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Original Article

Fishery characteristics, population dynamics and the impacts of the invasive red swamp crayfish (*Procambarus clarkii*) in the Nile River, Egypt

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Abstract
Alien intrusive species are one of the extreme pressures on biodiversity for their rapid reproduction and adaptation to new environments. Crayfish *Procambarus clarkii* entered Egyptian freshwater ecosystems at the beginning of 1980's. After many years of negative effects of its introduction onto the Egyptian waters, it became one of the commercially important species. Population parameters of *P. clarkii* are estimated based on 1355 specimens collected from the Nile off El-Minya during 2019–2020. The isometric growth of the species under the study is confirmed according to the obtained *b*-value of length–weight relationship (LWR). Annual sex ratio (female : male) was in favour of females with an annual sex ratio 1.44 : 1. The values of growth coefficient (*K*) and the asymptotic total length (L_∞) were assessed for males, females and combined sexes. Using mortality estimates, the exploitation ratio was 0.64 year^{-1}. Investigation of relative yield per recruit (Y'/R) and analysis of relative biomass per recruit (B'/R) for *P. clarkii* in the Nile off El-Minya provides the highest (Y'/R) at E_{max} = 0.81 and the $E_{0.5}$ (utilisation level that preserves the spawner stock biomass at 50% of the virgin spawning biomass) was 0.38. From fisheries management point of view, the current exploitation level should be decreased to that maintain the spawning stock biomass (from 0.64 to 0.38).

Keywords: aquaculture; freshwater crayfish; invasive crayfish; population parameters; river Nile; sustainable management

1 | INTRODUCTION

The red swamp crayfish (*Procambarus clarkii*), native to the southern United States and north-eastern Mexico, is currently the most widely distributed crayfish worldwide as well as one of the invasive species with most distressing impacts on freshwater ecosystems. Currently, the *P. clarkii* is present in 40 countries of four continents and there is still potential for further expansion (Oficialdegui *et al.* 2019). Introduction and transportation of exotic species have its adverse impacts on both the natural ecosystems and the native species (Mehanna 2018). The red swamp crayfish is an invader of Egyptian freshwaters, where it introduced by the mistake as shrimp larvae through a private fish farm in early 80's (Saad *et al.* 2015). It quickly expanded to inhabit all Egyptian freshwater ecosystems from canals to drains to basins and even agricultural lands and now they became abundant in the catch with considerable amounts (Ibrahim *et al.* 1995; Saad and Emam 1998; Saad *et al.* 2015). In the beginning, it caused many social and environmental problems as well as fearful farmers and fishermen due to the strength of its muscles, claws, and dark colour (Fishar 2006). It damaged the irrigation systems, rice fields, dams by its burrowing behaviour (Fishar 2006). Also, it showed an aggressive behaviour that dominates and eliminates some native predators. It is worth mentioning that not all the impacts of invasion by alien species are negative and recently, Egyptian realized the economic benefits generated by the freshwater crayfish (Saad *et al.* 2015; Mehanna 2018; El-Naggar *et al.* 2019; El-Naggar *et al.* 2021). Now, fishing is selectively carried out on wild populations of crayfish inhabiting Nile, rice fields and river branches for direct food consumption and to feed the processing factories in Egypt which consequently affected the crayfish production from the wild (SF Mehanna, personal observation). Egyptian people started to consume the freshwater crayfish as food resource in 2010, hence the price per kg rose from only 3 LE Kg^{-1} in 2010 to 80 LE kg^{-1} in 2023 [1 LE = 0.021 USD; SF Mehanna, personal observation]. Unfortunately, the amounts of crayfish harvested from the Nile is not exactly known and the recorded catch by the administrative bodies in the country does not reflect the real exploited amount (SF Mehanna, personal observation).

In the population dynamics studies of fish including crayfish, identified and considerate of population parameters like growth indices (growth coefficient *K*, asymptotic length L_∞ and growth performance index *Ø*), and mortalities (coefficients of total mortality *Z*, natural mortality *M* and fishing mortality *F*) has essential implications for population assessment (Rochet *et al.* 2000). Evaluation of these parameters delivers necessary data for forecasting population growth and evolving sustainable exploitation policies (Ochwada-Doyle *et al.* 2014). So, the main goal of this study was to calculate the growth parameters, deaths and exploitation rates of the commercial *P. clarkii* population in Nile River, Egypt. The outcomes will expectantly deliver background data to propose effective and sustainable management policies of *P. clarkii* commercial populations to face the great demand on the local markets and to feed the newly established processing factories.

2 | METHODOLOGY

2.1 Study area

The study area was selected along the River Nile and covered the area of the El-Minya governorate which is one of the governorates of Upper Egypt (Figure 1). Minya province (28.11°N 30.11°E) is one of the 29 provinces of Egypt, extends on the River Nile with distance of 135 km and located in the middle between the Upper and Lower Egypt. Seven villages and cities located on the Nile and covering this distance were surveyed to collect the crayfish samples (Figure 1).

