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The weight-length relationship and condition factor of the spiny lobster *Panulirus penicillatus* (Olivier, 1791) in the red sea coast

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Abstract
The objective of the present study was to establish the total weight (W)-carapace length (CL) relationship and condition factor (Cf) of the spiny lobster *Panulirus penicillatus* (Olivier, 1791) in the Sudanese Red Sea coast. Sixty specimens were used in the study. The male: female ratio was 1: 1.63. The minimum, maximum, and mean CL of male, female, and mixed male/female lobsters were (4.5-13.7, 8.34 cm), (4.2-12.3, 7.95 cm) and (4.2-13.7, 8.1 cm) consecutively. The corresponding W were (136-995, 488 gm), (170-1243, 456 gm) and (136-1243, 468.17 gm). The "b" values of the power regression of W vs. CL were 2.118, 2.281, and 2.208 for male, female, and mixed male/female lobsters in order, indicating negative allometric growth. Cf based on W and CL was 0.0837, 0.0865 and 0.0854 for male, female, and mixed male/female lobsters. The regression of Cf vs CL indicated that Cf decreased during growth. The study concluded that Sudan Red Sea coast water is conducive for lobster growth.

Keywords: *Panulirus penicillatus*, spiny lobster, Red Sea, length, weight, sex, condition factor.

1. Introduction
Lobsters are large decapod crustaceans of high commercial value. They are exposed to intensive fishing, or overfishing in their natural habitat, the tropical and temperate regions. In many parts of the world, lobster fisheries are regulated, in others they are not. In some areas, their coastal habitats were damaged by adjacent anthropogenic activities. Their main habitat is exposed, shallow, flat coastal or island reefs of mostly dead coral with many crevices and holes suitable for hiding [1]. Lobsters are fished by traps and nets or collected by gloved hands at night, they are nocturnal animals [2, 3].

In Sudan Red Sea coast there are three species of spiny lobster of economic value: *Panulirus penicillatus*, the common lobster portrayed in the fish market of Port Sudan, the major Sudanese Red Sea city; *Panulirus versicolor* is occasionally portrayed, while *Panulirus ornate* is commonly not [3]. Worldwide, *P. penicillatus* distribution extends from the Eastern Pacific to the Western Indian Ocean and the Red Sea. It is fished throughout this range, but at present, is considered a "least concern" species though is believed to be over-exploited in some areas. In Sudan, the lobster fishery is based mainly on *P. penicillatus*. This fishery is not regulated, the possibility of future overfishing must be avoided by adopting sound and viable management policy. However, the biological and fisheries indicators that will enable planning such policy is not available. The present study aimed to contribute in availing some descriptive statistics of *P. penicillatus* size (length and weight), sex ratio, weight-length relationship and condition factor, which are among the information that will be needed for planning the management.

2. Materials and Methods
2.1 Collection of the *Panulirus penicillatus* samples
Sixty *Panulirus penicillatus* (Olivier, 179, Fig. 1) were collected during a surveys carried out by "The Red Sea Fisheries Research Station" during 2015 to 2019 on coastal waters of the Red Sea in the vicinity of Port Sudan area (Fig. 2).

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Fig 1: *Panulirus penicillatus* (Olivier, 179). Photo by Mr. Shakir, Faculty of Oceanography and Fisheries, Red Sea University, Port Sudan, Sudan
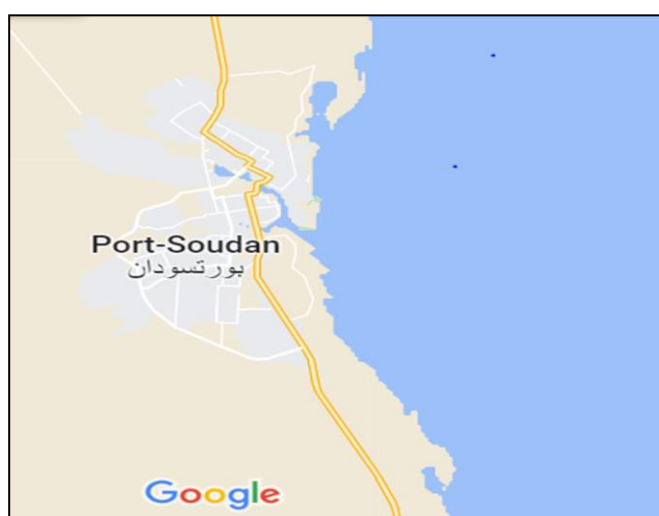

Fig 2: Port Sudan city (19°37′N 37°13′E) and the coastal area from which the *Panulirus penicillatus* used in the present city was collected

2.2 Sex determination
Sex was determined externally, and percentage of males: female was calculated.

2.3 The morphological measurements taken
- Carapace length of the individual lobsters was measured with a digital caliper to the nearest 0.1 centimeter.
- The corresponding total weight was established to the nearest 0.1 gram using a digital balance.

