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Population Dynamics and Yield per Recruit of Kawakawa (*Euthynnus affinis*, Cantor 1849) in the Natuna Sea, Indonesia

Hidayat T.[1], Jabbar M. A.[2]*, Fauzi M.[1], Widiyastuti H.[1], Mardlijah S.[1], NoegrohoT.[1], Lestari P.[1], Priatna A.[1], Yusuf H. N.[1]

[1]Research Center for Biota System, National Research and Innovation Agency (BRIN), Cibinong, Bogor, Indonesia

[2] Department of Aquatic Resources Management, Jakarta Technical University of Fisheries, Indonesia

***Corresponding Author:** meuthia.aula@gmail.com

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ABSTRACT

The kawa-kawa (*Euthynnus affinis*) is a pelagic fish species of significant commercial importance. Research on the population dynamics of *E. affinis* was undertaken in the Natuna Sea of Pemangkat from January to December 2021. Data were collected in 2021 at Pemangkat Fishing Port, West Kalimantan from drift gillnetters operating in the Natuna Sea. The dataset for fork length was organized and calculated within an Excel workbook, after which it underwent a detailed examination employing ELEFAN I from the FiSAT II. The findings indicated that length-frequency data gathered over a 12-month period exhibited a unimodal distribution, with a modal length class of 46–48 cm. Using the von Bertalanffy formulation, the species showed an asymptotic length ($L\infty$) of 77.7cm and a corresponding annual growth parameter (K) of 0.42 year^{-1}. The study found that the natural mortality rate (M), fishing mortality (F), and total mortality (Z) were 0.80, 0.45, and 1.25 year^{-1}, respectively. The exploitation rate (E) was 0.36. Recruitment reached its zenith in June and July. The yield-per-recruit study revealed that the present exploitation level is below the optimum ($E_{0.1}$ = 0.507), indicating the possibility for sustainable enhancements in fishing effort. The findings suggest that the kawakawa resource in the Natuna Sea is currently underutilized and has potential for further sustainable development.

INTRODUCTION

The Natuna Sea, situated in northern Indonesia, is one of the nation's most strategically significant maritime regions, both commercially and geopolitically. This area is located in the South China Sea, bordering Vietnam, Malaysia, and the contested Nine-Dash Line asserted by China, which intersects with Indonesia's Exclusive Economic Zone (EEZ) **(Isak *et al.*, 2020)**. The Natuna Sea is ecologically productive owing to its oceanographic features, rendering it a crucial fishing area that sustains coastal populations and notably contributes to Indonesia’s tuna fisheries industry **(Suman *et al.*, 2017)**.

Kawakawa fisheries in the Natuna Sea is derived from drift gillnetter (94%) and purse seiner (6%). Drift gill net vessels in Pemangkat are predominantly constructed of wood, varying across sizes from 16 to 47 gross tons. The average mesh size for these drift gill nets is 4 inches. The catch composition of the drift gill net is as follows: longtail tuna (*Thunnus. tonggol*) 44.7%, kawakawa (*Euthynnus affinis*) 34.8%, Spanish mackerel (*Scomberomorus commerson*) at 7%, sea catfish (Ariidae family) at 4%, sailfish (*Istiophorus platypterus*) at 2.5%, deep leatherskin (*Chorinemus tala*) and bigeye trevally (*Caranx sexfasciatus*) at 2%. The drift gillnet is the main fishing gear for kawakawa in the Natuna Sea.

Insight into the population ecology of kawakawa, addressing growth trends, survival rates, and the degree of exploitation, is critical for management and crucial for developing science-based management plans. These biological characteristics ensure the enduring availability of resources and inform sustainable fishing tactics. While numerous studies on kawakawa have been undertaken in Indonesian waters, research particularly addressing kawakawa in the Natuna Sea is few.

This research aimed to assess the population traits along with the prevailing abundance of *E. affinis* inhabiting the Natuna Sea. The findings are anticipated to yield significant insights for fisheries management and conservation initiatives, especially in reconciling exploitation with the sustainability of tuna resources in Indonesian waters.