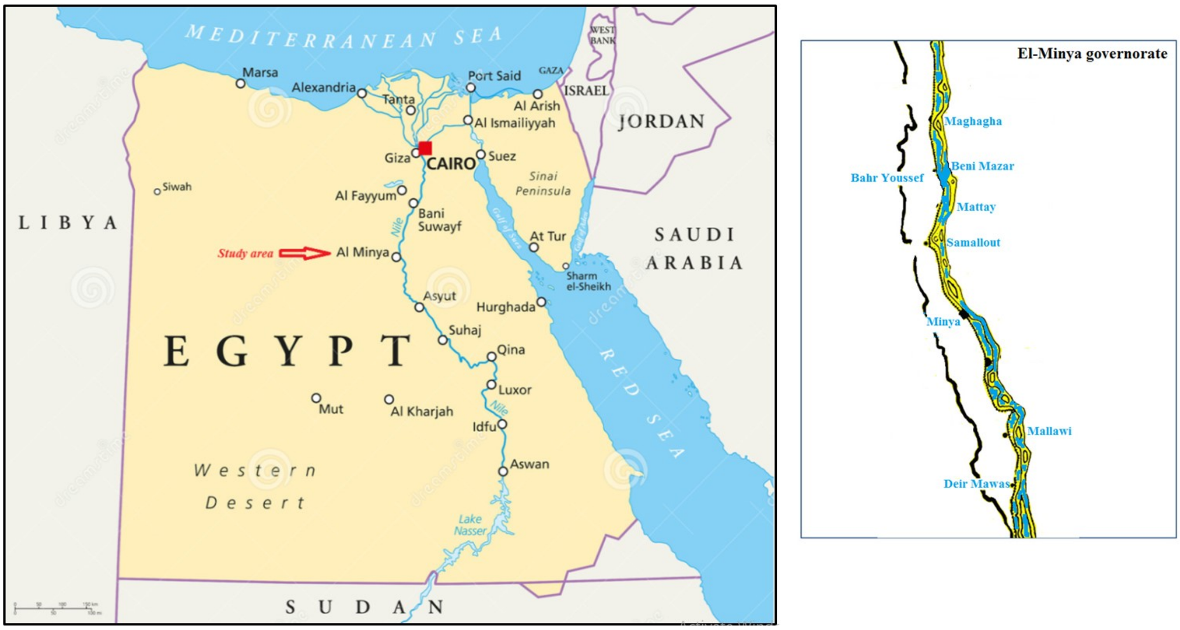

FIGURE 1 Map of Egypt showing the study area and the sample collection sites.

2.2 Sampling and biological measurements

A total of 1355 crayfish specimens (555 males and 800 females) were collected monthly from seven landing sites along the Nile River in El-Minya governorate to study its fishery status during 2019 and 2020 (Figure 1). The samples were collected using cylindrical traps (Gobia) that fishermen set it in the afternoon and collect it after one or two days according to the density of crayfish. Total length (TL) of each crayfish from the rostrum tip to telson tip was measured to the nearest 1 mm, Carapace length (CL) to the nearest 1 mm and total body weight (W) to the nearest 0.1 g were identified for each individual crayfish. Total length frequency data was gathered in 0.5 cm length intervals for further investigation. The sex was identified externally and the sex-ratio (females to males) for the whole samples was calculated. The deviation from 1:1 null hypothesis was statistically verified by Chi square test (χ^2).

The power equation $W = aL^b$ (Beckman 1948 and Le Cren 1951) was used to describe the TL and CL - body weight W relationships LWR, where *a* is the intercept and *b* is the slope that indicates isometric growth when equal to 3 or allometric growth (negative allometric, $b < 3$ or positive allometric, $b > 3$). Furthermore, 95% confidence limits CI of b were determined to demonstrate if the b-value was meaningfully different from 3 or not. To evaluate the parameters of the LWR, the least-square linear regression was applied.

The growth parameters *K* and L_∞ of freshwater crayfish were estimated using von Bertalanffy (1938) growth equation as $L_t = L_\infty [1 - e^{-k(t-t_0)}]$, where Lt is the mean length at age *t*, L_∞ is the asymptotic length, *K* is the growth coefficient that defines rates at which L_∞ is achieved, *t* is the age at the given length and t_0 is the age at length zero. Powell (1979) - Wetherall (1986) plot and ELEFAN I (Pauly 1987) method were used in this study.

Analysis of catch curve (Pauly 1984) method was applied to calculate the length at first capture L_C (the length at which 50% of the crayfish retained in the fishing gear).

Two diverse methods were implemented to evaluate *Z* (total mortality coefficient) of freshwater crayfish; analysis of the cumulative catch curve (Jones and Van Zalinge 1981) and analysis of the length converted catch curve (Pauly 1983). Natural mortality coefficient (*M*) was calculated as the geometric mean of two methods; Ursin's equation (1967) and Pauly's empirical equation (1980), while F (fishing mortality coefficient) was estimated as *Z–M*. Consequently, the exploitation rate (*E*) was estimated as $E = F / Z$ (Gulland 1971).

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) were analysed by means of Beverton and Holt (1966) model as modified by Pauly and Soriano (1986). Length frequency data were investigated using the software package FiSAT II (FAO-ICLARM Stock Assessment Tool). The model could be expressed as:

$$Y'/R = E\, U^{M/K} [1 - (3U/1+m) + (3U^2/1+2m) - (U^3/1+3m)]$$

Where, $m = (1-E)/(M/K) = (K/Z)$ and $U = 1 - (L_C/L_\infty)$.

