Population Structure of Vermiculated Spinefoot (*Siganusvermiculatus* Valenciennes, 1835) inthe waters of Makassar Strait, Indonesia

ABSTRACT

Intensive exploitation of vermiculated spinefoot in the Makassar Strait suggests a potential shift in population dynamics. This study aims to examine various biological aspects of the species, such as size distribution, growth patterns, condition factors, sex ratio, gonad maturity, and the size at first gonad maturity. Conducted through a survey method in the waters of the Makassar Strait, the research utilized tickle net fishing gear continuously operated in the area. Findings revealed that male fish had an average length distribution of 18.3 ± 0.325 cm, while female fish measured 19.8 ± 0.496 cm. Both genders exhibited negative allometric growth patterns. The condition factor was 0.999 ± 0.004 for males and 1.001 ± 0.005 for females. The sex ratio appeared unbalanced, with gonad maturity stages ranging from immature to spawning. The size at which males first matured gonads was 21.587 cm, while for females, it was 19.229 cm, indicating faster gonad maturation in females. To ensure sustainability, fishing efforts should target individuals above the size at which gonads first mature.

Key words: Biological aspects; vermiculated spinefoot; population; Makassar Strait

1. INTRODUCTION

The Makassar Strait, encompassed within the Republic of Indonesia Fisheries Management Area (WPPRI) 713, along with adjacent regions like the Flores Sea, Bali Sea, and Bone Bay, serves as a pivotal hub for fisheries in Central and Eastern Indonesia. It boasts a rich diversity of aquatic resources, including small pelagic fish, large pelagic fish, various demersal fish, and reef fish.

Demersal fish that live in coral include rabbitfish of all types. Rabbitfish are included in the Siganidae family with a diversity of species spread across various water areas in Indonesia. Fish from this family consist of one genus, namely *Siganus*, of which there are 12 types in Indonesia. All types of rabbitfish have quite high economic value [11].Fish from this family use the seagrass ecosystem as a nursery, spawning area and place to find food. This rabbitfish is distributed in almost all shallow waters and corals. However, [24]revealed that there are also rabbitfish that are not directly associated with coral, but whose movements are associated with the special structure of the coral.

In the waters of the Makassar Strait, fishermen frequently encounter several rabbitfish species, including the white spotted spinefoot (Siganuscanaliculatus), streaked spinefoot (Siganusjavus), orange-spotted spinefoot (Siganusguttatus), and vermiculated spinefoot (Siganusvermiculatus).One of the four types of rabbitfish that is still intensively caught by the public is the vermiculated spinefoot (*Siganusvermiculatus*). This fish lives by associating with seagrass beds like other rabbitfish. Several studies conducted by [19] and [15]reported that seagrass beds were used as a place for rearing, foraging and protection.

It is feared that the fairly intensive vermiculated spinefoot fishing activity by fishermen in the Makassar Strait could threaten the availability of this rabbitfish resource as a result of the lack of supervision. The lack of supervision of vermiculated spinefoot utilization activities causes the vermiculated spinefoot population to experience pressure, which can lead to changes in the population and a decrease in potential in nature. This change and decrease in potential is a concern that has an impact on changes in resources both individually and in populations. These changes will affect biological and reproductive activities, which are one of the fish's strategies for maintaining continuity in their lives. In this regard, this research was carried out with the aim of analyzing the population structure of vermiculated spinefoot from a biological aspect, such as size distribution, growth patterns, condition factors, sex ratio, gonad maturity and size of the first gonad maturity.

2.MATERIALS AND METHODS

2.1 Location and Time of Research

This research was carried out from February to April 2022. The fish sampled in this research were caught in the waters of Sabangko (4°42'21.084"S,119°28'24.469"E), Salemo (4°41'21.205"S 119°28'7.988"E), Sagara (4°41'56.840"S,119°27'21.288"E), Bangko-Bangkoang (4°46'20.777"S, 119°26'8.742"E) and Laiya Islands (4°49'13.126"S, 119°25'12.289"E) in the Makassar Strait (Figure 1). The caught fish are then measured and observed at the fish landing site..

