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Spatial and Temporal Effect of Environmental Factors on the Length-Weight Relationship of the Bali Sardinella (*Sardinella lemuru* Bleeker, 1853) in Bali Strait Water

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ABSTRACT

Length-weight relationship (LWR) is an important parameter in the fish biology study since genetic and environmental factors govern fish growth. This study aimed to understand the growth pattern of *Sardinella lemuru*, related to different locations and seasons, to estimate *S. lemuru* fishing grounds with good growth patterns of this fish. Specimens (n=3282) of *S.lemuru* catch were collected at Pengambengan fishing port, Bali, from April 2022 to January 2023. *S.lemuru* landed at Pengambengan fishing port were caught from three zones of the fishing grounds in Bali Strait(zones 2, 5, and 6). Monthly data of the study area's environmental parameters, including SST and Chl-a, were downloaded from the Ocean Color-SeaDAS website. The relationship between LWR and the environmental parameters was statistically analyzed using the Partial Least Square (PLS) model. The LWR parameters, intercept 'a' and regression coefficient 'b', varied from 0.00261 to 0.12607 and 2.201 to 3.382, respectively. The condition factor ranged from 0.14 to 1.84. Simultaneously, both environmental variables play an important role in the growth of *S.lemuru* in all zones of the fishing grounds. The PLS analysis of the regression coefficient of the SST and CHL -a variable has a positive relationship with LWR. Environmental variables proved to have an indirect effect on the growth pattern of *S. lemuru*.

INTRODUCTION

The relationship between fish length and weight is very important in the science of population dynamics, among other things, to provide mathematical statements about the relationship between fish length and weight, estimating variations in weight estimates for certain lengths **(Froese *et al*., 2011; Baitha *et al*., 2018)**. Apart from analyzing the relationship between length and weight, it can also be used to estimate the yield and biomass of a fish population **(Anderson *et al*., 1983)**, to evaluate the condition of fish in aquaculture environments, and to study the environmental impact on fish **(Al Nahdi *et***

***al*., 2016)**. Condition factor is a useful parameter to indicate a condition of fatness, or the well-being of fish and provide information about food abundance and spawning season (**Dieb-Magalhães *et al*., 2015)**. By understanding the relationship, one may determine the number of fish landed, measuring populations spatially and temporally (**Khan *et al*., 2011)**. Differences in the regression coefficient 'b' length-weight relationship between locations, in terms of spatial and temporal variations, are due to dynamic environmental conditions, such as temperature, habitat types, and fish behavior in different habitats (**Al Nahdi *et al*., 2016)**.

The relationship between the length and weight of *S. lemuru* fish species have been profoundly addressed **(Nurhakim & Merta, 2004; Wujdi & Wudianto, 2015; Annisa *et al*., 2021; Laia *et al*., 2021; Aprianti *et al*., 2022)**. Growth patterns for the same fish species can differ in different locations **(Hasibuan *et al*., 2018; Nurtira *et al*., 2021)**. The differences may be influenced by both internal factors (e.g. fish genetics) and external factors, particularly water conditions, fishing time, and food availability in these waters **(Effendie, 2002)**. Condition factors indirectly indicate the physiological condition of fish, which is influenced by intrinsic factors (fat reserves, growth and gonadal maturation) and extrinsic factors (availability of food resources and environmental pressure) **(Gupta & Banerjee, 2020)**. Meanwhile, the condition factor indicates the condition of the fish, it also provides information on fish spawning time **(Henderson, 2005; Obasohan *et al*., 2012)**. The condition factor has been shown to be an efficient key and shows changes in fish conditions throughout the year.

Fish growth patterns and environmental variables could estimate the well-being condition of a fish population. This research aimed to provide detailed information on the spatial and temporal growth patterns of *S. lemuru* to support the formulation of the *S. lemuru* fisheries management plan in the waters of the Bali Strait. Thus, this study mainly used the partial least square (PLS) model. It is useful to indicate the growth patterns of fish by the regression coefficient of 'b' and its relation with environmental variables. This model could be used to predict *S. lemuru* growth patterns as the water environment changes.

