Growth, mortality, recruitment pattern, and exploitation rate of shared stock flying fish (Exocoetidae) at border area of Indonesia and Timor Leste in Ombai Strait

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Abstract. Flying fish (Exocoetidae) is one important small pelagic fisheries commodity in border areas of Indonesia and Timor Leste. However, the data of population parameters in Ombai Strait are not yet known, which is important to inform unit stock management and sustainable fisheries. This study aimed to provide information about growth and mortality parameters, recruitment pattern, and exploitation rate of flying fish. Data collection was carried out during May 2018-June 2019 by measuring and observing the flying fish landed at the fish landing sites in Belu Indonesia and Bobonaro Timor Leste. Data analysis used the FAO-ICLARM Stock Assessment Tools (FiSAT) program. The results showed that the asymptotic length (L∞) was 330.5 mm, growth constant (K) was 0.99 per year, and growth performance indices (Φ) was 0.50. The natural mortality (M) was 0.92 per year, fishing mortality (F) was 0.12 per year, and total mortality (Z) was 1.04 per year. The highest recruitment occurs in May to September with peak season in June (14.82%) and September (15.16%). Exploitation rate (E) flying fish in the border area of Indonesia and Timor Leste in Ombai Strait is relatively low about 0.11 and still at a rational and sustainable utilization range (E < 0.5).

Keywords: flying fish; Ombai Strait; population dynamic; shared stock

1. Introduction

Flying fish is a small pelagic fish group that has a high economic value because its meat and eggs can be used [1]. This encourages flying fish to become a target to catch and source of livelihood for fishermen as well as a source of animal protein for coastal communities. Rehatta et al. [2] stated that flying fish an important fishery commodity in the border area of Indonesia and Timor Leste.
The stock of flying fish in the Ombai Strait is a shared stock used by fishermen in Indonesia and Timor Leste. Fishermen in Belu (Indonesia) and Bobonaro (Timor Leste) carry out fishing activities in Ombai strait using drift gillnet. Gillnets dominate the structure of fishing gear in Belu around 49.0% [3] and Bobonaro around 80% [4]. The production of flying fish in Belu in 2018 was 120.5 tons and contributed around 22% to the production of small pelagic fisheries [3]. Flying fish production in Bobonaro District in 2018 was 45.0 tons and contributed around 17% of small pelagic fisheries [4].

Biological aspects of flying fish that have been studied in Indonesia include aspects of reproductive biology in Tual, Southeast Maluku [5], growth parameters in Binuang, Banten [6], species diversity and size distribution in Eastern Indonesian waters [7], reproductive strategies in Indonesian waters [8], biology and fisheries of flying fish in the South Makassar Strait [9], maturation and spawning in the Makassar Strait [10], morphometry, growth factors and conditions in the East Seram Sea [11], species determination [12]. However, none of these studies have focused on the biology and parameters of the flying fish population in Ombai Strait.

Given the importance of flying fish resources in Ombai Strait and the lack of data and information availability, this research is important to provide data and information needed for flying fish sustainable resources management. One important aspect to support the management of flying fish resources is basic knowledge about population dynamics, especially parameters of growth, mortality, recruitment, and exploitation rates aspect.

2. Methods

2.1. Study area
The research was conducted from May 2018 to June 2019. The locations of data collection of fish caught by fishermen in Belu Regency, Indonesia include Dualaus, Jenilu, Kenebibi, and Silawan villages. Meanwhile in Bobonaro District of Timor Leste, locations of data collection includes Batugade, Sanirin, and Aidabaleten villages at Enelaran and Beacou (figure 1).

![Figure 1. Research locations in Belu Regency, Indonesia, and Bobonaro District, Timor Leste.](image-url)
2.2. Sampling procedure

The collecting of flying fish samples totals 2405 fish from any proportion catch of drift gillnet fisheries in each month. Sampling was taken continuously every month from May 2018 to June 2019 with measuring the total length of samples.

2.3. Data analysis

Length frequency analysis was carried out using the FiSAT II (FAO-ICLRAM Stock Assessment) - ELEFAN (Electronic Length Frequency Analysis) program, which is a program package for analyzing length-frequency data with the help of a computer device [13]. Estimation of the length at the first mature (Lm) using the formula, as equation (1) [14]:

$$Log L_m = 0.8979 \times Log L_\infty - 0.078$$

(1)

Estimation of the average size first captured (Lc) is done by calculating the L50 value. A lethal value of 50% is considered as the optimum point of fishery resource utilization. The process of estimating the value of Lc is carried out with the FISAT II-ELEFAN software program [15].

