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LENGTH-WEIGHT RELATIONSHIP AND POPULATION DYNAMICS OF FRINGESCALE SARDINELLA, *SARDINELLA FIMBRIATA* (CLUPEIFORMES, CLUPEIDAE), FROM MALAMPAYA SOUND, PALAWAN, PHILIPPINES

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Length-Weight Relationship and Population Dynamics of Fringescale Sardinella, *Sardinella fimbriata* (Clupeiformes, Clupeidae), from Malampaya Sound, Palawan, Philippines. Vicente, J. A., Palla, H. P. — The study investigated the growth, mortality, exploitation rate and recruitment of Fringescale sardinella (*Sardinella fimbriata* Valenciennes, 1847) found in Malampaya Sound, Palawan, Philippines. A total of 1200 samples were collected from April 2023 to March 2024. The relationship between length and weight was expressed as y = 0.0291 × 2.561 for combined sex, y = 0.0404 × 2.4254 for males, and y = 0.0355 × 2.4856 for females. The resulting b values pinpoint to a negative allometric growth. The calculated regression model showed a significant association during which the p-values were below 0.0000 and the r^2 values ranged between 0.76 and 0.79. Estimation using the FISAT II software resulted in an asymptotic length (L∞) = 16.28 cm, growth rate (K) = 0.68 yr^{-1}, maximum length (L_{max}) = 15.78 cm, theoretical age at birth (t_0) = –0.5515 years and growth performance index (ϕ') = 2.256. The estimated average total mortality rate (Z), natural mortality (M), and fishing mortality (F) were 2.69, 1.68, and 1.01 per year, respectively. Recruitment occurs throughout the year and peaks in June. It can be noted that the exploitation is calculated as 0.38, which is considered lightly exploited. To have a sustainable population and avoid overfishing, an optimum total yield (E_{50}) can be set at an exploitation rate of 0.278. The maximum yield (E_{max}) is at an exploitation rate of 0.421.
Key words: fish growth and mortality, sardines, stock assessment, West Palawan water.

Introduction

The global capture fisheries production follows an increasing trend. It was recorded that it already reached 96.4 million tons in 2018 (FAO, 2020). Ninety-one percent of the world's fish supply was derived from marine capture fisheries and the Philippines were listed as one of the major producing countries. As an archipelagic country with 2,200,000 km^2 of marine area, it provides food, income, and employment to its 109 million inhabitants. Based on statistics, the fisheries sector has contributed significantly to the country's economy (Barut et al., 2003). In 2019 alone, it increased the Gross Domestic Product (GDP) at constant 2000 prices by 1.3 %, equivalent to Php 9,207 billion (PSA, 2020).

Sardines are major fish component caught in Malampaya Sound. In 2020, it comprised 17 % of the country's total catch from commercial and marine municipal fisheries, of which, 9,504.24 mt came from Palawan province, in the western Philippines (PSA, 2020). There are at least six species of sardines found in Malampaya Sound (Gonzales, 2013), of which Fringescale sardinella (*Sardinella fimbriata* Valenciennes, 1847) is the most common. This ray-finned fish from the herring family (Clupeidae) is not just sought as food, but they are also used in the production of fish meal and fish oil. They are small, approximately < 20 cm in length (Ditty et al., 2006), with light blue to dark grey and bright silvery hue compressed deep bodies (Stern et al., 2016) and found in schools in coastal waters (Watson & Sandknop, 1996) of Indo-west Pacific, from Kuwait to southern India and Bay of Bengal to the Philippines (Whitehead, 1985).

However, the increasing demand for marine fish food did not spare the Sound from overexploitation. Stocks cannot sustain their population due to the compounding effect brought about by natural and anthropogenic causes, which resulted in the depletion of the natural population of marine species (Pauly et al., 2002, 2005). The area is so overfished that it was closed to all commercial fishing in 1973 (Ronquillo and Llana, 1987). A stricter conservation measure was introduced in 1986, restricting fishing in the area to municipal fishing boats (3 GT or less) using only hand lines, spears, crab hooks, cover pots, fish traps, fish pots, pole and line, gill nets for fish and shrimp, corral nets and beach seines. In order to protect the remaining marine resources from further degradation, ensure the continuity and sustainability of species, replenish fish stocks and increase the biodiversity of flora and fauna in the area, it was declared a protected landscape and seascape in 2000.

