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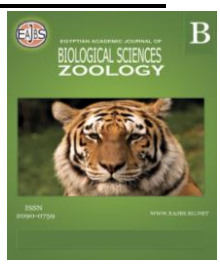

Spatial Variations in The Length-Weight Relationship and Relative Condition Factor of The Introduced Freshwater Crayfish, *Procambarus clarkii,* (Girard, 1852) from the River Nile and Its Tributaries, Egypt

Eman, A. Shaaban [(1)]; Awaad, A. M. El-Sayed [(2)]; Faten El Feky [(3)], Soad, Mohammed Abdel Gawad [(1)] and Neveen H. Mohammed [(3)]

1- National Institute of and Oceanography and Fisheries, Al Kanater.
2- Faculty of Science (Boys), Al-AzharUniversity, Cairo, Egypt.
3- Faculty of Science (Girls), Al-Azhar University, Cairo, Egypt.

E.mail*: e.a_ahmed@yahoo.com

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ABSTRACT

The biometric relationships for the freshwater crayfish, *Procambarus clarkii* (Girard, 1852) collected from four different sites of the River Nile and its tributaries (Helwan, El Warraq, El Rahawy and El Rayah El Menoufy) had calculated during the present study. The size of these individuals varied from 6.6 to 14.3 cm in total length, and from 3.6 to 80.8 g in total body weight. There was an obvious gradual increase in average weight, varied from 26.81 ±14.47g at Helwan to 27.46±18.6 g and, 27.52 ±17.22 g at El Warraq and El Rayah El Mounofy, respectively, reaching the highest average of 34.48±22.5 g at El Rahawy. The relationship between the total length and total body weight for the whole population (sexes combined) showed curvilinear relation at all sites, with positive allometric regression coefficient "b" higher than an isometric value ‘3”, recorded 3.169, 3.301 and 3.228 at Helwan, El Warraq and El Rahawy, respectively, but declined to negative allometry of 2.576 at El Rayah El Mounofy. The values of “b” were also higher in males than females at all between sexes (P> 0.05). The values of relative condition factor "Kn" (wellbeing) for this species was generally higher than ‘1” at most sites and averaged 1.14 ± 0.20, 0.96± 0.18, 1.12± 0.14 and 1.11+0.27 at Helwan, El Warraq, El Rahawy and El Rayah El Mounofy, respectively. It was also relatively higher in small and medium-sized individuals than the larger sizes.

INTRODUCTION

The red swamp crayfish, *Procambarus clarkii* (Girard, 1852), family Cambaridae (Crustacea: Decapoda) considers very common native species that live in many freshwater bodies of the south-central U.S.A., particularly Louisiana (Huner and Avault, 1995). It invaded other countries including Europe, Australia and China (Huner *et al*., 1993), and represents at the present times the most common widespread species from over 400 species of freshwater crayfishes belonging to the families Astacidae, Cambaridae and Parastacidae around the world (Huner and Lindqvist, 1995). This

species was introduced into the Egyptian freshwater systems, the River Nile and its drainage canals, during the early 1980s via a private fish farm (Ibrahim *et al*., 1995; Ibrahim and Khalil, 2009).

Several attempts in different countries around the world were carried out to remove or overcome the occurrence of this species from its new habitats due to its harmful effects on natural biodiversity, but all failed. Therefore, during the last few years, many studies had made to maximize its use as a source of protein, as live bait, as animal diet, or even as experimental animals in the classroom in order to eliminate a considerable number of its population (Lodge *et al.,* 2000; Ibrahim and Khalil, 2009). This species can tolerate a wide range of water qualities (Ibrahim and Khalil, 2009). It has about 20-25% of its total body weight is edible meat, even other wastes (carapace, viscera and cephalothorax) have high protein sources, and can be used as human food(Zaglol and Eltadawy, 2009; El-Sherif and Abd El-Ghafar, 2015), fish meal (Agouz and Tonsy, 2003), or as food for egg and meat producing poultry (Raafat, 2006).