2.4 The total weight-carapace length (W-CL) relationship
The relationship between total weight (W) and corresponding carapace length (CL) was established by means of linear (W = a + b*CL), logarithmic (W = a + b*log CL) and power (W = $_aL^b$) regressions for male, female, and mixed (male/female) lobsters, Where: W = total weight in grams [4, 5, 6]. CL" corresponding carapace length in millimeters, and "a" and "b" are constants, "a" is the intercept of the regression line on the y axis, and "b" is the slope of the line.

2.5 The condition factor (Cf) of the lobster
The condition factors (Cf) of male, female, and mixed male/female lobsters were calculated as the percentage ratio between total weight and carapace length:

$Cf = 100W/L^3$. W in grams, and Cl in millimeters [7, 8].

Lobsters with higher Cf are considered to be in better condition (stouter/fatter). Cf of mixed male/female lobsters was related to carapace length by linear, logarithmic and power regressions to infer how the condition of the lobster changes during growth (growth is indicated by increase in carapace length), that is to say, to infer whether the lobster becomes slimmer, fatter, or maintains its status quo as it grows. Cf of male or female lobsters alone were not related to carapace length by regression equations because the difference between them was not statistically significant.

2.6 Statistical analysis
Excel, SPSS and Minitab statistical packages were used to establish basic statistics, t-tests, binary correlations, regressions, tabulation and graphics.

3. Results
3.1 The sex ratio, the mean carapace length and the total weight of *Panulirus penicillatus*
The coastal survey carried out during the present study showed that there are three species of spiny lobster in the Sudanese Red Sea: *Panulirus penicillatus*, *Panulirs versicolor* and *Panulirus ornatus*, the former being the most common.
The male: female ratio of *Panulirus penicillatus* was 1: 1.63 in favor of females. The mean CL of the male lobsters was 8.34 cm that of the female was 7.95 cm (Table 1). The average W of the male was 488.00 gm., that of the female was 456.06 gm. Differences between the mean CL, and mean W, of male and female lobsters were not significant (Table 1). The mean CL of mixed male/female lobsters was 8.1 cm, and the corresponding W was 468.17 gm.

Table 1: Basic statistics of carapace length and total weight of male, female, and mixed male/female *Panulirus penicillatus*. Means with similar superscripts are not statistically different

Parameter	Sex	N	Minim	Maxim	Mean	STD ER
Carapace length (cm)	Males	22	4.50	13.70	8.34[a]	.44
	Females	36	4.20	12.30	7.95[a]	.31
	Mixed males / females	58	4.20	13.70	8.1[a]	.25
Total weight (gm)	Males	22	136.00	995.00	488.00[a]	52.85
	Females	36	170.00	1243.00	456.06[a]	49.29
	Mixed males / females	58	136.00	1243.00	468.17[a]	36.34

3.2 The total weight-carapace length relationship of *Panulirus penicillatus*
The linear, logarithmic and power regressions expressed the relationship between W and CL of male, female, and mixed male/female lobsters very well (Table 2 and Fig 3, 4, and 5), as indicated by their high R^2, the power and linear regressions

were slightly stronger than the logarithmic one because they had slightly higher R^2. The three regressions were highly significant. The "b" value of the power regression of 2.118, 2.281, and 2.208 of male, female, and mixed lobsters in order indicated negative allometric growth.