After several years of commercial fishing bans in the Sound and the implementation of various conservation measures, there are very few reports or literature published on the recovery of the fish population in the area. Studying changes in the population can describe the status of the Fringescale sardinella population. It includes birth, growth, mortality, exploitation rate and sustainable yield calculation and can therefore give us a picture of the current health and future trends of the population. More importantly, this information can be used as a basis for improving the fishery by identifying overfishing and applying management measures that can improve fish abundance.

This study aims to assess the length-weight relationship and population dynamics of the Fringescale sardinella found in Malampaya Sound, Palawan (fig. 1). Specifically, this study aims to determine the growth, mortality, exploitation rate, and recruitment of this species.

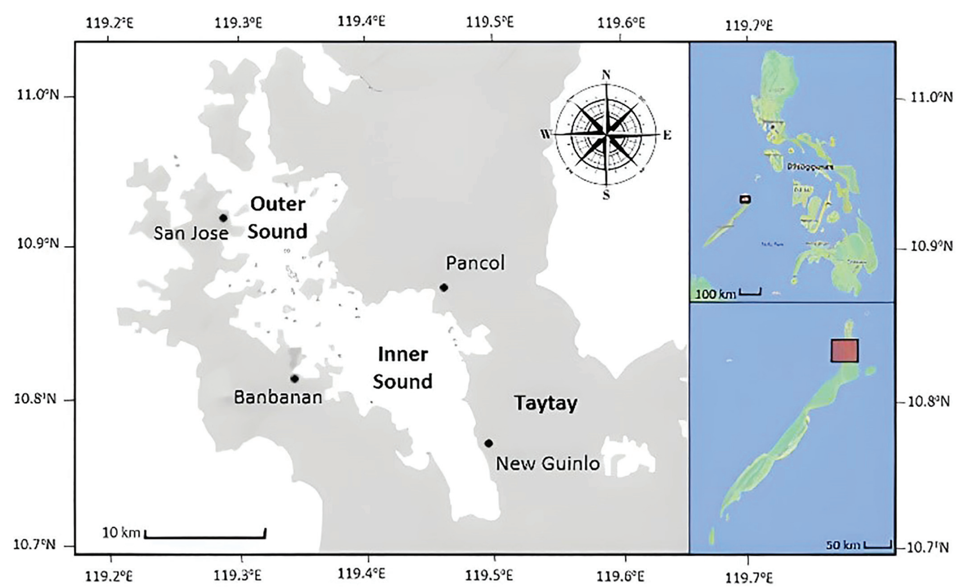

Fig. 1. The map of Malampaya Sound, Palawan.

Material and Methods

Malampaya Sound (fig. 1) is one of the important and richest traditional fishing grounds in the Philippines. It is part of the bigger Malampaya Sound Protected Landscape and Seascape, positioned at 10.8464° N and 119.3654° E, on the northwestern side of Palawan Province, Philippines. It is a protected inlet composed of complex sheltered bays, coves, and islands covering a marine area of approximately 240 km^2 which serves as a catchment of 30 rivers and harbours diverse ecosystems of the seagrasses, mangroves, and corals (DENR, 2020). It was considered as one of the important and richest traditional fishing grounds of the Philippines contributing 18 % of the total national municipal landings (Pido et al., 1996).

Samples of *Fringescale sardinella* were collected from Barangay Pancol, the primary fish landing site in the area. At least 100 samples of varying sizes were bought every month from April 2023 to March 2024. They were randomly picked in the catch, kept in a storage box with ice and later brought to the laboratory for measurements. The total length (TL) of each fish was measured from the tip of the snout to the end of the upper caudal fin to the nearest 0.1 cm using a ruler. Whole body weight (BW) was measured to the nearest 0.01 g using a scale.

The relationship between the length and weight of the fish was analysed by measuring the length and weight of the specimens gathered. The statistical relationship between these parameters of fish was determined by using the parabolic equation formulated by Froese (2006) as follows:

$$W = aL^b,$$

where, W = weight of fish (g), L = length of fish (cm), a = intercept (constant) and b = an exponential expressing relationship between length-weight (slope). The relationship ($W = aL^b$) when converted into the logarithmic form gives a straight-line relationship graphically. The same equation mentioned above is written in logarithmic form as:

$$\ln W = \ln a + b \cdot \ln L.$$

Moreover, the b and the coefficient of determination r^2 were estimated at the 95% confidence limit.