MATERIALS AND METHODS

The field study to collect fish samples was conducted from April 2022 to January 2023 at the Pengambengan fishing port, Bali. The fish samples were collected using two fishing gears, namely gillnet and purse seine. According to the Lemuru Fisheries Management Plan (Ministry of Marine Affairs and Fisheries Decree No. 68 of 2016), the fishing ground of the *S. lemuru* in the Bali Strait is distributed into seven fishing zones (Fig. 1). Based on the fishing activities of fishers from Bali Island, they fished for *S. lemuru* in three zones: zone 2 (Sembulungan, Anyir, Watu Layar, Sekeben, Senggong, Klosot, Lampu Kelip, Kapal Pecah, Prepat), zone 5 (Pengambengan, Kayu Gede), and zone 6 (Bukit, Benoa, Jimbaran, Pemancar).

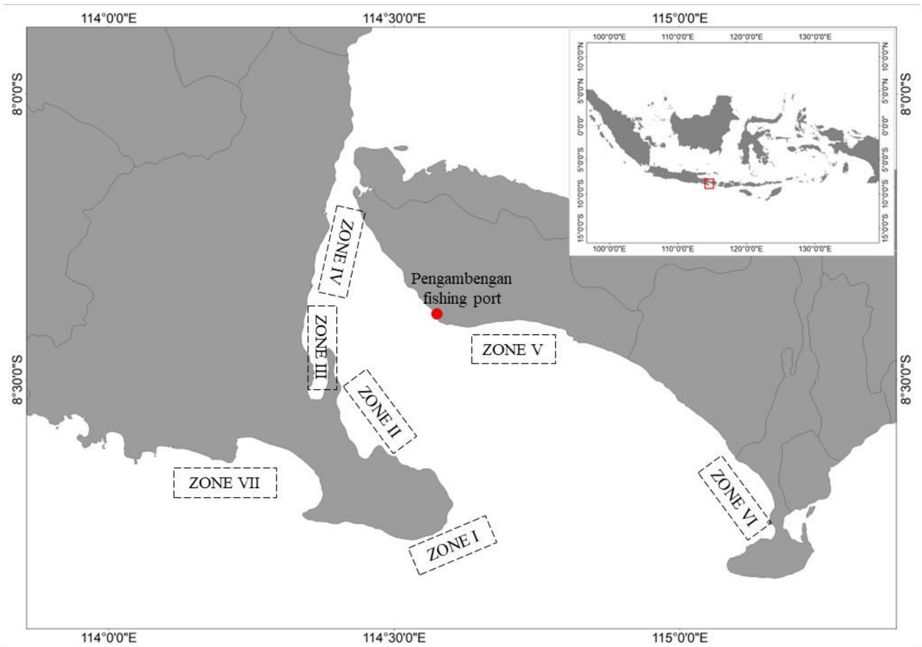

Fig. 1. Distribution of *S. lemuru* fishing ground in the Bali Strait. It consist of seven fishing zones

Monthly data on fish length and weight were administered for one year to consider the monsoon season and then grouped according to the season. *S. lemuru* specimens were divided into 3 size groups, namely: the juvenile size with value <11cm of the total length size, the sub-juvenile size with 11- 15cm of the total length size, and the adult size (>15cm) of total length size **(Aprianti *et al*., 2022)**. The division of monsoon seasons consists of 4 seasons, namely: West (December– February), West-East/Transition I (March– May), East (June– August), East-West/Transition II (September–November) **(Wyrtki, 1961)**. All fish samples were obtained from fishers' catches, and the fish were in dead condition. There were no live fish used in this research. A total of 3282 *S. lemuru* were collected from the three fishing zones. Fish length was measured using a measuring board with an accuracy of 0.5mm. The weight of the fish was measured using a digital scale with an accuracy of 0.10g. Monthly data on SST (Sea surface temperature) and CHL-a (Chlorophyl-a) parameters were obtained from the Ocean Color-SeaDAS website for the period April 2022 – March 2023.

