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Population Dynamic and Spawning Potential Ratio of Indian Mackerel *Rastrelliger kanagurta* (Cuvier 1817) in the Aru Sea, Indonesia

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ABSTRACT

The Indian mackerel (*Rastrelliger kanagurta*) holds significant economic value in Indonesian fisheries. However, the continued increase in fishing activities may impact its population, leading to a decline. Therefore, studying the population dynamics and the spawning potential ratio (SPR) using a length-based data approach is essential to determine population parameters and to assess exploitation status. This research was conducted in 2021, with fish length measurements collected from mini purse seine vessels operating in the Aru Sea and landing their catches in Kaimana, West Papua, Indonesia. The results showed that the length distribution of the Indian mackerel ranged from 10 to 31.5cm fork length (cmFL), with a mode at 22.5 cmFL. The asymptotic length (L_∞) was estimated at 33.08 cmFL per year, while the growth rate (K) was 0.8 per year. The natural mortality rate (M) was 1.55 per year, and the fishing mortality (F) was 1.04 per year, resulting in a total mortality rate (Z) of 2.59 per year. The exploitation rate (E) was 0.4. The exploitation level of the Indian mackerel in the Aru Sea is still moderate, indicating that increasing fishing effort or the number of fishing gears is still possible. The estimated length-based SPR (LB-SPR) was 57%. The spawning potential ratio of mackerel in the Aru Sea exceeds the minimum reference point, and the target reference point suggests that its exploitation is still sustainable. This indicates that further development efforts can be pursued.

INTRODUCTION

The small pelagic fish known as the Indian mackerel (*Rastrelliger kanagurta* Cuvier, 1816) is very valuable as a main source, particularly for the coastal community economic activity. The Indian mackerel lives in epipelagic waters in tropical areas, spread across the waters of the central West Indo-Pacific, from the Andaman Sea to Oceania. The Indian mackerel habitat generally has relatively low salinity and a temperature range of 20–30^{o}C **(Collette & Nauen, 1983)**. This species is commonly found in the Indonesian waters and is also widely caught in the Aru Sea, west of Papua.

The main fishing gear that serves as the primary fishing gear for catching the Indian mackerel is the purse seiner **(Zamroni *et al.*, 2017)**. Catches from purse seiners in the Aru Sea consist of 97% Indian mackerel **(Fauzi *et al.*, 2020)**. In 2021, the Indian mackerel catch in Kaimana reached 454.9 tons **(Kaimana, 2021)**. There is concern that the growing quantity of Indian mackerel harvested with various fishing gears may threaten the sustainability of its resources **(Astuti *et al.*, 2019)**. The Indian mackerel has a high vulnerability value **(Triharyuni *et al.*, 2015)**. Year-by-year intensive fishing activities may lead to a decline in its population **(Suwarso *et al.*, 2015)**. To prevent the depletion of fish stocks, particularly Indian mackerel, a study of population dynamics is needed to develop effective management strategies.

Several studies on the Indian mackerel have been conducted; **Suwarso *et al*. (2015)** examined reproductive biology on the north coast of Java; **Zamroni *et al*. (2017)** explored genetic variation in the waters of eastern Indonesia; **Zamroni and Ernawati (2019)** studied population dynamics on the north coast of Java; and **Saputra and Taufani (2021)** researched population dynamics in the same region. However, studies on the population dynamics of this species in the Aru Sea are limited. Therefore, this research is essential to update the existing information.

This paper aimed to study the population dynamics of the Indian mackerel, including parameters of growth, mortality, exploitation levels, and spawning potential ratio in the Aru Sea. The results of this research can serve as foundational information for determining management policies for small pelagic fisheries, particularly the Indian mackerel, in the Aru Sea.

MATERIALS AND METHODS

1. Study site and data collection

Data collection was carried out from January to December 2021. Monthly length frequency data of the Indian mackerel (*Rastrelliger kanagurta*) were collected from the catch of mini purse seiners (5–29 GT) operating in the Aru Sea, with landings at the Kampung Kaki Air fish landing site in Kaimana, West Papua, Indonesia. Fish were measured by fork length, and the length data were then grouped into length classes for each month to obtain the length frequency data. Data collection was supported by enumerators appointed at the sampling site, as shown in Fig. (1).

