Egyptian Journal for Aquaculture
P-ISSN: 2090-7877
E-ISSN: 2636-3984
www.eja.journals.ekb.eg/
Makkey *et al.,* 2022; 12 (3):01-25
DOI: **10.21608/EJA.2023.181764.1087**

Population dynamic parameters, economic evaluation of Crayfish (*Procambarus clarkii*) and value added of its shells from River Nile, Egypt

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Received: August 18, 2022; Accepted: August 30, 2022 published: 2022 Vol.12 (3):01-25

ABSTRACT

This work was planned to study the population dynamic parameters, economic evaluation of crayfish *Procambarus clarkii* (Girard, 1852) besides value-added products extracted from its shells. A total of 4682 crayfish specimens were collected from the Nile River from September 2021 to July 2022.

Results of the length-weight relationships of *P. clarkii* showed an isometric growth (b= 2.99). Total and natural mortality coefficients were recorded at 4.64 yr^{-1} and 1.41 yr^{-1}, respectively. Consequently, the fishing mortality was estimated as 3.23 yr^{-1} and the present level of exploitation rate of *P. clarkii* was 0.70. For management purposes, the exploitation rate should be reduced from 0.70 to 0.38 or (32 %) to maintain the spawning stock biomass. An economic fishery evaluation of crayfish population size showed that crayfish production from the studied region of Nile River was recorded by GAFRD during the period from 2015 to 2020. Beni-Suef was considered the most productive governorate (with an average of 3337 tons or 43.4% of the total catch). The seasonal factor of crayfish was recorded at 2.8.

Concerning value-added products extracted from wet and dried crayfish shells; the values of vitamin A, lutein, β-carotene, Chlorophyll A, Chlorophyll B, and total carotenoids were recorded in wet shells; it sharply reduced in dried shells as affected by the drying process. Chitosan extracted from dried shells has good properties and antioxidant activity however, extracted from wet shells showed a good antimicrobial activity. The dominant essential amino acids (EAAs) of dried shells were lysine (312.98µg/g) followed by tyrosine (238.16µg/g).

In conclusion, freshwater crayfish can contribute to reduce the fish gap. This study recommended that crayfish require more management by decision makers than at the current time.

Keywords: Crayfish, population dynamic parameters, economic value and bioactive compounds.

INTRODUCTION

Although red swamp crayfish (*Procambarus clarkii*) are unacceptable product for the most Egyptian consumers due to its ability to dig the soil and attack the dominated fish species however, they were reproductive successfully in the Egyptian waters, high nutritive value of edible part and their wastes could be exploited as source of bioactive compounds. So, several studies have been carried out on crayfish ecology (**Ibrahim *et al*., 1995 & 1997; Mubarak, 1996 and Ahmed, 2012**), populations dynamics (**Emam & Khalil, 1995 and Saad *et al*., 2015**), biodiversity (**Fishar, 2006**), biology (**Soliman *et al*., 1998; Hamdi, 2001; Sayed, 2002 and Ibrahim *et al*., 2005**), hepatopanreas (**Garo & saad, 1999; Heiba, 1999**), pollutants (**Sharshar & Geasa,1998; Tolba, 1999 and Aly, 2000**), management (**Aly *et al*., 2020**), and nutritive value of raw and processed products (Ibrahim, **2010 & 2017 and El-Sherif *et al*., 2021**) of invasive crayfish Procambarus clarkii (**Girard, 1852**).

Therefore, this study was designed to investigate the population dynamics, evaluate of economic value of crayfish production and to produce some value added products from its waste.

MATERIALS AND METHODS

1. Study area and crayfish sampling

The study area was chosen along the Nile River, from Beni Suef Government to El-Kanater El Khayria **(Fig. 1)**. *Procambarus clarkii* specimens were gathered on a monthly basis from September 2021 to July 2022. Specimens were kept in hard plastic bags and transported immediately alive to the Fish Processing Technology Lab., Fisheries Division, National Institute of Oceanography and Fisheries, El-Kanater El Khayria Branch. A total of 4682 crayfish (*P. clarkii*) specimens were collected by fishermen. Length frequency was grouped in 1.0 cm length classes; the number and weights of these classes were recorded. Representative samples were taken as sub-samples.

Fig. (1): A map showing the studying location at The Nile River, Egypt.

2. Technological process

Crayfish samples were manually peeled, edible part was taken in other study while wastes were washed, divided into two batches as follows: (a) Raw shells and (b) Other batch was dried at 50°C for overnight, grinded, sieved (mesh size: 60µ) to obtain a coarse powder, packed in polyethylene bags and stored in dry place until further treatments.

3. Populations' dynamics parameters for *P. clarkii*:-

The materials for the study collected a monthly were measured the total length (TL) was masured to near 1.0 cm , carapace length (CL) to near 1.0 cm and total body weight (W) masured to near 1.0 gm, for subsample. Population dynamics parameters were estimated according the following relationships:

Total length (TL) - Body weight (W) relationship was expressed by the following equation:

(**Beckman, 1948 and Le Cren, 1951**) $W = a L^b$

Where: W is total weight, L is Length (total body length or carapace length), a & b constants. Estimation of theoretical growth in length (**von Bertalanffy, 1938) model**:

$$L_t = L_\infty [1 - e^{-k(t-t_0)}]$$

Where: Lt is mean length at age t, L_∞ is asymptotic length, K is growth coefficient that determines rates, at which L_∞ is attained, t is age at length L_t,

t_o is age at which the length is theoretically equals zero, Von Bertalanffy growth in weight equation was derived from as follows:

$$\mathbf{W_t = W_\infty\ [1 - e^{-k\,(t - t_o)}]^{\,b}}$$

Where: W_t is weight at age t, W_∞ is asymptotic weight.