Length frequency analysis was used to analyze the length and weight of *S. lemuru* fish during the study. The frequency distribution was estimated by determining the range = maximum value - minimum value. The number of interval classes followed **Sturges (1926)** equation with K = 1 + 3.3 log n, where K = number of interval classes; n = number of fish samples, and log n = logarithm base 10. The length of interval class *P* = Range/number of interval classes. Analysis of the length-weight relationship of the samples was used to estimate the growth pattern of the fish in natural habitat, according to the formula of Hile (1936) as cited in **Effendi (1979)** as follows:

$$W = aL^b$$

Where,
W = weight (g);
L = length (cm);
a and b are constants

Based on the constant b and statistically significant differences, the growth pattern was identified as b = 3 for isometric growth (I), b > 3 for positive allometric growth (+), and b less than 3 for negative allometric growth (-) **(Ragheb, 2023)**. Fulton condition factor K (Fulton, 1904) was calculated as follows:

$$K = W\frac{100}{L^3}$$

Where,
W = weight (g),
L = total length (cm).

The relative condition factor 'Kn' of **Le cren (1951)** was implemented in the present study as follow:

$$Kn = \frac{Wt}{We}$$

Where,
Wt = obeserve weight,
We = expected weight, which is quantified to understand the health and condition of the fish.

Regression of weight growth (Y) with environment variables (X) used the PLS (Partial Least Square) modelling **(Chandran *et al.*, 2023)**.

RESULTS

1. Length frequency distribution

The number of *S. lemuru* observed from April 2022 to January 2023 was 3282 specimens. Length-weight distribution of *S. lemuru* in Bali Strait is shown in Fig. (2).

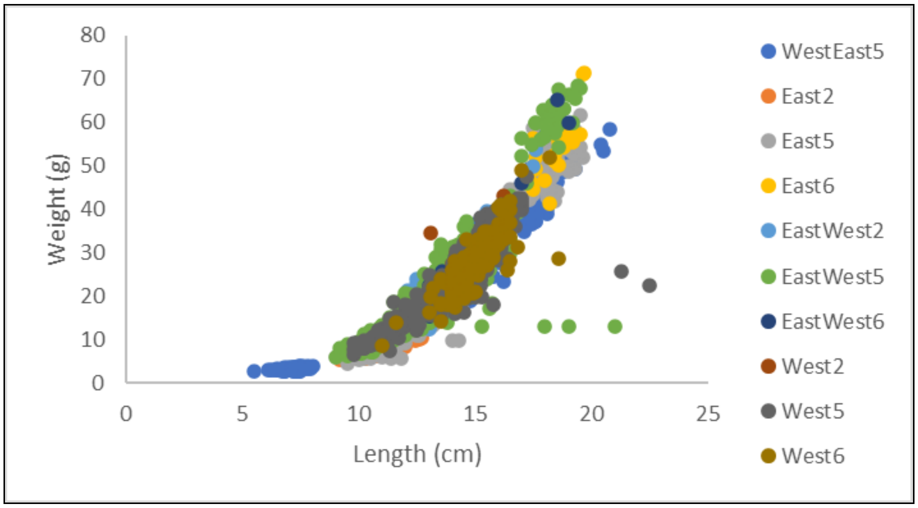

Fig. 2. Length-weight of *Sardinella lemuru* in Bali Strait

The total length of the fish samples ranged from 5.5– 22.5cm. The number of fish samples observed each month varied depending on the fishers' catches. The smallest fish caught in the Bali Strait water was in zone 5 of the transition I (WestEast5), with a size of 5.5cm in length. In this zone (East5), in another season, the smallest fish caught was 9.2cm in length, 17.2cm during transition II (EastWest5), and 11.4cm during the West season (West5). This confirms that the fish length growth increases along with the seasonal changes in the same area. The frequency distribution of *S. lemuru* fish lengths based on size groups is shown in Fig. (3).