We certify that all fish specimens used in this study were deceased prior to the research process. No fish were subjected to any form of torture, stress, or discomfort during the study. Additionally, no procedures were carried out that involved the infliction of torture, stress, or discomfort on the fish.

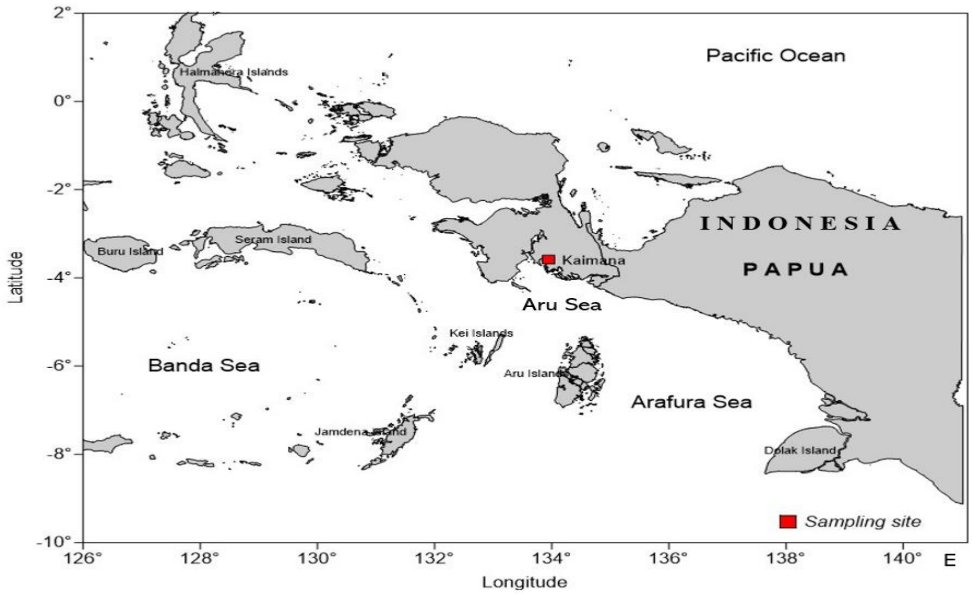

Fig. 1. Sampling site of Indian Mackerel in The Aru Sea

2. Analytical framework

Length at first capture

Half of the retained fraction (the fish captured) corresponds to the length at first capture (Lc), which is determined by the fishing gear. The Lc value is derived from the length frequency distribution data, calculated using the formula provided by **Sparre and Venema (1999)**:

$SLest= 1/(1+exp^{(S1-S2*L))}$

$Lc=S1/S2$

Where, SLest is a logistic curve, S_1 and S_2 are constant.

Growth parameters

Several growth parameters were analyzed using the FiSAT II program. To determine the asymptotic length and growth rate, the ELEFAN I method was employed. ELEFAN I analyzes the forward movement of several modes, connecting mode to mode of monthly length frequency in a time series to form a growth curve. Growth analysis was performed using the formula proposed by von Bertalanffy **(Sparre and Venema, 1999)**:

$Lt = L\infty\ (1-e^{-K(t-t0)})$

Where, Lt stands for length at age t; L∞ denotes asymptotic length; K denotes growth rate; e stands for the exponential constant; and t_0 = Theoretical age of the fish at zero length.

The formula used to estimate the theoretical age of the Indian mackerel when the fish's length is zero (t_0) **(Pauly, 1980)** was as follows:

$Log\ (-t_0) = -0.3922 – 0.2752\ Log\ L\infty-1.038\ Log\ K$

Pauly's (1980) empirical connection was used to estimate the natural mortality rate (M):

$$\text{Log}(M) = -0{,}0066 - 0{,}279\text{Log } L\infty + 0{,}654\text{Log } K + 0{,}4634\text{Log}T$$

Where, L∞= asymptotic length; T= Mean water temperature annually (˚C)

Mortality and exploitation rate

Using the length-converted catch curve technique in FiSAT II, we can estimate the total mortality rate (Z). The formula for calculating fishing mortality (F) is the total mortality (Z) minus natural mortality (M):

$$\mathbf{F = Z - M}$$

The exploitation rate (E) is determined using the following equation **(Sparre & Venema, 1999)**:

$$E = F/Z \text{ or } E = F/(F+M))$$

Spawning potential ratio (SPR)

An SPR database that is based on length was utilized to determine the exploitation state using the spawning potential ratio (SPR) **(Hordyk *et al*., 2015)**. Here, SPR makes use of **Hordyk *et al*. (2015b)** LB-SPR model. The LB-SPR model utilizes M/k, L∞, and length at first maturity as inputs.

