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Bioecological Comparison of Angelfish (*Pomacanthus* sp.): Diversity of Habitat, Sex Ratio, Growth and Production Status in Coral Triangle Waters

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Angelfish (*Pomacanthus* sp.) is an ornamental fish that inhabits lush coral reefs. Despite requiring a healthy coral environment to grow and develop, this fish species is often hunted for its high price in the international market. This research aimed to determine the bio-ecology of angelfish, including its habitat, activity, size, structure, growth, and sex ratio, as well as to provide insights into its production status in the last nine years in South Sulawesi, especially in the waters of Pangkajene

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dan Kepulauan (Pangkep). The angelfish population was observed in waters adjacent to coral reefs in the coastal area of Pangkep. For this research, we used locally caught samples and determined their age using Gulland plot analysis. This study shows that the presence of angelfish does not have a positive correlation with live coral cover. However, their existence is influenced by coral growth forms, such as branching, sub-massive, and massive coral fissures. The samples of the caught angelfish were young, and their gonads were undeveloped. The allometric relationship between the weight and length of angelfish is slow, with them reaching a maximum length of 41.7 cm at 13 years. Based on the results of the study, we found that angelfish with a length of 10.1cm to 15cm are still relatively young and their gonads are still not developed. This size is in great demand in the market. This research also shows a decline in angelfish production. Thus, it is necessary to control the amount of catch and the minimum size of the first catch or provide a catch quota system for each year. The findings of this research can serve as a reference for policymakers, fishermen, and aquascape experts who wish to protect the angelfish population in their natural habitat.

Keywords: Angelfish; coral; angelfish population; fish species.

1. INTRODUCTION

Indonesia boasts the world's largest coral reef area. These reefs are found in the Coral Triangle, with over 500 recorded coral species and 2,057 identified fish species across an area of 51,000 km^2 [1,2]. The country's abundant fish resources, including ornamental fish, make it the world's second-largest exporter of marine ornamental fish after the Philippines [3]. However, *Pomacanthus* sp., the most expensive type of angelfish, faces significant overfishing due to its high market value [4]. The Indonesian Ornamental Fish and Shellfish Association (AKKII) and the Sulawesi Ornamental Fish and Coral Association (AKIS) have reported a drastic reduction in *Pomacanthus* sp. with a significant decrease in the number of fish caught and the size of fish caught over the years [5].

Pomacanthus sp. is found in several waters in Indonesia—Aceh, Pelabuhan Ratu, Labuan, Ujung Genteng, Sibolga, Lampung, Binungaeun, Sulawesi, and Kalimantan. The fish spend their entire lives in channels and outer slopes of coral reefs, with juveniles settling in coral reef caves with good algae growth at depths of 5 to 25 m [6]. *Pomacanthus* sp. has rainbow-like colors and changes color during its growth phase. The fish live solitarily and in pairs [7]. *Pomacanthus* sp. is characterized by its yellow dorsal, pectoral, and caudal fins with weak rays on the dorsal fin, a black dot on the back, and a round or rounded caudal fin with a blue border [8]. The pelvic and anal fins are white with blue edges.

Despite the distribution and morphological characteristics of *Pomacanthus* sp., information on the species is limited, and overfishing has become a pressing issue [9]. Sustainable fisheries resource management requires more information on the biological aspects of Angelfish *(Pomacanthus xanthometopon)* [10]. Conservation of coral reefs and the sustainability of the ornamental fish business is critical for Indonesia, which is one of the centers of the greatest diversity of coral reefs and marine life on the planet [11]. The enormous potential of marine ornamental fish resources offers high economic value, and innovative management strategies must be implemented to promote sustainable resource use and prevent the decline of marine biodiversity [12].

Indonesia is the largest marine ornamental fish exporter worldwide and produces high-value marine ornamental fish in demand by the global market [13] The country's coral reefs are among the world's most biologically rich and provide a habitat for exotic marine biota [14]. While research has primarily focused on freshwater commercial ornamental fish species in large lakes and rivers, marine ornamental fish species remain relatively unexplored, despite their potential for diversity and abundance of fish. Therefore, this research aims to determine the condition, abundance, structure, size, and age of angelfish in Pangkep waters, providing information for sustainable utilization and management of marine ornamental fish resources.

2. MATERIALS AND METHODS

2.1 Experimental Set-up

The research was conducted in Pangkep Regency from April to August 2022 with approval from the Indonesian. Observations and data collection were carried out in the waters of the Liukang Tuppabiring District, which includes the islands, Karanrang, Pammanggangan, Sarappokeke, Sarappo, Makalere, Lanyukang, Sanane, Suranti, and Kondongbali, and Makalere Reef and the waters of the Liukang Tangaya District islands, which include Sapuka Caddi, Sanana, Sumanga, Tinggalungan, and Sarege (Fig. 1).

2.2 Observation of the Abundance of Angelfish

2.2.1 Habitat condition inventory

The habitat conditions were determined using the point intercept transect (PIT) method, as described by Wahib and Luthfi, [15]. This method is used to easily and efficiently monitor the condition of live coral and other supporting biota and estimate the condition of coral reefs in a location based on the percentage of live coral cover. The data collection process for habitat conditions using the PIT method at the observation location is presented in Fig. 2.

2.2.2 Estimation of the abundance and size of the fish

To estimate the abundance of *P. xanthometopon*, a visual census method was used with transect lines to observe the shape of coral cover in each zone. Additionally, the number of *P. xanthometopon* according to the market standard set by the AKKII was also recorded [16]. The population abundance of *P. xanthometopon* can be accurately calculated by using this method. Observing the habitat condition and the abundance of the fish is crucial in gaining a better understanding of its bio-ecology and the development of effective conservation strategies.