In Egypt, only about 4.6 tonnes are the annual yield per year estimated by Emam and Khalil, (1995), while Aly *et al*. (2020) described different fishing methods used for the collection of this species along the River Nile. Now, this species considers as a new natural protein resource, with high nutritive value, and can be consumed by the Egyptian peoples as cheap food, with high protein (Elmossalami and Emara, 1999; Mona *et al*., 1999; Raafat, 2006; Ibrahim and Khalil, 2009; El-Sherif and Abd El-Ghafour, 2015), instead of the other high expensive marine shrimps and lobsters. Fishar (2006) presented a case study on *Procambarus clarkii* in the River Nile and pointed out the negative and positive impacts for this species in the Egyptian waters. He proposed two scenarios for dealing with this species either consume locally or export to other countries. Heikal *et al*. (2018) used *Procamarus clarkii* as a biological control agent of the mosquito larvae, *Culex quinquefasciatus* where both males and females testes as predators of all instar larvae at different populations, the 4th instar were the most consumed stage.

As with other crayfishes, there is no easy way to determine the rate of growth or age, since these animals do not retain any permanent features during or after molting such as the growth rings on the scales of fish. The most common criteria used to describe the size and rate of increments of crayfish included: increments in carapace length, the annual instantaneous growth rate in weight, molt increments, and percentage of premolt carapace length (Brewis and Bowler, 1982; Lowery, 1988). Other authors have described the patterns of differential growth that occur at particular stages in the life cycle as detected by determining the ratio between the size of different parts of the body or heterogenic growth (Rhodes and Holdich, 1979; Thomas,1983; Hogger,1984).

In Egypt, Saad *et al*. (2015) studied the growth of this species, based on the b-value of the length-weight relationship and from the length-frequency distribution analysis for combined sexes. They estimated the asymptotic length (L∞), growth coefficient (K), instantaneous total mortality (Z), natural mortality (M), fishing mortality (F), exploitation ratio (E), and length at first capture (Lc). The relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) analyses for *P. clarkii* in the River Nile were estimated.

This study aims to throw light on the biometric relationships of *Procambarus clarkii* indicating the possibility of exploitation as mass stock proteins resource from this invasive aquatic animal into the Egyptian freshwater habitats.

MATERIALS AND METHODS

A total of 693specimens of *Procambarus clarkii* were collected seasonally during

the period from summer 2015 until spring 2016 from four study sites along the River Nile and its tributaries. The site I was chosen at the main River at El Maasara and Helwan (Cairo governorate). It affects industrial sources of pollution and anthropogenic effects. Site II was chosen also along the main River at El Warraq (Giza governorate), threatened by anthropogenic effects; while site III was chosen at El Rahawy Drainage (Qalyubia governorate), which represents the agricultural runoff and anthropogenic effects and site IV was chosen at El Rayah El Menoufy (Menoufiya governorate) represents the agricultural water drainage. All observations on sources of pollution, water levels, vegetation type and density, water current and decomposed wastes were recorded.

The collected specimens were transported to the Hydrobiology Lab, National Institute of Oceanography and Fisheries, Al Kanater Branch. All individuals were sexed and weighed after blotting excess water with absorbent tissues to the nearest 0.1 g using an electric balance with an accuracy of 0.01 g. The total body length, standard length (length without telson and uropods), right chela length and abdomen width (maximum breadth of abdominal segments) were measured with a Caliper Vernier with an accuracy of 0.01 mm. The length-weight relationship for these individuals was calculated according to the following logarithmic equation:

$Y = a \pm b X$ (Hile, 1936, Bagenal and Tesch, 1978).

Where Y= body weight (g), X = carapace length (cm), a = constant and equals to the intercept of the straight line with Y-axis, and b = the coefficient of allometry.

The method of least squares was used and the coefficients (a) and (b) were calculated by plotting log Y against log X according to the formula of Hile (1936) and Bagenal & Tesch, 1978) as follows:

$\text{Log } Y = \text{Log } a \pm b \log X$

The well-being or the relative condition factor "Kn'" was calculated for the collected crayfish individuals according to the following formula:

$Kn = W/W`$ (Hile, 1936, Bagenal and Tesch, 1978)

Where W = observed weight and W`= calculated weight from the length-weight relationship.

