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Population Dynamics of the White-Spotted Spinefoot (*Siganus canaliculatus*, Park 1797) in the Luwu Seas, South Sulawesi, Indonesia

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ABSTRACT

The white-spotted spinefoot (*Siganus canaliculatus*) is a potential demersal fish with a high economic value, and it is widely found in the Luwu Seas, especially in Buntu Matabing Village. The capture uses several types of fishing gear, including gill nets, stake nets, and spears. The white-spotted spinefoot's size structure, age group, growth, mortality, exploitation rate, and Y/R were all examined in this study's population dynamics, followed by the examination of the utilization status of this fish species caught in the Luwu seas. The study was implemented in four months: November – December 2023 and January – February 2024. The stratified random sampling technique was employed for sampling, stratifying the fishing gear used, and the depth and size of the fish. The total sample size reached was 1287 fish, which demonstrated a length range of 10 to 22.8cm TL, along with an average length of 14cm TL. Results of the analysis were collected for one group in the following length ranges: 10 to 22.8cm, $L\infty$ = 35cm, K = 0.28 in relative time, M = 0.77 year^{-1}, F = 2.56 year^{-1}, and Z = 3.33 year^{-1}. A value of E = 0.77 was recorded, which exceeded the optimum exploitation rate value (0.50), indicating an overfishing in the location. The yield recruitment^{-1} (Y/R') value was 0.0134 grams recruitment^{-1}. Due to this, the recruitment process was abnormal caused by over exploitation.

INTRODUCTION

The white-spotted spinefoot belongs to the Siganidae family, which is easy to find in seagrass meadows **(Madduppa, 2019)**. The Siganidae family is widely distributed throughout the tropics and subtropical waters of the western Indo-Pacific region **(Gabr *et al.*, 2018)**. This fish is used for consumption needs, income, and export commodities **(Gili *et al*., 2020)**.

The fish under study is widely used in the economic activities of the coastal communities in the Luwu seas **(Halid *et al.*, 2016)**. This fish is known as a phytoplankton eater **(Paruntu, 2015)**. It prefers different habitats based on its life stage; adult fish prefer seagrass beds with single vegetation, and small fish take advantage of various habitats for growth and self-protection **(Latuconsina *et al.*, 2020)**. Notably, the juveniles of the white-spotted spinefoot have a narrow cruising area and a strong area facilating the ability to return so it can affect the spatial range of adult fish and the role of the ecosystem **(Bellwood *et al*., 2016)**. The great diversity of marine life, which includes the white-spotted spinefoot of the Siganidae family, is sustained by coral reefs **(Nanami, 2018)**. Differences in ecosystems affect the maturation and spawning processes of the fish under investigation **(Huyen *et al.*, 2023)**.

The condition of low-density seagrass has an affect on the white-spotted spinefoot's existence because the seagrass ecosystem and coral reefs are the places where they live. Since they are essential to fish survival, growth, and development, changes in the environment would impact the availability and distribution of food in the natural world **(Indriyani *et al.*, 2020)**. The diversity and abundance of species in the seagrass area are important since seagrass can provide habitat, food, and protection from predators **(Zuhdi *et al.*, 2019)**.

Fishing activities for the white-spotted spinefoot can affect changes in the population structure of resources, potentially seen from the size and number of catches. This, in turn, decreases the quantity of fish present in the waters, and thus management based on biological information is needed to maintain the sustainability of the white-spotted spinefoot population. Eminently, the increase in consumption needs would decrease resource stocks because fishing is carried out without adjusting to the conditions of the water populations.

In recent years, increasing market demand for the white-spotted spinefoot has resulted in the intensification of fishing efforts, which has the potential to threaten the sustainability of its population **(Soliman *et al.*, 2021)**. Fishing is often performed without considering the concept of sustainable management, catching fish that are not yet suitable for catching, therefore it is necessary to ensure the spawning period for adult fish **(Anand & Reddy, 2017)**.

Given its important economic and ecological role, a sustainability evaluation of the utilization status of the white-spotted spinefoot is radical to ensure the sustainability of the resource in the future. While, an adaptive management approach that considers biological, ecological, and socio-economic aspects is the key to maintaining a balance between utilization and conservation **(Teichert *et al.*, 2016)**. Overfishing of the white-spotted spinefoot without proper management policies can result in population decline, and if left unchecked, the population would diminish **(Suwarni *et al.*, 2019)**.