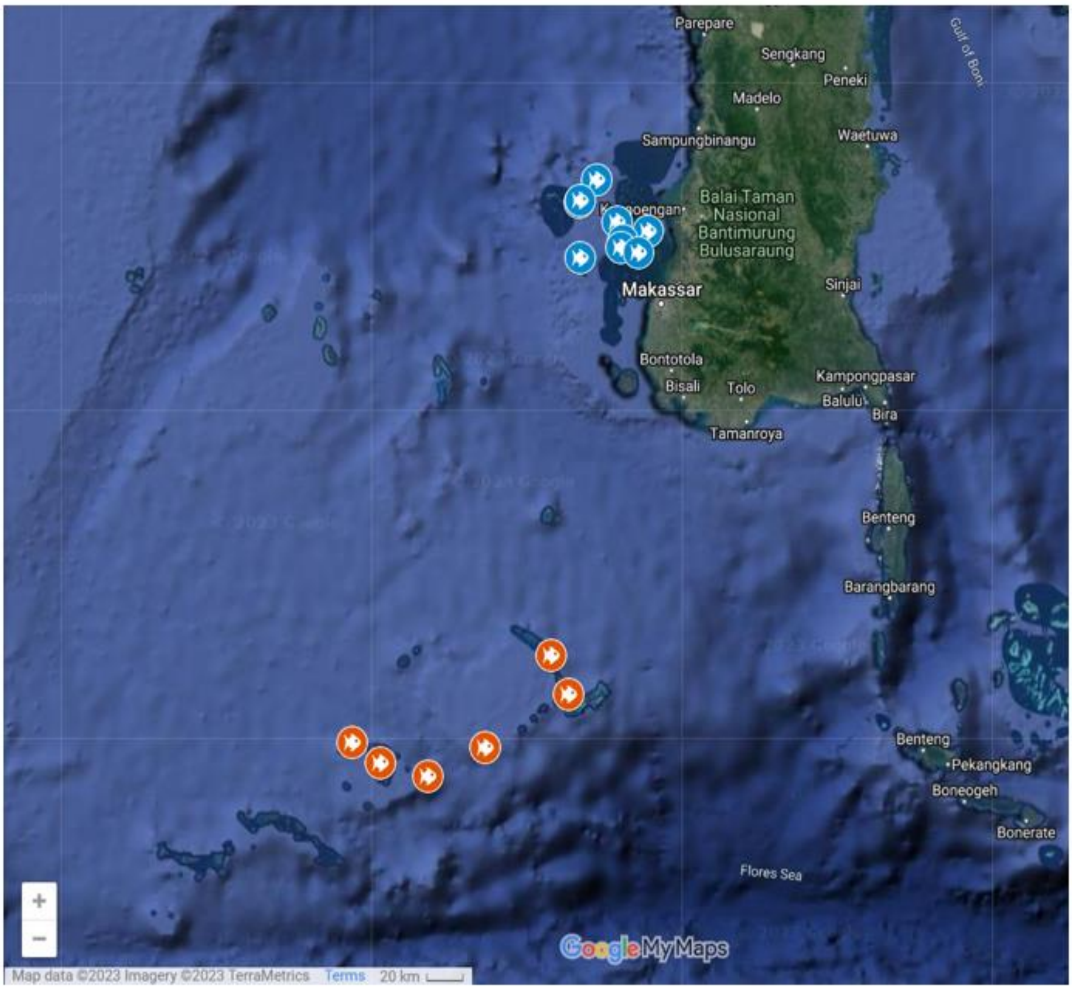

Fig. 1. Map showing study location

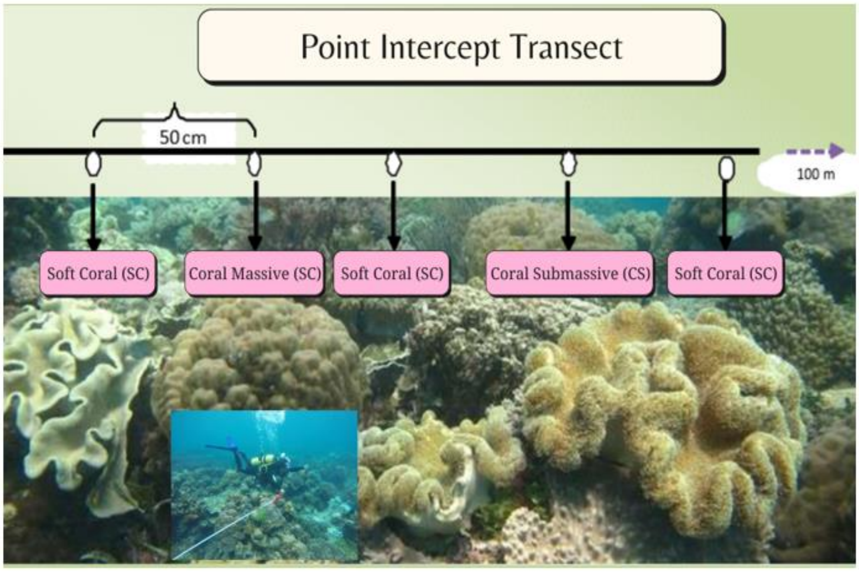

Fig. 2. Data collection process for habitat conditions using the PIT method

2.3 The Size and Age Structure

2.3.1 Size structure

The size structure of *P. xanthometopon* is determined by measuring its structural dimensions, such as length and weight, using a plastic ruler and an electronic scale. This measurement method was used in the study to collect the necessary data for analyzing the growth characteristics of the *P. xanthometopon* population.

2.3.2 Age determination

The age of the fish is determined using the otolith analysis, a method developed by Habibie et al. [17]. This method was used in the study to collect the necessary data for analyzing the growth characteristics and age structure of the *P. xanthometopon* population (Fig. 3).

Fig. 3. Growth characteristics and age structure of the P. xanthometopon population

2.3.3 Fecundity estimation

Fecundity estimation was conducted on mature female *P. xanthometopon* using the method described by Murua et al. [18]. The number of eggs was determined by the volumetric method, which involves diluting the egg grains, as described by Agustiari et al. [19]. This method was used to estimate the reproductive ability of the *P. xanthometopon* population and gain a better understanding of their reproductive biology.

2.3.4 Histological testing

Sex determination of the fish was done using histological testing based on the method recommended by Yamada et al. [20] and Agustiari et al. [19] with some modifications. This testing method involves the microscopic examination of fish gonads to identify the presence of male or female reproductive structures.

2.4 Data Analysis

2.4.1 Habitat conditions and availability of angelfish

Habitat characteristics between research stations were analyzed descriptively. Data were displayed in the form of graphs and pictures [21].

Habitat characteristics or percentage of the cover of live, dead coral and other types of lifeforms were determined using the following formula by Gauch & Gauch Jr., [22].

$$C = \frac{a}{A} \times 100\% \quad (1)$$

Where:

C = Percentage of closure of lifeform i
a = Frequency of appearance of lifeform i
A = Total lifeforms i

The abundance of *P. xanthometopon* was determined using the proposed formula of Walters and Martell (2004), given below:

$$Ni = \frac{\sum ni}{A} \quad (2)$$

Ni = Density of fish species I (heads/m^2/ha)
$\sum ni$ = Number of individuals of type i
A = Sampling area (m^2/ha)

$$\text{Abundance } = Ni\ x\ lt \quad (3)$$

Where:

Ni = Density of fish species I (heads/m^2/ha)
Lt = Productive coral area (ha)

2.4.2 Biological aspects and growth of angelfish

Fecundity was determined using a combination of several existing methods [23] using the below formula.

$$F = \frac{GxVxX}{Q} \quad (4)$$

Where:

F: Fecundity (eggs)
G: Weight of gonads (g)
V: Dilution volume (mL)
Q: Egg sample (g)
X: Number of eggs per mL

The increase in length (L) of *P. xanthometopon* at each life stage is a function of the increase in length (L), which can be expressed using the Von Bertalanffy growth equation in the logarithmic form [24] to estimate growth parameters.

The growth of *P. xanthometopon* was assumed to follow the Von Bertalanffy growth formula as described by Pauly [25].

$$L_t = L_\infty(\,1 - \,exp^{-K\,(t-t0)}) \quad (5)$$

where:

Lt = Fish length (cm) at the age of t (relative time)
$L\infty$ = Asymptote length of fish (cm)
K = Growth coefficient (per relative time)
$T0$ = Theoretical life at zero length (relative time)

To estimate growth ($L\infty$ and K), the absolute age estimation results from the volumetric analysis were substituted into the plot method [26] as follows:

$$\frac{\Delta L}{\Delta t} = KL_\infty KL(t) \quad (6)$$

Using $L(t)$ as a free variable and $\Delta L/\Delta t$ as a non-free variable, the above equation becomes a linear regression:

$$\frac{\Delta L}{\Delta t} = a + b\ .\ L(t) \quad (7)$$

Parameters *K* and *L*∞ are specified from:
K = - *b* and *L*∞ = - *a/b*
The estimated value of “to” is considered zero.

3. RESULTS AND DISCUSSION

3.1 Habitat and Abundance of *Pomacanthus* sp.

The live coral cover in Pangkep waters is in good condition and serves as suitable habitat for Pomacanthus sp. The live coral cover condition was observed in two locations, Liukang Tuppabiring Island and Liukang Tangaya, in the coral reef zone. The coral cover was found to be good in the reef flat, crest, and slope zones, as indicated in Fig. 4.

The average condition of live coral cover in the waters of Liukang Tangaya was relatively better compared to the waters of Liukang Tuppabiring, as the fishing sites of Pomacanthus sp. are far from reach.