Table 2: The total weight-carapace length linear (Li), logarithmic (Log) and power (Po) regressions of male, female, and mixed male/female *Panulirus penicillatus*

Parameter	Sex	Regression	A	B	R^2	P
Total weight-carapace length relationship	Male	Li	-449.73	112.43*	0.867	0.000
		Log	-1393.54	899.53*	0.835	0.000
		Po	5.042*	2.118**	0.870	0.000
	Female	Li	-760.38	153.01*	0.895	0.000
		Log	-1972.52	1185.42*	0.799	0.000
		Po	3.65*	2.281**	0.885	0.000
	Mixed male/female	Li	-625.35	135.03*	0.869	0.000
		Log	-1718.51	1058.92*	0.796	0.000
		Po	4.21*	2.208**	0.876	0.000

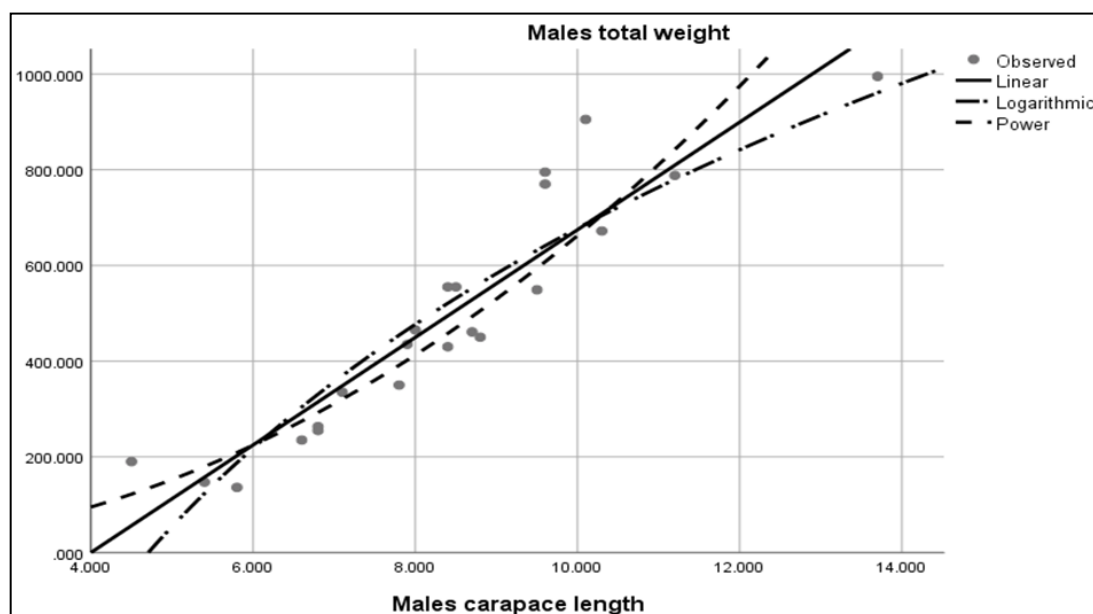*: significant at 0.05 level, **: significant at 0.01 level

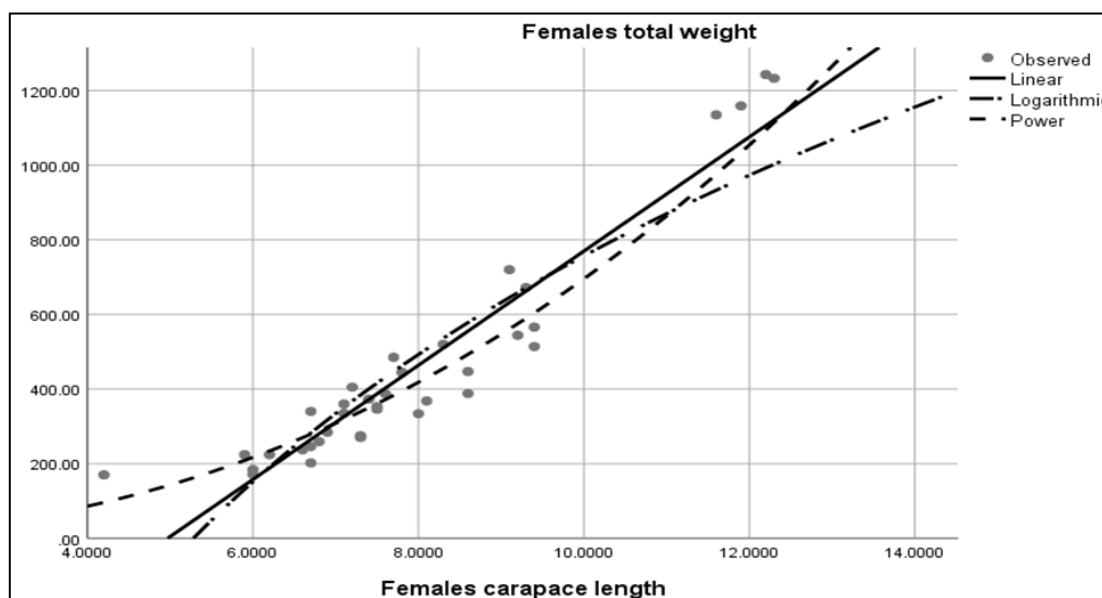**Fig 3:** The total weight-carapace length relationship of male *Panulirus penicillatus*.