SPR analysis uses the following method, which was introduced by **Prince *et al.* (2014)**:

$$SPR_t = \frac{\sum_{t=0}^{t} EP_t}{\sum_{t=0}^{tmax} EP_t}$$

$$EP_t = (N_{t-1^e} - M)f_t$$

Where, SPRt is the proportion of reproductive potential at age t, EP_t is the reproduction output at age t, N_t is the number of individuals at time t, with N_0 being 1000, M is natural mortality, and f_t is the average fecundity.

However, since f_t's value is unavailable, we calculate EP_t using the following equation:

$$EP_t = N_t \times W_t \times m_t$$

Where, W_t is the weight of the fish at age t, and m_t is the average size of fish with mature gonads.

RESULTS

1. General situation of the small pelagic fisheries

- Indian mackerel (*Rastrelliger kanagurta*) plays a vital role in Indonesia's marine ecosystems and fisheries. As a mid-trophic species, they feed on phytoplankton (diatoms) and zooplankton (cladocerans, ostracods, larval polychaetes, etc.) **(Hulkoti *et al*., 2013; Hakimelahi *et al.*, 2017; Mascarenhas & Desai 2023)**.

They also serve as prey for larger predators such as the longtail tuna, the yellowfin tuna and sharks **(Rohit *et al*., 2010; Varghese & Somvanshi, 2016; Silva *et al*. 2019; Hidayat, 2022)**. This helps regulate the population sizes of both their prey (planktons) and large predators, contributing to the overall balance of the ecosystem.

- The Indian mackerel (*Rastrelliger kanagurta*) is a small pelagic fish inhabiting coastal waters (neritic). This species can be found in Indonesian waters, particularly in the Natuna Sea, West Sumatra, Java Sea, Malacca Strait, Muna-Buton Sea, Arafura Sea, and South Sulawesi Sea **(Utami *et al.*, 2014)**. This fish is extensively consumed domestically and is also exported. Indian Mackerel is frequently caught by mini purse seiner in the Aru waters with boats size ranging from 5 to 29 GT, representing a small-scale fishery that sustains the coastal communities of West Papua.

2. Length-frequency distribution

A total of 5665 sample fish were measured as a result of mini purse seine catches in the Aru Sea. The frequency distribution of Indian mackerel length was normal. The length of the smallest fish was 10cm, and the longest was 31.5cm, with a mode of 22.5cm (Fig. 2).