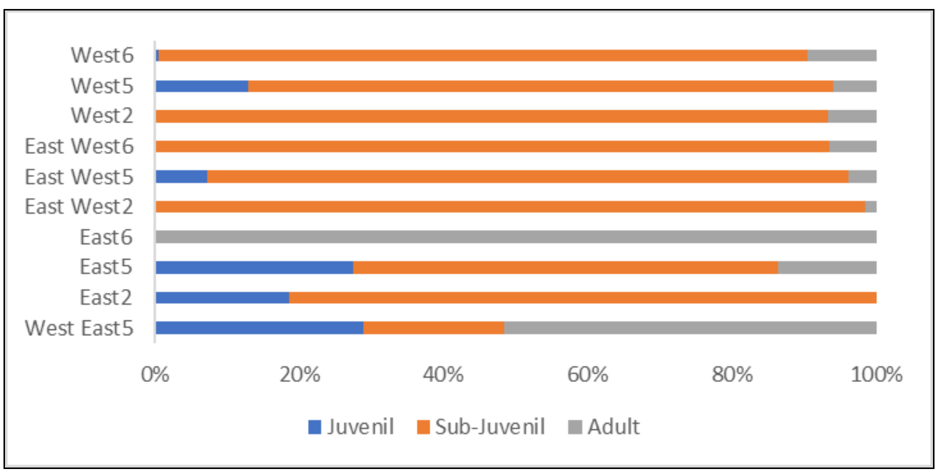

Fig. 3. Length frequency of *Sardinella lemuru* fish based on size groups

In Fig. (3) the juvenile fish size was only found in the West-East zone 5 (28.9%), East zone 2 (18.7%), East zone 5 (27.5%), East-West zone 5 (7.3%), West zone 5 (13.1%) season and West zone 6 (0.6%). The sub-juvenile fish sizes were found in almost all seasons and zones, except the East zone 6 season. Adult fish sizes were found in almost all seasons and zones, except the East Zone 2 season.

2. Length-weight relationship

Length-weight relationship and condition factor among different location in Bali Strait for *S.lemuru* are presented in Table (1).

Table 1. Length-weight relationship and condition factor among different location in Bali Strait for *S.lemuru*

Fishing zone	Regression parameter			Fulton's condition factor (K)		Relative condition factor (Kn)		Growth tipe
	a	B	R^2	Range	Mean ± SD	Range	Mean ± SD	
West East5	0.009223	2.81	0.99	0.32 - 1.62	0.81 ± 0.13	0.66 – 2.44	1.44 ± 0.18	(-)
East2	0.002607	3.38	0.77	0.43 - 0.95	0.70 ± 0.09	0.66 – 1.44	1.04 ± 0.14	(+)
East5	0.003248	3.28	0.95	0.34 - 1.09	0.72 ± 0.08	0.50 – 1.51	1.09 ± 0.12	(+)
East6	0.038555	2.20	0.49	0.68 - 1.05	0.86 ± 0.08	1.80 – 2.69	2.29 ± 0.20	(-)
East West2	0.005547	3.06	0.84	0.56 - 1.22	0.87 ± 0.09	0.87 – 1.87	1.34 ± 0.14	I
East West5	0.12607	3.00	0.85	0.14 - 1.30	0.86 ± 0.10	0.01 – 0.10	1.06 ± 0.008	I
East West6	0.00631	3.00	0.88	0.70 - 1.02	0.85 ± 0.06	1.11 – 1.64	1.36 ± 0.10	I
West2	0.020472	2.47	0.68	0.80 - 1.53	0.91 ± 0.11	1.59 – 2.93	1.87 ± 0.20	(-)
West5	0.008662	2.84	0.84	0.19 - 1.84	0.82 ± 0.35	0.37 - 15.78	1.45 ± 0.63	(-)
West6	0.006274	2.99	0.71	0.44 - 1.06	0.81 ± 0.09	0.73 - 1.73	1.33 ± 0.15	I

In Table (1), the 'b' values ranged from 2.20 (in the East6) to 3.38 (in the East2), while the 'a' values ranged from 0.002607 (in the East2) to 0.12607 (in the EastWest5). Positive allometric growth with 'b' value of 3.38 was observed in East monsoon zone 5 and 3.28 in zone2, and in the transition II season in zone 2 (EastWest2) with the 'b' value of 3.06. Meanwhile, the negative allometric growth patterns were observed in the transition I season in zone 5 with the 'b' value of 2.81, in the East season zone 6 with the 'b' value of 2.20, in the West season zones 2 with the 'b' value of 2.47 and zone 5 with the 'b' value of 2.84. In other zones and seasons, i.e. in EastWest seasons zones 5, 6, and West6 seasons indicated an isometric growth pattern. The coefficient of determination (R^2) ranged from 0.49– 0.99. Additionally, the value of the Fulton K condition factor ranged from 0.14– 1.84.

3. Fish growth and environment variables

The temperature distribution in the waters of the Bali Strait from March 2022– February 2023 ranged from 26.8– 30.7°C with an average temperature of 28.7°C (Table 2).