RESULTS

The Length-Weight Relationship:

A- Sexes Combined (whole population):

A total of 693specimens (471 males, 222 females) of *P. clarkii* were used for studying the relationship between total length (TL) and total body wet weight (W) for the sexes combined population at the four studied sites. These specimens varied from 6.6 to 14.3 cm in total length, and between 3.6 to 80.8 g in total body weight. Most individuals of this species have a hard- rigid outer exoskeleton, with dark- red, or deep brownish color carapace, some of them have prominent whitish granules during old stages, but others are characterized by green or grey color with scars and dull color for old carapace. The present data showed that the whole population of this species has total body weight averaged 26.81 ±14.47, 27.46±18.6, 34.48±22.5 and 27.52 ±17.22 g at Helwan, El Warraq, El Rahawy and El Rayah El Menoufy, respectively. It is obvious that the highest average weight was recorded at El Rahawy, but the lowest average body weight was calculated at Helwan. These data are in agreement with that determined by Amer *et al*. (2016) which averaged 30.01 g total weight for *P. clarkii* collected from Al- Kanater.

The results of this relationship for all individuals from the four studied sites are given in Tables (1-4) and presented in Figures (1-4) and were represented by the least

square equations according to the following logarithmic formulae:
Log W= -1.867 + 3.169 Log TL, "r= 0.821" (Helwan)
Log W= -1.997 + 3.301 Log TL, "r= 0.891" (El Warraq)
Log W= -1.902 + 3.228 Log TL,"r= 0.834" (El Rahawy)
Log W= -1.214 + 2.576 Log TL, "r= 0.653" (El Rayah El Menoufy)

These relations are curvilinear and positively correlated with positive regression coefficient "b" beings higher than the isometric value "3", at all sites except El Rayah El Mounofy with negative regression coefficients " b" or negative allometric value, b =2.576.

The regression coefficients value were higher than 3 at Helwan, El Rahawy and El Warraq denote to faster increase in body weight than total length but declined to negative allometric, below than the isometric values at El Rayah El Menoufy denote to faster increase in total length than body weight. This may be attributable to an accumulation of increased water in the body of the collected specimens from the first three sites as a result of increasing bioaccumulation of heavy metals in animal tissues.

Table 1: The values of observed and calculated length-weight relationship and relative condition factor for *P. clarkii* collected from Helwan.

Items / Size class (cm)	Mean weight (g)		Relative condition factor "Kn"
	Observed	Calculated	
7	7.95	7.64	1.04
8	16.92	9.88	1.71
9	17.83	14.45	1.23
10	24.64	23.02	1.07
11	32.1	30.57	1.05
12	37.39	37.01	1.01
13	50.85	55.87	0.91
Averages ± SD	26.81±14.47	25.49± 17.2	1.14± 0.2

Table 2: The values of observed and calculated length-weight relationship and relative condition factor for *P. clarkii* collected from El Warraq.

Items / Size class (cm)	Mean weight (g)		Relative condition factor "Kn"
	Observed	Calculated	
6	3.85	6.63	0.58
7	7.44	6.95	1.07
8	14.15	12.09	1.17
9	17.12	14.88	1.15
10	23.3	22.62	1.03
11	32.28	35.47	0.91
12	41.05	50.67	0.81
13	54.98	63.19	0.87
14	62.3	63.2	1.01
Averages± SD	27.46±18.6	29.74±22.0	0.96 ± 0.18

Table 3: The values of observed and calculated length-weight relationship and relative condition factor for *P. clarkii* collected from El Rahawy.

Items / Size class(cm)	Mean Weight (g)		Relative condition factor "Kn"
	Observed	Calculated	
7	10.8	8.78	1.23
8	13.57	12.11	1.12
9	18.3	15.77	1.16
10	24.21	23.27	1.04
11	35.3	33.30	1.06
12	40.78	39.98	1.02
13	69.05	48.98	1.41
14	63.9	67.26	0.95
Averages± SD	34.49±22.25	33.96±24.16	1.12± 0.14

Table 4: The values of observed and calculated length-weight relationship and relative condition factor for *P. clarkii* collected from El Rayah ELMenoufy.