Fishing of the white-spotted spinefoot in the Luwu seas is continuously achieved without the application of rational fishing principles, so it can disturb resource sustainability. In addition, overfishing can be observed, which could result in a decline in the stock of this fish resources. Moreover, this decline may result from employing non-selective fishing equipment, which captures young fish that aren't yet ready to be released and damages the aquatic environment. Based on research by **Halid (2018)**, the catchable size for the white-spotted spinefoot is> 16cm. Apart from that, numerous fisheries management policies are not yet based on the results of adequate scientific studies; certain features of population dynamics like age groups, size structure, growth, mortality, rate of exploitation, and Y/R’ must be considered when formulating policy. The sustainability of the white-spotted spinefoot is closely related to the Sustainable Development Goals (SDGs), particularly:

- SDG 14 (Life below water): Ensuring sustainable use of marine resources by implementing responsible fisheries management to prevent overfishing and habitat destruction.
- SDG 12 (Responsible consumption and production): Encouraging sustainable fishing practices that minimize environmental impact and ensure long-term resource availability.
- SDG 2 (Zero hunger): Supporting food security by maintaining fish stocks that contribute to the nutrition and livelihoods of coastal communities.

To achieve these goals, it is crucial to implement responsible fisheries management, enforce sustainable fishing policies, and conduct further research on population dynamics to maintain the balance between utilization and conservation. Therefore, research on the analysis of the dynamics of the white-spotted spinefoot (*Siganus canaliculatus*) population in the waters of Buntu Matabing Village, Luwu, is essential to support sustainable fisheries management.

MATERIALS AND METHODS

The study period extended for 4 months (November – December 2023 and January – February 2024), during which the waters of Buntu Matabing Village, Luwu were addressed. Fig. (1) provides a map of the study site.

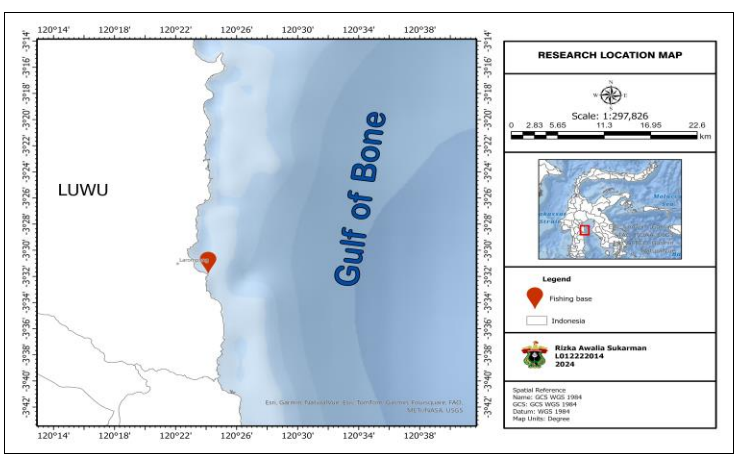

Fig. 1. Research location map

Data collection was conducted three times a week using the census method or total sampling. All the white-spotted spinefoot specimens were measured to obtain accurate data. Based on the information obtained, there are several types of fishing gear used to catch the white-spotted spinefoot, namely stake net, gill net, and spear. After that, the total length of the fish was measured from the tip of the front head to the tip of the outermost tail fin using a ruler with an accuracy of 0.1cm. The white-spotted spinefoot samples were taken directly from the fishermen's catch.

In data collection, stake net fishing gear was used with different levels of depth to represent the sample, as well as the gill net, and spearfishing gear. The white-spotted spinefoot caught by the three types of fishing gear were all measured. Regarding the number of samples obtained, to represent the size structure of individuals that exist in nature in a sample, the number of individuals in the sample or the number of samples were maintained. The total number of samples used during the study was 1287 individuals.