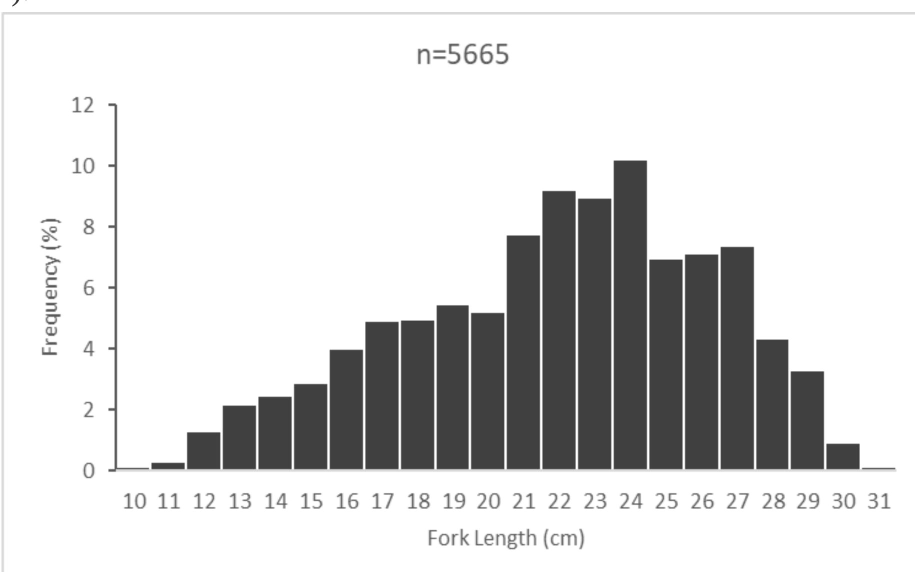

Fig. 2. Length frequency distribution of Indian mackerel in the Aru Sea

3. The estimated length at first capture (Lc)

The probability of a fish escaping or being retained by a fishing gear depends on the size of the fish. Plotting the relationship between the probability of a fish being retained and its length results in a capture selection curve. This curve is then used to estimate the length at first capture (Lc).

The estimated length at first capture (Lc_{50}) is half of the retained fraction (fish captured). India mackerel in the Aru Sea has a half-life of 20.05cm. (Fig. 3).

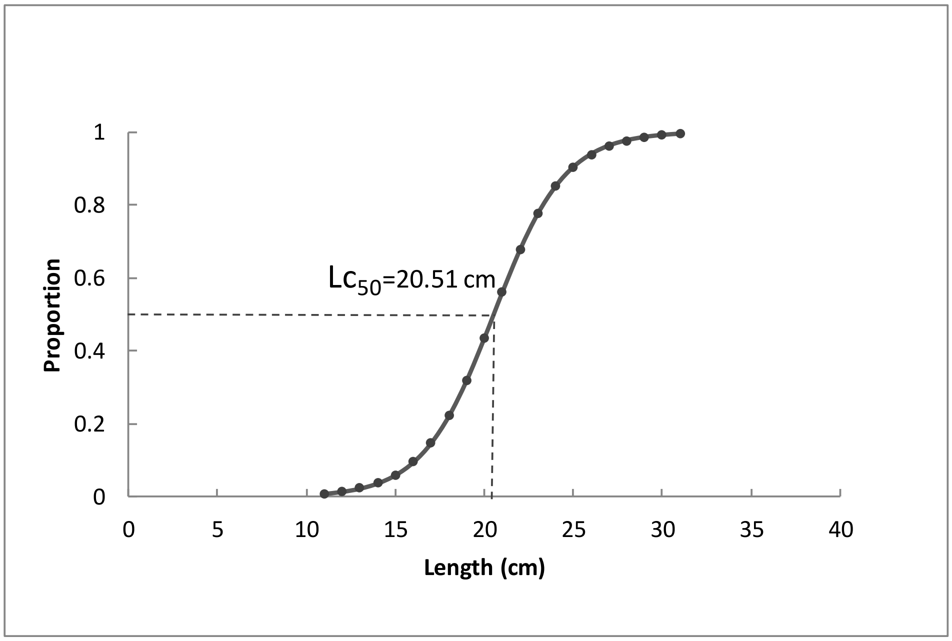

Fig. 3. Length at first capture (Lc) of the Indian mackerel in the Aru Sea

4. The estimated growth

The asymptotic length (L∞) of the Indian mackerel is 33.08cm, and the growth rate (K) is 0.8 per year. These data were obtained by tracking the fork length frequency from month to month, which is analyzed using ELEFAN I in the software FiSAT II (Fig. 4). This species can reach its maximum length of 54 months.

Fig. 4. von Bertalanffy growth curve of Indian mackerel in the Aru Sea

5. Mortality and exploitation rate

Fig. (5) shows that the annual total mortality rate is 2.59 per year (M = 1.55 per year for natural mortality and F = 1.04 per year for fishing mortality). Moderate usage is indicated by an exploitation rate (E) of 0.4.