Table 2. Estimates of 'b' (linear regression), coefficient of determination (R^2) from regression, and distribution of SST and CHL-a over three fishing zone in Bali Strait

Fishing zone	b (LWR)	Environmental variable		PLS (R^2)	
		SST	CHL-a	SST	CHL-a
WestEast5	2.807	30.2	0.81	**0.432**	-0.081
East2	3.382	27.1	1.14	-0.326	-0.152
East5	3.280	26.9	3.54	-0.573	0.170
East6	2.201	26.8	3.05	-0.146	0.066
EastWest2	3.064	27.5	2.96	-0.068	**0.426**
EastWest5	3.003	27.1	2.96	-0.052	0.097
EastWest6	2.998	30.3	3.44	0.123	0.103
West2	2.470	30.7	0.3	0.135	-0.138
West5	2.840	30.7	1.15	0.312	-0.361
West6	2.991	30.4	0.8	0.259	-0.101

The highest chlorophyll-a concentrations occurred in the East and EastWest (transitional) seasons, while low chlorophyll-a concentrations occurred in the West and WestEast (transitional) seasons. The distribution of chlorophyll-a concentrations ranged from 0.3– 3.54mg/ m3, and the average value was 2.01mg/ m3. Dendrogram of similarity of Bray-Curtis SST and CHL-a data in each *S.lemuru* fishing zone in the waters of the Bali Strait is presented in Fig. (4).

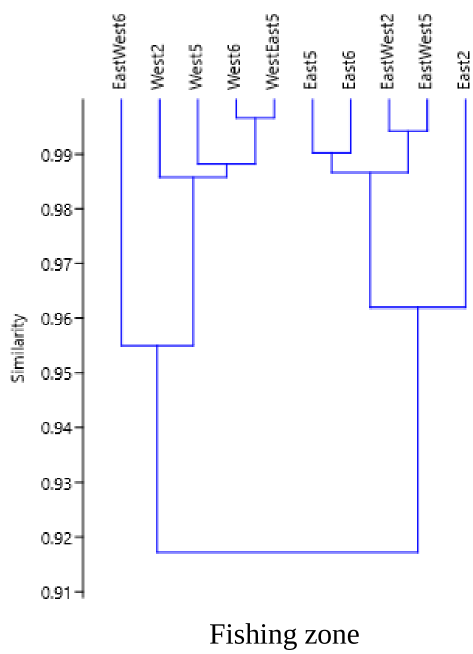

Fig. 4. Dendrogram of similarity of Bray-Curtis SST and CHL-a data in each *S. lemuru* fishing zone in the waters of the Bali Strait

The cluster analysis of the environmental conditions of the Bali Strait, based on Bray-Curtis, shows two clear groups formed in seasonal groupings at a similarity level of 0.91 and consisting of various other seasonal group. Furthermore, the most similarity among clusters with value higher than 0.99 was noted between the groups of West6 with WestEast5, and EastWest2 with EastWest6.

Bivariate Pearson correlation coefficient 'b' (LR) with SST and chlorophyll-a was calculated to test the significance correlation with a coefficient value of $P= 0.05$. The range of Pearson correlation value for this relationship is from -1 to 1 (Fig. 5).