Items / Size class cm)	Mean Weight (g)		Relative condition factor "Kn"
	Observed	Calculated	
6	4.67	2.53	1.84
7	9.43	9.5	0.99
8	11.69	12.17	0.96
9	22.28	20.25	1.10
10	27.62	26.05	1.06
11	32.89	31.93	1.03
12	36.30	36.6	0.99
13	51.23	45.71	1.04
14	51.55	52.60	0.98
Averages± SD	27.52±17.22	26.7±17.45	1.11± 0.27

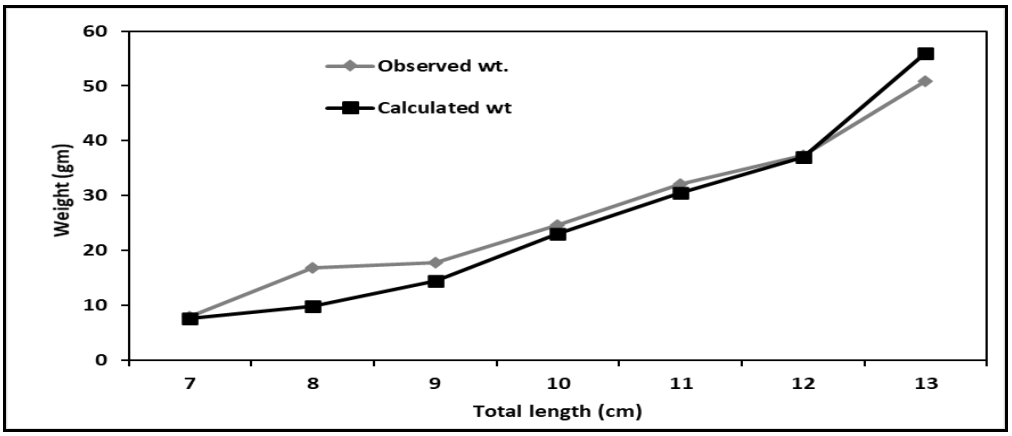

Fig.1: The values of observed and calculated body weight from the length-weight relationship for *P. clarkii* whole population at Helwan.

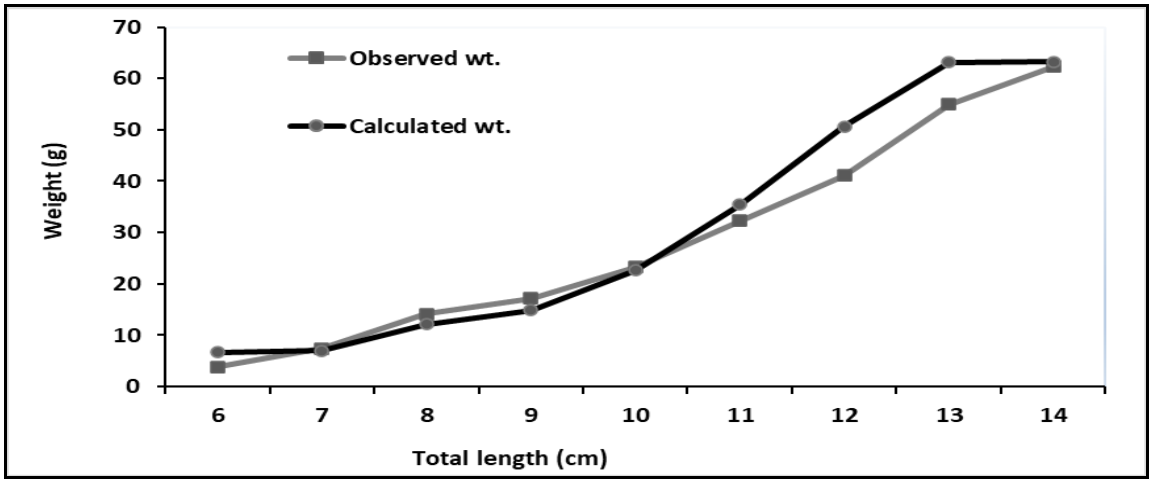

Fig.2: The values of observed and calculated body weight from length-weight relationship for *P. clarkii* whole population at El Warraq.