Estimation of von Bertalanffy growth model constants: L∞ and K were estimated using the methods of **Ford (1933), Walford (1946)**, **Powell (1979)**, **Wetherall (1986)** and **ELEFAN I** method "K-scan routine" (**Pauly, 1987**). Powell and Wetherall method involved in the FiSAT software, allows the estimation of L∞ and Z/K from a sample by pooling a series of length-frequency data. While, ELEFAN I was applied to give an approximate value for L∞ and scan for the best estimation for K. t_0 was estimated from the following rearranged formula of the von Bertalanffy equation:

$$\mathbf{-\ln [1 - (Lt/L\infty)] = - k*t_0 + k*t}$$

Length ($\mathbf{L_c}$) and age ($\mathbf{T_c}$) at first capture: The length at the first capture ($\mathbf{L_c}$) is the length at which 50% of the crayfish retained in the gear was estimated by the analysis of catch curve using the method of **Pauly (1984)**, while the corresponding age at the first capture ($\mathbf{T_c}$) was computed by converting Lc to age using the von Bertalanffy growth equation as follows:

$$\mathbf{T_c = t_0 - (1/k * \ln [1- (L_c/L_\infty)])}$$

Length **($\mathbf{L_m}$)** and age **($\mathbf{T_m}$)** at first sexual maturity: The length at first sexual maturity (L_m) is the length at which 50% of crayfish reach. Their sexual maturity was estimated by fitting the percentage maturity against mid lengths. L_m was estimated as the point on X-axis corresponding to 50% point on Y-axis, while the corresponding age at first sexual maturity (T_m) was computed by converting L_m to age using the von Bertalanffy growth equation as follows:

$$\mathbf{T_m = t_0 - (1/k * \ln [1- (L_m/L_\infty)])}$$

Estimation of mortality rates: total mortality coefficient (**Z**) using equation of (**Jones & Van Zalinge, 1981**) and (**Pauly, 1983**) in which both are depending on length frequency data; natural mortality coefficient (**M**) using **Ursin Method (1967)** $\mathbf{M = W^{-1/3}}$ where: W = mean total body weight and fishing mortality coefficient (**F**) as the follow

$$\mathbf{F = Z - M}$$

Exploitation rate (E) was estimated by the formula of **Gulland (1971):**

$$\mathbf{E = F / Z}$$

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) were estimated using the model of **Beverton & Holt (1966)**.

4. Economic evaluation

Economic evaluation of *P. clarkii* population size was estimated based mainly on data reported by **GAFRD (2020)** by using some statistical equations.

5. Value added products extracted from crayfish waste

Value added products extracted from both wet (WS) and dried (DS) crayfish shells were determined.

Pigment fractions

Pigment fractions; (vitamin A, lutein, β-carotene, Chlorophyll A, Chlorophyll B and total carotenoids) were determined as described methods by **Sachindra *et al*. (2006)**.

Chitosan

The chitosan was extracted according to the method described by **Kurita (2001).**

a- **Physico-chemical characteristics**

Molecular weight (MW) (**Tamer *et al*., 2016**), viscosity (**Rao *et al.,* 2007**), degree of deacetylation (**Qin *et al*., 2004**) and purity (**Fernandez – Kim (2004**) were determined.

b- **Antioxidant activity**

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging activity of samples was determined according to the method described by **Shen *et al.* (2010)**. The radical-scavenging activity of the samples evaluated by using 0.1 mm (DPPH) dissolved in methanol. After incubation for 30 min in the dark at room temperature, the absorbance was measured at 517 nm and a reference wavelength of 690 nm. Ascorbic acid was used as positive control at different concentration ranging from 1.1-2.7 µ/ml. The DPPH / methanol mixture was used as a negative control. The DPPH scavenging activity of samples was calculated according to the following equation:

$$\textbf{Reduction (\%)} = [1 - (X / (av\ (NC))]^{*}\ 100$$

Where: **X**: the absorbance of sample, **av**: the average absorbance of control and **NC**: the absorbance of negative control.

c- **Antimicrobial activity**

The antimicrobial activity of wet and dried shells was tested at NRC, Egypt according to the method described by **Valgas *et al*., (2007)**. The antimicrobial susceptibility of the tested samples was examined against Gram-negative bacterium (*Esherichia coli* ATCC 25955*)*, Gram-positive bacterium (*Staphylococcus aureus* NRRL B-767), unicellular fungus (*Candida albicans* ATCC 10231) and filamentous fungus *(Aspergillus niger*). The antimicrobial activity of the samples was investigated through the agar well procedure in compared with untreated plates, separately. In order to the samples were corresponding to chitosan (soluble in acidified water) the acidified water was (5% glacial acetic acid) also considered as a positive control. Firstly, the bacterial strains were incubated in nutrient broth medium (lab M Limited,

Heywood, Lancashire BL9JJ, United Kingdom) at 37°C and 180rpm for 24 h. all fungal strains were also incubated on the potato broth (Ponadisa, Laboratories Conda S.A, Madried, Spain) at 28°C and 180rpm for 48 h. all suspension was swapped over the nutrient agar medium (bacterial strains), and PDA agar medium (fungal strains), and the well with corkborer was made in the agar and the soluble samples were loaded into the agar well. The bacterial plates were incubated at 37°C for 24h while the fungal plates were incubated at 28°C for two days for unicellular-like fungal and 4 days for multicellular-like fungal strains and the inhibition zone was observed during the incubation period, each experiment was conducted in duplicate.