3.2 Fish Abundance per Zone and Habitat Characteristics

The abundance of Pomacanthus sp. in the Liukang Tuppabiring Waters was 111 in the reef flat zone, 102 in the reef top zone, and 108 in the reef slope zone. Meanwhile, in the Liukang Tangaya waters, the abundance was higher with 135 individuals found in the reef flat zone, 121 individuals in the reef crest zone, and 124 individuals in the reef slope zone, as presented in Table 1. The data on fish abundance in each zone and different coral shapes significantly affected the percentage of coral cover. The zones with a higher percentage of coral cover, such as the flat crest-shaped coral cover, had a greater number of fish, as seen in both Liukang Tuppabiring and Liukang Tangaya waters.

Adult *P. xanthometopon* eats more algae in massive coral crevices, as shown in Fig. 5. The population and distribution of reef fish are influenced by various biological and physical factors in coral reef areas, such as waves, currents, weather, sedimentation, water depth, physiography, and the complexity of coral reefs. Therefore, there is no single factor that can explain the community structure of reef fish. The distribution of different reef fish species varies depending on the bottom conditions of the waters. The differences in coral reef habitats can lead to differences in the composition and size of fish populations. Intra- and inter-species interactions also play a role in determining the territorial spacing of reef fish. Each group of fish has its preferences for certain habitats, resulting in differences in their spatial distribution. Reef fish tend to adapt to their environment and hide in crevices when disturbed.

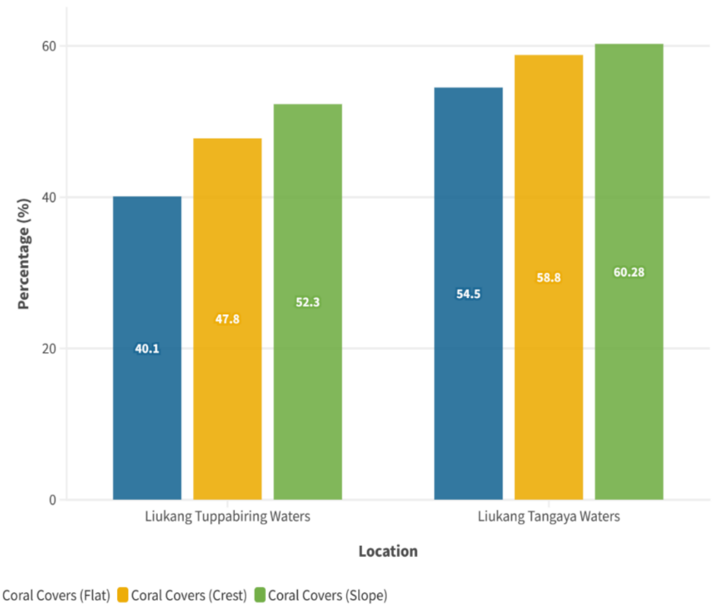

Fig. 4. Coral cover in the reef flat, crest, and slope zones

Fig. 5. massive coral crevices

Table 1. Catchment zone and abundance of angelfish

Zones	Coral Covers		The number of fish (indiv)
	Form	%	
P. Liukang Tuppabiring	Flat	50.10	111
	Crest	57.80	102
	Slope	62.30	108
P. Liukang Tangaya	Flat	64.50	135
	Crest	68.80	121
	Slope	70.28	124

The habitat characteristics preferred by angelfish include cbCM, csCM, aCS, acCB, CBA, CSCMA, bACT, cACT, and cCF, as these types of corals provide safe areas for shelter in the form of large rocks, caves, holes, and crevices. Typically, adult-sized fish (M and L) are found in the reef flat zone, while the crest zone tends to have a variety of sizes, indicating a transitional area. The reef flat zone, on the other hand, mostly contains small (juvenile) or TT, T, and S-sized fish.

The availability of food for reef fish partially and temporarily affects the existence of reef fish communities [27]. The settlement process of reef fish larvae is influenced by the presence of plankton in the coral reef habitat and is called recruitment [28]. The presence of larvae in a habitat is a dominant factor in the formation of community structure [29]. For instance, some fish larvae prefer coral reef habitats with small scales [27]. After the attachment process, competition and predation occur between the new fish, which have been recruited and form groups that affect the composition of reef fish.

The coral reef provides food, shelter, and breeding grounds for many species of fish. The complexity of coral reefs, with their various shapes and sizes, provides hiding places and shelter for many species, protecting them from predators. In addition, the presence of algae and other types of small organisms on coral reefs provides a food source for many species of fish. Coral reefs are also important breeding grounds for many species of fish, with larvae settling on coral reefs and then growing to maturity. The high diversity of habitats in coral reef areas is a key factor in the high diversity of species found in these areas. The complex interactions between different species and their environment play an important role in determining the distribution and abundance of fish populations.

The spatial distribution of various types of reef fish varies according to the bottom conditions of the waters, and differences in coral reef habitats lead to differences in fish aggregations. Intra- and inter-species interactions play an important role in determining spatial zoning, as each group of fish has its habitat preferences, resulting in different areas being inhabited by different fish groups.

3.3 Biological Aspects and Growth of *Pomacanthus* sp.

3.3.1 Sex ratio dan fekundity

The results of the gonadal observations of 30 samples showed that the caught *P. navarchus* were juveniles. No gender was found and all 20 individuals of *P. navarchus* with a size range of 5.1–10 cm (*N* = 20) had empty gonads. In 20 individuals of *P. navarchus* with a size range of 10.1–15 cm (*N* = 20), two were male, six were female, and 12 had empty gonads. Meanwhile, in 20 individuals of *P. xanthometopon* with a size range of 15.1–20 cm (*N* = 20), six were male, 10 were female, and four were hermaphrodites, as shown in Table 2. These findings are consistent with the observation that out of 20 individuals of *P. xanthometopon* with a size range of 15.1–20.0 cm (*N* = 20), only six were male, four were hermaphrodite, and none had gonads (empty).

The results of the gonadal observations of 60 samples showed that the caught *P. xanthometopon* were juveniles. The total length of the samples used in the fecundity analysis ranged from 6.8–19.2 cm TL, with a weight range of 72–774.9 g, and a sample size of 30 individuals. Histological observations of the gonads from all 30 individuals indicated that the fish were young. The dominant type of gonad in the population was undeveloped gonad in 16 individuals (53%), followed by female in eight individuals (26%), male in four individuals (14%), and hermaphrodite in two individuals (7%). In 10 individuals of *P. xanthometopon,* with a size range of 5.1–10 cm (*N* = 10), no gender or empty gonads were found in all individuals. In 10 individuals of *P. xanthometopon* with a size range of 10.1–15 cm (*N* = 10), one was male, three were female, and six had empty gonads. Meanwhile, in 10 individuals of *P. xanthometopon* with a size range of 15.1–20 cm (*N* = 10), three were male, five were female, and two were hermaphrodites, as shown in Table 3. These findings are consistent with the observation of Setiawati et al. (2011) that out of 15 individuals of *P. xanthometopon* wrasse with a size range of 10.1–20.0 cm (*N* = 15), only one was male, four were hermaphrodite, and 10 had empty gonads.

The general trend among reef fish families, such as Labridae, Scaridae, Serranidae, Pomacanthidae, Pomacentridae, and Pinguipididae, is to undergo sex change from female to male, a process known as protogynous hermaphroditism [30]. This is because the proportion of males tends to increase with the growth of the fish.

In this study, fecundity could not be calculated due to the absence of gonads containing eggs that could be counted. However, an earlier study by Anggraeni et al., 2017 reported that the fecundity of angelfish ranged between 92,536 and 610,461 eggs from female parents that were between 20.1 and 30.0 cm TL with a weight of 395–869 g. The study also reported a higher proportion of females (26%) compared to males (14%), and 7% hermaphrodites. Based on these findings, it is recommended to implement size limits and catch quotas for ornamental angelfish to maintain the population, as most of them are still juveniles.