Fig 4: The total weight-carapace length relationship of female *Panulirus penicillatus*.
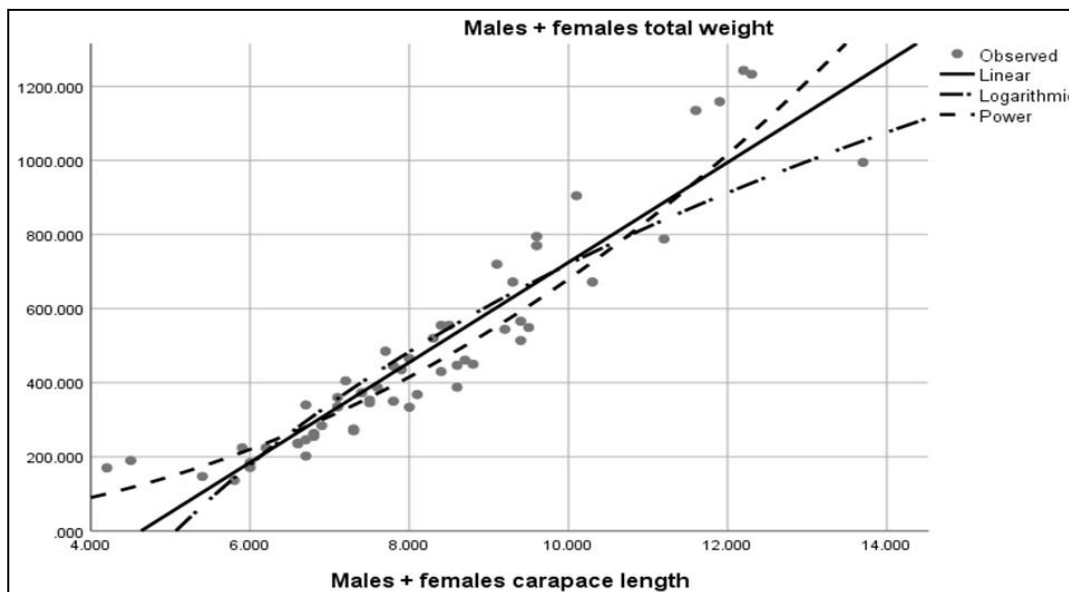
Fig 5: The total weight-carapace length relationship of mixed male/female *Panulirus penicillatus*

3.3 The condition factor (Cf) of *Panulirus penicillatus*

The "health" condition of male, female, and mixed male/female *Panulirus penicillatus* was similar. Cf for the three groups ranged from 0.0837 to 0.0865, the differences were statistically insignificant (Table 3). The linear, logarithmic and power regressions of Cf of mixed male/female lobster vs carapace length had negative "b" values (Table 4) indicating that the condition of the animal decreases during growth (Fig. 6), i.e. the animal gets slimmer as it grows (as its carapace length increases). All the regressions had medium R^2 values and were highly significant. The linear regression was better in expressing the relationship than the other two as it had the higher R^2 value.

Table 3: Basic statistics of the condition factor (Cf) of male, female, and mixed male/ female *Panulirus penicillatus*. Means with similar superscripts are not statistically different

Sex	N	Minimum	Maximum	Mean	Std. Error
Cf male	22	.04	.21	.0837[a]	.00668
Cf female	37	.06	.23	.0865[a]	.00460
Cf male + female	58	.04	.23	.0854[a]	.00385

Table 4: Linear, logarithmic and power regressions of the condition factor (Cf) of mixed male/female *Panulirus penicillatus* vs. carapace length

Regression	A	B	R^2	P
Linear	0.1575	-0.0089*	0.337	0.000
Logarithmic	0.2557	-0.0825*	0.431	0.000
Power	0.421*	-0.792**	0.482	0.000