Amino acids (AAs) composition

Amino acids **(**AAs) composition of only DS was determined according to the method by **Moore *et al.*, (1958)** by using HPLC, at National Research Center, Egypt.

RESULTS AND DISCUSSION

Population structure

The length frequency data of the random sample for one (cm) intervals of TL is arranged between 5 to 12 cm and the result is graphically represented in **Fig. (2)**. From this figure, it is clear that most samples from small to medium lengths exist more than the large length in the random sample representing the catch, indicating overfishing in the study area, and this leads to a loss of biomass.

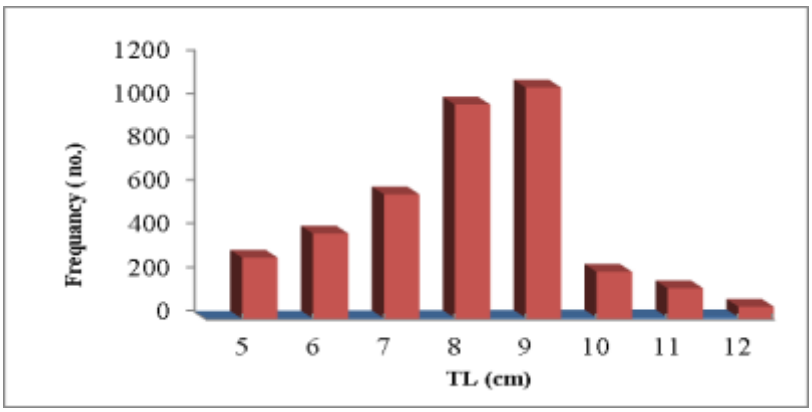

Fig. (2): Length-frequency distribution of *P. clarkii* for total length

Length-weight relationship

Length-weight relationship is an important biological tool in the fisheries management. The length-weight relationship was calculated for *P. clarkii* using total length (TL) data. The value of the constant "b" was (2.9865) in the regression **(Fig. 3)**. Therefore *P. clarkii* showed a nearly isometric growth for weight and length (b = 3) according to **Wootton (1992)**. **Lindqvist & Lahti**

(1983) concluded that length–weight relationship values varied among crayfish species according to sex, sexual stage, and ecological conditions. These variations may be reflection of a number of factors, including photoperiod, population density, food abundance, water level fluctuations, water temperature and water quality **(Huner & Romaire 1979; Chien & Avault 1983**). Thus, understanding length–weight relationship might have important implications for culture and management of crayfish. There were different results reported for *Procambarus zonangulus* (**Romaire *et al.*, 1977**), *Procambarus alleni* (**Acosta & Perry 2000**) and *Procambarus acutus acutus* **(Mazlum *et al.* 2007)**. Previous studies calculated values of "b" in length-weight relationship of *P. clarkia* were presented in **Table (1)**.

Table (1): Values of b in the current study compared with the previous studies

Location	Species	b	Authors
Egypt	*P. clarkii*	2.9865	**Present study**
Egypt	*P.clarkii*	3.1891	**Aly *et al*. (2020)**
Egypt	*P. clarkii*	3.0804	**Saad *et al.* (2015)**
China	*P.clarkii*	3.467	**Wang *et al*. (2011)**

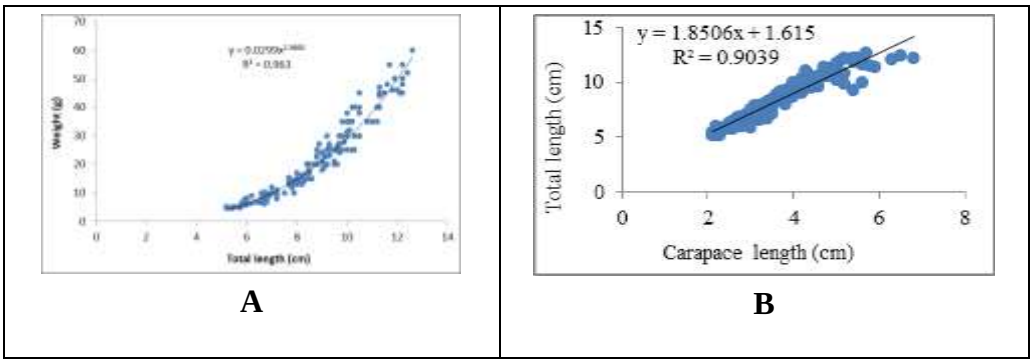

Fig. (3). A. Length-weight relationship of *P. clarkia*; **B.** Total length - carapace length relationship of *P. clarkia*

Growth parameters

From our results we found that growth in length $\mathbf{L_t = 16.3\ (1-e^{-0.6(t-0.05)})}$ whereas growth in weight $\mathbf{W_t = 124.70\ (1-e^{-0.6(t-0.05)})^{2.9865}}$. The present study show some differences with **Saad *et al.*, (2015)** who found $L\infty$ = 16.45cm TL, growth coefficient K = 1.60/year. this difference is attributed to the differences between regions and the size of the individual samples in each area. And it is also possible that the variations in population parameters of the

species genetic responses (**Bagenal and Tesch, 1978**) also, to the different environmental conditions (temperature, food, and biodiversity) in different areas.