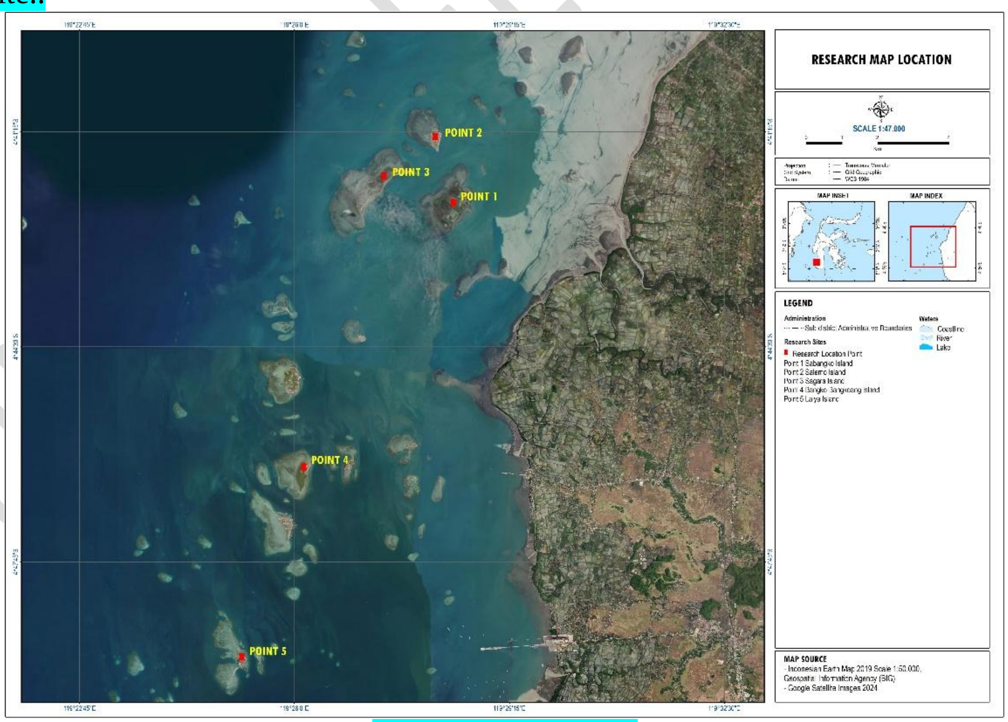

Fig 1. Research sites

2.2 Sampling Techniques

2.2.1 Alat tangkap dan jumlahsampel

The fishing gear used in this research was a trammel net which was operated on the bottom of the waters. A total of 306 fish were measured and observed, consisting of 194 males and 112 females for the entire fishing ground.

2.2.2Measurement and weighing of samples

The length of the fish measured was the fork length using digital calipers with an accuracy of 0.5 cm, while the weight measured was the total weight of the fish using a digital hanging scale with an accuracy of 0.01 g. Selection of fork length with consideration of this size will also be used in determining the size distribution and size of the first gonad maturity.

2.2.3.Gonad maturity

Observations of fish gonad maturity were carried out on males and females in all samples that were measured and weighed, then the gonad maturity was observed according to the stage of development, which refers to [6] and [1]. The samples measured were all caught by fishermen from the specified research location. The stages of gonad maturity are separated to obtain immature gonad conditions (gonad maturity level I and II), mature gonads (gonad maturity level III and IV) and spawning gonad maturity level V.

2.2.4. Sample measurements and observations

Measurements and observations are carried out twice a week and are adjusted to the fishermen's fishing conditions.

2.3 Data Analysis

2.3.1.Size distribution

Size distribution is the frequency distribution of sizes in a certain length group. The frequency distribution of lengths is obtained by determining the class interval, class mean value and frequency in each length group. Size distribution is not separated based on observation area but based on gender

2.3.2Growth

Growth is obtained from the regression relationship between fork length and fish weight. The data is not separated based on the area where the fish are caught considering that they are in the same waters and are close to each other with relatively almost the same water characteristics, namely the waters of the Makassar Strait.

