) yang didaratkan di PPN Sibolga. *Jurnal Enggano*, *5*(3), 473–482. https://doi.org/10.31186/jenggano.5.3.473-482

Gebremedhin, S.; Bruneel, S.; Getahun, A.; Anteneh, W. and Goethals, P. (2021). Scientific methods to understand fish population dynamics and support sustainable fisheries management. *Water*, *13*(4), 574. https://doi.org/10.3390/w13040574

Goodyear, C.P. (1993). Spawning stock biomass per recruit in fisheries management: Foundation and current use. In: *Risk Evaluation and Biological Reference Points for Fisheries Management;* Smith, S.J.; Hunt, J.J. and Rivard, D., Eds.; Canadian Special Publication of Fisheries and Aquatic Sciences, pp. 67–82.

Gulland, J.A. (1983). *Fish Stock Assessment: A Manual of Basic Methods*. FAO/Wiley Series on Food and Agriculture.

Hariati, T.; Chodrijah, U. and Taufik, M. (2009). Perikanan pukat cincin di Pemangkat, Kalimantan Barat. *Jurnal Penelitian Perikanan Indonesia*, *15*(1), 79–91. https://doi.org/10.15578/jppi.15.1.2009.79-91

Hilborn, R. and Walters, C.J. (1992). *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall.

Hutubessy, B.G. and Mosse, J.W. (2015). Ecosystem approach to fisheries management in Indonesia: Review on indicators and reference values. *Procedia Environmental Sciences*, *23*, 148–156. https://doi.org/10.1016/j.proenv.2015.01.023

Jennings, S.; Kaiser, M.J. and Reynolds, J.D. (2001). *Marine Fisheries Ecology*. Blackwell Science.

Jones, R. (1984). Assessing the effects of changes in exploitation pattern using length composition data. *FAO Fisheries Technical Paper*, *256*, 118.

Kindong, R.; Wu, F.; Tian, S.; Zhu, J.; Dai, X.; Wang, J. and Dai, L. (2020). Biological parameters estimate for the sickle pomfret (*Taractichthys steindachneri*) in the west-central and eastern Pacific Ocean. *Indian Journal of Geo-Marine Sciences, 49*(3), 373–381.

Kritzer, J.P.; Davies, C.R. and Mapstone, B.D. (2001). Characterizing fish populations: effects of sample size and population structure on the precision of demographic parameter estimates. *Canadian Journal of Fisheries and Aquatic Sciences*, *58*(8), 1557–1568. https://doi.org/10.1139/cjfas-58-8-1557

Li, M.; Xu, Y.; Sun, M.; Li, J.; Zhou, X.; Chen, Z. and Zhang, K. (2023). Impacts of strong ENSO events on fish communities in an overexploited ecosystem in the South China Sea. *Biology*, *12*(7), 946. https://doi.org/10.3390/biology12070946

Mokoagow, O.S.; Pasisingi, N. and Kasim, F. (2024). Estimation of population dynamics parameters of *Selar crumenophthalmus* landed at Gorontalo Tenda fish landing. *Habitus Aquatica*, *5*(2), 67–76. https://doi.org/10.29244/HAJ.5.2.5

Naimullah, M.; Wu, Y.-L.; Lee, M.-A. and Lan, K.-W. (2021). Effect of the El Niño–Southern Oscillation (ENSO) cycle on the catches and habitat patterns of three swimming crabs in the Taiwan Strait. *Frontiers in Marine Science*, *8*, 763543. https://doi.org/10.3389/fmars.2021.763543

Panda, D.; Jaiswar, A.K.; Sarkar, S.D. and Chakraborty, S.K. (2016). Growth, mortality and exploitation of bigeye scad, *Selar crumenophthalmus* off Mumbai, north-west coast of India. *Journal of the Marine Biological Association of the United Kingdom, 96*(7), 1411–1416. https://doi.org/10.1017/S0025315415001459

Pauly, D. (1983). Length-converted catch curves: a powerful tool for fisheries research in the tropics (Part I). *ICLARM Fishbyte, 1*(2), 9–13.

Pauly, D. (1984). *Fish Population Dynamics in Tropical Waters: A Manual for Use with Programmable Calculators*. ICLARM Studies and Reviews 8.

Pauly, D. (1990). Length-converted catch curves and the seasonal growth of fishes. *Fishbyte*, *8*(3), 33–38.

Pauly, D. and Munro, J.L. (1984). Once more on growth comparison in fish and invertebrates. *Fishbyte, 2*(1), 21.

Pons, M.; Kell, L.; Rudd, M.B.; Cope, J.M. and Lucena Frédou, F. (2019). Performance of length-based data-limited methods in a multifleet context: Application to small tunas, mackerels, and bonitos in the Atlantic Ocean. *ICES Journal of Marine Science, 76*(4), 960–973. https://doi.org/10.1093/icesjms/fsz004

Prayogo, T. and Arthana, I.W. (2009). Study on oceanographic and weather conditions related to the abundance of small pelagic fishery in Natuna Sea using remote sensing data. *ECOTROPHIC: Jurnal Ilmu Lingkungan, 4*(1), 8–14.