Length and weight relationship was described and the difference to the value of b was calculated using the formula:

$$t_{count} = b - 3/Sb,$$

where Sb is the standard error of the value of b. Growth is isometric if the b value is equal to 3, while it is allometric if the b value is less or more than 3.

Parameters of the population such as growth parameters, mortality rate, recruitment pattern, yield per recruit, and biomass per recruit were estimated. They were analysed using the FAO-ICLARM Fish Stock Assessment Tools (FISAT II) program. These variables are computed based on the following formulas:

Growth parameters were determined using the Von Bertalanffy function. It describes the mass growth of animals as a function of time. The growth curve was computed based on the following differential equation (Carlson and Goldman, 2006):

$$L(a) = L_\infty \ (1 - \exp(-k(a - t_0))),$$

where a is age, k is the growth coefficient, t_0 is the theoretical age when size is zero, and L_∞ is asymptotic size. The theoretical age (t_0) was derived from the formula developed by Pauly (1984):

$$\log(-t_0) = -0.3922 - (0.275 \cdot \log(L)) - (1.038 \cdot \log(k).$$

Mortalities were determined for the population of *Fringescale sardinella* in Malampaya Sound. Total mortality (Z) is the sum of natural mortality (M) and fishing mortality (F) (Pauly, 1980). Total mortality was estimated from the mean length using the expression:

$$\text{Total mortality (Z)} = K(L - L_{ave}) / L_{ave} - L'.$$

Natural mortality (M) was computed from the interrelationship between the length-growth data and the mean environmental temperature (Pauly, 1980), as follows:

$$\log_{10}M = -0.0066 - 0.279\log_{10}L + 0.6453\log_{10}K + 0.4634\log_{10}T,$$

where L_∞ and K are parameters of the von Bertalanffy growth equations, L_{ave} is the mean length in the catch, L' is the smallest length of animals that are fully represented in catch samples (Beverton and Holt, 2012) and T is the mean temperature in Malampaya Sound of 29.30° C (Estudillo et al., 1987).

The exploitation rate was computed based on the formula:

$$\text{Exploitation Rate (E)} = F/Z.$$

The values of total and fishing mortalities were derived from the previous calculations. The percentage level of exploitation was further computed using the equation:

$$\text{Level of exploitation (\%)} = (E/0.5) \cdot 100.$$

The result was described based on table 1.

A predetermined frequency distribution data in the FAO-ICLARM Stock Assessment Tools II (FiSAT II) was used to determine the recruitment pattern of the species. The yield per recruit (Y/R) and biomass per recruit (B/R) were calculated based on the formula developed by Sparre and Venema (1998) and Pauly (1980), respectively. They are described below.

$$\text{Yield per Recruit}\left(\frac{Y}{R}\right) = E \cdot \frac{Um}{K}\left[1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} + \frac{U^3}{1+3m}\right]$$

$$\text{Biomass per Recruit}\left(\frac{B}{R}\right) = \frac{\frac{B}{R}}{F}$$

The variable E is the exploitation rate and F is the fishing mortality. The values of U and m were derived from the following equation: $U = 1-(Lc/L_\infty)$ and $m = (1-E)/(M/K)$.

Results

Length weight relationship

The relationship between the length-weight will reveal details about the health of the fish species and how sustainable are the ecosystems. In the survey conducted between April 2023 to March 2024, 1200 fish were collected whose sizes ranged from 10.7cm to 15.5 cm. Table 2 below presents the length-weight parameters of the fimbriated sardines in Malampaya Sound. The longest lengths observed for male and female samples are 14.7 cm and 15.5 cm, respectively. It has been noticed that males (mean length 12.4 cm and mean weight 18.34 g) are smaller and lighter (mean length 12.8 cm and mean weight 20.13 g) which is the general trend exhibited in most fish species.

The relationship between length and weight is shown in figure 2, which demonstrates that the weight of fimbriated sardines increased as their length increased. The calculated regression model showed a significant association among the two variables during which the p-values were below 0.0000 and the r^2 values ranged between 0.76 and 0.79. The computation of b resulted in 2.5078 for combined sex, 1.1520 for males, and 1.1751 for females. These values pinpoint a negative allometric growth in the population of the species.