Mortality and exploitation rates

The natural mortality is defined as the death created by all other causes than fishing e.g. predation including cannibalism, diseases, spawning, stress, starvation, and old age. The same species may have different natural mortality rates in different areas depending on the density of predators. The fishing mortality coefficient (**F**) is the rate at which fish was being caught, as a proportion of the exploited fish stock. The available data are not sufficient to produce a direct estimation of the fishing mortality. So, fishing mortality coefficient (F) was evaluated by subtracting the value of the natural mortality coefficient from the value of the total mortality coefficient as follows: **F = Z – M** By using length converted catch curve in the present study, the total mortality coefficient (Z) of *P. clarkia* was found to be 4.64 yr^{-1} and natural mortality coefficient (M) was 1.41 yr^{-1}. Consequently, the estimated F-value was 3.23 yr^{-1}. Accordingly, the E value was 0.70 **(Fig. 4 A&B and C)**.

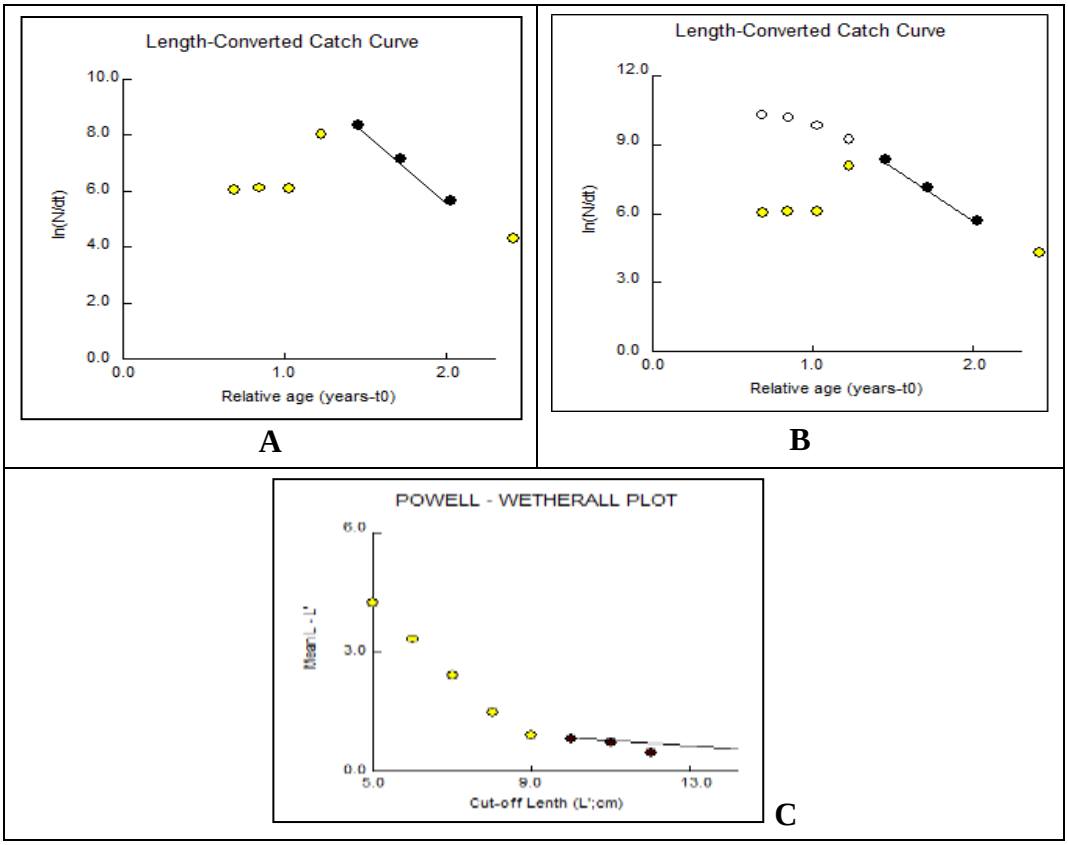

Fig. (4). A&B. Converted catch curve of *P. clarkii* in the Nile River**; C.** Powell- wetherall plot of *P. clarkii* in the River Nile, Egypt.

Length and age at first capture (L_c and T_c)

The length at first capture (the length at which 50% of the fish at that size are vulnerable to capture) for *P. clarkii* was estimated as a component of the length converted catch curve analysis (FISAT_II, **Pauly, 1984**). In our study, the results show that the length L_c was at 8 cm **(Fig. 5)**. This value was corresponding to ages of 6 month. These results differed with that of (**Saad *et al* 2015**); they mentioned that L_c and T_c were estimated of L_c at 9.11 and 9.25 cm for males and females, and T_c was of 7 and 8 months for males and females, respectively. This different may be to environmental condition, water quality and growth rate.