The ability to determine the age of individual fish is crucial in fisheries biology. There are two ways to determine the age of fish—by studying annual markings on the body and by measuring length frequency. Certain parts of their body, such as vertebrae, operculum bones, fin spines, and otolith bones have annual signs. Learning the age of an individual fish can help identify when the individual learned to find food based on parental habits and when its gonads matured [31].

Table 2. Total length and sex of angelfish (*Pomacanthus navarchus*)

Total Length (cm)	Females	Males	Hermafrodit	Undeveloped Gonad	Total
5.1-10	0	0	0	10	10
10.1-15	3	1	0	6	10
15.1-20	5	3	2	0	10
Percentage (%)	26.00%	14.00%	7.00%	53.00%	100.00%

Table 3. Total length and sex of angelfish (*Pomacanthus xanthometopon*)

Total Length (cm)	Females	Males	Hermaphrodite	Undeveloped Gonad	Total
5.1-10				20	20
10.1-15	6	2		12	20
15.1-20	10	6	4		20
Percentage (%)	26.00%	14.00%	7.00%	53.00%	100.00%

Estimating fish populations is an important parameter in fisheries management. The number of individuals in a fish population is constantly changing and is influenced by various factors. Learning the population size of a fish species can help determine its potential in a given aquatic environment [32].

Pandian, T. J. [33] mentions that the reproductive glands of fish are called gonads. The ovaries are the female gonads, while the testes are the male gonads [33]. Typically, the gonads of adult fish are found in separate individuals, except in some species. Occasionally, some individuals possess both male and female gonads, called ovotestes.

Fig. 6 shows the stage of gonadal maturity, which is a crucial stage of development that occurs before and after fish spawning. According to Yonvitner et al. [34] the stages of gonad development are important to compare immature and mature fish, between those about to reproduce and those already reproducing, and to determine at what size the individuals of a fish species first reach gonadal maturity and spawn. Gonadal maturity is related to the growth of the fish and environmental factors. Therefore, understanding the changes in gonadal development between individuals is important in fisheries biology. The shape and size of gonads vary depending on the capacity of the cavity and the shape of the fish. Gonads are a determinant of the sex of fish and other aquatic animals.

Knowledge of fecundity is important in both fishery biology and aquaculture. It helps predict the number of larvae or seeds that will be produced if individual fish spawn, as well as the number of stocks a fish population can sustain in an aquatic environment.

Madeira et al. [35] emphasized that understanding the fecundity of fish is a crucial step in comprehending population dynamics and predicting spawning fish populations [35]. By knowing the number of eggs produced per year and the ratio of male and female fish in the population, it becomes possible to estimate the number of offspring that will be produced at each spawning event. In aquaculture, knowledge of fecundity is essential for managing breeding programs and maximizing seed production.

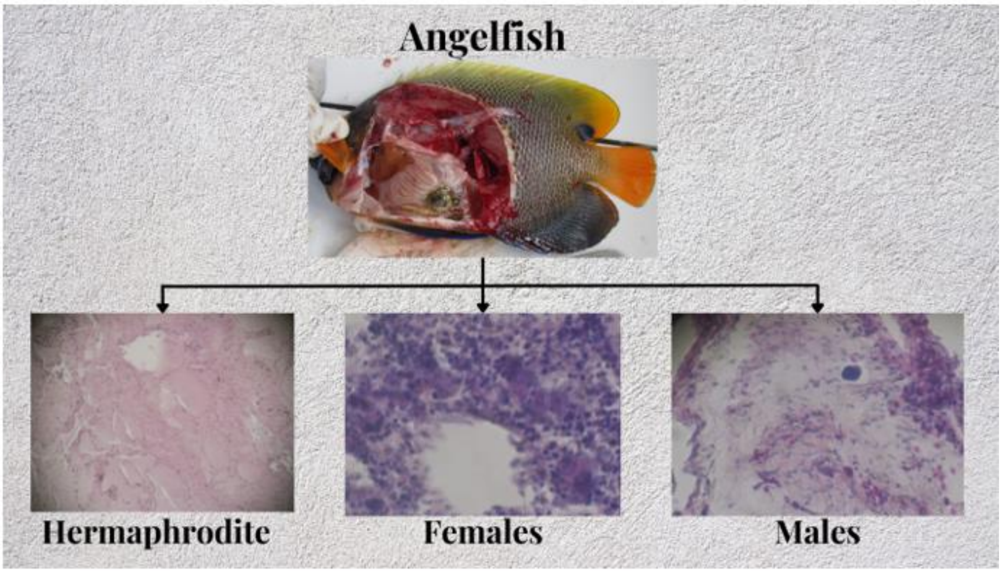

Fig. 6. Stage of gonadal maturity

3.3.2 Size structure

The number of observed Angelfish was 163, with 120 individuals from Pangkep waters (22 in July and 98 in August) and the remaining 43 from Selayar waters. The analysis of variance indicated that there were no significant differences in the length and weight of fish caught at different times in Pangkep waters (P > 0.05). Therefore, the two sets of data were combined for further analysis.

The average length of fish caught in Pangkep and Selayar waters was 10.70 ± 3.34 cm and 8.79 ± 3.90 cm, respectively, while the average weight was 5.89 ± 14.10 g in Pangkep waters and 12.42 ± 11.27 g in Selayar waters. In Pangkep waters, the highest and lowest size classes caught were represented by nine and four fish, respectively, while in Selayar waters, the highest and lowest size classes caught were represented by nine and two fish, respectively. The size distribution of angelfish caught in both glasses of water showed a similar pattern with a narrow size range and a dominant class interval between 9.5–11.5 cm, as shown in Fig. 3 and 4. However, the analysis of variance indicated that the fish caught in Selayar waters were significantly longer than those caught in Pangkep waters (P < 0.05), but there was no significant difference in the average body weight.

The size distribution of angelfish caught during the study is presented in Fig. 7, with the largest size being S (38.1%), followed by M (29.4%), TT (14.1%), T (11.7%), and the lowest being L (6.7%).

In terms of the production of angelfish sizes in South Sulawesi waters, based on secondary data from angelfish exporters between 2011 and 2021 in the fishing areas of Liukang Tangaya and Taka Bonerate Islands, it can be seen in Fig. 8.

P. xanthometopon samples were collected from Pangkep waters in November 2020 and April 2021, as well as from Selayar waters in April 2021. The total number of samples obtained from Pangkep waters was 120, with 22 individuals collected in November 2020 and 98 individuals collected in April 2021.