Table 1. Level of exploitation and its corresponding descriptive rating (Bintoro et al., 2019; FAO, 1995)

Descriptive Rating	Level of Exploitation, %
Unexploited	< 25
Lightly Exploited	25–50
Moderate	50–75
Fully Exploited	75–100
Over Exploited	100–150
Depleted	> 150

Growth parameters

Growth parameters for *Sardinella fimbriata* are calculated based on the von Bertalanffy method. The size distribution of the fish was clustered around the length classes

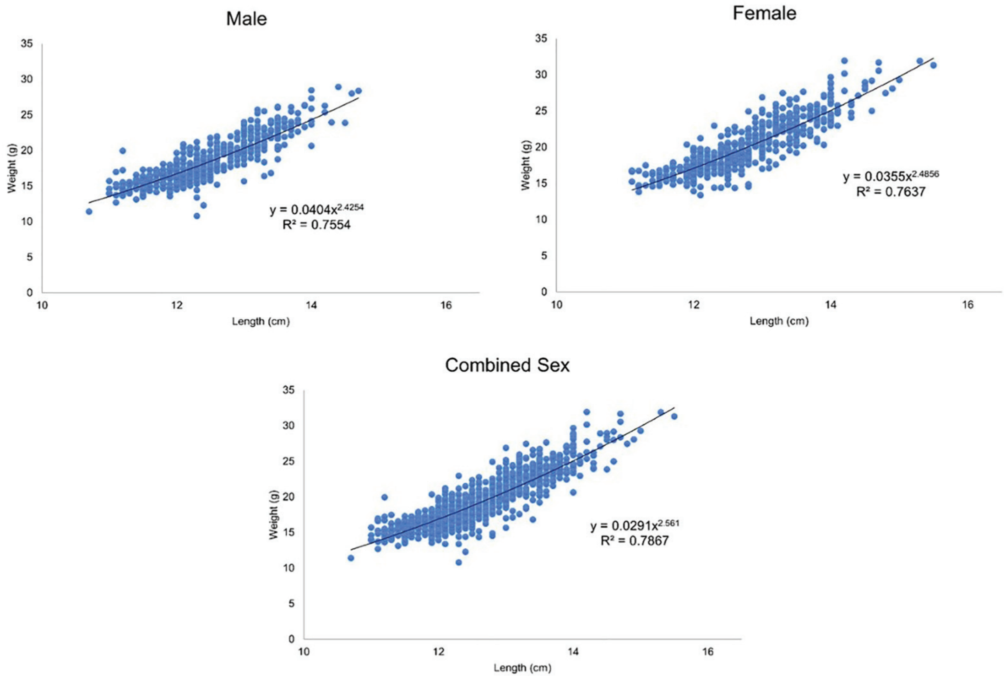

Fig. 2. Length and weight relationship of Fringescale sardinella (*Sardinella fimbriata)* from Malampaya Sound, Palawan.

between 11.5 and 13.5 cm, as illustrated in the generated length-frequency histograms presented in figure 3. The study observed that the maximum length (L_{max}) and the average length of fully grown *S. fimbriata* individuals (L_{∞}) were 15.78 cm and 16.28 cm, respectively. A moderately high fish growth rate coefficient (K) of 0.68 was also observed. The theoretical age at birth (t_0) was estimated to be -0.5515 per year. The growth performance index (ϕ') was found to be 2.26, which is comparable to the results of the previous studies conducted in Manila Bay (2.51), Visayan Sea (2.57), and Guimaras Strait (2.65) (Dicdiquin et al., 2017; Guanco et al., 2009; Lavapie-Gonzales et al., 1997).