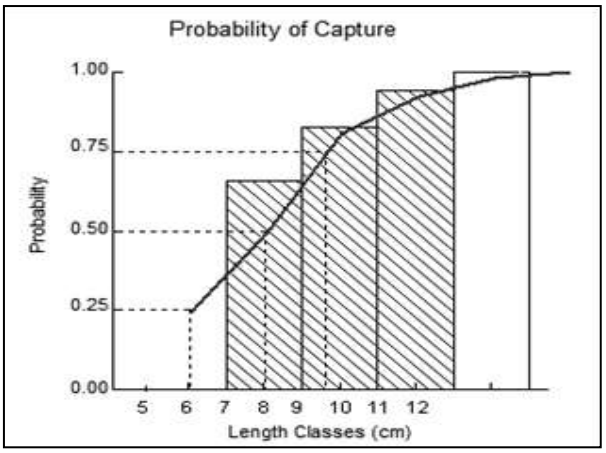

Fig. (5): Length at first capture of *P. clarkii* from the River Nile, Egypt.

Relative Yield per Recruit (Y/R)

The maximum (Y/R)' of *P. clarkii* was obtained at E_{max} was 0.84. The exploitation level which conserves 50% of the spawning stock biomass E= 0.5 was estimated at 0.38. The present level of exploitation to *P. clarkii* (0.70) was higher than E= 0.5. For management purposes, the exploitation rate should be reduced from 0.70 to 0.38 or (32 %) to maintain the spawning stock biomass. So, keeping the exploitation ratio at its current value or reducing it to E= 0.5 value will be achieve more economic return **(Fig. 6)**. These results differ from **Saad *et al*.,(2015)** whose results that relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) analysis for *P. clarkii* in the River Nile gives a maximum (Y'/R) at E= 0.70 and the exploitation level which maintains the spawning stock biomass at 50% of the virgin spawning biomass $E_{0.5}$ was estimated at 0.37. In the present study, the relative yield per recruit was applied to evaluate the fishery status of *P. clarkii* in the River Nile. In general, it is clear from Fig. 6 that the curve starts at the origin where the relative yield per recruit is zero when the exploitation rate is zero. Then the relative yield per recruit increases rapidly as the fishing mortality and exploitation level increase and reached their maximum value, after which the

yield per recruit decreases with a further increase in exploitation rate. So, keeping the exploitation ratio at its current value or reducing it to an E0.5 value (E= 0.38) will achieve a more sustainable economic return. This difference is due to the fishing effort in each region.

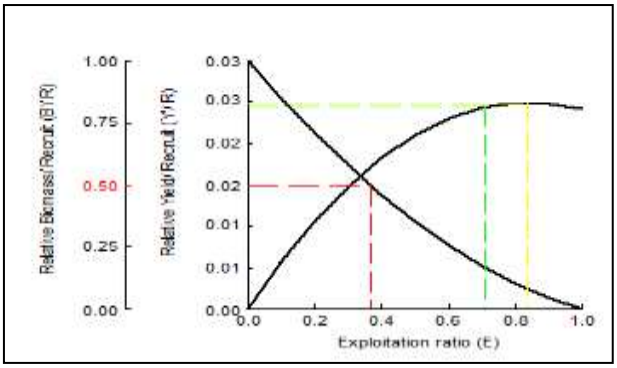

Fig. (6): Yield per recruit analysis of *P. clarkii* in the River Nile

Economic evaluation

Results showed the geographical distribution of crayfish caught from the Nile River and its branches during the period of 2015-2020 **(Table, 2)**. Results showed that Beni-Suef was considered the most productive governorate; the average production during this work was estimated at 3337 tons (43.39%), Luxor (871 tons, 11.33%), Menoufia (677 tons, 8.8%) while Aswan (640 tons) and Minya (415 tons) ranked fourth and fifth, respectively. Based on these data, Beni-Suef and Luxor can establish some value-added industries for crayfish, which would provide new job opportunities and also open export this product, which affects the Egyptian balance of payments.

The seasonal production (metric tons) of crayfish caught from the Nile River and its branches during the period of 2015-2020 is presented in **Table (3)**. Results showed that there was a seasonal variation, and the seasonality factor of crayfish recorded **2.8**. The seasonal production increased in the spring and summer seasons, it was estimated at 873 and 922 metric tons, respectively while it decreased during the autumn and winter to 404 and 309 metric tons, respectively. This variation in crayfish throughout different seasons is due to many factors; natural, biological and economic factors.

Table (2): Geographical distribution of crayfish caught from the Nile River, Egypt and its branches during the period of 2015-2020 (Data from GAFRD, 2020)

Government	Crayfish catch production (tons)						Mean (tons)	%
	2015	2016	2017	2018	2019	2020		
Kafr Elshiekh (Desouk)	-	-	3	3	3	3	3	0.04
Gharbia (Kafr Elzayaat)	-	-	93	48	49	41	58	0.76
Menoufia (Menouf)	-	-	640	562	944	560	677	8.86
Qalyoubia (Qanater)	-	-	25	42	11	68	37	0.48
Qalyoubia (Benha)	-	-	18	7	40	10	19	0.25
Daqahlia (Mansoura)	-	-	264	264	274	243	261	3.42
Sharkia (Zakazig)	-	-	-	-	445	479	462	6.05
Giza	-	-	-	-	-	120	120	1.57
Fayoum	-	203	236	270	210	232	230	3.01
Beni-suef	2220	3276	4095	4100	3200	2828	3337	43.02
Menya	-	180	350	550	480	516	415	5.44
Assiut	-	-	280	310	250	340	295	3.86
Sohag	-	-	-	-	60	88	74	0.97
Kena	-	-	-	-	168	214	191	2.50
Luxor	-	-	313	960	1092	1120	871	11.41
Aswan	-	-	195	500	672	1194	640	8.38
Total	2220	3659	6512	7616	7898	8056	7689	100.00