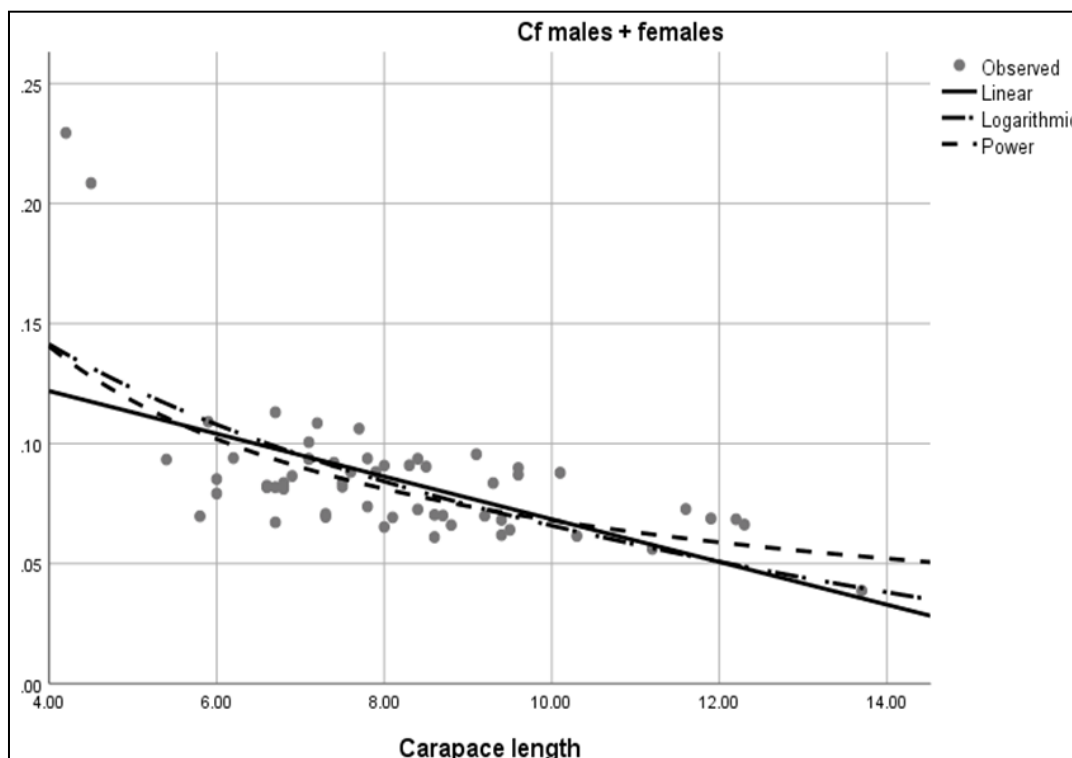*: significant at 0.05 level, **: significant at 0.01 level

Fig 6: Linear, logarithmic and power regressions of the condition factor (CF) of mixed male/female *Panulirus penicillatus* vs. carapace length.

4. Discussion

Panulirus penicillatus distribution extends from the eastern Pacific Ocean to the western Indian Ocean and the Red Sea [1, 9, 3]. The present study showed that this species is the commonest spiny lobster in the Sudanese Red Sea. *Panulirus versicolor* is less common, while *Panulirus ornate* is rare. *P. penicillatus* is of high economic importance. It is collected by fishers during night from shallow, flat, mostly dead reefs facing the waves. The biology and fisheries of this species have not been studies in Sudan, and future overfishing is possible.

The male: female ratio of *P. penicillatus* of the present study was 1: 1.63 in favor of females. Survey of the literature showed that, in general, sex ratio of lobsters (of various species) has no specific trend of dominant male or female ratio, the ratio tends to be close to unity. Karisma *et al.* (2017) [10] reported sex ratio of 1:1.04 for *P. penicillatus* in the east Simeulue beach (Indian Ocean – Sumatra - Indonesia). Munandar *et al.* (2019) [7] reported a ratio of 1.108 for the same species in Labangka waters, south Sumbawa, Indonesia. The mean carapace length (CL) of male, female, and mixed male/female *P. penicillatus* of the present study was 8.3, 7.95 and 8.1 cm in order. The corresponding mean total weights (W) were 488, 456.06 and 468.17 gm. These values were good when compare with values reported in the literature. For example, for the same species in the east Simeulue beach, Karisma *et al.* (2017) [10] established mean CL and W, as 8.676 cm and 375.43 gm. Munandar *et al.* (2019) [7] found that means of CL and W of male, female, and mixed male/female *P. penicillatus* in Labangka waters, south Sumbawa, Indonesia were 7.060, 6.852 and 6.951 cm, and 278.61, 274.47 and 276.44 gm consecutively. Based on MAFM (2015) [11] and (2016) [12], one can suggest that in Sudan's Red Sea only spiny lobsters with CL > 8 cm or W > 200 gm per individual should be fished, that is after they have reached first maturity. *P. penicillatus* reaches maturity when CL is between 5.7 to 6.7 cm and W between 130 to 180 gm [13]. Salim *et al.* (2019) [14] reported male CL and W at first maturity of the same species as 6.775 mm and 273 gm, the values for the female were 6.257 mm and 217 gm. According to Asrial *et al.* (2020) [15], the CL of 1 years old *P. penicillatus* is expected to be 8.93 cm, while that of 9 years and 5 months old would be 13.35 cm. The CL of *P. penicillatus* of the present study ranged from 4.2 to 13.7 cm, mean of 8.1 cm, indicating the presence of many old lobsters in the population. The mean of 8.1cm is slightly higher than that required by MAFM.