To evaluate the impacts of crayfish invasion (negative versus benefits), two activities were used, the first was to collect all previous studies concerning this issue and the second to make a survey for the hotspot areas that impacted by the invasion of crayfish. The survey started in 2015 and continued until now to interview both the fishermen and people inhabiting the areas surrounding the Nile from Giza in the north to Aswan in the south Egypt.

3 | RESULTS AND DISCUSSION

3.1 Length-weight relationship

Length (TL/CL)-weight relationship (LWR) of fishes is significant in fisheries biology studies because it allows the estimate of the fish average weight of a given length group by creating a mathematical relation between the two factors (Beyer 1987). LWR is frequently used as a sign of fatness, general wellbeing (Le Cren 1951) or of gonad enlargement of fish and are useful for between region comparisons of life history of a specific species (Wooton 1998).

The total length-weight relationship was investigated for *P. clarkii* from Nile off El-Minya governorate (Figure 2). The values of the constant *b* were not meaningfully different from 3 for both sexes, therefore males and females *P. clarkii* show an isometric growth (CI for *b*-value was 2.921 – 3.126 for females, 2.912 – 3.072 for males and 2.929 – 3.083 for pooled data). The LWR of *P. clarkii* in the current work was significantly strong ($r^2 = 0.94$ for females and 0.97 for males). The resultant LWR equations were:

$W = 0.03\, L^{3.0234}$ for females
$W = 0.0276\, L^{2.9924}$ for males
$W = 0.0291\, L^{3.0063}$ for pooled data

The sex effect was non-significant for the length-weight relationship ($p > 0.05$). Length (TL/CL)-weight relationships fluctuate among crayfish species conferring to their sex, and to their ecological circumstances (Lindqvist and Huner 1999). Such variance may be a reflection of diverse reasons comprising photoperiod, foodstuff richness, population mass, water temperature, and water quality (Huner 1981; Huner and Barr 1991).

3.2 Total length-carapace length relationship

The carapace length of *P. clarkii* in the current study was varied from 2 to 7 cm with a mean (± SD) value of 3.81 ± 1.02 cm for females and from 2 to 6.9 cm with a mean value of 3.80 ± 0.98 cm for males. While the total length TL was ranged between 5 and 13 cm with a mean value of 8.65 ± 1.96 cm for females and between 5 and 12.8 with a mean value of 8.61 ± 1.11 cm for males. Saad *et al.* (2015) in the Nile River, Egypt estimated the mean CL at 5.7 ± 0.083 cm in females and 5.6 ± 0.088 cm in males. Our measurements were lower than that of Saad *et al.* (2015) and this variance in length may be due to the high exploitation level of *P. clarkii* in the Nile especially after the exceeded market demand on this species in recent years.

There is no significant variance in length composition amongst males and females ($p > 0.05$), and the TL–CL length relationship of *P. clarkii* in the Egyptian Nile (Figure 3) was as follows:

$TL = 2.4600 + 1.5262\, CL$ $r^2 = 0.94$ (females)
$TL = 2.6053 + 1.4575\, CL$ $r^2 = 0.96$ (males)
$TL = 2.5306 + 1.4943\, CL$ $r^2 = 0.95$ (combined sexes)

Harper *et al.* (2002) and Saad *et al.* (2015) found in their studies an extremely significant linear relationship ($r^2 = 0.97$ and 0.98, respectively) between CL and TL for *P.*

clarkii; in the current research a comparable significant linear relationship (r^2 = 0.903) between the same parameters was documented.