Growth parameters were estimated using the von Bertalanffy growth model with mathematical equation (2) [16]:

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

(2)

where Lt is the length of the fish at age t (time unit), L∞ is the theoretical maximum length (asymptotic length), K is the growth coefficient, t0 is the theoretical age. Estimation of the value of the K and L∞ growth coefficients were carried out using the Ford Walford Plot method which is derived from the von Bertalanffy model for t equals t + Δt. Estimates for the value t0 (theoretical age of fish when the length is equal to zero) are obtained through the equation (3) [17]:

$$log (-t_0) = 3.3922 - 0.2752 \times (log L_\infty) - 1.038 \times (log K)$$

(3)

Estimated maximum fish age (tmax) = 3/K + t0 [17].

The total mortality rate (Z) was estimated using a linear catch curve based on length composition data [13], which was calculated using the FISAT II program package. The natural mortality rate (M) was estimated using the empirical formula of Pauly (1980) in [16] as equation (4):

$$ln M = -0.0152 - 0.2700 ln L_\infty + 0.6543 ln K + 0.4630 ln T$$

(4)

M is natural mortality, L∞ is the asymptotic length in the von Bertalanffy growth equation (mm), K is the growth coefficient in the Von Bertalanffy growth equation, and T is the mean surface temperature of water (°C). The catch mortality rate (F) is determined by equation (5):

$$F = Z - M$$

(5)

The exploitation rate (E) is determined by comparing the fishing mortality rate (F) with the total mortality rate (Z) [17], as equation (6):

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

(6)

E is the rate of exploitation, M is the natural mortality rate, F is the capture mortality rate and Z is the total mortality rate.

Recruitment patterns were analyzed with the FISAT II program in the recruitment pattern subprogram to determine the construction of a time series of recruits from length frequencies in determining the relative peak recruitment per year.

3. Results

Five species of flying fish were identified (table 1) and length measurements indicated that total length ranged from 140-314 mm with a mean length of 197 mm (table 2).
Table 1. Flying fish species collected from fishermen’s catches in Belu and Bobonaro.

| No. | Species                                      | Genus       | Common name            |
|-----|----------------------------------------------|-------------|------------------------|
| 1   | Cheilopogon abei Parin, 1996                 | Cheilopogon | Abe’s flying fish      |
| 2   | Cheilopogon intermedius Parin, 1961          | Cheilopogon | Intermediate flying fish|
| 3   | Cheilopogon spilopterus (Valenciennes, 1847) | Cheilopogon | Many spotted flying fish|
| 4   | Cypselurus poecilopterus (Valenciennes, 1847) | Cypselurus  | Yellowing flying fish  |
| 5   | Hirundichthys oxycephalus (Bleeker, 1852)    | Hirundichthys | Bony flying fish       |

Table 2. Minimum length ($L_{\text{min}}$), maximum length ($L_{\text{max}}$), mean length ($L_{\text{mean}}$), length at first captured ($L_c$), and length at first maturity of gonad ($L_m$) of flying fish in Ombai Strait.

| Location         | $L_{\text{min}}$ (mm) | $L_{\text{max}}$ (mm) | $L_{\text{mean}}$ (mm) | $L_c$ (mm) | $L_m$ (mm) |
|------------------|------------------------|------------------------|------------------------|------------|------------|
| Belu             | 140.00                 | 269.00                 | 197.20                 | -          | -          |
| Bobonaro         | 146.00                 | 314.00                 | 196.70                 | -          | -          |
| Ombai Strait     | 140.00                 | 314.00                 | 197.03                 | 153.86     | 152.86     |

Table 2 shows that the total length of flying fish landed in Belu ranges from 140-269 mm with a mean length of 197.2 mm, while in Bobonaro ranges in 146-314 mm with a mean length of 196.7 mm. The average length at first captured ($L_c$) was 153.86 mm and the average length at first maturity of gonads ($L_m$) was 152.86 mm (table 2).

The frequency distribution of the total length of flying fish in Ombai Strait during the study period was dominated by the size of class 200-214 mm (figure 2). The distribution of the total length-frequency according to the time of observation is presented in figure 3.