Priatna, A.; Boer, M.; Kurnia, R. and Yonvitner, Y. (2024). Population dynamics of the Indian scad *Decapterus russelli* (Rüppell, 1830) in the Natuna Sea, Indonesia. *Egyptian Journal of Aquatic Biology and Fisheries, 28*(4), 1701–1721. https://doi.org/10.21608/ejabf.2024.374560

Roos, D.; Roux, O. and Conand, F. (2007). Notes on the biology of the bigeye scad, *Selar crumenophthalmus* (Carangidae) around Reunion Island, southwest Indian Ocean. *Scientia Marina, 71*(1), 137–144. https://doi.org/10.3989/scimar.2007.71n1137

Safitri, I. and Magdalena, W. (2018). Perikanan tangkap purse seine di Pelabuhan Perikanan Nusantara (PPN) Pemangkat Kalimantan Barat. *Jurnal Laut Khatulistiwa, 1*(3), 89–96. https://doi.org/10.26418/lkuntan.v1i3.29168

Simanjuntak, F. and Lin, T.-H. (2022). Monsoon effects on chlorophyll-a, sea surface temperature, and Ekman dynamics variability along the Southern Coast of Lesser Sunda Islands and its relation to ENSO and IOD Based on satellite observations. *Remote Sensing, 14*(7), 1682. https://doi.org/10.3390/rs14071682

Skern-Mauritzen, M.; Ottersen, G.; Handegard, N.O.; Huse, G.; Dingsør, G.E.; Stenseth, N.C. and Kjesbu, O.S. (2016). Ecosystem processes are rarely included in tactical fisheries management. *Fish and Fisheries, 17*(1), 165–175. https://doi.org/10.1111/faf.12111

Somers, I.F. (1988). On a seasonally oscillating growth function. *Fishbyte, 6*(1), 8–11.

Sparre, P. and Venema, S.C. (1998). *Introduction to Tropical Fish Stock Assessment. Part 1. Manual*. FAO Fisheries Technical Paper No. 306.1, Rev. 2.

Syam, A.R.; Andamari, R. and Zubaid, T. (2017). Aspek biologi ikan kawaliya (*Selar crumenophthalmus*) di perairan sekitar Maluku Tengah dan Maluku Utara. *Jurnal Penelitian Perikanan Indonesia*, *9*(3), 63–72. https://doi.org/10.15578/jppi.9.3.2003.63-72

Szuwalski, C.S.; Burgess, M.G.; Costello, C. and Gaines, S.D. (2017). High fishery catches through trophic cascades in China. *Proceedings of the National Academy of Sciences*, *114*(4), 717–721. https://doi.org/10.1073/pnas.1612722114

Taylor, M.H. (2025). *Using the TropFishR ELEFAN functions*. The Comprehensive R Archive Network. https://cran.r-project.org/web/packages/TropFishR/vignettes/Using_TropFishR_ELEFAN_functions.html

Taylor, M.H. and Mildenberger, T.K. (2017). Extending electronic length frequency analysis in R. *Fisheries Management and Ecology*, *24*(4), 330–338. https://doi.org/10.1111/fme.12232

Then, A.Y.; Hoenig, J.M.; Hall, N.G. and Hewitt, D.A. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science*, *72*(1), 82–92. https://doi.org/10.1093/icesjms/fsu136

Thompson, W.E. and Bell, F.H. (1934). Biological statistics of the Pacific Halibut. 2. Effect of the changes in fishing intensity upon total yield and yield per unit of gear. *Report of the International Fisheries Commission*, *8*, 1–49.

Tirtadanu; Pane, A.R.P.; Kembaren, D.D.; Mardlijah, S.; Fauzi, M.; Amri, K.; Widiyastuti, H. and Barido, F.H. (2025). Exploring the stock status of big eye scad (*Selar crumenopthalmus* Bloch, 1793) fishery after a lobster stock decline in Gunungkidul waters: A length-based approach. *Thalassas: An International Journal of Marine Sciences*, *41*(3), 129. https://doi.org/10.1007/s41208-025-00888-2

Tirtadanu; Prihatiningsih; Yusuf, H.N.; Zamroni, A.; Amri, K. and Chodrijah, U. (2023). Assessing the stock status of areolate grouper (*Epinephelus areolatus*) in Java Sea, Indonesia. *Regional Studies in Marine Science*, *66*, 103116. https://doi.org/10.1016/j.rsma.2023.103116

Wetherall, J.A.; Polovina, J.J. and Ralston, S. (1987). Estimating growth and mortality in steady-state fish stocks from length-frequency data. *ICLARM Conference Proceedings*, *13*, 53–74.

Wiyono, E.S. (2012). Analisis efisiensi teknis penangkapan ikan menggunakan alat tangkap purse seine di Muncar, Jawa Timur. *Jurnal Teknologi Industri Pertanian*, *22*(3), 164–172.

Yang, X.; Luo, K.; Fu, J.; Kang, B.; He, X. and Yan, Y. (2025). Fish community resource utilization reveals benthic–pelagic trophic coupling along depth gradients in the Beibu Gulf, South China Sea. *Biology*, *14*(2), 207. https://doi.org/10.3390/biology14020207