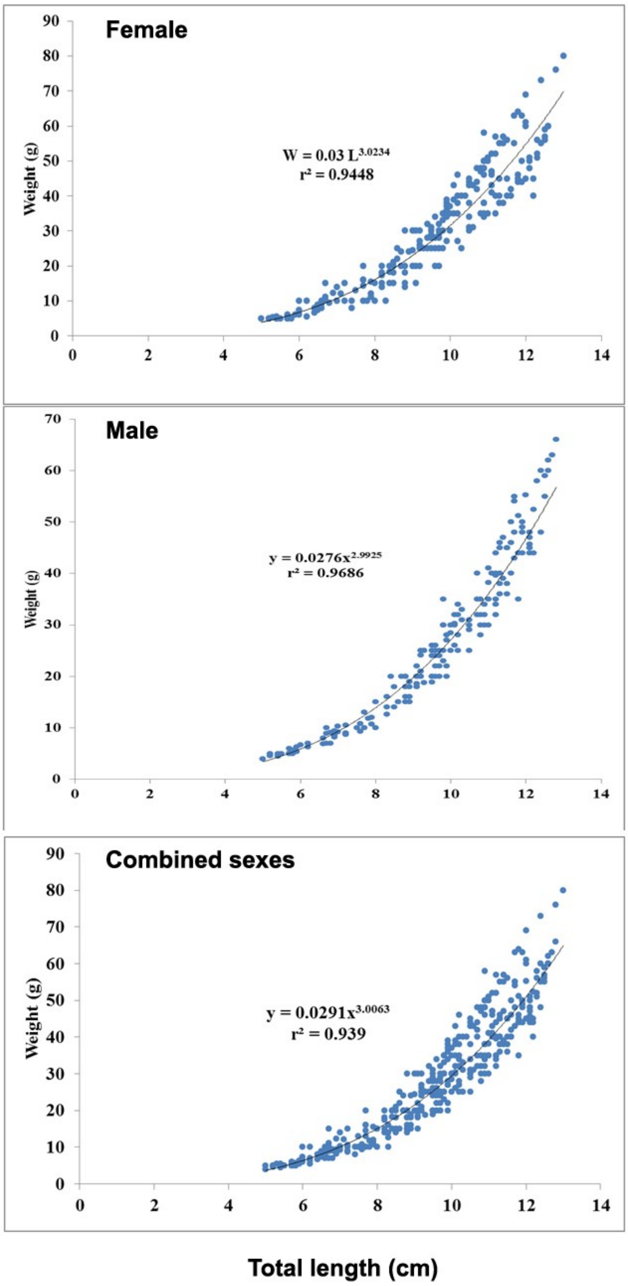

FIGURE 2 Length-weight relationship of *Procambarus clarkii* from the Nile, Egypt.

3.3 Sex ratio

A total of 1355 crayfish individuals (800 females and 555 males) were caught during the study period. The overall sex ratio was 1.44 : 1 (female : male) with domination of females which was significantly varied from the theoretical sex ratio 1 : 1 (χ^2, $p < 0.05$). The dominance of females could be attributed to their active behaviour that makes them vulnerable for fishing gears used.

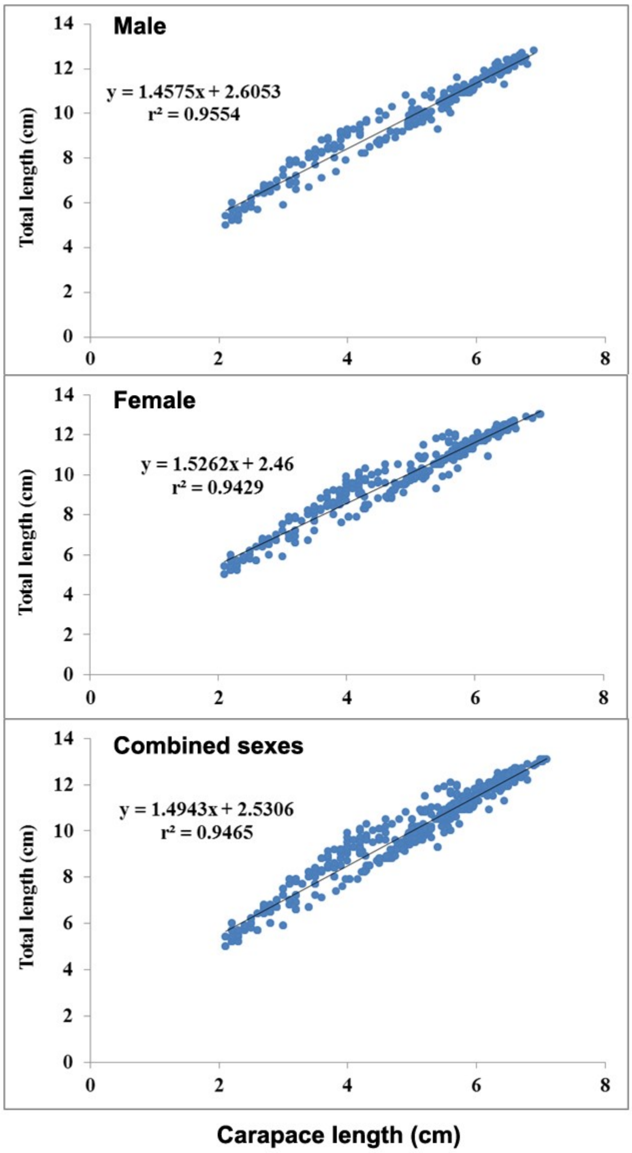

FIGURE 3 Length-length relationship of *Procambarus clarkii* from the Nile, Egypt.

3.4 Growth parameters

The growth parameters were assessed by means of ELEFAN I package and the initial L_∞ values was attained via Powell (1979)-Wetherall (1986) plot (Figure 4). The values of K and L_∞ for males, females and combined sexes were 0.72, 0.68 and 0.69 year^{-1} and 15.83, 16.57 and 16.36 cm respectively. There is no difference in the growth parameters between sexes so all the further computations were done for sexes combined.

The von Bertalanffy growth model is a valuable model for studying the growth of shellfish or crustacea species (Garcia and Le Reste 1981; Mehanna and Khalifa 2007; Mehanna and El-Gammal 2008; Mehanna *et al.* 2012; Saad *et al.* 2015). The present L_∞ value was lesser than those gained from previous studies. The possible reason could be the greater exploitation and targeting this species in the Nile now which caused the elimination of big individuals. The higher values of L_∞ that noted in earlier studies such as the Trasimeno Lake (Dörr and Scalici 2013), may be due to the habitat in these studies characterized by an abundant amount of trophic and spatial resources.