![Figure 2](image_url)

**Figure 2.** Length frequency distribution of flying fish landed in Belu, Indonesia and Bobonaro, Timor Leste.

Figure 3 shows that in May-July there are two age groups of fish and another month there is one age group of fish. In May–July, August–October, and November–January there was no shift mode of length and the size of the fish structures did not differ significantly. In February, May, and August there is a shift in the mode of length to the left, and in April and November, there is a shift in mode length to the
right. November–April the frequency of fish length was dominated by large fish (>197 mm) and in August, it was dominated by small fish (<197 mm).

Figure 3. Length frequency distribution of flying fish caught in Ombai Strait.
The analysis of the mode shift in the total length of flying fish based on the time of observation shows that there are two age groups (cohorts) of flying fish in Ombai Strait (figure 4).

![Figure 4. Growth graph of flying fish in Ombai Strait.](image)

The results of the analysis of the growth parameters of flying fish in Ombai Strait show that the asymptotic length \((L_\infty)\) is 330.53 mm TL, the growth rate \((K)\) is 0.99 per year, and the age at zero fish length \((t_0)\) is \(-0.0832\) years. The growth curve of flying fish in Ombai Strait follows the equation \(L_t = 330.53 \cdot (1 - \exp[-0.990(t + 0.0832)])\). The maximum age of fish \((t_{\text{max}})\) is 3.03 years. Growth performance indices \((\Phi)\) was 0.50. The growth curve of flying fish based on the Von Bertalanffy equation in the waters of the Ombai Strait is presented in figure 5.

![Figure 5. Von Bertalanffy growth graph of flying fish in Ombai Strait.](image)

A linear analysis of fishing yield curves to estimate the total mortality rate \((Z)\) of flying fish in Ombai Strait gives a yield of 1.039 per year (figure 6). The natural mortality rate \((M)\) at 29°C is 0.922 per year and the fishing mortality rate \((F)\) is 0.117 per year. The estimated exploitation rate \((E)\) of flying fish in Ombai Strait is 0.11.
Figure 6. Length-converted catch curve of flying fish in Ombai Strait.

Pattern recruitment of flying fish in Ombai Strait shows that recruitment occurs throughout the year. The highest recruitment occurred in the period May-September with peak recruitment occurring in September and June with relative recruitment values of 15.16% and 14.82% (figure 7).

Figure 7. Recruitment pattern graph of flying fish in Ombai strait.
4. Discussion

The length range of flying fish in the border areas of Indonesia and Timor Leste in Ombai Strait is 140 - 314 mm TL with a mean length of 197.0 mm TL. The length range is wider and has a maximum length (L_{max}) that is greater than the size of the flying fish as a result of previous studies. Harahap and Djamali [6] stated that the length of flying fish (Hirundichthys oxycephalus) in Binuangeun Banten waters ranges from 214.5-278.5 mm TL. Furthermore, Tuapetel et al. [11] reported that the length range of flying fish in the East Seram Sea was 208.7-274.4 mm FL. The difference in the length range is thought to be due to differences in aquatic environmental conditions [18] and differences in the fishing gear used [19, 11].

The lengths of flying fish caught in Ombai strait and landed in Belu (Indonesia) and Bobonaro (Timor Leste) indicate differences in the total length range. The flying fish landed at Belu had a smaller total length range (140-269 mm) than the flying fish landed at Bobonaro (146-314 mm). Differences in geographic location [20] and the conditions of the aquatic environment [18] may have influenced the differences in length. Ali [1] also stated that the overfishing factor can lead to population diversity between flying fish groups. Furthermore, Harahap and Djamali [6] stated that the level of exploitation can affect the total length range of flying fish.

The estimate of the length at first captured (L_{c}) of flying fish in Ombai strait of 153.86 mm TL is relatively the same as the length at first captured of flying fish Cypselurus oxycephalus, C. oligolepis, and Exocoetus volitans in Makassar Strait, ranging from 150-160 mm [9]. Dalzell [21] reported L_{c} of flying fish Cheilopogon nigricans was 149 mm, Cypselurus opisthopus was 140 mm, and Oxyporhamphus convexus was 152 mm in Camotes Sea Philippines. The difference in L_{c} size between fish species and populations is influenced by factors of differences in fishing gear and methods and fish size distribution [22].