Table (3): Seasonal production (metric tons) of crayfish caught from the River Nile,Egypt and its branches during 2015-2020 (Data from GAFRD, 2020)

Season	Month	2015	2016	2017	2018	2019	2020	General		Seasonal		Seasonally indicator
								Total	Mean	Total	Mean	
Winter	January	-	-	4	76	96	337	513	128	926	308.7	5.2
	February	-	-	3	22	171	328	524	131			
	March	130	401	154	873	816	823	3197	667			
Spring	April	130	240	216	855	875	928	3244	719	2620	873.3	1.4
	May	420	618	718	893	1011	988	4648	903			
	June	500	603	658	1065	1173	1094	5093	998			
Summer	July	510	593	783	1011	929	1029	4855	938	2765	921.7	1.1
	August	530	644	897	977	993	959	5000	957			
	September		560	858	856	935	832	4041	870			
Autumn	October	-	-	762	788	799	620	2969	742	1212	404.0	3.4
	November	-	-	730	19	57	72	879	220			
	December	-	-	728	181	43	46	998	250			
Total		2220	3659	6512	7616	7898	8056	35961	626.9	7523	626.9	2.8
%		6.17	10.17	18.11	21.18	21.96	22.40	100.0				

*** Seasonal indicator = Higher production in quarter \ lower production in quarter**

The highest production of crayfish during this study period (2015-2020) was found in May, June, July, August and September, which confirms that the production season for crayfish was started from May to September. The highest total production was noted in June (5093 tons), while the lowest was estimated in January (513 tons). Consequently, the time trend, fisheries of crayfish from the River Nile and its branches are very important to develop and growth of production during the period of (2015-2020), which reflected the productive policies. The equation of crayfish production showed that there was increase by an annual rate (0.734 tons). The statistical significance based on the coefficient of determination (R^2), indicated that about 83.7% of the annual production changes which are due to the factors that are explained by the time change **(Table, 3)**. Nowadays, fish consumption, frequency, and preferences are affected by individuals' socioeconomic characteristics; consumers' geographic; cultural characteristics age, gender groups, and education groups, as well as between marital statuses. Fish consumption level and frequency were significantly positively correlated with education (**Pieniak *et al.*, 2011; Verbeke & Vackier, 2005; Can et al., 2015**). The factors suspected to affect exports of fish consumption include the types of fish exported, the price of fish consumption in the country/for the importing country, prices fish consumption abroad, the number of export destination countries, and the exchange rate of currency (**Hasanah *et al.*, 2020**). **Musaba & Namukwambi (2022)** confirmed that the strong income, age and household size effects on the purchase of fish species. The implication of the findings is that fish marketers and processors should consider these factors in the formulation of marketing strategies aimed at promoting fish consumption.

Value added products

- **Pigment fractions**

Results in **Table (4)** showed the pigment fractions (mg/100g sample) extracted from wet and dried crayfish shells. The values of vitamin A, lutein, β-carotene, Chlorophyll A, Chlorophyll B and total carotenoids extracted from wet shells recorded 1.04, 0.213, 2.342, 4.61, 8.65 and 10.37 mg/100g sample, respectively. While in case of dried shells, they decreased sharply and recorded only 0.44, nil, 0.01, 1.36, 2.15 and 1.60 mg/100g sample, respectively. The loss rates of these fractions as affected by drying process recorded 57.69%, 100%, 99.57%, 70.50%, 75.14% and 84.57%, respectively. The highest loss rates were observed in lutein and β-carotene whereas the lowest was found in vitamin A. This result showed that wet crayfish shells are a good source to obtain pigment fractions compared to dried shells. Drying process led to breakdown most components of pigment extracted from crayfish shells. These data confirmed the important role of natural pigments in different sectors where the astaxanthin, canthaxanthin and zeaxanthin

componunts were transformed into vitamin A, and also astaxanthin, zeaxanthin, lutein and tunaxanthin were directly converted into vitamin A2 (**Schiedt *et al.* (1985); Katsuyama & Matsuno, 1988**). Carotenoid pigments give most of the bright red, yellow and orange colors well appreciated not only in aquaculture (**Toyomizu *et al.*, 2001**). In addition, the carotenoids are widespread and important pigment classes in the organisms as well as contributing characteristic quality criterion for marketing and consumer demands of aquaculture products (**García-Chavarría & lara-flores, 2013**).

Table (4): Pigments fractions (mg/100g sample) extracted from crayfish shells

Crayfish shells	Vit. A	Lutein	β-carotene	Chlorophyll A	Chlorophyll B	Total carotenoids
Wet	1.04	0.213	2.342	4.61	8.65	10.37
Dried	0.44	Nil	0.01	1.36	2.15	1.60

- **Chitosan**

The results in **Table (5)** exhibited some properties of chitosan extracted from wet and dried crayfish shells. Results of molecular weight (MW), viscosity, degree of deacetylation (DDA), purity and DPPH as a free radical scavenging activity (antioxidant activity) of chitosan extracted from wet and dried shells were 24 and 27KDa, 2.23 and 2.60cps, 62 and 73%, 67 and 84% and 10 and 60%, respectively. Based on these results, it could be observed that these properties of chitosan extracted from dried shells were better than that extracted from wet shells.