2.3.3.Condition factors

The condition factor of the fish is determined using the relative condition factor because the growth pattern of the fish is negatively allommetric, i.e

$$Kn = \frac{W}{aL^b}$$

Where:

Kn= Condition factor in total weight (g)

L = average length of fish (cm)

W = weight of fish from weighing

a and b = Constant

2.3.4.Sex Ratio

Sex ratio is the ratio of male and female fish in a population. Determination of the sex ratio is carried out by comparing the number of male and female fish caught and the data obtained is separated based on the fishing area with the consideration of testing the balance. The sex ratio is calculated using the formula:. The sex ratio is calculated using a formula:

$$X = \frac{J}{B}$$

Where:

X: Sex ratio

J: Male fish

B : Female fish

Next, to see whether the number of male and female fish is balanced, a test was carried out using the chi-square test (X^2), with the formula:

$$x^2 = \sum_{i=1} (\frac{O_{i-E_i}}{E_i}$$

Where:

X^2= Chi square value

Oi = observation value (observation)

Ei = expectation value (hope)

2.3.5. Size of the first time the gonads mature

According to [25], gonad maturity stages three and four are categorized as fish that have mature gonads so that the calculation of the size of the first gonad maturity begins at gonad maturity three and four. The samples used in the calculations were vermiculated spinefoot that had immature gonads and mature gonads, namely male and female. The size of the first mature gonads of vermiculated spinefoot fish was analyzed using the Spearman Karber method [32] with the formula:

$$\log m = X_K + \frac{X}{2} - (X \times \sum pi)$$

at the 95% confidence interval the formula is used:

$$anti \log m = (m \pm 1{,}96 \sqrt{x^2 \times \frac{p_{i\times}q_i}{n_1 - 1}})$$

Where:

Log m = logarithm of fish length at first gonad maturity

Xk = logarithm of the middle value when the fish is 100% gonad mature

X = logarithm of the increase in length to the middle value

pi = number of gonad mature fish in length class 1; qi= 1-pi

ni = number of fish in the 1st length class

m = the length of the fish when the gonads first mature to the antilog m

3. RESULTS AND DISCUSSION

Biological aspects of vermiculated spinefoot observed during the research consisted of size distribution, growth patterns and condition factors, sex ratio, gonad maturity stages and size of the first gonad maturity, as described below.

3.1 Size distribution

Distribution of vermiculated spinefoot fork length for males ranges from 9.0 to 32.4 cm (18.3 ± 0.325 cm) (Figure 2 left) and females ranges from 9.7 to 32.3 cm (19.8 ± 0.496 cm) (Figure 2right). Figure 2 shows that the largest size of male vermiculated spinefoot caught was in the middle 16.5 cm class, as many as 58 individuals (29.90%) and the lowest was in the middle 31.5 cm class, as many as two individuals (1.03%). Meanwhile, the highest fork length of female vermiculated spinefoot was obtained in the 20.2 cm class, with 29 individuals (25.89%) and the lowest in the middle class, 32.3 cm, with four individuals (3.57%).

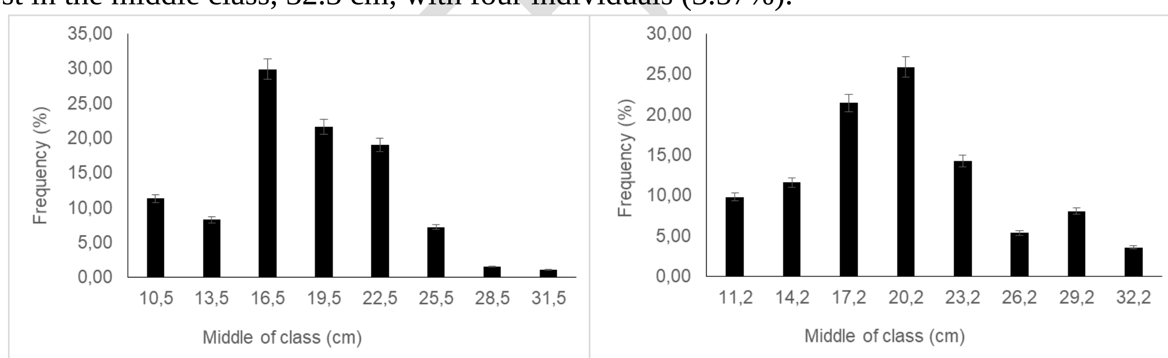

Fig 2. Distribution of fork lengths of male (left) and female (right) vermiculated spinefoot during the study.