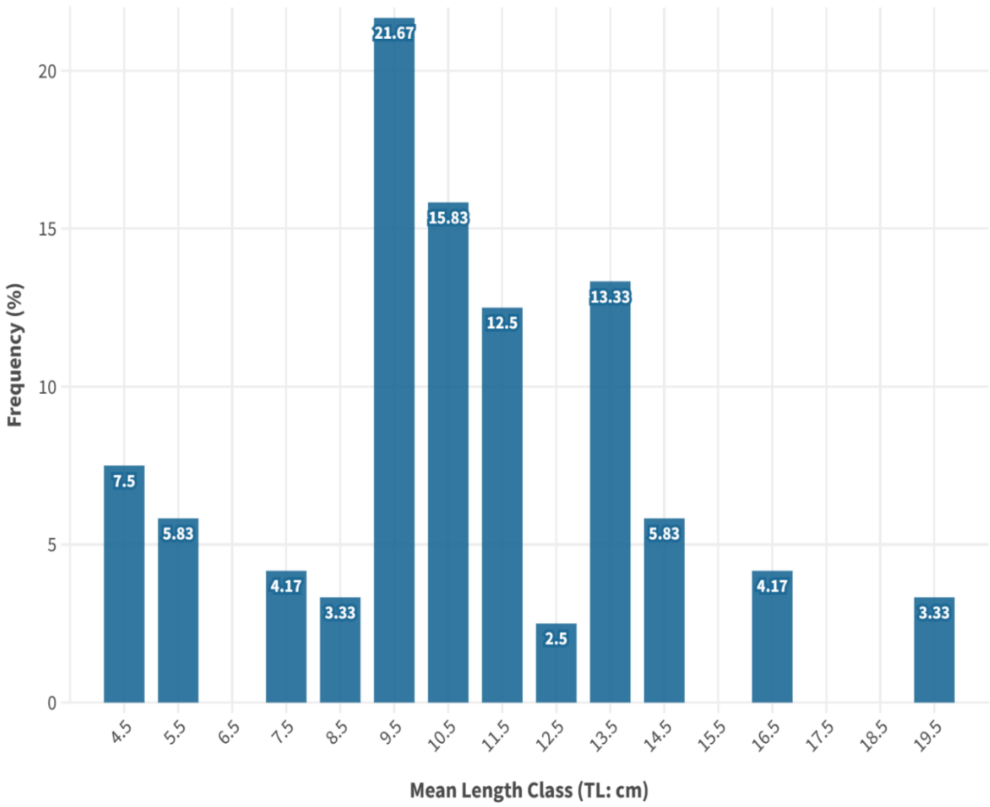

Fig. 7. Size distribution of angelfish caught during the study

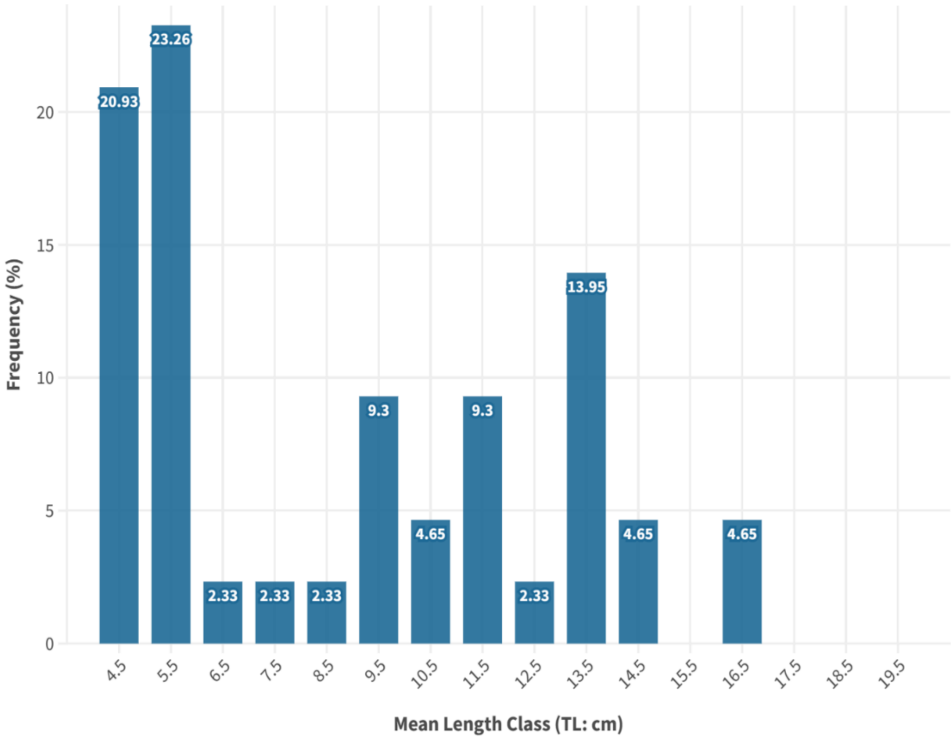

Fig. 8. Fishing areas of Liukang Tangaya and Taka Bonerate Islands

3.3.3 Growth

The size structure of angelfish caught during the study (Fig. 7) was similar to those caught in South Sulawesi waters (Fig. 8). The dominant sizes were S and M, followed by T (sissy angel) and TT (Bluston angel), with consistent composition over the years. Exporters indicated that the sizes, M and S were in high demand due to their bright colors and higher survival rates in aquariums. This preference for small sizes suggests that overexploitation and recruitment overfishing may be contributing to the decline in the angelfish population. Catching excessively young fish (juveniles) limits their chances to reproduce in nature, despite the potential of adult fish coming from younger age groups [36]. Proper management of fishery resources is necessary to prevent overfishing, which can occur in various forms, including recruitment overfishing, biological overfishing, economic overfishing, and Malthusian overfishing.

Heavy Long Relations: The results of the analysis of the relationship between the length and weight of angelfish using the linear regression model can be seen in Table 4. The table shows that the two models analyzing the relationship between the length and weight of the fish have almost the same *b* value. This indicates that an increase of 1 cm in the length of the fish causes an additional 2 g in weight. The *b* value not being equal to 3 ($P > 0.05$) also suggests negative allometric growth in this species, meaning that the growth in length is not proportional to the increase in weight.

The relationship between length and weight was studied in 120 individuals of *P. navarchus* and 43 individuals of *P. xanthometopon*, from the Pangkep waters. The measured range of the length was 4.3–19.4 cm TL and 4.3–16.3 cm TL, with a corresponding weight range of 1.9–77.4 g and 1.9–40.4 g, respectively. The length-weight relationship was modeled using the equation W = aLb with logarithmic transformation, where a and b are the constants that were estimated through linear regression of the logarithmic transformation. The regression models for *P. navarchus* and *P. xanthometopon* from the Pangkep waters are:

$$W = 0.071 * TL^{2.2079} \ (R^2 = 0.9544)$$
$$W = 0.0906 * TL^{2.1496} \ (R^2 = 0.9412)$$

Based on the data, it can be inferred that the length and weight of the two species are positively correlated, and the relationship can be described by the corresponding regression equations. Fig. 9 illustrates the relationship between the length and weight of *P. navarchus* caught from the Pangkep waters.

The relationship between the length and weight of *P. xanthometopon* with a sample size of 43 individuals caught in the Pangkep waters showed a high R^2 value and the exponent "*b*" significantly differed from 3 ($p > 0.05$), as obtained from the length-weight regression model of *P. xanthometopon* presented above. Fig. 10 illustrates the relationship between the length and weight of *P. xanthometopon* caught from the Pangkep waters.

The relationship between the length and weight of *P. xanthometopon* with a sample size of 98 individuals caught in the Pangkep waters showed a high R^2 value and the exponent "*b*" significantly differed from 3 ($p > 0.05$), as obtained from the length-weight regression model of *P. xanthometopon* presented above.