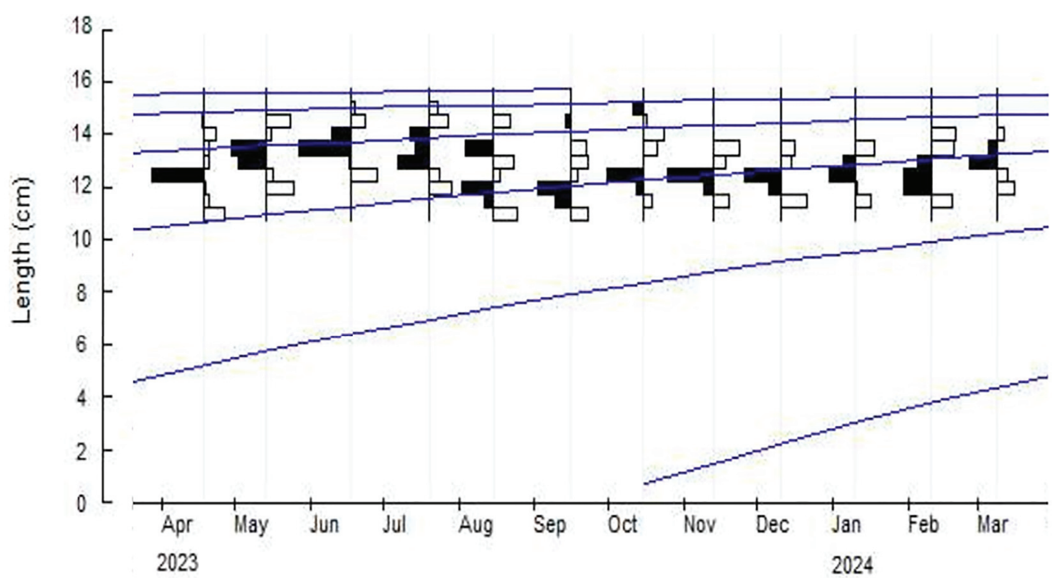

Fig. 3. Monthly length frequency distribution of fimbriated sardines (*Sardinella fimbriata*) from Malampaya Sound, Palawan from April 2023 to March 2024 generated using the von Bertalanffy growth model.

Table 2. Growth parameters of fimbriated sardines (*Sardinella fimbriata*) from Malampaya Sound, Palawan, Philippines

Sex	L_{max} (cm, TL)	L_{∞} (cm,TL)	K	ϕ'	t_o	a	b
Combined sex	15.78	16.28	0.68	2.256	−0.5515	0.0291	2.561
Male	14.69	15.33	0.45	2.024	−0.3582	0.0404	2.4254
Female	15.76	16.17	0.66	2.243	−0.5374	0.0355	2.4856

This study also analysed the growth parameters of *S. fimbriata* for separate sexes. The estimated values are presented in table 2.

Mortality and Exploitation Rate

The estimated average total mortality rate (Z), natural mortality (M), and fishing mortality (F) for *S. fimbriata* were 2.69, 1.68, and 1.01 per year, respectively. It can be noted that the exploitation is calculated as 0.38, which is lightly exploited based on the descriptive rating published by FAO (1995) and Bintoro et al. (2019).

Recruitment pattern

Fimbriated sardines typically spawn in nearshore coastal areas of high productivity (Garibaldi & Limongelli, 2015) like the Malampaya Sound (Estudillo et al., 1987). The recruitment pattern illustrated in figure 4 is continuous throughout the year, where the peak occurs in June (17.38 %). The estimated yield (Y/R) and biomass (B/R) per recruit were based on the Beverton and Holt model (fig. 5). Based on the model, the exploitation rate at which the marginal increase of Y'/R is 10 % of its virgin stock (green line) is 0.355. To have a sustainable population and avoid overfishing, an optimum total yield (E_{50}) can be met at an exploitation rate of 0.278 (red line). This is where the fish biomass is reduced to half. The maximum yield (E_{max}) will be attained with less effort at an exploitation rate of 0.421.

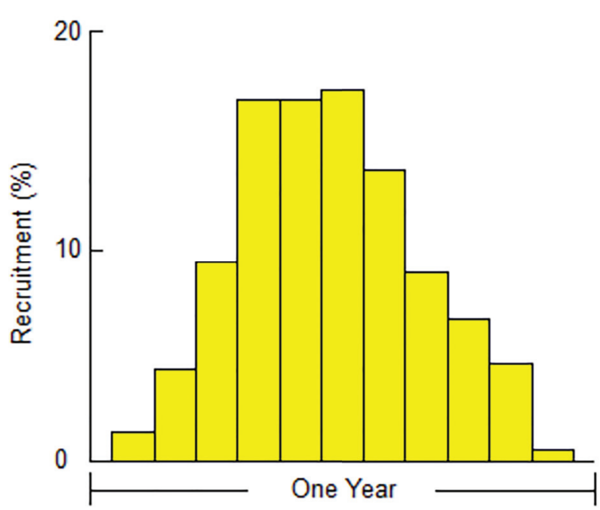

Fig. 4. Recruitment pattern of *Sardinella fimbriata* generated by FISAT II.