Based on the information in Figure 2, the size of the dominant vermiculated spinefoot caught is larger in females than in males. This indicates that female fish come to the fishing area for the purpose of looking for food in order to meet energy intake for the reproductive maturation process. In this research, it is suspected that the spawning season is currently underway, which is marked by the discovery of fish that have already spawned.

There is still little information about vermiculated spinefoot research results that have been reported and can be accessed, so comparative data is taken from fish of the same family or species. [27] found the size of vermiculated spinefoot (*Siganusvermiculatus*) ranging from 29-34 cm. streaked spinefoot (*Siganusjavus*) ranges from 14-19 cm. The results of research [31], obtained the length of large male white spotted spinefoot(*Siganuscanaliculatus*) ranging in size from 178-200 mm and small ones ranging from 131-154 mm, while samples of large female rabbitfish ranged from 207-226 mm and small-sized samples ranged from 127 mm. -146mm.

The size distribution of vermiculated spinefoot in this study ranged from 9.0 to 32.4 cm, wider than the results of research [27] ranging from 29 to 34 cm. This wide size distribution is thought to be related to fishing technology, fishing methods, and fishing pressure. The fishing technology associated with the clitic net fishing gear used has three layers of mesh with small, medium and large sizes. The smallest mesh size used by the community has been adjusted to [17] that the mesh size is over 1.5 inches with a net length of under 500 m (P < 500 m), using motor boats under sized (< 10 GT). Fishermen use clitic nets measuring 2 inches, 4 inches and 5 inches or 5 cm, 10 cm and 12.5 cm. This condition causes the vermiculated spinefoot caught to be medium to large in size.

Meanwhile, the weight distribution of vermiculated spinefoot for males ranged from 98.56 to 233.40 g (160, 267 ± 2,291 g). The highest weight of male vermiculated spinefoot was obtained in the middle class of 154 g with 47 fish (24.23%) and the lowest in the middle class of 234.6 g with two fish (1.03%) (Figure 3 left). The caught female vermiculated spinefoot weighed around 113.50-257.00 g (169,457 ± 3,320 g) with the highest number obtained in the middle class 140.5 g with 25 fish (22.32%) and the lowest in the middle class 230.5 g as many as four individuals (3.57%) (Figure 3right)

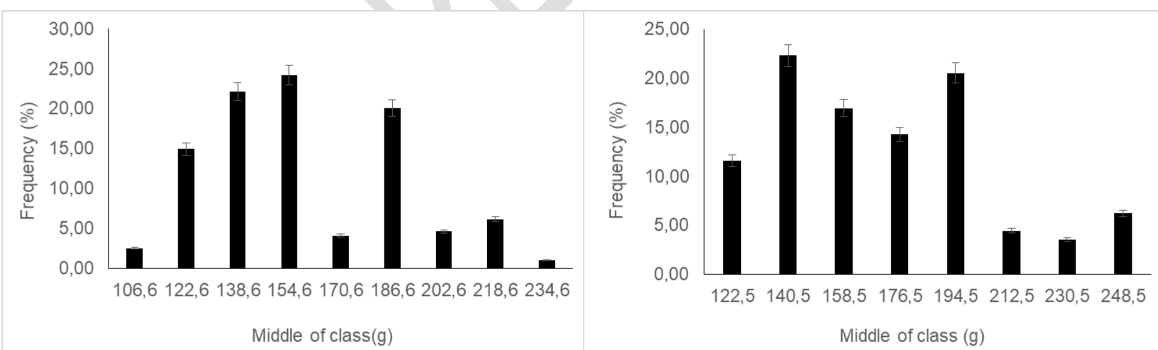

Figure 3. Distribution of weight measurements of male (left) and female vermiculated spinefoot (right) during the study

These results show that female vermiculated spinefoot have a larger average catch weight compared to male vermiculated spinefoot. This is thought to be related to the reproductive season. On the other hand, it is thought to be related to the time of fishing, installation of fishing gear, tidal conditions and current strength when installing the gear. However, increasing fishing effort is thought to cause fishing pressure [16], causing a decrease in the size of the fish caught and the fish will migrate to other areas in search of a supportive environment.