Data analysis methods

1. Size structure and age groups

The white-spotted spinefoot's overall length was used to estimate the fish's size structure. The fish length data obtained was represented in a histogram, namely data arranged into certain classes. The steps for determining class are based on Sturges rules **(Sudjana, 1982)**:

1) Determination of the range between maximum and minimum length sizes.

2) Determine the number of size classes; 1 + (3.3) log N.

In estimating the size structure, the average length ($\bar{L}$), standard deviation (SD), and number of samples (N) were evaluated.

The FAO-ICLARM Stock Assessment Tools (FISAT II) of **Gayanilo *et al.* (2005)** was used to calculate the age groups. The method used in estimating the age group of the white-spotted spinefoot was the length frequency method proposed by **Bhattacharya (1967)** by dividing the fish into several class lengths, employing a certain class interval (dl) via calculating the frequency (f) of each class length formed and the middle of the class (x) to create a graphic image of the age group.

Once the age group formed was known, the length measurement of the fish categories was grouped according to the number of groups identified. This step was followed by the calculation of the average length via separating the aggregate of the multiplied values of length frequencies and class midpoints (∑(fx TK)) through the total frequency (∑f) within each cohort. If the distribution within an age group was not normally distributed, then normalization was carried out by calculating the calculated frequency (Fc) employing the equation of **Sparre *et al.* (1989)**:

$$Fc = \frac{n.dl}{s\sqrt{2\pi}} \exp\left[\frac{-(x-\bar{x})^2}{2S^2}\right]$$

Where:

FC : Calculated frequency or theoretical frequency
n : Number of fish
dl : Class interval
S : Standard deviation
$\bar{X}$: Average length
x : Middle of class
π : 3.14159

2. Growth

A growth model linked to fish length that applies the von Bertalanffy growth equation was used to estimate the growth of the white-spotted spinefoot, as suggested by **Sparre *et al.* (1989)**:

$$Lt = L\infty \ (1 - eK(t\text{-}t_0))$$

Where:
Lt : The length of the fish at the age of t (cm)
$L\infty$: Asymptotic length (cm)
K : Coefficient of growth rate (year^{-1})
t_0 : Estimated age of the fish at its length to zero (year)
t : Age of Fish

After that, t_0 was determined using the following equation assessed in the study of **Pauly (1980)**:

$$\text{Log} \ (-t_0) = -0.3992 - 0.2752 \ (\text{Log} \ L\infty) - 1.038 \ (\text{Log} \ K)$$

Where:
$L\infty$: Asymptote fish's length (cm)
t_0 : Estimated age of the fish at its length to zero (year)
K : Coefficient of growth rate (year)

3. Mortality

3.1. Natural mortality (M)

The estimation of natural mortality was performed by applying the empirical formula by **Pauly (1980)** as follows:

$$M = 0.8 \ x \ \exp \ (-0.0152 - 0.279 \ (\ln L\infty) + 0.6543 \ (\ln K) + 0.4634 \ (\ln T))$$

Where:
M : Natural mortality rate (year^{-1})
$L\infty$: Asymptote fish's length (cm)
K : Coefficient of growth rate (year^{-1})
T : Temperature of the water (°C)

3.2. Total mortality (Z)

The estimation of total mortality was carried out employing FAO-ICLARM Stock Assessment Tools II (FISAT II) **(Gayanilo *et al.*, 2005)**. Then, the asymptote value of the fish length ($L\infty$), the coefficient of growth rate (K), and the estimated age of the fish were plotted in the catch curve when the length was equal to zero (t_0).

3.3. Fishing mortality (F)

Once the estimates for natural mortality (M), and total mortality (Z) were obtained, fishing mortality was estimated employing this mathematical expression:

$$Z = F + M \text{ or } F = Z - M$$

Where:

F : Fishing mortality rate (year^{-1})

M : Natural mortality rate (year^{-1})

Z : Total mortality rate (year^{-1})

4. Rate of exploitation

The rate of exploitation (E) was derived from assessing the fishing mortality rate (F) to the total mortality rate (Z) employing the equation suggested by Beverton and Holt in **Sparre *et al.* (1989)** as follows:

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

Where:

E : Rate of exploitation (year^{-1})

F : Fishing mortality rate (year^{-1})

Z : Total mortality (year^{-1})