Discussion

Biological characteristics such as length and weight of fimbriated sardines were determined in this study. Based on the study of Nguyen et al. (2016), this species grows faster in length than weight at the early stages of its life. However, as they grow older, the rate of increase in weight is much faster than length. The results of this study follow the same trend. However, fish samples are smaller as the area is still used for artisanal fisheries and was declared overfished some years ago. The maximum length reported for this species was 29.6 cm (Mondol et al., 2017) while the largest sample observed in this study was only 15.5 cm.

Fish growth is generally described by the von Bertallanfy curve which has the form of the asymptotic sigmoid curve which is common among many species (Hopkins, 1992; Jobling, 2002; Pauly, 1994). Fishes are known to grow fast during their juvenile stage while mitigating most of their energies towards breeding when they are mature and adult (Claro and Garcia-Arteaga, 2014; Hutchings, 2003; Jobling, 1995). The current research found the "b" value to be lower than 3, suggesting negative allometric growth in fimbriated sardines. This implies that the growth rate of certain body parts (like fins or sensory organs) in relation to body length is slower as the fish matures. Negative allometric growth in fish can have several implications, including reduced agility and manoeuvrability (Domenici, 2001; Webb, 1994), impaired reproductive success (Fitzpatrick & Liley, 2008; Yeates & Einum, 2017), increased metabolic demands (Claireaux & Lagardere, 1999) and ecological (Persson, 1991; Werner & Gilliam, 1984). Previous studies on the growth performance index of the same species in various fishing grounds in India (Bennet et al., 1992; Ghosh et al., 2013; Karuppiah et al., 2020; Rajesh et al., 2021), Malaysia (Musel et al., 2022), Bali Strait (Bintoro et al., 2019), Savu Sea (Ginzel et al., 2022), Alas Strait (Rilani et al., 2017), Samar Sea (Dioction, 2016) and Honda Bay (Schroeder, 1982) reported a similar result of the index between 2.252 to 2.946.

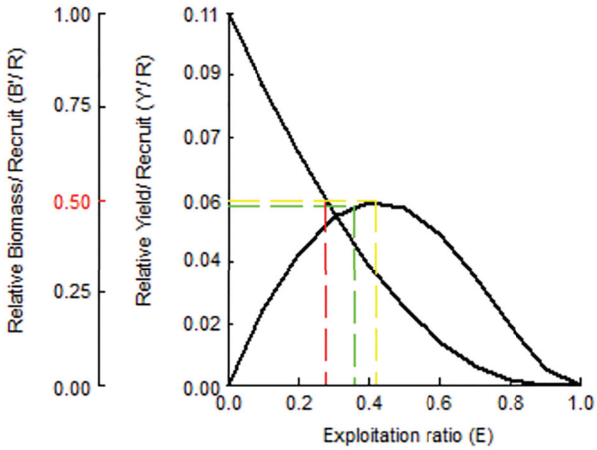

Fig. 5. Relative yield per recruit and average biomass per recruit for *Sardinella fimbriata* using Beverton and Holt's model where E_{50} — optimum sustainable yield, redline, and the E_{max} — maximum sustainable yield, yellow line.

The association between the weight and length of fimbriated sardines is proportional, therefore, the growth of weight complies with the increase in length. The relationship between the ratio of body mass and tissue height provides a morphometrical measurement of how a species allocates mass allometrically, which in turn can be used to evaluate standing crop biomass, assess how species adapted to the environment through time, and gain insight into production capabilities. According to the study by Jennings and Polunin (1997), this relationship between length and weight is one of the key performance indicators used to measure a fish's bodily mass and its ability to survive over a period of time. This relationship between length and weight will enable us to have profound insights into the standing crop biomass (Abd-Allah et al., 2015), species fitness (Bolger & Connolly, 1989), and production capabilities (Jobling, 2002) of fimbriated sardines. A positive growth by the species as seen in this study is an indication of increased biomass (Asriyana et al., 2004). This was further supported by the moderately high K value presented by the present study which suggests a fast growth rate and good overall health and nutritional condition. This can be an indication of improved environmental conditions of Malampaya Sound after its closure for commercial fishing. According to Jobling (1994) and Brett and Groves (1979), adequate food availability, nutritional quality, and optimal environmental conditions positively impact the condition factor. While, diseases, parasitic infections, competition for resources, pollution, and predation pressure can reduce fish condition by altering energy allocation and affecting feeding behaviour and metabolic processes (Woo & Buchmann, 2012; Huntingford et al., 2012). However, the fast growth rate means that the fish will also reach the asymptotic length faster and thus short-lived (Sparre & Venema, 1998).