[13] and [14] revealed that the size distribution of aquatic resources caught by fishing gear can be influenced by fishing methods which are related to differences in fishing time, feeding time of aquatic resources, type of bait and the depth of operation of the fishing gear. [16] believes that the biological nature of aquatic resources is that they tend to flock together with the same size and the same type so that when caught they are similar in size.

3.2 Growth Patterns

The growth pattern of male vermiculated spinefoot analyzed using the simple regression method showed that the coefficient of determination (R2) was 92.12% and for females it was 94.41%. The determination value (R2) is a coefficient that explains the ability of the independent variable (X) to explain the dependent variable (Y), so that it can be determined whether individuals in the population can predict their body weight by knowing their body length. The results of the analysis of the relationship between fork length (L) and weight of vermiculated spinefoot (W) after substitution into the equation obtained W=18.816L0.7381 (Figure 4) for male vermiculated spinefoot and W=18.828L0.7371 (Figure 4 left) for female vermiculated spinefoot (Figure 4 right).

The equation of the relationship between fork length and weight of the vermiculated spinefoot means that with the b coefficient values all being below three, it indicates a minor allometric or negative allometric growth pattern. This negative allometric growth pattern means that the increase in length of vermiculated spinefoot is faster than the increase in body weight.

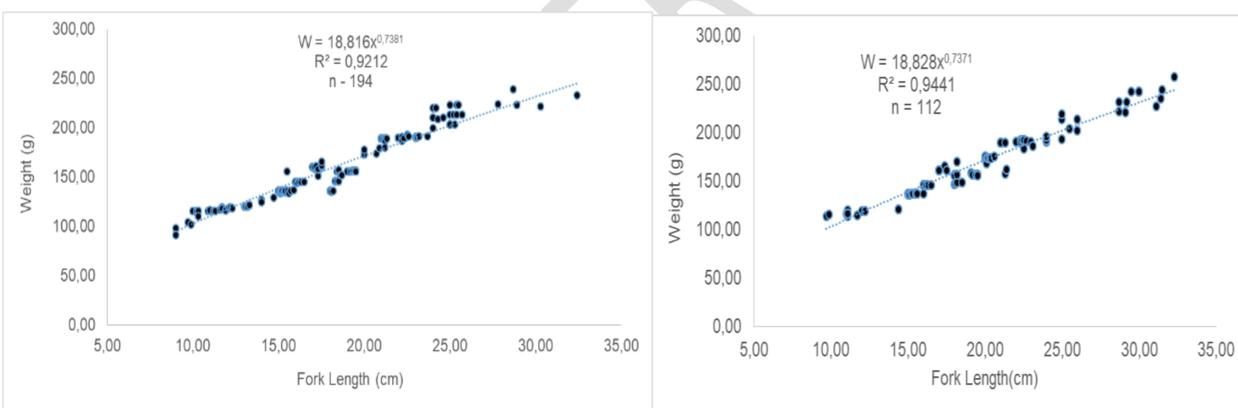

Figure 4. Relationship between length and weight of male (left) and female (right) vermiculated spinefoot during the study.

The growth pattern of male and female vermiculated spinefoot (*S. vermiculatus*) in the waters of Arakan Village is isometric with values of r = 0.910 and R2 = 84.46% for male individuals and r = 0.883 and R2 = 78.07% for female individuals [30]. In this study, a minor or negative or different allometric growth pattern was obtained compared to previous studies that have been reported. This difference is thought to be due to differences in the age of the fish, the rabbitfish is in its growth period so energy is used to increase weight rather than increase length. Apart from that, it is suspected that the fish sampled have finished spawning. When the gonads have entered the mature stage, the body weight will exceed the normal weight.