5. Yield per recruitment (Y/R')

The relative yield per recruitment of the fish under investigation was done by employing the equation proposed by Beverton and Holt in **Sparre *et al.* (1989)** as follows:

$$Y/R' = E.U^{M/K}\left[1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} - \frac{U^3}{1+3m}\right]$$

Where:

U : $1 - \frac{L'}{L_\infty}$

m : $\frac{1-E}{M/K}$

E : Exploitation rate (year^{-1})

M : Natural mortality (year^{-1})
K : Coefficient of growth rate (year^{-1})
L' : Smallest fish's length caught (cm)
L∞ : Asymptote fish's length (cm)

RESULTS

1. Size structure and age groups

Using set net fishing gear, gill nets, and spears, 1287 individuals of the white-spotted spinefoot were caught. The fish ranged in length from 10 to 23cm overall, using a mean length of 14cm and a standard deviation of 2.06, and the majority of the catch was between 13 & 14cm in size. Fig. (2) shows the size structure of the white-spotted spinefoot, harvested in the seas of Luwu with spears, gill nets, and set net fishing gear.

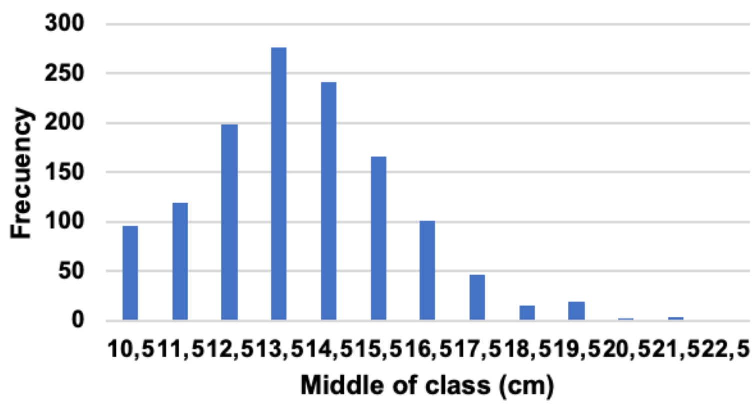

Fig. 2. Size structure of fish caught by stake nets, gill nets, and spears in the Luwu seas

Only one age group (Fig. 3) was identified upon examining the white-spotted spinefoot age group in Luwu waters, employing the Bhattacharya approach in the FISAT II program.

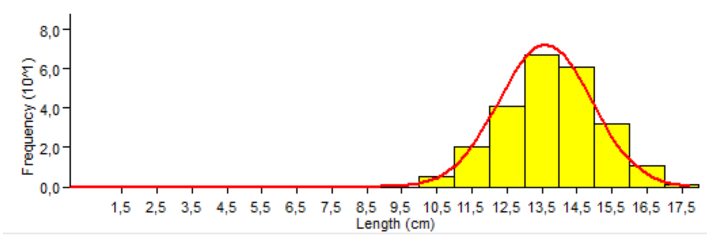

Fig. 3. White-spotted spinefoot age groups in the Luwu seas

Based on cohort analysis, one age group was obtained which had a length range of 10 – 23cm with L' = 14cm, standard deviation (SD) = 2.06, and a population of 8421.44 individuals.

Fig. (4) shows the difference between the class mean value and the natural logarithm of theoretical frequency for the age group of the white-spotted spinefoot captured in the Luwu seas.

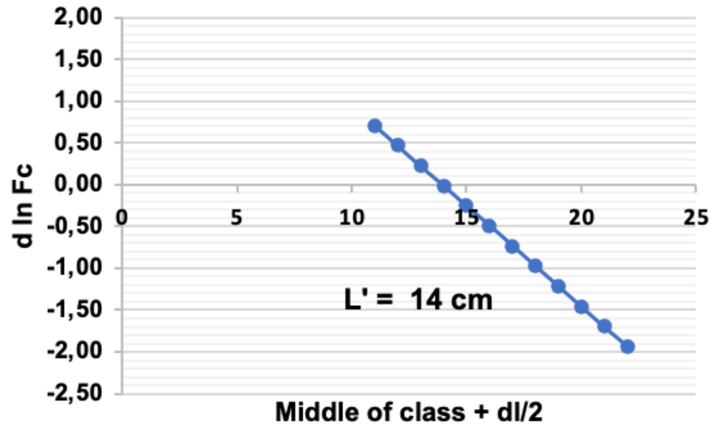

Fig. 4. The discrepancy between the class mean value as well as the estimated frequency in the age group (cohort) natural logarithm of the white-spotted spinefoot collected in the waterways of Luwu, as mapped