The length at first maturity of gonads (L_{m}) of flying fish in the border area of Indonesia and Timor Leste in Ombai Strait is 152.86 mm TL. These results indicate a slight difference with L_{m} Hirundichthys oxycephalus in the Makassar Strait of 151.1 mm FL [23], male Cypselurus oxycephalus 132.6 mm and female 117.7 mm, male Cypselurus oligolepis 145.7 mm and female 120.8 mm, male Exocoetus volitans 114.2 mm and 138.2 mm [9], Cypselurus oligolepis 229.0 mm and C. spilocephalus 284.8 mm in Tual [5]. Oliveira et al. [24] stated that the size at the first maturity of gonads is not the same and even varies between individuals of the same species. Furthermore, Ndiaye et al. [25] stated that the length at the first maturity of gonads varies according to sex, site, and season. This difference is influenced by the availability of energy for gonad development [26], differences in fishing grounds, fishing pressure, sampling time and season [27], and length composition [28].

Estimation of the length at first captured can be used as a reference in determining fisheries resource management efforts [29]. Further explanation that if the fish has a size of L_{c}>L_{m}, then this situation does not endanger the fish population because the fish are allowed to spawn. The length at the first maturity of gonads is an important parameter in determining the size of the mesh and the minimum size of fish that can be caught [28, 24]. The results of this study indicate that the length at first captured is greater than the length at first maturity of the gonad (L_{c}>L_{m}). Thus, the use of gillnets with a mesh size as currently used by fishermen in Belu and Bobonaro can still be maintained at a mesh size of 1.25 inches, and does not endanger the flying fish population in Ombai Strait because the fish caught are dominated by adult fish.

The estimated asymptotic length (L_{\infty}) of flying fish in Ombai Strait of 330.5 mm TL tends to be larger than that which has been reported. Dalzell [21] reported that L_{\infty} Cheilopogon nigricans and Cypselurus opisthopus in the Camotes Sea Philippines were 210 mm and 280 mm, respectively. Further reported by [30] that the asymptotic length of Hirundichthys affinis in the Barbados Sea was 245 mm, while Hirundichthys oxycephalus was 254 mm in the East Taiwan Sea [31]. In Indonesia, several researchers have reported the asymptotic length of the flying fish Hirundichthys oxycephalus was 182 mm in the Flores Sea and Makassar Strait [1], 321.1 mm in Binuangeun Banten [6], 245 mm in East Seram Sea [11]. The growth coefficient (K) of flying fish in Ombai strait was 0.99 per year, which is greater than the growth coefficient of Hirundichthys oxycephalus in Binuangeun Banten [6] and in the East Taiwan Sea [30], but smaller than the growth coefficient of Cheilopogon nigricans and Cypselurus...
opisthopus in the Comotes Sea, Philippines [21], Hirundichthys affinis in the Barbados Sea [31] and Hirundichthys oxycephalus in the Flores Sea and Makassar Strait [1], and the East Seram Sea [11] (table 4). This result indicates that the flying fish in Ombai Strait are estimated to be able to grow to a maximum length of 330.5 mm TL with a growth rate of 0.99 per year and a maximum age (t_{max}) of 3.03 years. [32] stated that the difference in the value of the growth coefficient (K) and the asymptotic length (L_{\infty}) is probably caused by the structure of the data collected and data analysis performed. Furthermore, Motlagh et al. [18] stated that this difference is thought to be due to variations in fishing intensity and environmental conditions. The maximum length (L_{max}) of flying fish caught from the Ombai Strait is 314 mm. This shows that the fishing intensity is still low and the waters are relatively fertile so that the flying fish population can live longer and the size is close to the asymptotic length.