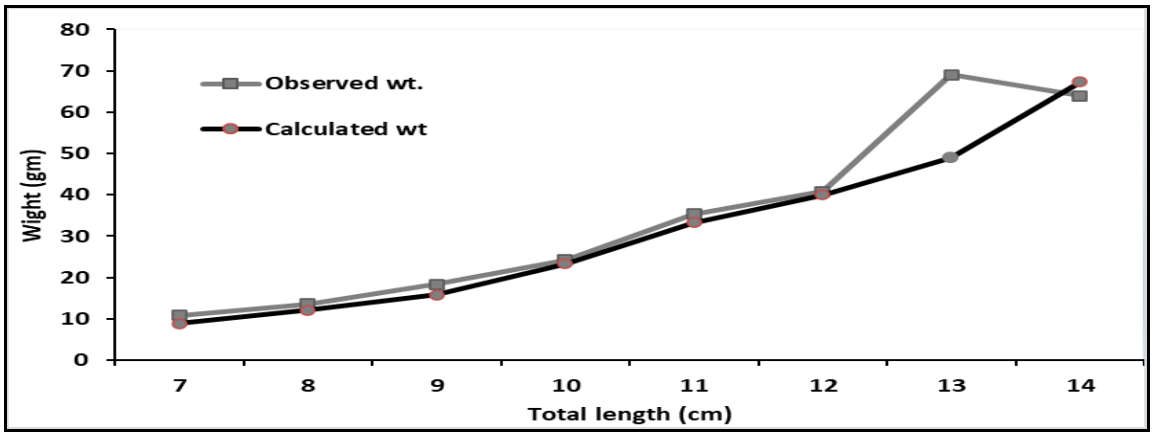

Fig. 3: The values of observed and calculated body weight from the length-weight relationship for *P. clarkii* whole population at El Rahawy.

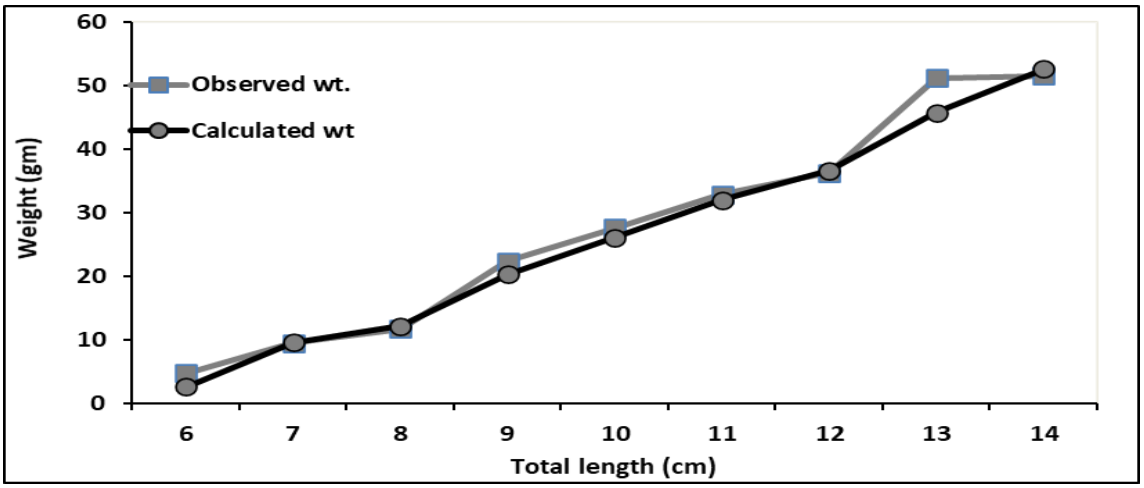

Fig.4: The values of observed and calculated body weight from the length-weight relationship for *P. clarkii* whole population at El Rayah El Menoufy.