2. Growth

The values of asymptote length ($L\infty$) = 35cm, coefficient of growth rate (K) = 0.28 year^{-1}, and the estimated age of the fish (t_0) = -1.7510 years are derived from the analysis of growth characteristics that was conducted. Fig. (5) shows the white-spotted spinefoot's growth curve.

Fig. 5. The White-spotted spinefoot's growth curve

3. Mortality and exploitation rate

The values obtained for natural mortality (M) = 0.77 year^{-1}, fishing mortality (F) = 2.56 year^{-1}, and total mortality (Z) = 3.33 year^{-1} are based on the analysis of mortality estimates and exploitation rates that have been conducted. The White-spotted spinefoot in the Luwu seas may be over-exploited, as suggested by the exploitation rate (E) value of

0.77 that was obtained. Fig. (6) shows the white-spotted spinefoot's mortality and exploitation rate.

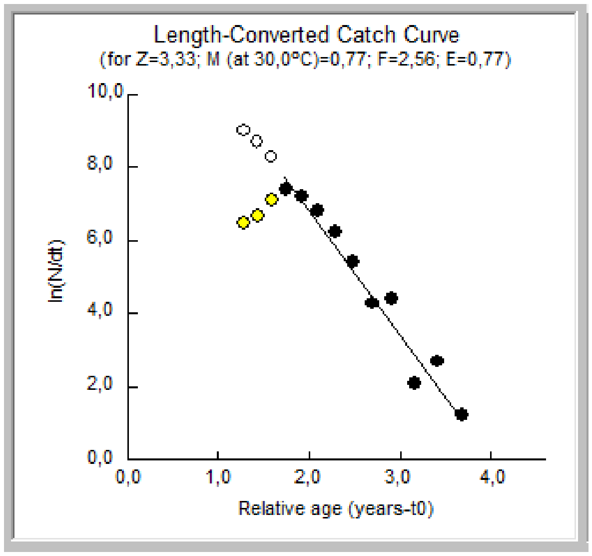

Fig. 6. Mortality and Exploitation rate curve

4. Yield per recruitment (Y/R')

Fig. (6) shows the White-spotted spinefoot's rate of exploitation in the waterways of Luwu.

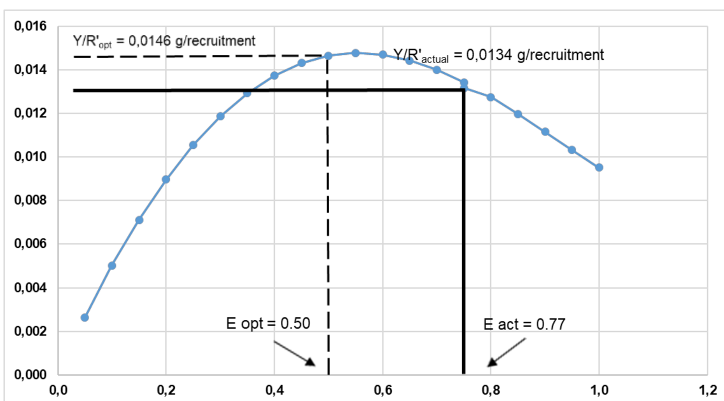

Fig. 7. Curve yield per recruitment

The exploitation rate value (E) = 0.77, as shown in Fig. (7), indicates that the White-spotted spinefoot stock provides the maximum catch recruitment at an exploitation rate of 77%. The maximum Y/R' value of this species in the Luwu seas is 0.0134 grams recruitment^{-1}. The optimum Y/R' value is 0.0146 grams recruitment^{-1} with the exploitation rate value (E) = 0.50. This shows that at a 50% exploitation rate, fish stocks provide optimal results viewed from the perspective of long-term sustainability and productivity.