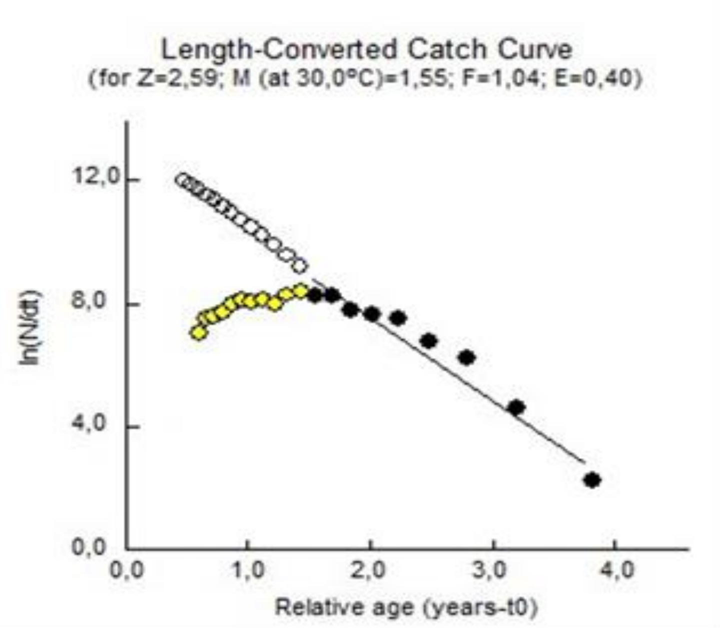

Fig. 5. Length converted catch curve of the Indian mackerel in the Aru Sea

The Indian mackerel's length structure was used to examine the spawning potential ratio (SPR) in the Aru sea. The gonad maturity at 50% (Lm_{50}) and 95% (Lm_{95}) as well as the spawning potential ratio of the Indian mackerel could be calculated by dividing the natural mortality rate (M) by the growth rate (K). The Lm_{50} value of this species is 19.96cm **(Fauzi *et al.*, 2021)**. The estimated spawning potential ratio for the Indian mackerel in the Aru Sea is 57%. This condition shows that 57% of the adult Indian mackerel population remaining in nature will spawn.

DISCUSSION

The length at first capture (Lc) of the Indian mackerel in this study was higher than the size reported by **Saputra and Taufani (2021)** in the Java Sea, which was 18.5cm. According to **Hargiyatno *et al.* (2013)**, changes in fishing gear mesh size, the time of year (month or season), and the location where the fish are caught can all lead to variations in the length at first capture (Lc). Female Indian mackerel in the Aru Sea reach a length of 19.96cm at first maturity (Lm) **(Fauzi *et al.*, 2020)**. This study used a first capture size (Lc50) of 20.05cm FL. The size at first capture (Lc) exceeds the size at first maturity (Lm), which is favorable for the fish population. This suggests that the majority of the Indian mackerel caught have already spawned, facilitating the recruitment process.

The research results from several areas show different values for the growth rate (K) and asymptotic length (L∞) (Table 1).

Table 1. Growth parameter of the Indian mackerel from several areas

Area	K	L∞	Reference
The Strait of Malacca	0.73	27.2	Hariati *et al.* (2015)
West Coast of Aceh	0.56	27.3	Arrafi *et al*. (2016)
Coast of Ternate Island	0.71	28.4	Tangke *et al*. (2014)
North Kwandang Gorontalo	0.8	27.3	Faizah *et al*. (2017)
Raja Ampat water Papua	0.97	28.4	Oktaviani *et al*. (2019)
Aru Sea	1.33	27.9	Fauzi *et al*. (2020)
Java's North Coast	0.45	28.9	Saputra & Taufani (2021)
Kupang bay	0.51	28.4	Kurnia *et al*. (2023)
Bone bay	0.84	30.5	Jalil & Makkatenni (2024)
Aru Sea	0.8	33.08	This study

Various factors in the environment, including population density, water temperature, and the availability of prey, influence the changes in K and L∞ values **(Ju *et al.*, 2016; Cominassi *et al*., 2020; Armstrong *et al*., 2021)**. Meanwhile, according to **Ghosh *et al*. (2016)**, growth parameters are affected by variations in environmental factors, food availability, predators, fishing pressure, and fishing gear type.