Table (5): Properties of chitosan extracted from wet and dried crayfish shells.

Chitosan	Properties of chitosan extracted from crayfish shells				
	MW	Viscosity	DDA (%)	Solubility (%)	DPPH (%)
Wet shells	24 KDa	2.23 cps	62	67	10
Dried shells	27 KDa	2.60 cps	73	84	60

The molecular weight MW in this study was highly lowest (24-27Kda) than 213-549 KDa (**Yen *et al.*, 2009**), 1050 KDa (**Hossain & Iqbal, 2014**), 134.86-189.29 KDa (**Abou Zeed, 2016**), and higher than 11.4-21.1 KDa (**Ibrahim *et al.*, 2019**). The DDA value was lower (62-73%) than 83.3-93.3% (**Yen *et al.*, 2009**), 89.79% (**Puvvada *et al.*, 2012**), 87-92% (**Ghannam *et al.*, 2016**), 86.5-95.5% (**Ibrahim *et al.*, 2019**), however, it was higher than 53.4% (**Sarbon *et al.*, 2015**), and 23.64-52.18% (**Gaikwad *et al.*, 2015**) and it is

harmonized with 73.11-84.68% (**Abou Zeed, 2016**). Variation in chitosan characteristics is due to source raw materials, drying conditions (i.e. temperature and time), extraction method, chemicals purity and others (**Li *et al*., 1992** and **Roberts, 1997**). Besides, the solubility of chitosan was lower value than 93.3 - 98.8% (**Abou Zeed, 2016**), 81.78 - 87.21% (**Gaikwad *et al*., 2015**). Our results showed that chitosan properties extracted from dried shells were more efficiency than that extracted from wet shells under the same conditions. However, they are disagreement with those reported by (**Shawer *et al*., 2022**).

Antimicrobial activity

Antibacterial activity (inhibition zone, mm) of chitosan extracted from wet and dried crayfish shells against *Esherichia coli ATCC 25955* and *Staphylococcus aureus* NRRL B767 is presented in **Table (6)**. Efficacy of wet and dried chitosan as antimicrobial agent against *Esherichia coli*, *Staphylococcus aureus* showed that chitosan extracted from wet shells have more positive impact on these strains than other extracted from dried shells.

Table (6): Antibacterial activity (inhibition zone, mm) of chitosan extracted from wet and dried crayfish shells against *Esherichia coli* and *Staphylococcus aureus*.

Chitosan	Antimicrobial activity (inhibition zone, mm)	
	Esherichia coli ATCC 25955	*Staphylococcus aureus* NRRL B767
Wet shells	6±0.00	0. 6± 0.00
Dried shells	NZ	3±0.01

Antifungal activity (inhibition zone, mm) of chitosan extracted from wet and dried crayfish shells against *Candida albicans* ATCC 10231 and *Aspergillus niger* is shown in **Table (7)**. Efficacy of chitosan extracted from wet and dried shells as antimicrobial agent against *Candida albicans* and *Aspergillus niger* showed that chitosan extracted from wet shells have more positive impact on these strains than dried shells. In this work, the chitosan extracted from wet shells having an antimicrobial activity in the broad spectrum including all tested microorganisms, which gave a maximum activity of microbial growth reduction in case of *S.aureus* followed by *E.coli*, and moderate activity towards *A. niger and C. albicans.* The high efficacy of chitosan extracted from wet shells as antimicrobial activity is due presence of antimicrobial bioactive compounds which were affected by drying process in case of chitosan extracted from dried shells.

Table (7): Antimicrobial activity (inhibition zone, mm) of chitosan extracted from wet and dried crayfish shells against *Candida albicans* and *Aspergillus niger*.

Chitosan	Antimicrobial activity (inhibition zone, mm)	
	Candida albicans ATCC 10231	*Aspergillus niger*
Wet shells	4±0.001	6±0.00
Dried shells	2±0.001	1±0.00

Our results agreed with many studies; the antimicrobial activity of chitosan increased with increasing deacetylation degree (DD) and it was stronger against bacteria than against fungi (**Tsai *et al.*, 2008**), the antibacterial activity against all bacterial species is due to the sequential process beginning with adsorption to bacterial surfaces culminating in the leakage of intracellular constituents and cell death (**Yildirim-Aksoy and Beck, 2017**), the lowest zone of inhibition was recorded against *Enterococcus faecalis ATCC 29212* with only 12 mm by commercial and extracted chitosan (**Zaghloul and Ibrahim (2019),** chitosan–gentamicin conjugate (CS-GT) possesses good antibacterial activity and could protect shrimps from pathogenic bacteria infection (**Li *et al.*, 2022**), and the antimicrobial activity contained numerous active biomolecules and other compounds which exert antimicrobial and antioxidant activities (**Shawer *et al.*, 2022**).