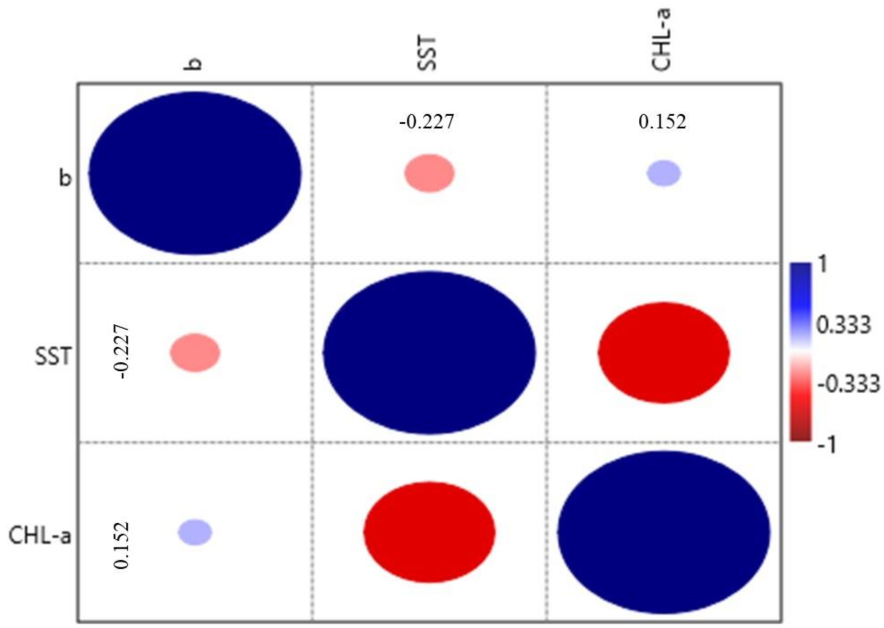

Fig. 5. Coefficient correlation fish growth and environmental variables

When the correlation value is positive, there is a relationship between variables, but if the value is negative, then the relationship is inversely proportional. Simultaneously, SST (-0.227) and chlorophyll-a (0.152) are correlated with the 'b' value.

DISCUSSION

1. Length frequency distribution

The smallest fish with a minimum length of 5.5cm caught in the zone 5 resulted from the gillnet. The mesh size of the gillnet governs the length of the fish catch. The mesh size of the gillnet used by fishers in the PPN Pengambengan was an average of 2.5'' (5cm) **(Himelda *et al*., 2011)**. Catching *S. lemuru* fish using fishing gear with a mesh size of 0.5 inches or smaller can cause recruitment over fishing. Recruitment overfishing is a condition where the fish caught have immature gonads (juvenile). During the study, the frequency distribution of *S. lemuru* samples was from 5.5 to 22.5cm in length.

Coincidently, in a study by **Wudianto and Wujdi (2014)**, the length of *S. lemuru* fish caught in the Bali Strait from August 2010 to December 2011 ranged from 6.5- 19.5cm.

The size distribution of *S.lemuru* caught in the waters of the Bali Strait showed varying patterns in each zone and fishing season. The same fish species but living in different areas have different body sizes **(Effendie, 2002)**. The unequal length frequency distribution of the fish is caused by differences in temperature in each fishing location and other factors that influence the distribution of fish in the fishing zone area **(Tampubolon *et al*., 2015)**. In Fig. (3), the most dominant size of *S. lemuru* caught was the sub-juvenile size group caught throughout the seasons, followed by the adult size group and then the juveniles. There were no adult *S. lemuru* size groups caught in the West zone 2, EastWest zone 6, EastWest zone 2, and East zone 2. Most adult and the juvenile fish were caught in the East season (July-August) until the beginning of transition season 2 (September), which is an indication of the spawning season in all fishing zones. The tropical Indo-West Pacific group of the Clupeid fish usually reaches maturity within 4 to 12 months. Based on the gonadosomatic index (GSI) in year 2010-2011, spawning occurs in September, indicating that there is one only spawning season occurring annually **(Wujdi *et al*., 2013)**. In this study, many fish caught were smaller in size at first gonad maturity. Their size at first gonad maturity decreased to 16.8cm in 2015 **(Wujdi & Wudianto, 2015)**. This can be an indication of growth overfishing since a huge number of fish are caught beforereaching the length of the first gonad maturity, and having no opportunity to grow and reproduce.