A coefficient b value below three is classified as having a negative allometric growth pattern or the vermiculated spinefoot length growth is faster than its body weight growth, this indicates a rather thin body condition. This condition is caused by limited food availability and variations in body size of vermiculated spinefoot which indirectly contribute to fish length and weight. [9] suggested that the length-weight relationship of aquatic biota can vary between habitat, size range, growth, sex, reproductive phase and season. [10] reported that the weight and size of food contained in the digestive tract, the age of the biota and the environmental conditions in which they live can influence the body condition of aquatic biota.

The growth pattern of vermiculated spinefoot is not different for males and females, it is suspected that in the fishing area there is high fishing pressure. Fishing pressure causes damage to the ecosystem, thereby reducing the environmental carrying capacity, growth and reproduction of fish. Limited environmental carrying capacity can cause competition between fish to obtain food, and perhaps even competition with other aquatic resources. [8] revealed that high food supply and predator density can contribute to the weight of aquatic resource individuals. Sufficient food supplies can contribute to the growth of aquatic resources. However, an adequate food supply can also attract predators. The presence of this predator can cause inconvenience for other aquatic resources in obtaining food and is thought to influence the weight of individuals in the population. [28] reported that continued fishing pressure on resources has the potential to reduce the quality of the catch.

3.3 Condition Factors

The condition factor is a value that indicates the fatness/plumpness of the vermiculated spinefoot obtained during the research. The condition factor value for male vermiculated spinefoot ranged from 0.85 to 1.12 (0.999 ± 0.004) and for females ranged from 0.88 to 1.13 (1.001 ± 0.005) (Table 1)

Table 1 Condition factors for vermiculated spinefoot based on gender

	Male fish			Female Fish		
	L (cm)	W (g)	K	L (cm)	W (g)	K
Min	9.00	98.56	0.850	9.70	113.50	0.880
Max	32.4	233.40	1.120	32.30	257.00	1.130
Average	18.30	160.27	0.999	19.80	169.46	1.001
SE	0.325	2.291	0.004	0.496	3.320	0.005

Note: L = Fork length; W = fish weight; K = condition factor

The growth of an organism is closely related to condition factors, namely fat accumulation and gonad development. Good growth will be accompanied by an increase in condition factors. Condition factors indirectly provide an overview of the physiological condition of an organism which is influenced by intrinsic factors (fat reserves and gonad development) and extrinsic factors (environmental pressure and availability of food resources) [23].

The condition factor value of female vermiculated spinefoot tends to be wider than that of males so they are fatter. Similar things have been reported by [20] revealing that condition factors are closely related to growth, and growth depends on the supply of energy obtained from food. The ability and method of obtaining food will contribute to the condition of aquatic biota. [21] revealed that supportive aquatic environmental conditions will provide opportunities for fish to grow.

3.4 Sex Ratio

There were 306 vermiculated spinefoot measured during the research, consisting of 194 males and 112 females. The sex ratio of vermiculated spinefoot obtained during the research was 1.73 : 1.00 (63.40 : 36.60%). After conducting a non-parametric test using Chi Square, the result was that X^2 calculated (2.957) < X^2 table (5.990), which means that there is no difference in the sex ratio based on the fishing ground.However, this shows that the number of male vermiculated spinefoot caught is more dominant than the female ones. The difference in the sex ratio of the vermiculated spinefoot is thought to be related to the behavioral patterns of the fish species for spawning and foraging. [29] reported the results of research on population biology and reproduction of the orange-spotted spinefoot (*Siganusguttatus*) which showed that the male to female sex ratio was 3.12 : 1.00. Meanwhile [34] reported the results of a comparison of female and male orange-spotted spinefoot (*Siganusguttatus* Bloch, 1787) in an unbalanced condition, namely 64 (30.47%) females and 146 (69.52%) males or 1.0 : 2, 2.