MATERIAL AND METHODS

1. Research location and data collection

Data were collected at the Pemangkat Fish Port in West Kalimantan, Indonesia, on the harvested individuals of kawakawa (*Euthynnus affinis*) traced back to the Natuna Sea (Fig. 1). The sampling regime data spanned the entire year of 2021, with measurements taken at monthly intervals from January to December. Using a 4-inch mesh drift gillnet, fish were collected and the fork length of each selected sample was precisely measured to 0.1cm accuracy. Trained enumerators facilitated the data collection procedure.

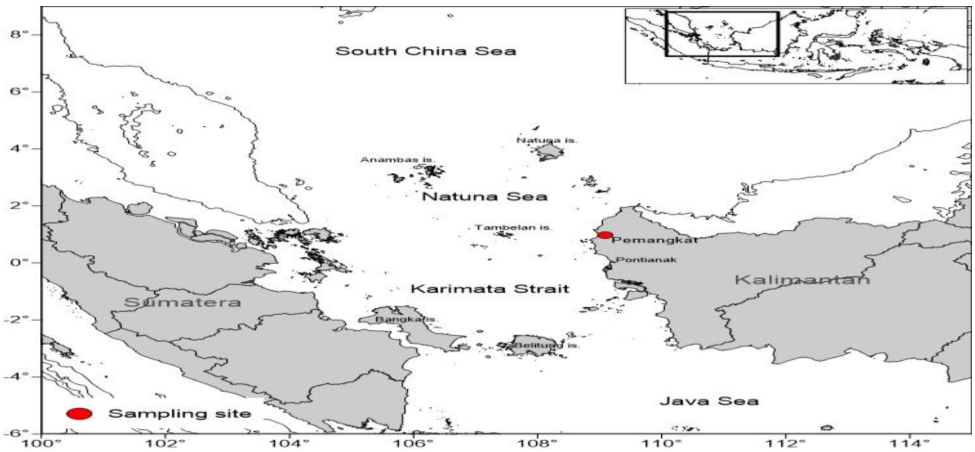

Fig. 1. Sampling site for longtail tuna data collection in the Natuna Sea

2. Analytical framework

Growth parameters

Determination of the growth coefficient (K) and asymptotic length (L_∞) was conducted with the *ELEFAN I* (*Electronic LEngth Frequency ANalysis*) model, as incorporated within the *FiSAT II* toolkit (*FAO-ICLARM Stock Assessment Tools*) **(Gayanilo *et al.*, 2005)**. The starting point for theoretical age (t_0) computation was assessed using Pauly's formula **(Pauly, 1983)**:

$$\text{Log}\,(-t_0) = -0.3922 - 0.2752\ \text{Log}\ L_\infty - 1.038\ \text{Log}\ K$$

Subsequently, values for length, growth rate (K), and theoretical age (t_0) were determined to assemble the von Bertalanffy growth function **(Sparre & Venema, 1998)** as described in the subsequent section:

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

Where, L_t corresponds to length at age t (cm), L_∞ designates the asymptotic length (cm), K defines the annual growth coefficient, and t_0 identifies the theoretical age in years.

Mortality

The total mortality parameter (Z) was assessed employing the Length-Converted Catch Curve offered by *FiSAT II* **(Gayanilo *et al.*, 2005)**. Moreover, natural mortality (M) underwent an estimation procedure following **Pauly (1983)**:

$$\text{Log}\,(M) = -0.0066 - 0.2795\ \text{Log}\,(L_\infty) + 0.6543\ \text{Log}\,(K) + 0.4634\ \text{Log}\,(T)$$

Where, M signifies the baseline mortality occurring naturally each year, whereas T corresponds to the yearly average of water temperature in degrees Celsius **(Pauly, 1983)**:

$$F = Z - M$$

Exploitation rate

Utilizing annual monitoring data, the exploitation index (E) functions as a surrogate for gauging the ongoing exploitation intensity of *E. affinis* **(Gulland, 1971)**:

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

Yield per recruit (Y'/R)

Estimation of yield per recruit (Y'/R) was performed employing the analytical construct proposed by Beverton and Holt **(Sparre & Venema, 1998)** embedded in FiSAT II, which constructs recruitment trajectories and selectivity ogives. The expression for Y'/R is defined as follows:

$$Y/R = F * A * W\infty * \left\{ \frac{1}{Z} - \left(\frac{3U}{Z+K} \right) + \left(\frac{3U^2}{Z+2K} \right) - \left(\frac{U^3}{Z+3K} \right) \right\}$$

Where, W∞ denotes the maximal attainable weight (grams), tc refers to the average age when first caught, and tr signifies the mean recruitment age. The parameter U is calculated as 1−(Lc/L∞).