B -Separate sexes:

The relationship between total carapace length and total body weight for the separate males and females was calculated at different study sites and are represented by the following equations:

- Site I (Helwan):

Log W= -1.947 + 3.256 Log TL (For males, "r"= 0.812)
Log W= -1.798 + 3.083 Log TL (For females, "r " = 0.864),

- Site II (El Warraq):

Log W= -2.095 + 3.410 Log TL (for males, "r" =0.892)
Log W= -1.945 + 3.227 Log TL (for females, "r " = 0.901),

- Site III(El Rahawy):

Log W= -0.918 + 3.230 Log TL (for males, "r" = 0.852)
Log W= -2.098 + 3.375 Log TL (for females, "r " =0.849), and

- Site IV(El Rayah El Menoufy):

Log W= -1.526 + 2.90 Log TL (for males, "r"= 0.687)
Log W= -0.994 + 2.315 Log TL (for females, "r " =0.677),

These relations demonstrate that males are heavier than females and all have positive allometric regression coefficients, greater than the isometric regression coefficients "b=3" at sites I, II and III, except only El-Rayah El Menoufy which has negative allometry for both sex and El Rahawy where females were the heavier. However, no significant differences were detected between values of the first three regression coefficients of both sex but were statistically significant (T-test = 1.36, $P < 0.05$) at site El Rayah El Menoufy.

The obtained results indicated a good relationship between total length and total body wet weight of *P. clarkii* at all studied sites. This relation had an allometric positive regression coefficient, ‘b’ equal 3.169, 3.301 and 3.228 for the sexes combined at sites I, (Helwan), II (El Warraq) and III (El Rahawy), respectively but declined to negative allometry (b= 2.576 2,2248) at El Rayah El Menoufy). The value of "b" displays a remarkable increase in body weight at the first three mentioned sites greater than increasing in length but vice versa was noted at site IV (El Rayah El Mounofy). However, these results are to some extent greater than recorded by Saad *et al*. (2015) from Qalubia and Cairo, and with Amer *et al*. (2016) on the same species from Al Kanater. They reported *b* values of 3.1910, 3.0999, and 3.0804 for males, females, and combined sexes respectively which consensus with the results of the present study. As well as with that reported by Aly *et al*. (2020) on the same species collected from the main River Nile from Assiut (south) to Qalubia (north), which had nearly an isometric regression coefficients" of 3.0804, 2.9998 and 3 respectively

These results are also in full agreement with that mentioned by Bagenal and Tesch (1978) in most fish species. They pointed out that, a decrease or an increase in ‘b’ value beyond that indicates either to an allometric negative growth (less than 2.5) or an allometric positive growth (more than 3.5).

The high values of “b” indicate the stability of this species within the prevailing environmental conditions and availability of natural resources for this species in the Egyptian habitats as mentioned by Ibrahim and Khalil (2009). However, the value of "b" was slightly higher in males than females at all sites except at El Rahawy. This indicates slightly heavier males but without a significant difference between the regression coefficients of both sexes ($P > 0.05$). This may be attributed to a slight increase in males' chelae size or an increased length of males than comparable females' size. The present results agree with those reported previously by Saad *et al*. (2015) on the same species from the River Nile. These results are also in agreement with those reported by Abrahamsson (1971) on *Pacifastacus leniusculus* and *Astacus astacus* in the Rogle pond (Southern Sweden); Shimizu and Goldman (1981) on *Pacifastacus*

leniusculus (USA); Hogger (1984) on the same species and *Autropotamobius pallipes* from southern England; Lowery (1988) on different species of crayfishes; or between sexes of the same species as mentioned by Lahti and Lindqvist (1981) on *Astacusa stacus*.

II- Relative Condition Factor "Kn":

The values of the relative condition factor "Kn" or wellbeing of *P. clarkii* are given in Tables (1-4) and figures (1-4), averaged 1.12±0.19, 0.95± 0.18, 1.07± 0.9 and 1.11±0.27, for the same sites, respectively. It is clear that the spatial variations in relative condition factors are evident. It recorded its higher values at Helwan and El Rayaha El Menoufy, which had the lowest average body weight, while the lowest average of "Kn" was recorded at El Warraq.

However, there are significant differences between size classes were detected. The values of "Kn" were above "1.0" at all sizes except those of 13 cm total length at Helwan and El Rahawy, and for those varied between 7-10 and 9-11 cm at El Warraq, and El Rayah El Mounofy, respectively. It declined to the lowest (0.58) for those who have 6 cm total length at El Warraq, but did not decline below 0.96 at the El Rayah El Menoufy (Tables1-4).