[4] revealed that the imbalance in the sex ratio between male and female fish can be caused by differences in behavior patterns, growth and mortality rates. Male fish tend to gather with other types of fish, while female fish gather with their own group of female fish. Likewise with the fishing factor, fishermen tend to catch fish that live in groups.

The sex ratio is a reproductive parameter to determine the possibility of the availability of male and female parents for which spawning is expected to occur. According to [6] the sex ratio can indicate excessive exploitation of one sex or an indication of environmental changes. Unbalanced sex ratios can occur due to random chance, selective mortality, and harvesting of particular sexes. [14] reported that sex ratio is one of the variables to see the balance between male and female sex. Balance reflects a higher chance of survival because when female spawning occurs more quickly. If the population is in balance, the opportunity (probability) of fertilization is greater.

3.5 Gonad Maturity Stage

The distribution of gonad maturity stage of vermiculated spinefoot obtained starting from gonad maturity stages IV or from immature to the spawning stage. The results of observations of the gonad maturity stages of vermiculated spinefoot obtained during the research from gonad maturity stage I to IV were 306 fish with a distribution of 194 male fish and 112 female fish (Figure 5).

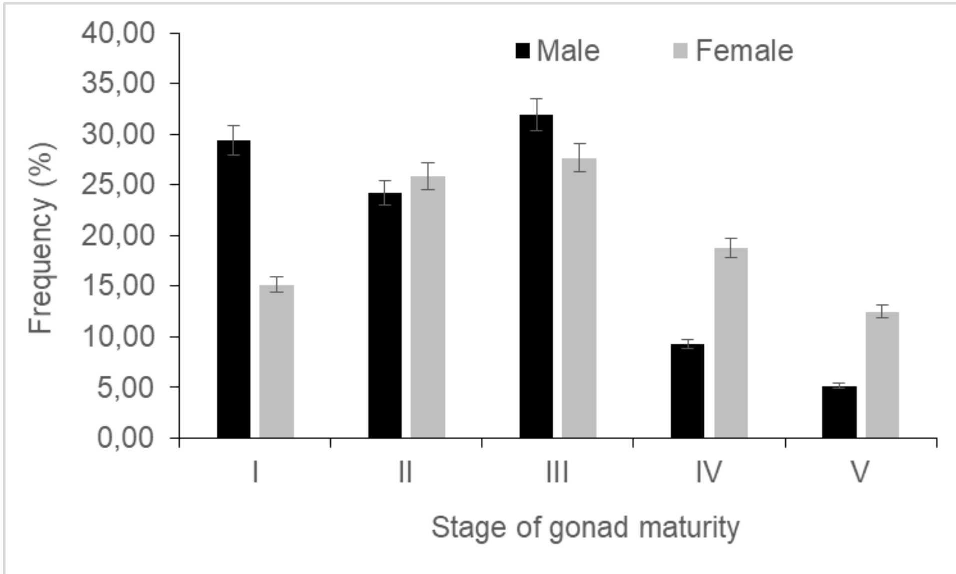

Fig5. Distribution of vermiculated spinefoot gonad maturity stage based on gender during the study.

Figure 5 shows the condition of immature gonads (I and II), mature conditions (III and IV) and spawning (V). The immature condition of the male vermiculated spinefoot is 53.61% and the female is 41.07%, while the mature condition of the gonads for the male vermiculated spinefoot is 41.24% and the female is 46.33%, while the male vermiculated spinefoot has spawned. amounting to 5.15% and females 12.50%. Overall, vermiculated spinefoot caught were dominated by immature fish of 150 (49.02%), mature gonads of 132 (43.14%) and 24 of them that had spawned (7.84%).

This shows that the vermiculated spinefoot is thought to have entered the spawning season. The vermiculated spinefoot is a schooling fish of relatively the same size which is characterized by almost the same stages of gonad maturity. This clustered condition is thought to be a weakness for these fish, making them easier to catch in certain situations for both males and females. The high proportion of vermiculated spinefoot that have immature gonads is due to fishing technology and the characteristics of the fish which have limited migration ability. This limited migration means that this fish is very easy to catch in certain locations, ranging from small or large sizes or from immature gonads to spawning.