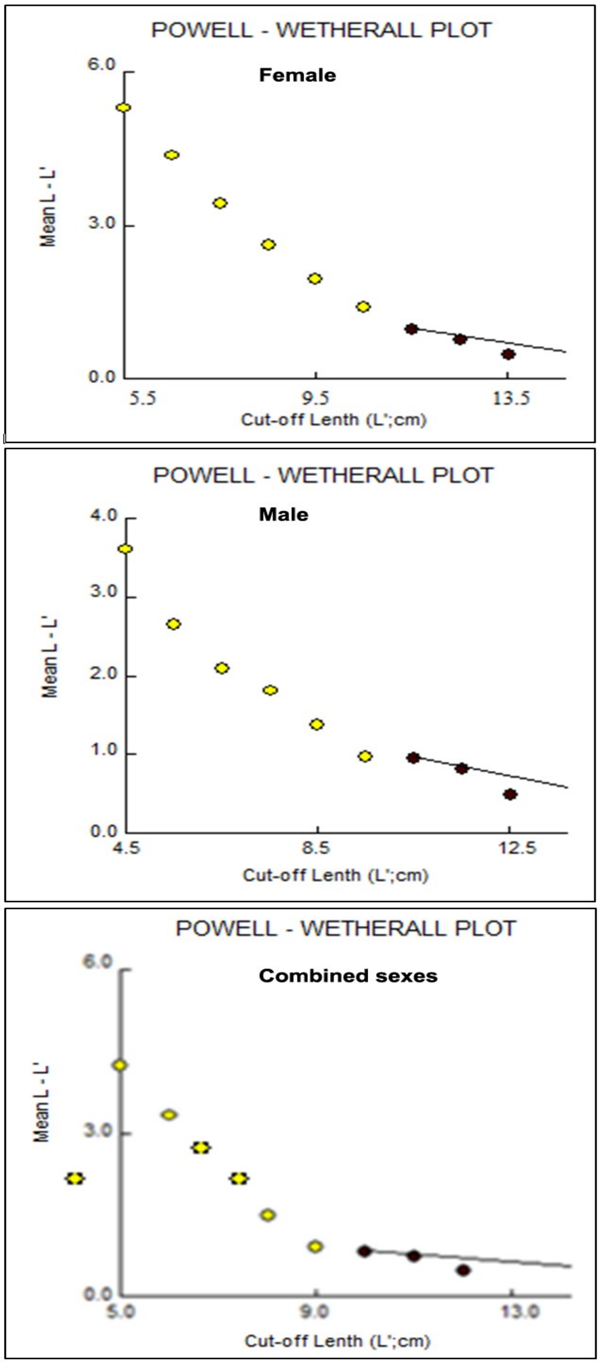

FIGURE 4 Powell-Wetherall plot of *Procambarus clarkii* from the Nile, Egypt.

The growth coefficient (*K*) appraised in this study was considerably high. It is close to that estimated by Scalici and Gherardi (2007) in Italy, but lower than that of the Saad *et al.* (2015) for the northern Nile River population, Qianjiang population, China (Jin *et al.* 2019) and Veroli *et al.* (2021) for the Nazzano Tevere-Farfa population, Central Italy.

3.5 Growth performance index (Ø)

The Phi Prime index (Ø) is used to evaluate the overall growth performance. The Phi Prime or growth performance index (Ø) for *P. clarkii* in the River Nile, Egypt is 2.27 for pooled data. The obtained Ø value is comparable to several studies, except for that of Jin *et al.* (2019). Red swamp crayfish growth rate is influenced by numerous ecological aspects and the most significant ones are temperature and food accessibility (Chucholl 2011; Dörr *et al.* 2006; Dörr and Scalici 2013). Accordingly, the high growth parameters estimated by Jin *et al.* (2019) are primarily owing to their direct feeding by individuals and the higher temperature.

3.6 Mortality and exploitation rates

The mean *Z* and M values of *P. clarkii* were 4.64 $year^{-1}$ and 1.68 $year^{-1}$ respectively. Accordingly, the assessed *F*-value was 2.96 $year^{-1}$ and the exploitation ratio *E* was 0.64 $year^{-1}$.

The exploitation ratio is very essential to evaluate the status of the stock which optimum, underexploited or overexploited. Gulland (1971) advised that a fish stock is operated at its optimum case when F_{opt} (optimum fishing mortality) = *M* (natural mortality) *i.e.*, at a fishing mortality level that produces *E* equivalent to 0.5. Pauly in 1987 suggested a lesser optimal F that equivalent to 0.4**M*. In the current research, *E* was greater than both values of F_{opt} assumed by Gulland and Pauly demonstrating that the *P. clarkii* stock in the Nile River off El-Minya governorate is overexploited.

3.7 Length at first capture L_C

The length at first capture L_C is very important for fisheries managers as it helps in detection of the most appropriate mesh sizes. The length at first capture of *P. clarkii* collected from the study area was estimated as 8.21 cm (Figure 5).