The obtained results are in good agreement with that averaged 1.01±0.07, reported and by Amer *et al*. (2016) on the same species collected from Al Kanater. They also demonstrated that "Kn" values were higher and above "1" in small and medium-sized individuals, but decline and varied between 0.89- 0.94 at larger individuals. The high averages of relative condition factor at El Rahawy may be attributed to the availability of food and provided calm and favorite habitats with low water movements or to increasing high levels of heavy metals, which lead to accumulation of tissue water as reported, by Zhaglol *et al*. (2016), Abdel Gawad, *et al*. (2018) and Shabaan *et al* (2018). These results also agree well with that mentioned by Hile (1936), Bagenal and Tesch (1978), El- Sayed (1992, 1997).

The fluctuations in condition factors may reflect either the effects of cyclic gonadal maturation as mentioned by Thomas (1977) on *Penaeus japonicus*, Hossain *et al*., (1987) on *Nephrops norvegicus*, Abd El-Razek*et al*. (1989) on lobster *Thenu sorientalis*, Abd El-Razek (1987) on *Portunus pelagicus*, Fouda (2000) on *Leptodius exarartus* and *Metopograpsus messor*, El-Sayed (2004) on *Leptodius exarartus*, or reflects changes in feeding rates, accumulation of storage materials prior molting within hepatopancreas as reported by Skinner (1962), Warner (1977), Willing and Keller (1973), and/ or due to the effect of an increase in relative growth particularly chelae weight of males as mentioned by Lowery (1988) on crayfishes and Turoboyski (1973) on *Rithropanopeus harrisii* crab. Consequently, the spatial variations in relative condition factors reflect the favorite conditions and availability of foods at sites of higher values.

III- Relative Growth Rates:

The relationships between total length and both carapace length, abdominal length as well as right chelae length in the sexes combined and sex separate are treated and given in Table (5). The values of regression coefficient between total length and lengths of these variables were varied between different sites and showed an isometric (b=1) as well as both positive (b> 1) and negative (b<1) allometric values. In spite of the value of "b" being isometric between TL and CL for all at Helwan, El Warraq and El Rahawy, it declined slightly to 0.981 at El Rayah El Menoufy. These values are in good agreement with those retorted by Hartnoll (1974, 1978), Hossain *et al*. (1987), Hartnol, and Bryant (1990) in many species of crustaceans.

However, the relationships between TL and ChL showed also variable values between different study sites and were relatively higher in males than females but with

no significant differences (P> 0.05).

On the other hand, the relationship between TL and AbdL has regression coefficient "b" begins slightly lower in males than females and varied from 0.715 in males at El Warraq to 1.139 for females at Helwan.

Table 5: Values of coefficients of relative growth rates against total carapace length for *Procambarus clarkii*.

Sites & sex / Parameters			Intercept "a"	Regression coefficient "b"	Correlation coefficient "r"
Helwan	All	CL	-0.313	1.013	0.887
		ChL	-0.354	1.227	0.714
		AbdL	-0.301	0.877	0.826
	Males	CL	-0.333	0.826	0.880
		Chl	-0.497	1.395	0.856
		Abdl	-0.227	0.803	0.809
	Females	CL	-0.243	0.943	0.885
		ChL	-0.58	1.38	0.77
		AbdL	-0.571	1.139	0.873
El Warraq	All	CL	-0.372	1.069	0.971
		ChL	-0.265	1.131	0.676
		AbdL	-0.199	0.768	0.839
	Males	CL	-0.376	1.074	0.968
		ChL	-0.429	1.319	0.826
		AbdL	-0.147	0.715	0.797
	Females	CL	-0.388	1.081	0.982
		ChL	-0.259	1.063	0.742
		AbdL	-0.339	0.906	0.943
El Rahawy	All	CL	-0.280	0.982	0.962
		ChL	-0.125	1.003	0.594
		AbdL	-0.268	0.839	0.810
	Males	CL	-0.288	0.992	0.969
		ChL	-0.431	1.33	0.834
		AbdL	-0.168	0.741	0.860
	Females	CL	-0.327	1.022	0.947
		Chl	-0.115	0.941	0.506
		AbdL	-0.487	1.048	0.752
El Ravah El Menoufy	All	CL	-0.275	0.981	0.922
		ChL	-0.073	0.962	0.421
		AbdL	-0.236	0.799	0.823
	Males	CL	-0.296	1.002	0.925
		ChL	-0.282	1.193	0.553
		AbdL	-0.207	0.769	0.841
	females	CL	-0.271	0.971	0.927
		ChL	-0.206	1.021	0.638
		AbdL	-0.249	0.818	0.789