2. Length-weight relationship

The length-weight relationship of fish caught was estimated by the regression function from the fish total length (mm) and fish weight (g) with a linear model Ln L (mm) for length and Ln W (g) for the weight of the *S. lemuru* fish. The positive allometric growth pattern of the *S. lemuru* fish in this study means that the increasing growth of the length parameter is relatively more dominant than weight. Meanwhile, a negative allometric pattern means that weight growth is relatively more dominant than length growth, while isometric is a growth pattern that shows an equal increase in length and weight. In the eastern monsoon, zones 2 and 5 recorded a negative allometric growth pattern, but in zone 6, the isometric growth pattern means that there are differences in growth patterns between spatial and temporal. These different growth patterns influenced by several factors, namely the level of gonad maturity, sex, season, habitat, water environmental conditions (pH, temperature, salinity), food factors and body size, geographical location, competition, parasites and diseases **(Roul *et al*., 2017; Nurtira *et al*., 2021; Segun *et al*., 2022)**. In Table (1), the average condition factor for *S. lemuru* fish fluctuates monthly. This study reveals that the condition factor for the *S.lemuru* fish caught in the West2 season is higher than in other locations. The highest average range for *S. lemuru* condition factors was 0.80– 1.53, with an average of 0.910 found in the West2 season and the lowest in the East2 season, with an average value of 0.70. The b coefficient varies by sex, regardless of fish size, season, and location variables **(Phan *et al*., 2021)**. Condition factors are used to detect and indicate the condition of fish, both in terms of physical capacity for reproduction and survival **(Le cren, 1951)**. The average value of condition factors spatially and temporally is influenced by location, fish size, and the life cycle of *S. lemuru*. The highest K value was found in zone 2 of the eastern monsoon, which is the nursery zone. The average catch of fishers in this zone is included in the sub-juvenile and adult groups where the *S. lemuru* fish are biologically ready to spawn.

3. Fish growth and environment variables

The temperature and chlorophyll-a of the waters of the Bali Strait fluctuate and annually. The highest temperatures occur in the West season to the transition season, and the lowest temperatures occur in the East season (Table 2). Spatially, the high concentration of chlorophyll-a is in zone 5, which is a fishing zone near the coast. Otherwise, zone 6 is a water area that has a bay so that phytoplankton can thrive in the waters around the river mouths or offshore waters where upwelling occurs. The results of the same research conducted by **Adivitasari and Wirasatriya (2022)** show that the East monsoon occurring from June to August has relatively low-temperature values with chlorophyll-a concentrations tending to increase, while the West monsoon occurring from December to February has relatively low-temperature values high with chlorophyll-a concentrations tending to decrease. The highest temperature variations occur in the West season in all fishing zones, ranging from 30.7– 30.4°C. While in the West season, there is a decrease in the upwelling intensity so that sea surface temperatures will be warmer **(Sukresno *et al*., 2018)**.

The cluster analysis of the water environmental conditions, based on Bray-Curtis technique, shows a cluster group between seasons and zones. The dendodgram presents the condition of the water environment divided into 2 groups, the West - Transitional season group and the East - Transitional season group. The higher the similarity value, the closer the environmental condition between fishing zones, with a maximal similarity value of 1. A similar cluster analysis has been previously carried out by **Balcı *et al*. (2014)** to investigate the similarity of water depths between station based on physicochemical variables of the coastal waters of the Kapidag Peninsula. The term similarity indices has also come to include its complement, dissimilarity or "distance" indices. The diversity and similarity indices have beenused, and they are normally calculated for a given taxonomic grouping, e.g. birds, mammals, plants or a given size or structural grouping such as trees, shrubs, herbs etc. When used in aquatic situations, these groupings may include macroinvertebrates, fish, or diatoms **(Washington, 1984)**.

In this case, the PLS method is used to predict the response of fish growth to the SST CHL-a variables and to identify interaction patterns between variables. Each variable contributed 43.2% to the transition I season (WestEast) zone 5, and 42.6% to the transition II season (EastWest) zone 2. In another case with the keting fish (*M. gulio*), environmental parameters (temperature, conductivity, TDS, hardness, resistivity, pH, DO, total oxygen, ORP, and salinity) had a low influence on fish condition factors **(Paujiah *et al*., 2023)**. Although the condition factor value has no relationship with environmental factors. This shows that the species is well adapted to its habitat **(Phan *et al*., 2021)**. Overall, both spatial and temporal environmental variables have a minor influence on growth. Consistently, **Chandran *et al*. (2023)** reveled that differences in environmental conditions between habitats have either a positive or a negative impact on fish growth. However, it is important to note that this study considers individual environmental variables, but synergistic interactions between them are not considered.

CONCLUSION

The growth patterns of *S. lemuru* in the Bali Strait indicated diverse patterns, i.e. isometric, positive and negative allometric growth patterns. Differences in growth patterns and condition factors of *S. lemuru* indicate changes that occur throughout the seasons and fishing zones. There is a relationship between weight growth variables and the environment confirmed by PLS model in this study. Scientific information on the populations and biological status of *S. lemuru* is important to support science-based strategies and policies for the sustainable management of *S. lemuru* fisheries in the Bali Strait.

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