**Table 3. Growth parameter of flying fish at various locations in Indonesia and surrounding waters.**

| Site                                      | Species                        | Asymptotic length (L_{\infty}) (mm) | Growth coefficient (K) (per year) | Reference |
|-------------------------------------------|---------------------------------|-------------------------------------|----------------------------------|-----------|
| Camotes Sea, Philippines                  | Cheilopogon nigricans           | 210.0                               | 1.75                             | [21]      |
|                                           | Cypselurus opisthopus           | 280.0                               | 2.05                             |           |
| Barbados Sea                              | Hirundichthys affinis          | 245.0                               | 2.90                             | [31]      |
| Flores Sea, Makassar Strait, Indonesia    | Hirundichthys oxycephalus       | 182.0                               | 1.30                             | [1]       |
| Binangun, Banten Indonesia                | Hirundichthys oxycephalus       | 321.1                               | 0.15                             | [6]       |
| Taiwan East Sea                           | Hirundichthys oxycephalus       | 254.0                               | 2.60                             | [30]      |
| East Seram Sea                            | Hirundichthys oxycephalus       | 245.0                               | 1.80                             | [11]      |
| Ombai Strait, Indonesia                   | Cheilopogon abei                | 330.5                               | 0.99                             | This study|
|                                           | C. spilopterus                  |                                     |                                  |           |
|                                           | C. intermedius                  |                                     |                                  |           |
|                                           | Cypselurus poecilopterus        |                                     |                                  |           |
|                                           | Hirundichthys oxycephalus       |                                     |                                  |           |

The total mortality rate (Z) of flying fish in Ombai Strait is 1.039 per year and is lower than the total mortality of Cheilopogon nigricans and Cypselurus opisthopus in the Camotes Sea Philippines of 5.44 per year and 10.47 per year as reported by Dalzell [21]. The same thing happened to the natural mortality rate (M=0.922 per year) and fishing mortality (F=0.117 per year) which were lower than the other locations. The natural mortality rate (M) is higher than the catch mortality rate (F) of flying fish in Ombai Strait. This indicates that the flying fish population experiences high levels of predation and competition, resulting in high natural mortality as well. [16] stated that natural mortality occurs due to various reasons including predation, disease, spawning stress, hunger, and old age. Furthermore, Morgan [26] stated that the different mortality rates between waters are caused by fishing gear targets. Migration, and ontogenic factors. In this study, the value of the Z/K ratio was 1.05 and less than 2, which means that the growth of flying fish in the Ombai Strait is more dominant than mortality, so even though the growth coefficient is relatively not high, the maximum length that can be achieved is high.

The pattern of flying fish recruitment in Ombai strait occurs throughout the year with the highest recruitment occurring in the period from May to September with peak recruitment occurring in September and June. Factors that influence recruitment include the availability of adult stocks, reproductive success, pre-recruitment mortality both at the larval and juvenile stages [33]. Furthermore, Nugroho and Chodrijah [34] stated that the size of the recruits is determined by the number of brood stock ready to spawn and the mortality in the period between spawning and fish reaching the stock size. Besides, the success of recruitment is also determined by the environmental conditions during the post-larval cohort on the nursery ground. The population of flying fish in Ombai Strait is dominated by adult-
sized fish (>L<sub>ma</sub>) and the mortality rate is low, resulting in high availability of brood stock fish that are ready to spawn. For this reason, to keep flying fish recruits in Ombai Strait high, it is necessary to regulate fishing activities so that more adult fish are available and ready to spawn.

The utilization rate of flying fish (E) in Ombai strait is 0.11 per year, lower than that of the Camotes Sea Philippines which ranges from 0.45 to 0.75 per year [21]. The E value of 0.11 per year indicates that the utilization rate of flying fish in Ombai strait is below the optimum conditions. Pauly [35] stated that the value of rational and sustainable utilization rates in the range of E<0.5 or the highest is E=0.5. The utilization rate of flying fish in Ombai Strait is low and can still be increased to reach an optimum utilization rate of 0.5. This can be done by increasing the fishing mortality rate through an increased fishing effort by fishermen in Belu and Bobonaro.

5. Conclusion

Five species of flying fish (Exocoetidae) were found in Ombai Strait and adult fish groups (>52.8 mm TL) dominated the flying fish population. Growth is classified as fast with a growth rate of 0.99 per year and an asymptotic length of 330.5 mm TL which is achieved at the age of >3 years. The natural mortality rate is higher than the fishing mortality rate of flying fish in Ombai Strait. The pattern recruitment of flying fish in Ombai Strait occurs throughout the year with peak recruitment occurring in September and June. The exploitation rate of flying fish in Ombai Strait is still within the limits of rational and sustainable use. The conclusion of this study provides information related to biological aspects that can be used as a basis for making flying fish fisheries management policies in the border areas of Indonesia and Timor Leste in Ombai Strait.

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