However, some studies found substantially greater death rates. The results of **Tangke (2014)** in Ternate Island, were F=1.72 $year^{-1}$, M=1.47 $year^{-1}$, and Z=3.19 $year^{-1}$. In the Pancana coastal area of Barru Regency. **Sonodihardjo and Yahya (2015)** found F=2.73 $year^{-1}$, M=0.51 $year^{-1}$, and Z=3.25 $year^{-1}$. In the Malacca Strait, studies carried out by **Hariati *et al*. (2015)** yielded F=3.17 $years^{-1}$, Z=4.38 $years^{-1}$, and M=1.21 $years^{-1}$. In the meantime, research conducted on the North Coast of Java by **Zamroni and Ernawati (2019)** yielded the following results: F=3.46 $years^{-1}$, M=2.02 $years^{-1}$, and Z=5.48 $years^{-1}$. F=1.43 $year^{-1}$, M=1.29 $year^{-1}$, and Z=2.72 $year^{-1}$, were determined on the north coast of Gorontalo by **Faizah *et al*. (2017)**. **Suradi *et al.* (2021)** reported that there was a comparatively low natural mortality rate (M) of 0.56 years, a fishing mortality rate (F) of 1.17 years, and a total mortality rate (Z) of 1.74 years for *R. kanagurta*.

Differences in mortality rates in several locations are influenced by fishing pressure, food availability and predation **(Ning *et al.*, 2018)**. Meanwhile, according to **Koolkalya *et al*. (2017)**, population factors are impacted by variations in stocks and fishing pressures, which in turn cause mortality rates to vary. Several factors impact variations in natural mortality rates, including fishing pressure, sea water temperature at sample time, illness, predators, stress, and advancing age **(Sparre & Venema, 1998; Bergström *et al*., 2022; Levangie *et al*., 2022)**.

The exploitation rate (E) is smaller than 0.5, so the level of exploitation of the Indian mackerel in the Aru Sea is still moderate. **Gulland (1971)** and **Pauly (1983)** reported that the exploitation rate of a fish stock will be at a sustainable level if smaller or equal to 0.5. The E-value of the Indian mackerel in the Aru Sea is 0.4. This shows the exploitation of this species in the Aru Sea is still moderate, therefore increasing effort or the number of fishing gear is still achievable.

After fishing pressure has been applied, the spawning potential ratio measures the proportion of fish that have the ability to spawn **(Walters & Martell, 2004; Prince *et al*., 2014)**. The estimated ratio of potential spawning for mackerel in the Aru Sea is 57%, indicating that around 57% of the uncaught fish population has the potential to spawn. According to **Prince *et al.* (2014)**, the SPR reference point is 20% as the minimum threshold (limit reference point), with the upper limit (target reference point) at 40%. The Indian mackerel in the Aru Sea have a spawning potential ratio (SPR) higher than the baseline, indicating that their exploitation is still sustainable. This suggests that fishing efforts could be increased by 17%.

Current fishing practices are sustainable, but there is potential for controlled expansion of fishing efforts by approximately 17%, as indicated by the SPR analysis. Future management strategies should continue monitoring population dynamics to maintain a balance between fishing activities and resource conservation. Continuous data collection on catch-effort, length-frequency, and biological characteristics is essential to obtaining high-quality data and reducing the uncertainty of study results, ensuring the sustainable management of the Indian mackerel population and other fisheries.

CONCLUSION

The size structure of the Indian mackerel (*Rastrelliger kanagurta*) caught in the Aru Sea ranges from 10 to 31.5cm, with a mode of 22.5cm. Most of the individuals caught have already spawned, which is beneficial for the population as it ensures the recruitment process can be successful. The asymptotic length is 33.08cm, and the growth rate (K) is 0.8 per year. The total annual mortality rate is 2.59, with 1.04 due to fishing (F) and the remainder (M) due to natural causes. The exploitation rate (E) is 0.4, indicating that the level of exploitation in the Aru Sea is still moderate. This suggests that further increases in fishing effort or gear are feasible.

With a spawning potential ratio (SPR) greater than the target reference point, the exploitation of the Indian mackerel in the Aru Sea is still classified as sustainable. Therefore, development efforts can be increased by up to 17%.

Overall, the research confirms that the Indian mackerel in the Aru Sea are being exploited sustainably, with potential for further development. Future management strategies should continue monitoring population dynamics to ensure a balance between fishing activities and long-term sustainability.

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