The present results are in agreement with that carried out by Amer *et al*. (2016) on the same species from Al Kanater, Fouda (2000) on *Leptodius exarartus* and *Metopograpsus messor*, El-Sayed (2004) on *Leptodius exarartus*. These results indicate a regular increment in both total length and length of chelae, carapace and abdominal length for both sexes. However, the spatial variations in values of this index reflect the prevailing environmental conditions at those sites or the onset of maturity as discussed by Warner (1977 Hartnoll (1974, 1978), Hossain *et al*. (1987), Hartnoll, and Bryant (1990) on different crustaceans.

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ARABIC SUMMARY

التباين المكاني في علاقة الطول بالوزن ومعامل الحالة في تجمعات عشائر استاكوزا الماء العذب، بروكامبارس كلاركي، بنهر النيل وفروعه، مصر

إيمان أحمد شعبان [(1)]، عواد عبده محمد السيد[(2)]، فاتن عبد الحميد الفقي[(3)]، سعاد سعدإبراهيم[(1)]، نفين حسين محمود[(3)]

(1) المعهد القومي لعلوم البحار والمصايد، فرع القناطرالخيرية،
(2) كلية اللعوم بنين، جامعة الأزهر بالقاهرة،
(3) كليةالعلوم فرع البنات،جامعة الأزهر بالقاهرة

أوضحت الدراسة الحالية التباين في قيم مؤشرات العلاقة بين الطول ووزن الجسم وكذلك العلاقة بين طول الجسم وأطوال الرجل الكلابية ومعامل الحالة النسبي في استاكوزا الماء العذب "بروكامبارس كلاركي"المجمعة موسميا خلال الفترومن – 2014 إلى 2015 من 4 مناطق شملت: حلوان، والوراق على المجرى الرئيس لنهر النيل، الرياح المنوفي ومصرف الرهاوي. وتوضح الدراسة النتائج التالية:

1- كانت معظم الأفراد المجمعة ناضجة وتراوح الطول الكلي من 6.6 إلى 14.3 سم شاملة طول الدرقة والبوز ونهاية القمة الذيلية، بينما تراوح الوزن الكلي للجسم فيما بين 3.6- 80.8 جم.

2- أن العلاقة بين الطول والوزن لجميع الأفراد علاقة اعتماد شرطية، تأخذ شكل المنحنى الصاعد، ويصل معامل الاعتماد (مؤشر الاعتماد) إلى أكثر من "3" أي أعلى من المؤشر المثالي في مناطق حلوان، والوراق والرياح المنوفي مع انخفاضة إلى 2.228 في عيانات الرهاوي.

3- أوضحت الدراسة أيضا أن قيم مؤشر معامل الحالة النسبيي "Kn"يعتبر من المؤشرات المثالثة تراواحت ما بين 0,89- 1,01 أي حول الواحد الصحيح، مع تسجيل ارتفاع نسبي في الأفراد صغيرة الحجم عنها في الأفراد الكبيرة، وتشير قيم هذه المعاملات على انتظام النمو ومقدرة أفراد هذا النوع على التأقلم مع الظروف البيئية السائدة.

4- كما أوضحت الدراسة أيضا وجود زيادة نسبية ملحوظة في طول الكُلاب الأيمن في الذكور عنها في الإناث بسبب وصول الأفراد إلى مرحلة النضج الجنسي والتي تتميز في الذكور بكبر نسبي في حجم الكُلاب الذي يستخدم في الكثير من الوظائف خاصة الغذاء والدفاع والتزاوج.

5- تشير هذه النتائج إلى وجود تباين في مؤشرات تلك العلاقات بين المناطق المختلفة يرجع إلى تأثير العوامل البيئية السائدة ووفرة الغذاء أو التأثر بالملوثات والأنشطة البشرية المختلفة في بعض المناطق.