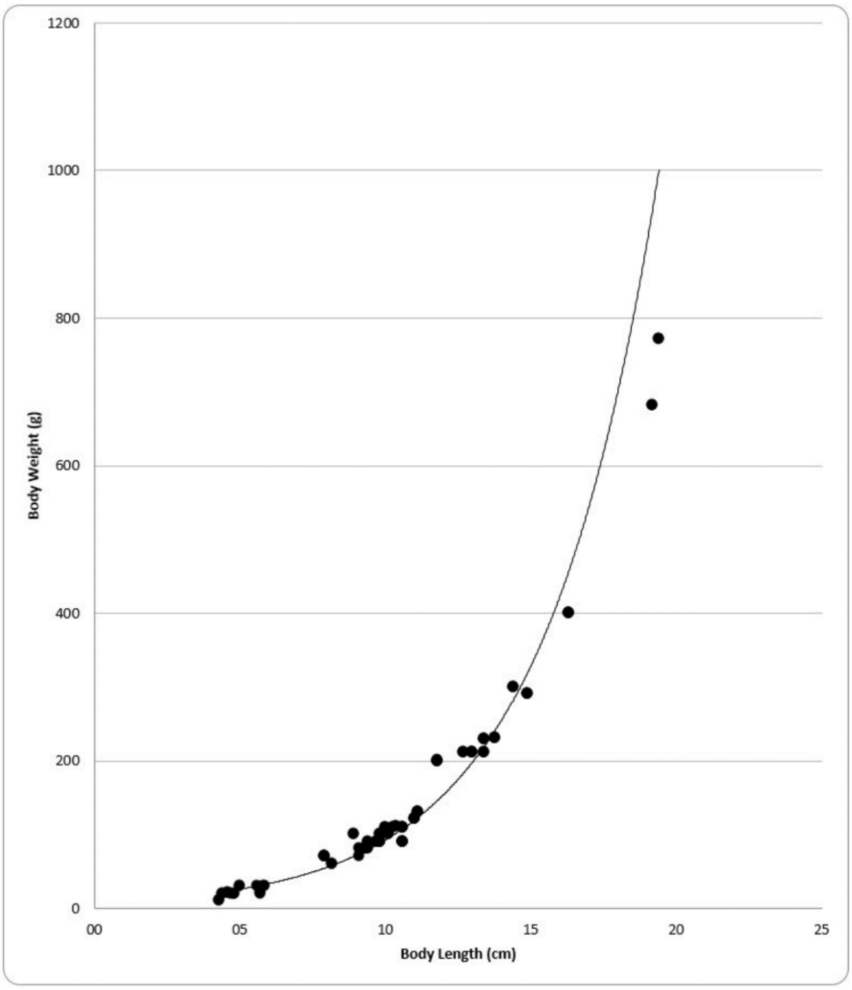

Fig. 9. The relationship between the length and weight of P. navarchus caught from the Pangkep waters

Table 4. Values of constants a, constants b, and R^2 for the long-weight relationship of angelfish (*Pomacanthus* sp.) using a linear regression model

Fishing Ground of Pangkep Waters	N	Intercept	Parameter	Estimated R^2
Liukang Tuppabiring	120	- 0.420	2.434	0.963
Liukang Tangaya	43	- 0.192	2.282	0.936

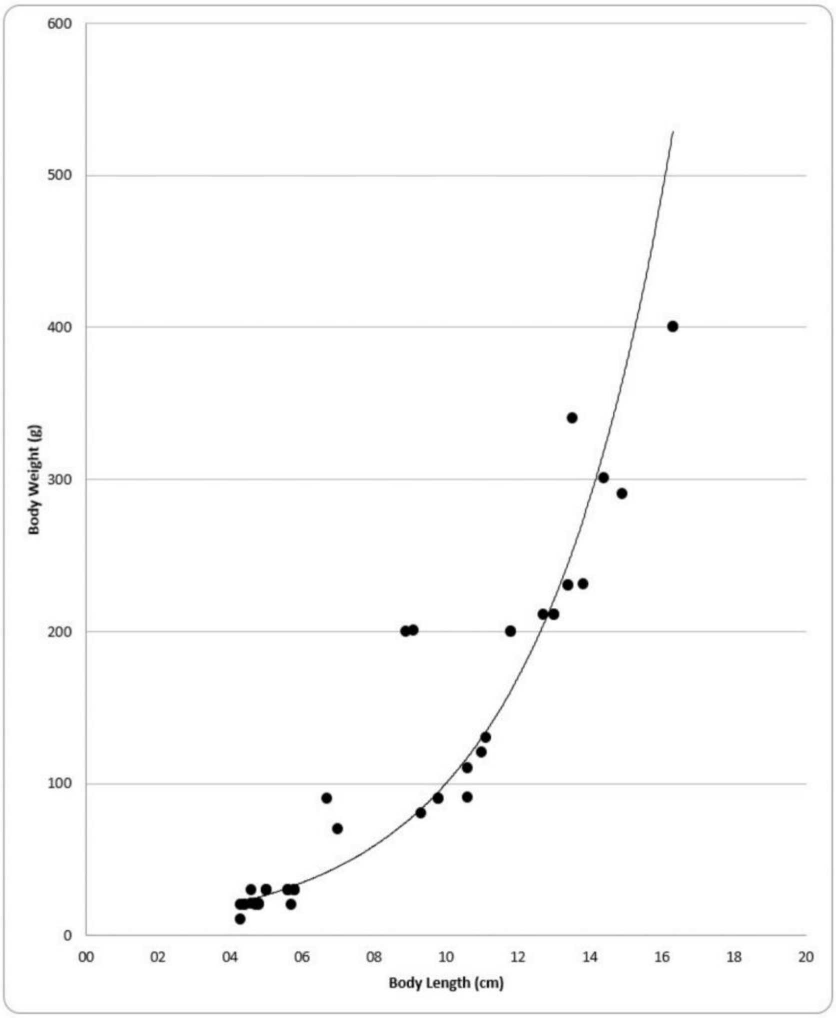

Fig. 10. The relationship between the length and weight of *P. xanthometopon* caught from the Pangkep waters

Length-weight regression models of both *P. navarchus* and *P. xanthometopon* presented above showed a high R^2 value and the exponent "*b*" significantly differed from 3 ($p > 0.05$). Fig. 11 illustrates the combined relationship between the length and weight of *P. navarchus* and *P. xanthometopon* caught from the Pangkep waters.

The average length and body weight of *P. navarchus* and *P. xanthometopon* from each fishing location in Pangkep waters showed a significant difference ($P < 0.05$) in the average length value of each fishing location but did not show a significant difference in body weight.

The sampling data was collected in two waters, namely Liukang Tupabbiring and Liukang Tangaya. Obtained data from nine individuals of *Pomacanthus* sp. with the highest length size (TL 19–20 cm). In addition, there were also data from four individuals of *Pomacanthus* sp. with the smallest size (TL 4–7 cm).

In the wild, *Pomacanthus* sp. undergoes striking color changes from the juvenile stage to maturity, as shown in Fig. 12. Juvenile bluston angelfish have white stripes with a dominant blue-black line encircling the sides of their body and are typically between four to six cm long. As the fish matures into the hermaphrodite angel stage, the body pattern and color slowly change, with the blue stripes transforming into white stripes. In the adult stage, the white stripes on the body disappear and become orange with a combination of blue along the body. The pattern and color of the body typically begin to change around 21–45 days from the juvenile stage, while in an aquarium. A fully mature *Pomacanthus* sp. can reach up to 40.5 cm TL with a weight of 1,025 g.

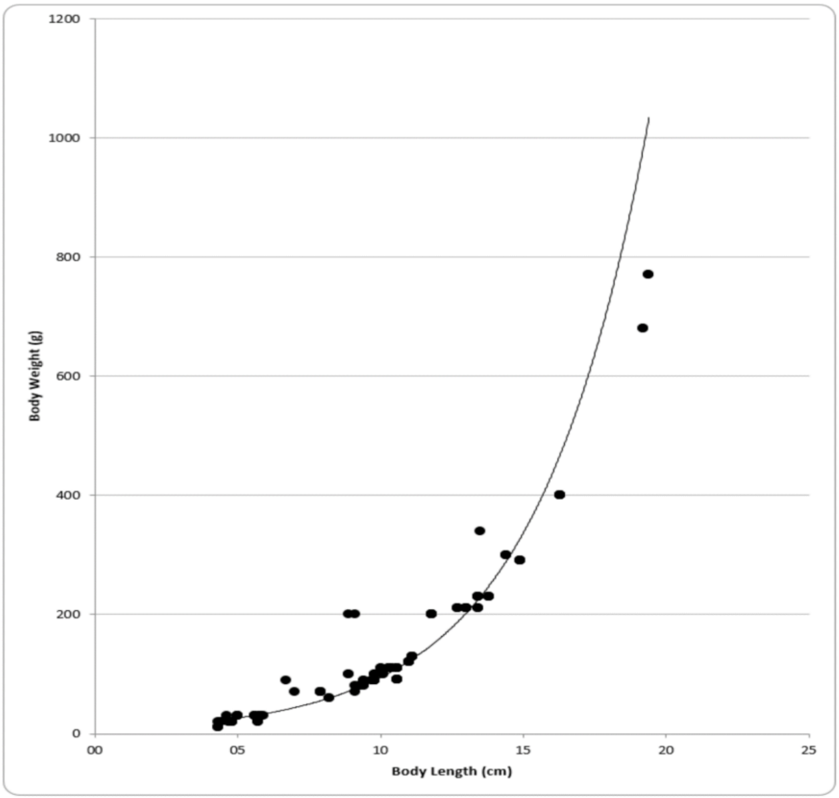

Fig. 11. the combined relationship between the length and weight of P. navarchus and P. xanthometopon caught from the Pangkep waters