RESULTS

1. Length-frequency distribution

Distribution patterns of kawakawa lengths obtained from the Natuna Sea covering the 12 months of research exhibited a unimodal normal distribution, ranging from 24 to 75cm, with the modal class being 46– 48cm (Fig. 2).

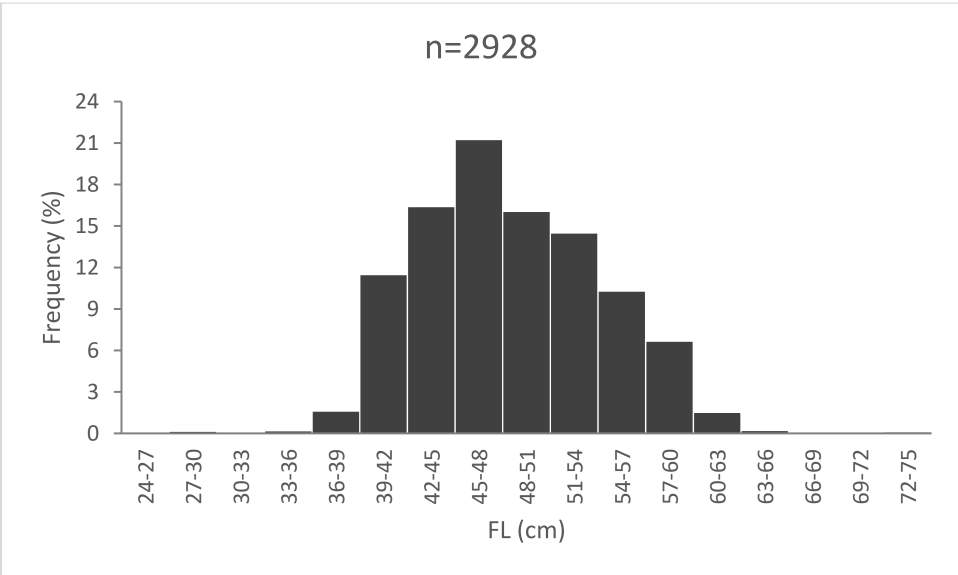

Fig. 2. Length frequency distribution of the kawakawa (*E. affinis*) in the Natuna Sea

2. Growth estimation

Using the ELEFAN I method in FiSAT II, monthly length-frequency data were evaluated to obtain von Bertalanffy growth characteristics (Fig. 3), indicating an asymptotic length ($L\infty$) of 77.7cm FL, a growth constant (K) of 0.42 year^{-1}, and t_0 at -0.04972.

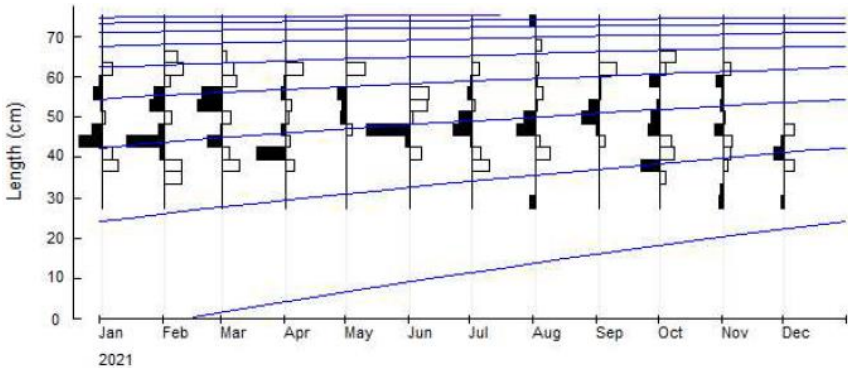

Fig. 3. The growth model of the kawakawa (*E. affinis*) in the Natuna Sea

The von Bertalanffy growth curve, depicting the correlation between age and fork length, is seen in Fig. (4), incorporating L_∞, K, and t_0. This model indicates that the annual growth of kawakawa in the 1st, 2nd, 3rd, 4th, and 5th years is 27.7, 44.85, 56.11, 63.51, and 68.38cm, respectively. This species can attain its maximum length within 7 years.