DISCUSSION

1. Size structure and age groups

The white-spotted spinefoot was caught over the course of four months, from November to December 2023 and January to February 2024, in the Luwu seas, especially in Buntu Matabing Village. A total of 1287 fish were sampled during this time. In these waters, stake nets, gill nets, and spears are the three types of fishing gear used for catching the white-spotted spinefoot. The length range of the examined fish in other waters can be seen in Table (1).

Table 1. Length range of the white-spotted spinefoot in other waters

Research location	Smallest length	Largest length	Average length	Reference
Karang-karangan, Luwu	5,7 cm	20,7 cm	13,9 cm	**Halid *et al*., 2016.**
Buntal Island, Kotania Bay, Maluku	14,4 cm	16,7 cm	15,81 cm	**Latuconsina *et al*., 2020.**
Pengudang	11 cm	17,9 cm	13,51 cm	**Jemi *et al*., 2022**
Bakau Bay	11,8 cm	17,8 cm	14,28 cm	**Jemi *et al*., 2022**
Dompak	12 cm	17,9 cm	13,81 cm	**Jemi *et al*., 2022**
Pengujan	12 cm	15,90 cm	13,20 cm	**Jemi *et al*., 2022**
Buntu Matabing, Luwu	10 cm	22,8 cm	14,16 cm	This research

Based on data displayed in Table (1), it can be seen that the difference in size compared to previous studies is due to different research locations and the use of different fishing gear. According to **Dahlan *et al*. (2015)**, growth patterns, migration and the addition of new fish species to a population can cause differences in the number of sizes in populations in waters. Differences in environmental conditions can affect fish growth, such as water temperature, habitat, and food availability **(Rypel, 2022)**. Higher populations take longer to reach sexual maturity and maximum size because they have a shorter reproductive period and slower growth rates **(Zarco-Perello *et al*., 2022)**. The age group of the white-spotted spinefoot is shown in Table (2).

Table 2. The age group of the white-spotted spinefoot in various localities

Research location	Age group	Reference
Karang-karangan, Luwu	5 cohort	**Halid *et al*., 2016**
Makassar strait	6 cohort	**Suwarni, 2020**
Flores Sea	8 cohort	**Suwarni, 2020**
Bone Bay	5 cohort	**Suwarni, 2020**
Buntu Matabing, Luwu	1 cohort	This research

Fish age group differences between places may be attributed to several factors, including local environmental factors, food availability, fishing pressure, and population growth characteristics. These variations may have an effect on fish survival and growth, which may affect the population's age distribution. Furthermore, the age distribution of fish populations can be impacted by varying fishing intensities at different sites, and overfishing can lead to a decline in the proportion of older age groups **(Robinson *et al*., 2022)**.

2. Growth

The L∞ value of 35 indicates the maximum length that can theoretically be achieved by thewhite-spotted spinefoot in this population. The length of this asymptote provides an idea of the maximum growth potential of fish in their natural habitat. The Coefficient of growth rate (K) of 0.28 year^{-1} indicates that the white-spotted spinefoot in Luwu waters grows at a moderate rate. The relatively moderate K value reflects that the fish needs sufficient time to reach its maximum size. When the fish's length reaches zero, its estimated age is displayed by the t_0 value of -1.7510 years.

Based on the curve, it is potentially seen that in the initial phase, the growth of the fish is very fast, according to the shape of the curve which rises sharply in the initial stage. Whereas, in the middle growth phase, growth begins to slow down as the fish ages. The growth curve begins to flatten in this phase. The succeeding growth phase reaches a maximum point approaching the L∞ value. At this point, the fish has almost reached its maximum length, and the growth rate slows considerably. The growth of the white-spotted spinefoot in other waters is exhibited in Table (3).