The distribution of gonad maturity of the vermiculated spinefoot, which was dominated by the immature gonad stage in this study, was also similar to the research results of the rabbitfish [19]. This shows that the time the research was conducted was not the season for gonad maturation and spawning. Meanwhile, in this research on vermiculated spinefoot. The results of previous research related to the reproduction of rabbitfish by [19] found that the gonad maturity stage of white spotted spinefoot (*Siganuscanaliculatus* Park, 1797) in the waters of Buntal Island, Kotani Bay, West Seram, Maluku was dominated by gonad immature fish, both male and female. On the other hand, [26] found that the rabbitfish *Siganuslineatus* in a mature condition had more dominant gonads. Differences in variations in gonad maturity stage are caused by the representativeness of the samples obtained, fishing gear, time of capture, and research location.

3.6 Size of Gonads First Mature

The size of the first mature gonads of male vermiculated spinefoot obtained in this study was 21.587 cm in the range of 20.664 – 22.551 cm. Meanwhile, female vermiculated spinefoot measure 19.229 cm in the range of 18.550-19.933 cm. This shows that female rabbitfish mature more quickly in their gonads. This is thought to be a reproductive strategy in the face of fishing pressure to maintain its sustainability.

The size of the first mature gonads of female orange-spotted spinefoot (*Siganusguttatus* Bloch, 1787) was found at 15.3 cm and male fish at 18.1 cm [34]. [18] obtained data on the size of the first mature gonads of the *Siganuscanaliculatus* at a size of 17.4 cm for females and 18.7 cm for males. [26] The size of first mature gonad of rabbitfish (*Siganuslineatus*) was 237.03 mm while white spotted spinefoot (*Siganuscanaliculatus*) was 180.97 mm. [3] obtained mature *Siganuscanaliculatus* gonads in the length range of 13.2-22.6 cm for males and 13.9-23.9 cm for females. According to [19] found the size of the first mature gonads of white spotted spinefoot (*Siganuscanaliculatus*) at 14.9 cm with a 95% confidence interval ranging from 14.5 -15.5 cm for females, while male gonads mature at 18.9 cm in 95% confidence interval ranged from 18.7 to 19.1 cm.

[29] reported that the size of first mature gonad of male *Siganuscanaliculatus* caught in the Makassar Strait was 252.09 mm, and female fish was 166.67 mm. Meanwhile, those caught in the Flores Sea were found to have the sie of first mature gonad for male fish of 240.60 mm and 227.13 mm for females, while in Bone Bay it was 179.19 mm for males and 153.10 mm for female fish.

The size at first maturity of the gonads in this study was smaller than in previous studies, which is thought to be representative of size in the analysis process, the size and type of fishing gear and the environment as a fish habitat. [12] revealed that fishing activities related to fishing methods and the type of fishing gear used will limit the size of the fish caught so that it can cause differences in the size of the fish when the gonads first mature when analyzed. Furthermore, [13] stated that the size of the mature gonads of the fish caught from each research location was due to overfishing, so fish were caught that were small in size but had mature gonads.

The size and age of the fish when the gonads first mature will not be the same from one species to another. In fact, fish of the same species will be different if they are in different conditions and geographical locations [5]. When fish first reach gonad maturity is influenced by many factors, including species, age and size. In general, fish that have a small maximum size and a short lifespan will reach maturity at a younger age than fish that have a larger maximum size [23]. According to [2], the size of fish when the gonads first mature is related to growth and environmental influences. According to [7], when each species first matures the gonads are not the same size, nor are the same species.

4. CONCLUSION

Biological aspects include the size distribution of female vermiculated spinefoot being wider than males, negative allometric growth patterns and condition factors. Female vermiculated spinefoot tend to be wider than males so they are fatter. The sex ratio is in an unbalanced condition with males being more dominant than females. The gonad maturity of the vermiculated spinefoot was found to be from immature gonads until spawning and female rabbitfish matured more quickly than males.

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