3.8 Relative yield per recruit (Y'/R)

The Y'/R analysis of the sexes combined was considered because no specific fishing gear was designed to catch each sex separately. As well as any regulations will be taken for the whole stock not for sex. The analysis of Y'/R and B'/R for *P. clarkii* in El-Minya off River Nile (Figure 6) provides the highest value of Y'/R at *E* level of 0.81. The utilization value that conserves the spawners' stock biomass at 50% of the virgin spawners' biomass was calculated at $E_{0.5}$ = 0.38. This designates that here is a chance to increase the freshwater crayfish fishery via raising the current *E* to that will provide the highest Y'/R (E_{max}) but rising the utilisation level to E_{max} will not be practical and will be accompanying by a very tiny ration of yield. Hence, keeping the utilization fraction *E* at its existing value or decreasing it to $E_{0.5}$ value (0.38) is recommended to attain extra financial return.

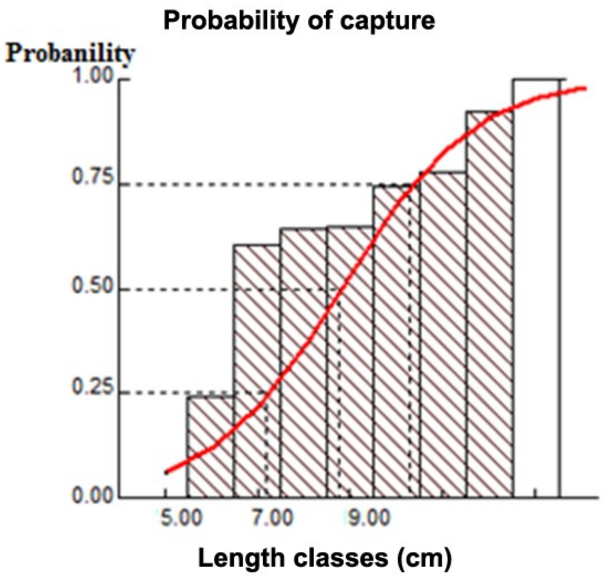

FIGURE 5 Probability of catching *Procambarus clarkii* from the Nile, Egypt.

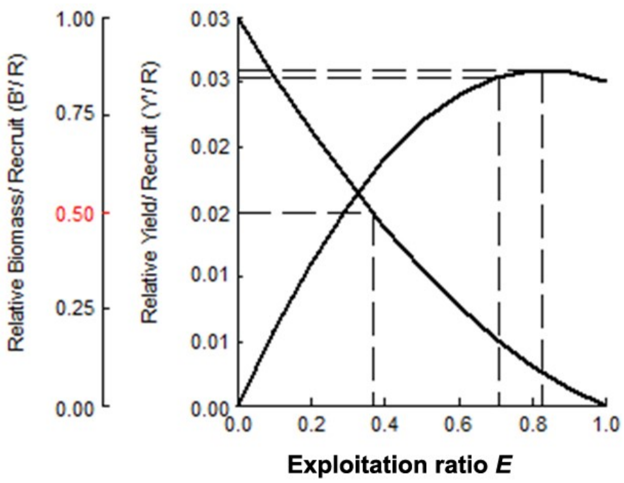

FIGURE 6 Relative yield per recruit analysis of *Procambarus clarkii* from the Nile, Egypt.

3.9 Impacts: negative versus benefits

Since early 1980s and the invasion of *P. clarkii* to the Egyptian freshwater habitats by mistake, it has been quickly expanded in all Egyptian aquatic ecosystems protracted from northern Egypt (from Giza to the whole Delta district), to its southern part (governorate of Qena to Aswan) (Ahmed 2012; SF Mehanna, personal observation). At the beginning, its introduction caused dramatic alterations in native plant and animal communities as well as it has damaged local infrastructure and landscapes by burrowing into dams' edges, Nile river, and lakes to create their nests. As a result, their digging has produced water canals to leakage, banks of the river and lakes to erode, and agricultural irrigation systems and rice fields to damage (SF Mehanna, personal observation; Galib *et al.* 2021 and 2022). The digging activity of *P. clarkii* is changed water quality, enlarged bioturbation, and amplified nutrient release from sediment. Also, *P. clarkii* is a path for several reportable diseases and predate on eggs of viable fishes as well as compete with viable fish species on food, and destruct the fish shelters and nursing areas which negatively influence the fishing industry.

After many years in fighting the spreading of *P. clarkii* in Egyptian fresh waters, many projects were established to convert the negative impacts to positive ones. Now, *P. clarkii* serve as a new food source in Egypt in low price. Crayfish is a low-priced source of seafood and animal protein, in contrast to higher luxurious shrimp and lobster which marketed in very high prices. It used as a biological controller agent to lessen the snails' numbers that act as intermediary hosts for schistosomiasis (Bilharzia) (Ibrahim *et al.* 1995). The freshwater crayfish are used as a bio-indicator of heavy metals and organic materials (*e.g.,* fertilizers and pesticides compounds) owed to its tendency to accumulate these ecological impurities (Fishar 2006). As well as this species may possibly useful in biological controller activities, it aggressively predates the rice pest (chironomid larvae). Crayfish enabled the establishment of an important industry in Egypt based on fishing, processing, and marketing in local and foreign markets. Many processing factories are established now employing many people and used many hundreds of fishermen to collect the crayfish from wild to feed these factories. Exo-skeleton of crayfish has proved to use as food additive to enhance the growth of animals as well as to produce some dyes, chitin and chitosan (Mehanna 2018).