- **Amino acids (AAs) composition**

Amino acids composition of dried crayfish shells (DS) is presented in **Table (8)**. Dried crayfish shells contained 8 essential amino acids (EAAS) and 7 non-essential amino acids (NEAAs). Total EAAs and NEAAs recorded 741.53 and 484.83 µg/g dried sample. The dominant EAAs were lysine 312.98µg/g followed by tyrosine 238.16 µg/g while the lowest was isoleucine 9.51µg/g. On the other side, the dominant NEAAs and lowest were glycine (155.61µg/g) and serine (18.92µg/g), respectively.

El-Sherif *et al.* (2021) showed that the high nutritional quality crayfish by-product meal was confirmed by the high of total amino acids (TAA, 73.90 g/16g N), total essential amino acids (TEAA, 34.62 g/16g N). With regard to AAs composition, variation in AAs composition is due to season, location, feeding behavior, sex, spawning period etc. Also, dried crayfish shells are considered a good source for AAs in particular lysine, tyrosine as EAAs and glycine as NEAAs.

Table (8): Amino acids composition of dried crayfish shells (DS).

EAAs	Value (µg/g)	NEAAs	Value (µg/g)
Lysine	312.98	**Aspartic acid**	55.53
Leucine	63.45	**Glutamic acid**	92.15
Isoleucine	9.51	**Serine**	18.92
Phenylalanine	65.32	**Arginine**	42.75
Methionine	20.76	**Glycine**	155.61
Tyrosine	238.16	**Alanine**	47.75
Threonine	17.92	**Cystine**	72.12
Histidine	13.43		
Total EAAs	**741.53**	**Total NEAAs**	**484.83**

CONCLUSION

through studying the population dynamics parameters of freshwater *P. clarkii* and its nutritional and economic significance, the study concluded, increasing the efforts to conserve *P. clarkii* freshwater and its sustainable optimal exploitation is an opportunity to increase national income from hard currency and maintain the biomass of *P. clarkii* as a sustainable economic species, it must reduce fishing effort by about 33 % based mainly on the data obtained in this study. Chitosan extracted from dried shells has good properties and antioxidant activity, however, extracts from wet shells have good antimicrobial activity. In general, this species is considered a promising source in the investment sector to contribute to the improvement of Egyptian national income and foreign currency.

Acknowledgements

The authors would like to thank **Asst. Prof. Dr. Taher Mohamed Ahmed Abu El-Nasr,** Egypt for his helping in the part of population dynamics of crayfish.

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المعايير الديناميكية والتقييم الاقتصادي لتجمعات استاكوزا المياة العذبة (*Procambarus clarkii*) والقيمة المضافة لمخلفاتها، من نهر النيل ، مصر

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يهدف هذا البحث الى دراسة المعايير الديناميكية والتقييم الاقتصادي لتجمعات استاكوزا المياة العذبة (*Procambarus clarkii*) والقيمة المضافة لمخلفاته من نهر النيل ، مصر. تم الحصول على عينات الاستاكوزا (٤٦٨٢ عينة) من نهر النيل في الفترة من سبتمبر ٢٠٢١ إلى يوليو ٢٠٢٢. أظهرت نتائج علاقات الطول والوزن أن معدل النمو كان متساويا فى القياس (ب = ٢,٩٩). تم تسجيل معدلات الوفيات الإجمالية والطبيعية عند ٤,٦٤ / سنة و ١,٤١/ سنة على التوالي. بينما سجل معدل وفيات المصيد بـقيمة ٣,٢٣/ سنة وكان المستوى الحالي لمعدل الاستغلال هو 0.70. وعليه فانه يجب العمل على خفض معدل الاستغلال من ٠,٧٠ إلى ٠,٣٨ أو (٣٢٪) للحفاظ على الكتلة الحيوية لمخزون التفريخ. وعلى الجانب الآخر فقد تناولت الدراسة كمية انتاج الاستاكوزا من منطقة الدراسة خلال الفترة من ٢٠١٥ إلى ٢٠٢٠ (الهيئة العامة لتنمية الثروة السمكية). وعليه فان محافظة بني سويف تعتبر من أكثر المحافظات إنتاجية (بمتوسط ٣٣٣٧ طن أو ٤٣,٤٪. من إجمالي المصيد) مقارنة بالمحافظات الأخرى. كما تم تسجيل العامل الموسمي للعينات عند ٢,٨. علاوة على ذلك فان نتائج المنتجات ذات القيمة المضافة (فيتامين أ ، اللوتين ، بيتا كاروتين ، الكلوروفيل أ ، الكلوروفيل ب) قد تأثرت بعملية التجفيف مقارنة بالقشور الرطبة. ومع ذلك فقد حاز الكيتوزان المستخلص من القشور المجففة على خصائص طبيعية وكيميائية ودرجة نشاط مضاد للأكسدة أفضل من تلك المستخلص من القشور الرطبة، والذى تميز بدرجة نشاط عالية كمضاد للميكروبات. كما سجلت بعض الأحماض الأساسية؛ الليسين (٣١٢,٩٨ ميكروجرام/جم) يليه التيروزين (٢٣٨,١٦ ميكروجرام/جم) للقشور المجففة مقارنة بمثيلتها فى القشور الرطبة. وبناءا على هذه النتائج فان استاكوزا المياه العذبة بامكانها العمل على خفض الفجوة السمكية من خلال الاستهلاك المحلي أو التصدير. كما توصى الدراسة بأن استاكوزا المياة العذبة تتطلب من صانعي القرار إدارة أكثر من الوقت الحالي.