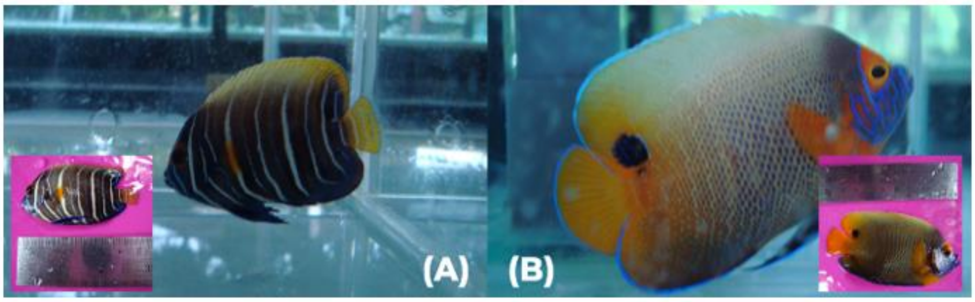

Fig. 12. Striking color changes from the juvenile stage to maturity

The number of individuals in fish populations can vary over time due to changes influenced by the success or failure of subsequent production, affecting recruitment into existing populations [37]. Mortality rates also affect population changes but are difficult to determine due to numerous influencing factors. The causes of mass death of fish in a habitat can include predators, disease, pollution, physical destruction by machines or humans, and natural phenomena. Indirect causes of death include food, unfavorable environmental conditions, several types of parasites, and social pressure [38].

Age and Growth: The researchers analyzed several otolith samples of *P. xanthometopon*, consisting of four samples with lengths of 5.8 cm, 10.4 cm, 13.0 cm, and 14.9 cm. Each sample showed an age of 86 days (0.24 years), 187 days (0.51 years), 252 days (0.69 years), and 302 days (0.83 years), respectively. The age of the fish is determined by counting the daily rings on the otoliths.

The estimated absolute age of *P. xanthometopon* was used to calculate the Gulland and Holt plot equation, which resulted in an estimated maximum length of 41.767 cm ($L\infty$ = 41.767 cm) at the age of 13 years, with a growth rate of 0.4934 cm/year (K = 0.4934 cm/year) (Fig. 13). If we assume that = 0, the von Bertalanffy growth curve of *P. xanthometopon* can be seen in Fig. 13.

The results of the Von Bertalanffy growth model show a relationship between the body length of the fish and its age, as shown in Fig. 14. *P. xanthometopon* samples caught in both glasses of water were still young, that is, under 1.5 years. This indicates that the *P. xanthometopon* population has experienced very high fishing pressure, necessitating the need for regulation and control of its utilization.

The results of the gonadal analysis revealed no specimens with mature gonads. To estimate the size at first gonadal maturity of *P. xanthometopon*, the first mature female was found to have a total length of 20.1 cm and a weight of 260 g, while the first mature male had a total length of 28.3 cm and a weight of 1053 g. Using these data in the Von Bertalanffy growth equation, the female *P. xanthometopon* was estimated to reach gonadal maturity at the age of 1.4163 years, while the male fish was expected to mature at 2.2941 years.

The study revealed that the bio-ecology of angelfish is greatly influenced by coral growth forms, including branching, submassive coral, and massive crevice coral, rather than live coral cover. The allometric relationship between weight and length of angelfish is slow, with a maximum length of 41.7 cm at 13 years of age. The relatively young size of the angelfish caught and the undeveloped gonads indicated the need for conservation efforts to protect the population. The findings of this study can serve as a reference for policymakers, fishermen, and aquascape experts to preserve angelfish populations in their wild habitat. In line with the study of Bawole, Thomas & Kawulur, [39] who emphasized the importance of paying attention to environmental factors in maintaining the abundance and diversity of coral reef fish species. The study of Bawole, Thomas & Kawulur, [39] showed that the spatial distribution of coral reef fish is influenced by habitat preferences and ecological processes that form associative relationships between coral reefs and fish in a specific area. The study was conducted in the Teluk Cenderawasih National Park and showed that several species of coral reef fish, such as Caesio lunaris, Pterocaesio bananas, Pterocaesio digramma, Lutjanus biguttatus, Monotaxis grandoculis, Siganus gutatus, Zebrasoma scopas, Parupeneus barberinus, Parupeneus multifasciatus, Cephalopholis cyanostigma, Lutjanus fulvus, and Siganus vulpinus, were widely distributed in several research stations.