4 | CONCLUSIONS

Procambarus clarkii initiates from regions of high latitudes and invade Egypt in the early 1980s. Its spreading has extended to numerous parts along the Nile River. After many years of adverse impacts of crayfish invasion that produces serious socio-economic losses, *P. clarkii* now has come to be one of the most vital freshwater goods and products in Egypt and the market stresses significantly overdo the resource. The exploitation rate of this species tends to lead to overexploitation. Given its positive impacts on Egyptian markets and human consumption, the use of this resource should be carefully and responsibly managed. This can be done by reducing fishing effort. Also, establish aquaculture farming and improved the present aquaculture practices are required to intensification the production of this species.

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CONFLICT OF INTEREST
The author declared that there is no conflict of interest here.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available on request from the corresponding author, SF Mehanna.

REFERENCES
Ahmed MAK (2012) Ecological studies on the crayfish, *Procambarus clarkii* (Girard, 1852) in some sectors of the River Nile and its tributaries in Egypt. MSc Thesis, Ain Shams University, Cairo, Egypt. 193 pp.

Beckman WC (1948) The length-weight relationship, factors for conversions between standard and total lengths and coefficient of condition for seven Michigan fishes. Transactions of the American Fisheries Society 76: 63–81.

Beverton RJH, Holt SJ (1966) On the dynamics of the exploited fish populations. Fisheries Investigation Series, part 2. Tables of yield functions. Rome: FAO, FAO Fisheries Technical Paper No. 38 (Rev. 1). 67pp.

Beyer JE (1987) On length-weight relationships. part 1: computing the mean weight of the fish of a given length class. Fishbyte 5: 11–13.

Chucholl C (2011) Disjunct distribution pattern of *Procambarus clarkii* (Crustacea, Decapoda, Astacida, Cambaridae) in an artificial lake system in Southwestern Germany. Aquatic Invasions 6(1): 109–113.

Dörr AJM, La Porta G, Pedicillo G, Lorenzoni M (2006) Biology of *Procambarus clarkii* (Girard, 1852) in Lake Trasimeno. Bulletin Français de la Pêche et de la Pisciculture 380–381: 1155–1170.

Dörr AJM, Scalici M (2013) Revisiting reproduction and population structure and dynamics of *Procambarus clarkii* eight years after its introduction into Lake Trasimeno (Central Italy). Knowledge and Management of Aquatic Ecosystems 408: 10.

El-Naggar MM, Abou-Elmagd WSI, Suloma A, El-Shabaka HA, Khalil MT, Abd El-Rahman FA (2019) Optimization and physico-chemical characterization of chitosan and chitosan nanoparticles extracted from the crayfish *Procambarus clarkii* wastes. Journal of Shellfish Research 38(2): 385–395.

El-Naggar MM, Salaah H, El-Shabaka FA, El-Rahman M, Khalil MT, Suloma A (2021) Efficacy of dietary chitosan and chitosan nanoparticles supplementation on health status of Nile tilapia, *Oreochromis niloticus* (L.). Aquaculture Reports 19: 100628.

Fishar MR (2006) Red swamp crayfish (*Procambarus clarkii*) in River Nile, Egypt. Biodiversity Monitoring and Assessment Project, Cairo, Ministry of State for Egyptian Environmental Affairs Agency, Egypt.

Galib SM, Findlay JS, Lucas MC (2021) Strong impacts of signal crayfish invasion on upland stream fish and invertebrate communities. Freshwater Biology 66(2): 223–240.

Galib SM, Sun J, Gröcke DR, Lucas MC (2022) Ecosystem effects of invasive crayfish increase with crayfish density. Freshwater Biology 67(6): 1005–1019.

Garcia S, Le Reste L (1981). Life Cycles, Dynamics, Exploitation and Management of Coastal Penaeid Shrimp Stock. FAO Fisheries Technical Paper, Rome. 215pp.

Gulland JA (1971) The Fish Resources of the Ocean West Poly Fleet, Survey Fishing News (Books) Ltd. FAO Technical Paper 97: 428.

Harper DM, Smart AC, Coley S, Schmitz S, de Beauregard AG, North R, Adams C, Obade P, Kamau M (2002) Distribution and abundance of the Louisiana red swamp crayfish *Procambarus clarkii* Girard at Lake Naivasha, Kenya between 1987 and 1999. Hydrobiologia 488: 143–151.

Huner JV (1981) Information about the biology and culture of the red swamp crawfish, *Procambarus clarkii* (Girard, 1852) (Decapoda, Cambaridae) for fisheries managers in Latin America. Anales del Instituto de Ciencias del Mary Limnología 8: 43–50.

Huner JV, Barr JE (1991) Red Swamp Crayfish, Biology and Exploitation, 3rd ed. Louisiana State University, Baton Rouge, Louisiana, USA. 136pp.

Ibrahim MA, Khalil MT, Mubarak MF (1995) On the feeding behaviour of the exotic crayfish *Procambarus clarkii* in Egypt and its prospects in the biocontrol of local vector snails. J. Union of Arab Biologist, Cairo, Egypt 4: 321–340.