Understanding the numerous sources of fish mortalities is vital for implementing effective fisheries management and conservation measures intended to mitigate human-induced impacts and preserve fish populations (Pikitch et al., 2004). In this study, it can be noted that the natural mortality is slightly higher than the fishing mortality. This implies that the fish population is more resistant to fishing pressure and can sustain current levels without considerable decline. While fishing is a contributing factor to mortality, it does not employ strong pressure as the natural factors. The population depends heavily on natural resources and processes for survival. These results were further transformed to a low exploitation rate of 0.38. This result is below the optimum and far better compared to the other fishing grounds around the Philippines (see table 3). Such findings were projected as stringent conservation measures for the area were executed since the 1970s. The area was once considered the "fishbowl" of the Philippines. However, due to overfishing the government was forced to close it for any commercial fishing activities (Ronquillo & Llana, 1987).

Given with the current findings of the study, it appears that the utilization of *Sardinella fimbriata* in Malampaya Sound is relatively low. However, balancing the fishing effort and conservation measures is still essential the ensure sustainable harvest. Musel et al. (2022) suggest offsetting fishing efforts with conservation measures can promote the well-being of *S. fimbriata*, the ecosystem, and human communities. Conservation measures may include habitat restoration, pollution control, and ecosystem-based management approaches to support population resilience. This emphasises the importance of maintaining healthy habitats and ecosystems to support fish populations.

Table 3. Mortality and exploitation rate of Fringescale sardinella from various fishing grounds in the Philippines

Fishing Ground	Year	Z ($year^{-1}$)	M ($year^{-1}$)	F ($year^{-1}$)	E	Author
Manila Bay	2014	5.86	1.98	3.88	0.66	Dicdiquin et al., 2017
Samar Sea	2013–2014	3.21	1.45	1.76	0.55	Diocton, 2016
Visayan Sea	1998–2002			4.17	0.61	Guanco et al., 2009
Sulawesi Sea	1994–1995	4.23	1.60	2.63	0.62	Aripin and Showers, 2000
Tayabas Bay	1987	5.3	2.12	3.18	0.60	Lavapie-Gonzales et al., 1997
Guimaras Strait	1984–1986	2.49	1.78	0.7	0.28	Lavapie-Gonzales et al., 1997
Leyte Gulf	1983–1986	3.29	1.89	1.4	0.42	Lavapie-Gonzales et al., 1997
Palawan	1965–1966	6.56	2.12	4.44	0.68	Ingles and Pauly, 1984
Malampaya Sound	2023–2024	2.69	1.68	1.01	0.38	This study

Conclusion

Based on the above, the study of population dynamics and length-weight relationships of Fimbriate Sardinella (*Sardinella fimbriata*) from Malampaya Sound, Palawan, Philippines, provides an important insight into the status and health of this important fish species and its ecosystem. As a major component of the local fish catch, understanding the population dynamics of *S. fimbriata* is essential for successful fisheries management and conservation.

The results of this study suggest that the population of *S. fimbriata* in Malampaya Sound is showing signs of resilience and recovery despite past overfishing and stringent conservation measures. Length-weight relationship analysis indicates negative allometric growth, suggesting changes in the body proportions of the species as they mature. Despite this, the population growth rate remains increasing and relatively high. This may indicate optimal environmental conditions and effective conservation measures.

Moreover, the estimation of mortality rates underlines low exploitation of the species studied, suggesting that current fishing efforts are sustainable and not exerting excessive pressure on the population. This implies that the conservation measures implemented for the area have been effective in preserving the fishery resources of Malampaya Sound.

Nevertheless, the balance between fishing activities and conservation efforts should continue to be maintained to ensure the sustainability of not only *S. fimbriata*, but the entire Malampaya Sound. Continued monitoring and adaptive management strategies are needed to respond to changes in population dynamics and environmental conditions.

Overall, this study highlights the importance of interdisciplinary research and collaborative efforts among scientists, policy makers and local stakeholders to promote sustainable fisheries management and marine biodiversity conservation in Malampaya Bay and similar coastal ecosystems. By promoting science-based management strategies and encouraging community participation, it is possible to guarantee the continued prosperity of *S. fimbriata* population and the well-being of coastal communities that rely on these valuable resources.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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