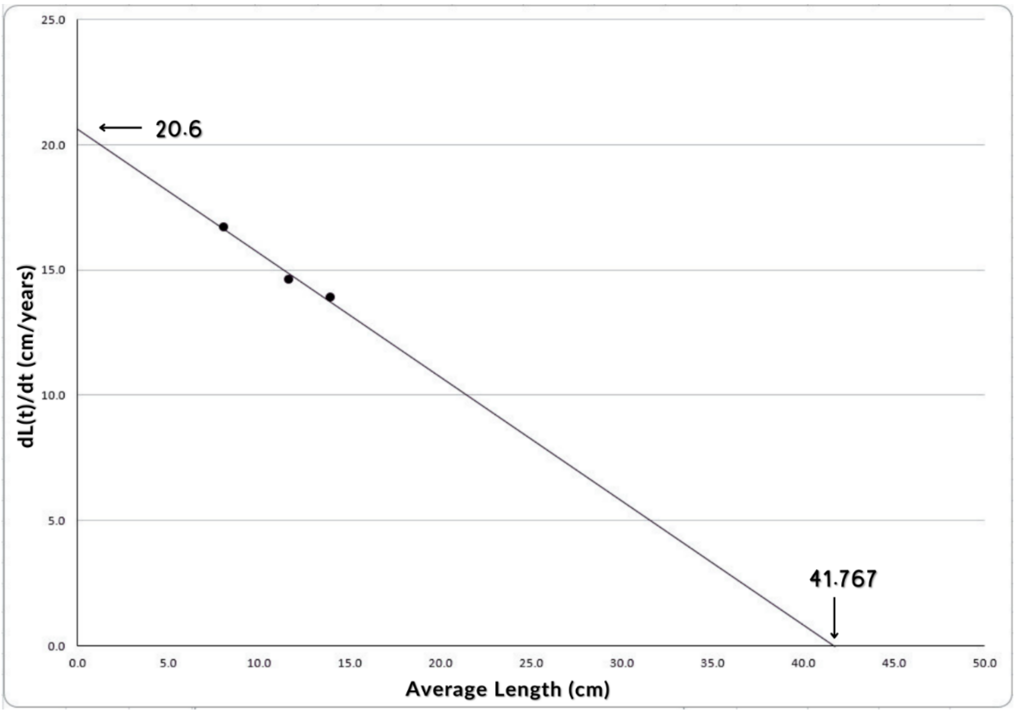

Fig. 13. Bertalanffy growth curve of P. xanthometopon

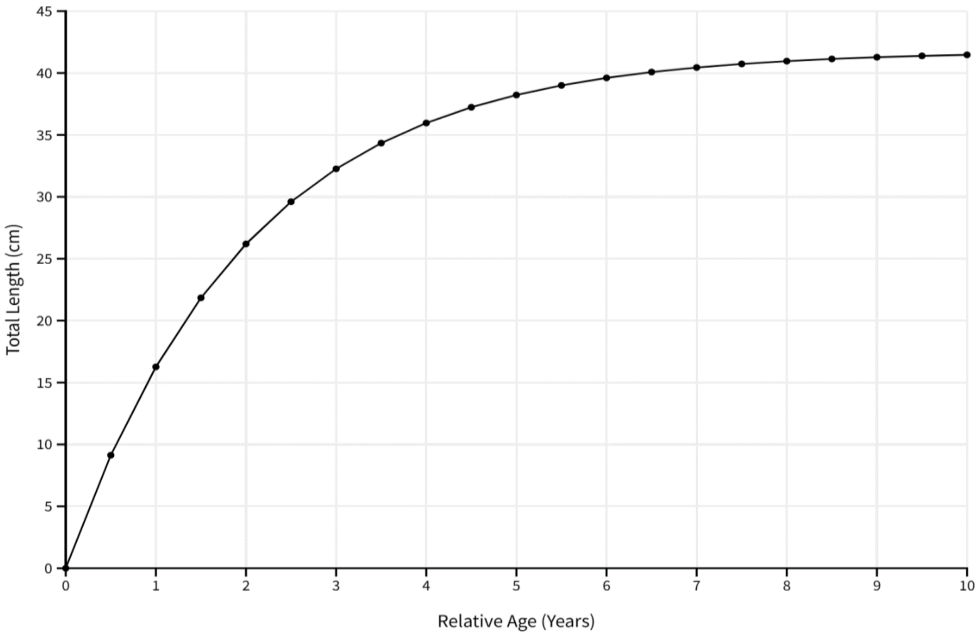

Fig. 14. Von Bertalanffy growth model show a relationship between the body length of the fish and its age

The present study found that the presence of angelfish was greatly influenced by coral growth forms, such as branching, submassive, and massive coral fissures, rather than live coral cover. The caught angelfish were young, with undeveloped gonads and slow allometric growth. The research finding is consistent with earlier research that examines the relationship between coral reef fish and their habitat. This study showed that habitat complexity plays a crucial role in determining the abundance of coral reef fish species, with more species found in habitats with more complex coral structures. This finding is consistent with research by Gratwicke and Speight [40] which shows that habitat complexity significantly contributes to determining the abundance of fish species. The study also found that specific coral reef fish species tend to be more abundant in particular areas of the reef zone, which may be influenced by factors such as coral species and other habitat shapes. Previous research by Madiyani, et al. [41] documenting the abundance and diversity of coral reef fish species in several locations in Indonesia also shows variations in the coral reef fish species found in different coral habitats. The consistency of the current study findings with previous research supports the importance of considering environmental factors in maintaining the abundance and diversity of coral reef fish species. On the other hand, a study by Jennings et al. [42] showed that the intensity of fishing activities could affect the biomass of several target fish species but did not increase the biomass of non-target species. The results emphasized the need for sustainable fishing management that focuses on target species as well as non-target species. In the context of marine biodiversity conservation, environmental factors such as habitat complexity should also be a major consideration, in addition to sustainable fishing activities. This study and previous studies indicated that maintaining the abundance and diversity of coral reef fish species in a region should consider the environmental factors present in the area.

Another study by Harsindhi et al. [43] conducted on Tidung Island showed that the type of coral in a location could affect the abundance of coral reef fish species found there. The study examined the abundance and spatial distribution of coral reef fish based on the type of coral found around Tidung Island. The results showed that the Pomacentridae family had the highest number of species and the highest individual density in the major fish group. The Scaridae family had the highest number of species in the target fish group, but the highest density was found in the Caesionidae family. The Chaetodontidae family dominated the indicator fish group with low species numbers and individual density. Correspondence analysis showed that the spatial distribution of coral reef fish based on the coral type was divided into two groups, —group I, which was scattered on encrusting, massive, foliose, and submassive coral, and group II, which was scattered on branching coral [44].

Overall, as obtained in the previous studies, this study suggested that the abundance and distribution of coral reef fish are influenced by various factors, including habitat preferences and complexity, coral type, and human activities such as fishing. Therefore, coral reef conservation and management efforts should consider these factors to ensure the sustainability, abundance, and diversity of coral reef fish species [45].

3.4 Status of the Production of *Pomacanthus* sp. in South Sulawesi Waters

The data on the production of *Pomacanthus* sp. in the last nine years in South Sulawesi waters of the Pangkep district was obtained from fishermen who caught *Pomacanthus* sp.

Table 5 shows that the effort of catching *Pomacanthus* sp. in 2014–2017 fluctuated with an increasing trend. The lowest catch occurred in 2016 and 2017 with 195 fishing vessels each, while the highest catch occurred in 2022 with 234 fishing vessels.

Table 5. Frequency of angelfish (*Pomacanthus sp.*) production decline in South Sulawesi (waters of Pangkep district)

Years	Effort	Total Catch	CPUE
2014	221	33,080	150
2015	221	33,025	149
2016	195	30,912	159
2017	195	28,105	144
2018	208	25,513	123
2019	208	23,201	112
2020	208	19,032	92
2021	221	14,956	68
2022	234	9,366	40

The effort to add fishing vessels, which is one of the alternatives to increase production, did not show a positive relationship or an increase in production from 2018 to 2022. Production in 2017 decreased from 28,108 individuals to 25,513 individuals in 2018, despite efforts to increase the number of fishing vessels. This is due to the intensive utilization of potential resources, which is one of the indicators of the overfishing of *Pomacanthus* sp. in South Sulawesi.

The decline in catch with an increase in the number of fishing efforts can be an indication of overexploitation. The size of *Pomacanthus* sp. caught is generally small with sample age not exceeding two years, and individuals with mature gonads have not been found. This indicates that the population of *Pomacanthus* sp. tends to have decreased, along with a decline in the frequency of *Pomacanthus* sp. production every year.

The precautionary principle in the utilization of *Pomacanthus* sp. in Pangkep waters should be applied immediately. If it is not managed wisely, the existing fishery resources will become extinct. Efficient management should control the number of fishing efforts and the smallest size of the first catch or implement a quota system for each year.

4. CONCLUSION

This study shows that the coral cover condition in three locations falls under the moderate to good category. Although the presence of *Pomacanthus* sp. is not positively correlated with live coral cover, its presence is influenced by the form of coral growth, namely branching, submassive, and massive coral gaps. The size structure of captured *Pomacanthus* sp. is still young, with undeveloped gonads. The relationship between the weight and length of the fish shows allometric growth, with a slow growth rate and a maximum length of 41.7 cm at the age of 13 years. Based on the research results, it is known that *Pomacanthus* sp. caught in the size range of 10.1–15 cm are still relatively young and their gonads are not yet developed, although this size range is highly in demand. Excessive fishing of *Pomacanthus* sp. with declining population structure and numbers does not support the recovery of the fish population to normal levels. Therefore, it is necessary to limit the catch of *Pomacanthus* sp., both in terms of size and quantity, to allow the population to reproduce and recover. These findings can be used to support the sustainable management of ornamental fish, especially in maintaining the conservation of coral habitats and regulating the utilization of *Pomacanthus* sp.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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