Jin S, Jacquin L, Xiong M, Li R, Lek S, Li W, Zhang T (2019) Reproductive pattern and population dynamics of commercial red swamp crayfish (*Procambarus clarkii*) from China: implications for sustainable aquaculture management. PeerJ 7:e6214.

Jones R, Van Zalinge NP (1981) Estimates of mortality rate and population size for shrimp in Kuwait waters. Kuwait Bulletin of Marine Science 2: 273–288.

Le Cren ED (1951) The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology 20: 201–219.

Lindqvist OV, Huner JV (1999) Life history characteristics of crayfish: what makes some of them good colonizers (pp. 23–30)? In: Gherardi F, Holdich DM (Eds)

Crayfish in Europe as alien species: how to make the best of a bad situation? Balkema / CRC Press / Taylor&Francis, Rotterdam.

Mehanna SF (2018) Impacts of some alien species in Egypt: crayfish as fresh water species and puffer fish as marine species. FishForum 2018. 10–14 December 2018. Rome, Italy.

Mehanna SF, El-Gammal FI (2008) Population dynamics and management of white shrimp *Metapenaeus stebbingi* (Penaeidae) at Lake Timsah, Suez Canal, Egypt. Asian fisheries science 21: 305–317.

Mehanna SF, Khalifa UA (2007) Small shrimp fisheries management at Southeastern Mediterranean (Port Said region), Egypt. Egyptian Journal of Aquatic Biology and Fisheries 11(3): 927–942.

Mehanna SF, Khvorov S, Al-Sinawy M, Al-Mosharafi M, Yehia A (2012) Stock assessment of the blue swimmer crab *Portunus pelagicus* (Linnaeus, 1766) from the Oman coastal waters. International Journal of Fisheries and Aquatic Sciences 2: 1–8.

Ochwada-Doyle FA, McLeod J, Barrett G, Clarke C, Gray CA (2014) Assessment of recreational fishing in three recreational fishing havens in New South Wales. Fisheries Final Report Series 139: 29.

Oficialdegui FJ, Clavero M, Sánchez MI, Green AJ, Boyero L, Michot TC, Klose K, Kawai T, Lejeusne C (2019) Unravelling the global invasion routes of a worldwide invader, the red swamp crayfish (*Procambarus clarkii*) Freshwater Biology, 64(8): 1382–1400.

Pauly D (1980) On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. ICES Journal of Marine Science 39: 175–192.

Pauly D (1983) Length converted catch curves: A powerful tool for fisheries research in the tropics (part 1) Fishbyte 1(2): 9–13.

Pauly D (1984) Length-converted catch curves: A powerful tool for fisheries research in the tropics (part II). ICLARM Fishbyte 2(1): 17–19.

Pauly D (1987) A review of the ELEFAN system for analysis of length- frequency data in fish and aquatic invertebrates. ICLARM Conference Proceeding 13: 7–34.

Pauly D, Soriano ML (1986) Some practical extensions to Beverton and Holt's relative yield-per-recruit model (pp. 491–495). In: Maclean JL, Dizon LB, Hosillos LV (Eds) The first Asian fisheries forum, Asian Fisheries Society, Manila, Philippines.

Powell DG (1979) Estimation of mortality and growth parameters from length frequency of a catch. Rapports et Procès-Verbaux des Réunions de Conseil International pour l'Exploration de la Mer 175: 167–169.

Rochet MJ, Cornillon PA, Sabatier R, Pontier D (2003) Comparative analysis of phylogenetic and fishing effects in life history patterns of teleost fishes. Oikos 91(2): 255–270.

Saad A, Emam W (1998) Field and semifield studies on the crayfish *P. clarkii* in Egypt. Egyptian Journal of Aquatic Biology and Fisheries 2(4): 331–344.

Saad A, Mehanna SF, Khalil MT, Said M (2015) Population Dynamics of the Freshwater Crayfish *Procambarus clarkii* (Girard, 1852) in the River Nile, Egypt. Egyptian Journal of Aquatic Biology and Fisheries 19(2): 101–116.

Scalici M, Gherardi F (2007) Structure and dynamics of an invasive population of the red swamp crayfish (*Procambarus clarkii*) in a Mediterranean wetland. Hydrobiologia 583: 309–319.

Ursin E (1967) A mathematical model of some aspects of fish growth, respiration and mortality. Journal of Fisheries Research Board Canadian 24: 2355–2453.

Veroli M, Martinoli M, Caprioli R, Angelici C, Pulcini D, Capoccioni F (2021) Population structure and dynamics of the invasive *Procambarus clarkii* (Girard, 1852) in a Tiber river Ramsar site, Central Italy. International Journal of Aquatic Biology 9(1): 23–32.

Von Bertalanffy L (1938) A quantitative theory of organic growth. Human Biology 10: 181–243.

Wetherall JA (1986) A new method for estimating growth and mortality parameters from length-frequency data. ICLARM Fishbyte 4: 12–14.

Wooten RJ (1998) Ecology of Teleost Fishes. Kluwer Academic Publishers, Dordrecht, The Netherlands. 386 pp.