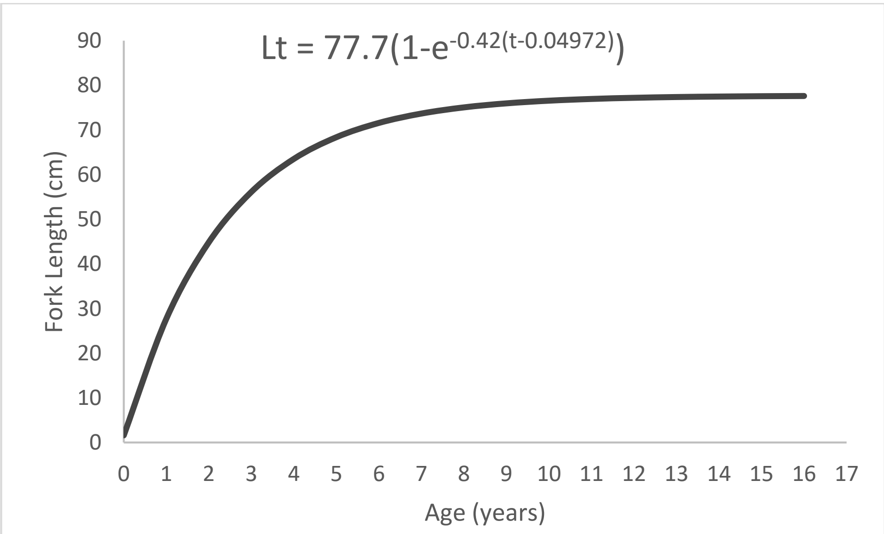

Fig. 4. The correlation graph between size and age of kawakawa within the Natuna Sea

3. Mortality and exploitation rate

The implementation derived from the curve converted according to size measurements yielded a natural mortality (M) of 0.80 year^{-1} at a mean sea temperature measuring 30°C. Calculations also showed fishing mortality (F) at 0.454 year^{-1}, total mortality (Z) at 1.25 year^{-1}, and an exploitation ratio (E) for kawakawa of 0.36 year^{-1} (Fig. 5).

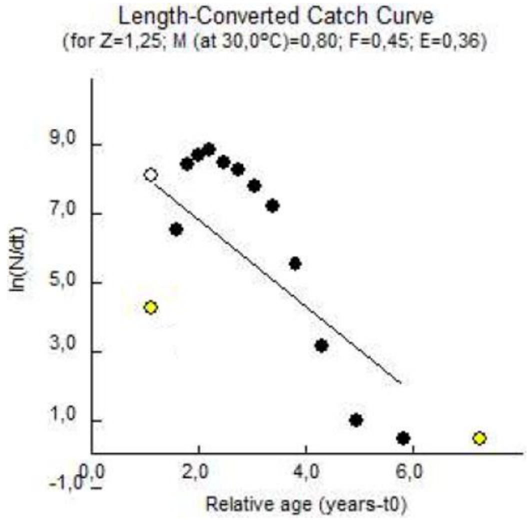

Fig. 5. Distribution pattern of catches standardized to length metrics for kawakawa in the Natuna Sea

4. Recruitment pattern

The apex of annual kawakawa recruitment in the Natuna Sea fishery, as indicated by the length-frequency data, evidently transpired between June and July (Fig. 6).