In the present study, linear, logarithmic and power regressions expressed the W-CL relationship of *P. penicillatus* very well. These regressions indicated negative allometric growth. The values of the constant "b" of the power regression were 2.118, 2.281, and 2.208 for male, female, and mixed male/female lobsters in order, which were less than 3, the theoretical value for isometry. Negative allometry means that growth in length (indicated by increases in total lobster length or carapace length) proceeds at faster pace than growth in weight, the animal gets slimmer as it grows. In positive allometry, where "b" is more than 3, growth in weight proceeds at faster rate than growth in length, and the animal gets stouter/plumper as it grows. When "b" equals 3, the growth is said to be isometric, i.e. increase in length and weight proceeds at the same rate. The magnitude of deviation from 3, expresses the magnitude of allometry (i.e. magnitude of deviation from isometry). Karisma *et al.* (2017) [10] estimated "b" of *P.*

penicillatus in the east Simeulue beach as 2,571. Munandar *et al* (2019) [7] reported 2.31 in Labangka waters, south Sumbawa. Indonesia. Negative allometry was also reported for *P. penicillatus* in Labangka tidal waters, Indonesia (b = 2.422) [15] and in south coast of GunungKidul and Pacitan [16]. An extensive list of "b" values of the total W-CL relationship of several *Panulirus* spp. presented by Situmorang *et al.* (2021) [17] shows clearly that negative allometry is a common phenomenon in the Genus *Panulirus.*

The condition factor (Cf) estimated for *P. penicillatus* of the present study based on W and CL was 0.0837, 0.0865 and 0.0854 for male, female, and mixed male/female lobsters, the differences were not significant. The regressions of Cf of mixed male/female lobster vs CL had negative "b" values indicating that the animal gets slimmer as it grew. This agrees with the negative allometric growth inferred from the calculated W- CL relationship (b < 3). Comparing Cf values of the present study with values obtained by the previous studies is not easy because the different methods used for calculating Cf for lobsters are not standardized, and so, they give different values for the same sample. Thus, Cf may be calculated by the formula $Cf = 100W/CL^3$ (where W is in grams and CL in millimeters) [17, 15, 8], or $Cf = 100W/L^3$ (where W is in grams and L (total length) in centimeters) as was originally proposed by Fulton (1902) [18] for fishes. The ratio index W/L or W/CL is also in use [19]. The allometric condition factor, $KA = W/L^b$ takes into consideration the allometric relationship between weight and length [20]. The relative condition factor Kn is computed as $Kn = W / Wp$ Where: W is real total weight, and Wp is the estimated total weight calculated by $Wp = aL^b$ [21], this approach eliminates the effect of length on the condition factor. Each method has its advantages and disadvantages. In lobsters, CL can be measured more accurately than the length of the highly flexible lobster body, but body length (total length) has the advantage of been the actual animal length. Cf calculated for male, female, and mixed male/female *P. penicillatus* in Labangka, south Sumbawa, Indonesia using CL was 0.079, 0.085 and 0.080. These values were close to the ones obtained in the present study. Based on CL, Asrial *et al.* (2020) [15] estimated CF value of *P. penicillatus* between 0.034, and 0.127, the mean value was 0.081. Generally, high values of Cf is taken as evidence of the suitability of the environment, but other factors such gonadal stage and age may be important. Cf values obtained in the present study indicated an environment conducive for the spiny lobster growth.

5. Acknowledgements

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