Table 3. The growth of the white-spotted spinefoot at various sites

Research location	L∞ (cm)	K ($year^{-1}$)	t_0 (years)	Reference
Karang-karangan, Bone Bay, Luwu	30,58	0,15	-1,4815	**Halid *et al*., 2016**
Panguil Bay, Filipina	33,20	0,54	-	**Gonzaga, 2020**
Makassar strait	59,1	1,52	-0,448	**Suwarni, 2020**
Flores Sea	51,4	1,51	-0,347	**Suwarni, 2020**
Bone Bay	42,6	0,85	-0,636	**Suwarni, 2020.**
Buntu Matabing, Luwu	35	0,28	-1,7510	This research

Based on the information in Table (3), Panguil Bay, Makassar Strait, Flores Sea, and Bone Bay have high growth rate coefficient (K) values and require a short time to reach their asymptotic length. Karang-Karangan and Buntu Matabing have low growth rate coefficient (K) values and require a long time to reach their asymptotic length.

Dahlan *et al.* (2015) stated that variations in the quantity of fish in a population can be caused by the pattern of growth, migration, and the introduction of new species. The existence of different environmental conditions can affect fish growth, such as water temperature, habitat, and food availability **(Rypel, 2022)**. Higher latitude populations take longer to reach sexual maturation and maximum size because they have shorter reproductive periods and slower growth rates **(Zarco-Perello *et al.*, 2022)**.

3. Mortality and exploitation rates

The mortality and exploitation rates of the white-spotted spinefoot in other waters are presented in Table (4).

Table 4. Mortality and exploitation rates of the white-spotted spinefoot in other waters

Research location	M ($year^{-1}$)	F ($year^{-1}$)	Z ($year^{-1}$)	E	Reference
Karang-karangan, Bone Bay, Luwu	0,6109	1,0804	1,6913	0,6388	**Halid *et al*., 2016**
Panguil Bay, Filipina	1,18	2,62	3,80	0,69	**Gonzaga, 2020**
Buntu Matabing, Luwu	0,77	2,56	3,33	0,77	This research

The higher total mortality value (Z) obtained, the greater the mortality rate due to fishing (F) of the white-spotted spinefoot **(Gonzaga, 2020)**. The ideal exploitation rate is attained if this amount equals 0.50 $year^{-1}$, as determined by the optimum rate notion established by **Gulland (1969)** and **Pauly (1984)**. The amount of fish harvested from fishing operations in a given year is known as mortality **(Bousseba *et al.*, 2021)**. High total mortality values (Z) and catch rates (F) can lead to high rates of exploitation **(Mallawa & Amir, 2019)**.

4. Yield per recruitment (Y/R')

Yield per recruitment of the white-spotted spinefoot in other waters is exhibited in Table (5).

Table 5. Yield per recruitment of the white-spotted spinefoot in other waters

Research location	Y/R' actual (g/*recruitment*)	Y/R' optimum (g/*recruitment*)	Reference
Karang-karangan, Bone Bay, Luwu	0,0127	0,0138	**Halid *et al*., 2016**
Buntu Matabing, Luwu	0,0134	0,0146	This research

Analysis of yield per recruitment (Y/R') of the white-spotted spinefoot using the FISAT II program

The correlation between exploitation rate and yield per recruitment is potentially utilized as a guide to inquire whether the exploitation rate is at an optimal level, not yet optimal, or over-exploited compared to the ability of the fish population to recruit. From the results of the analysis that has been carried out, there has been excessive fishing (over-exploitation) in the waters of Buntu Matabing Village, Luwu.

Yield per recruitment (Y/R') is the anticipated outcome of fish added to the population at a specific age. Fisheries managers may utilize the recruitment outcome model, adapted from the **Beverton and Holt**'s **(1957)** method, as a predictive model to help them understand the biological or economic effects of fishing in these stocks and help them take the necessary steps to ensure the sustainability of fishery products **(Ganga, 2017)**.

Environmental factors play a major role in recruitment success; the number of larvae produced during spawning is not as important as the impact made by the larvae after they reach the nursery region. Accordingly, environmental criteria must provide support to more precisely estimating recruiting results based on natural conditions **(Suwarni, 2020)**.

CONCLUSION

The findings of studies on the population dynamics of the white-spotted spinefoot in the Luwu seas suggest that the species' captures are limited to a single age group (cohort) and that their slow growth rate makes it difficult for them to reach full length. The indication is that compared to natural mortality, fishing mortality is substantially higher, the rate of exploitation is more than the optimal rate and the recruitment process is abnormal.

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