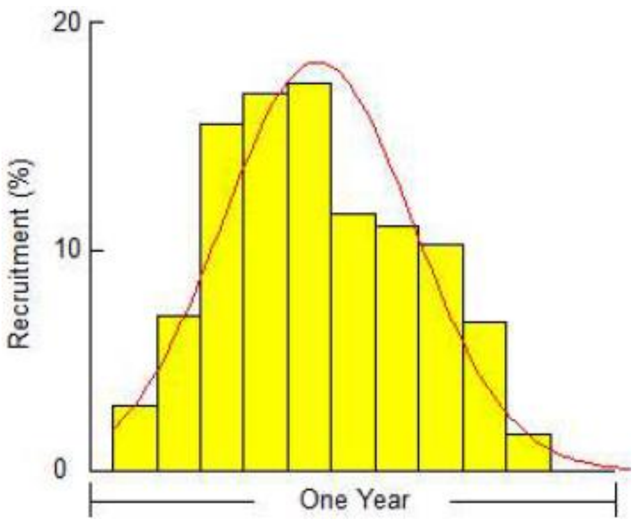

Fig. 6. Recruitment pattern of kawakawa (*E. affinis*) in the Natuna Sea

5. Yield per recruit (Y'/R)

The evaluation of Y/R revealed that under existing fishing practices, yield per recruit increases with fishing mortality until it attains maximum (Emax) when exploitation achieves 0.595 (Fig. 7). The exploitation rate corresponding to 10% of the marginal yield ($E_{0.1}$) was determined to be 0.507. The current exploitation rate ($E_{current}$ = 0.36) is below both E_{max} and $E_{0.1}$, signifying that the fishery is in a developmental phase with the potential for enhanced yields through increased exploitation.

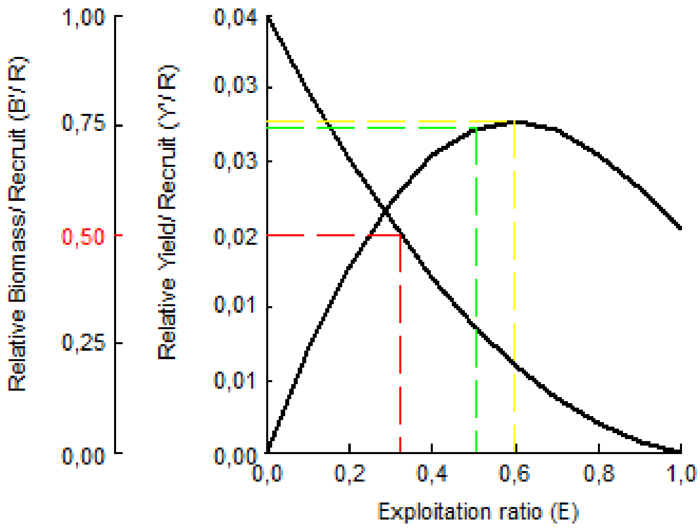

Fig. 7. E values of kawakawa (*E. affinis*) in the coastal waters of Pemangkat by Y'/R Beverton and Holt E_{10}=0.507 (green), E_{50}=0.322 (red), E_{max}=0.595 (yellow)

DISCUSSION

The investigation revealed that the *Euthynnus affinis* length-frequency arrangement in the Natuna Sea over the study duration conformed to a unimodal and statistically normal configuration, with the modal length class ranging from 46 to 48 cm FL. The unimodal distribution is characteristic of small tuna fisheries, where the catch predominantly consists of sub-adult individuals targeted by purse seine and gillnet methods **(Collette & Nauen, 1983)**.

The calculated von Bertalanffy growth parameters for kawakawa in the Natuna Sea are L∞ = cm and K = year-1, indicating that this species exhibits a reasonably sluggish development rate and achieves a moderately big maximum size. The K value corresponds with the prevailing notion that the species typically have reduced growth coefficients **(Sparre & Venema, 1998)**. The research findings from various domains reflect considerable differences regarding the growth parameter (K) and the maximum length attained (L∞) (Table 1).

Table 1. K and L∞ values from several areas

Location	K (Yr^{-1})	L∞ (cm)	Reference
Maharastra, India	0.79	81.7	Khan (2004)
Persian Gulf and Sea of Oman	0.51	87.66	Motlagh *et al.* (2010)
Indian water	0.56	81.92	Rohit *et al.* (2012)
West of Sumatera, Indian Ocean	0.63	65.53	Jatmiko *et al.* (2014)
Malacca Strait	0.96	64.25	Wagiyo *et al.* (2018)
Malacca Strait	0.7	58.85	Faizal *et al.* (2017)
Southern Lombok, Indian Ocean	0.67	85	Wujdi *et al.* (2020)
Gulf Aqaba, Red Sea	0.47	83.64	Mehanna (2024)
The Natuna Sea	0.42	77.7	Present study

Note: K: Growth rate; L∞: Asimptotic length.

The variation in growth parameters is attributable to several environmental conditions, encompassing elements such as species density, temperature of the aquatic environment, and prey abundance, which drive changes in both K and L∞ **(Ghosh *et al.*, 2016; Ju *et al.*, 2016; Armstrong *et al.*, 2021; Çiloğlu & Ateş, 2022)**.

For kawakawa, the measured natural mortality (M) reached 0.8 year^{-1}, with fishing mortality (F) at 0.45 year^{-1} and total mortality (Z) totaling 1.25 year^{-1}. Natural mortality coefficient in the present study is lower compared to values recrded in earlier studies **(Khan, 2004; Rohit *et al.*, 2012; Jatmiko *et al.*, 2014; Wagiyo *et al.*, 2018; Wujdi *et al.*, 2020)**, while being higher than those of **Motlagh *et al.* (2010)** and **Mehanna (2024)**. Differences in mortality rates in several locations are influenced by fishing pressure, food availability and predation **(Chen *et al.*, 2018)**. Several factors are associated with the variations in mortality rates, including fishing pressure, seawater temperature, stock variations, disease, predation, stress, and age **(Sparre & Venema, 1998; Koolkalya *et al.*, 2017; Bergström *et al.*, 2022; Levangie *et al.*, 2022)**. A population is deemed to be exploited efficiently when the intensity of fishing mortality matches the natural mortality (F = M), or E = 0.5, as per **Gulland (1971)**. The E value of 0.36 in this study signifies that the kawakawa stock in the Natuna Sea is currently being exploited below ideal levels, indicating that the stock is likely not overfished and is in a phase of developing exploitation.

Recruitment refers to the process of incorporating new individuals into the population targeted by fishing gear. **Noegroho and Chodrijah (2015)** emphasized that the recruitment of fish depends on the density of reproductively mature females prepared for breeding, with reductions experienced throughout the reproductive cycle, along with the aggregate count of individuals fulfilling the set stock criteria. The occurrence of recruitment peaks may be influenced by oceanic conditions, primary productivity and, subsequently, spawning and larval development **(Abesamis & Russ, 2010; Rabbaniha *et al.*, 2014)**. The significant recruitment surge in June-July likely aligns with spawning events that transpired during the August–September interval of the preceding year, taking into account the species' growth rate. This is similiar to prior reports from the Java Sea **(Hidayat *et al.*, 2016)**.

The evaluation through a yield-per-recruit approach demonstrated that the existing exploitation rate falls short of the reference optimal threshold. The present exploitation rate (Ecurrent = 0.36) is below both the $E_{0.1}$ (0.507) and Emax (0.59) reference benchmarks. This indicates that, in theory, there is potential to enhance exploitation beyond existing levels. A 15.2% increase in exploitation might attain the $E_{0.1}$

CONCLUSION

The population dynamics of *Euthynnus affinis* in the Natuna Sea indicate a stable and moderately growing stock, characterized by sustainable exploitation levels and continuous recruitment throughout the year. The current fishing pressure remains below biological reference points, suggesting that the stock is not yet overexploited and that the existing fishery practices have supported the maintenance of a healthy population structure and sustainable productivity. Furthermore, it is estimated that the exploitation rate could increase by up to 15.2%, potentially allowing for the expansion of fishing activities within precautionary management frameworks.

To ensure the long-term sustainability of the fishery, management efforts should aim to maintain exploitation levels until the $E_{0.1}$ threshold while enhancing monitoring systems, enforcing responsible fishing practices, and promoting gear selectivity. Future research should focus on studying ecosystem-based management strategies that integrate biological, ecological, and socio-economic considerations for the sustainable utilization of *E. affinis* resources in the Natuna Sea.

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