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Population dynamics and fisheries characteristics of the Blue Crab *Callinectes sapidus* (Rathbun, 1896) as an invasive species in Bardawil Lagoon, Egypt

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ABSTRACT

Population parameters of the blue crab, *Callinectes sapidus* were investigated based on the data collected from the commercial catches of Bardawil Lagoon covering 20 months during the fishing seasons 2016-2018. Growth parameters were estimated from the carapace length frequency distribution data of more than 1960 specimens. The von Bertalanffy growth parameters for males, females and sexes combined were K= 1.53, 1.45 and 1.42 y^{-1} respectively, L_∞= 9.71, 10.11 and 9.96 cm respectively and t_o= -0.14, -0.15 and –0.15 year respectively. The values of total mortality coefficient (Z), natural mortality coefficient (M) and fishing mortality coefficient (F) were 5.19, 2.31 and 2.88 y^{-1} for males, 6.21, 2.51 and 3.70 y^{-1} for females and 6.35, 2.57 and 3.78 y^{-1} for sexes combined respectively. Exploitation rate was estimated at 0.55, 0.60 and 0.59 for males, females and sexes combined respectively. The age-based yield per recruit analysis showed that the blue crab stock is being exploited at its optimum limit. The present study suggested that this fishery resource could be expanded with the increase of current fishing effort but such increasing is not acceptable because the commercial species in the lagoon are over exploited. The current management regulations must be revised and improved to sustain and optimize yields.

INTRODUCTION

Invasive species can dramatically alter the ecosystems where they invade (Didham *et al.*, 2005; Lockwood *et al.*, 2007). Invasive species have been shown to reduce the abundance of native species (Brenchley and Carlton, 1983), make changes in marine food webs (Kimbro *et al.* 2009) and can have negative impacts on directed fisheries (Walton *et al.* 2002). Also, the overall population growth rates of invasive species can increase as the survivorship become high due to the lack of natural predators. The blue crab, *Callinectes sapidus*, is native to the western Atlantic basin, from Canada to Argentina, including Bermuda, Nova Scotia, Maine, northern Massachusetts and the Antilles (GSMFC, 2001; Tavares, 2004). This species has been successfully introduced into both Asia and Europe, accidentally or intentionally. The ship ballast water is the main source responsible for accidental introduction of blue crab larvae. Throughout this range, the blue crab is an important component of estuarine food webs, acting as a dominant, opportunistic benthic predator and scavenger (Hines, 2007).

In turn blue crab is an important prey for fish, including, bass, bream, red drum and croaker. Thus blue crab represents an important link coupling benthic and pelagic food webs (Eggleston *et al.,* 1992; Hines, 2007). For its ecological importance, the blue crab supports important commercial and recreational fisheries throughout much of its range (Miller *et al.*, 2011).

Blue swimmer crabs, *Portunus pelagicus* and *Callinectes sapidus* (Decapoda, Portunidae) are one of the important fishery resources along Egyptian coasts of Mediterranean and Red sea. It supports a valuable commercial fishery in Bardawil lagoon where it contributed about 32% of the total catch in the lagoon (General Authority for Fisheries Resources Development GAFRD, 2006-2017). This constitutes about 26% of gross revenue of the lagoon due to the value of its meat and increasing its market prices year after year. Despite the great importance of the blue crabs to the economy of the Egyptian fisheries, a limited studies were conducted on the biology of these species in the Egyptian waters. All previous studies in the Egyptian waters focused on the blue swimmer crab, *P. pelagicus* (El-Sayed, 1992; Mehanna, 2005; Mehanna and Haggag, 2007; Mehanna and El-Aiatt, 2011). On the other hand, there were no studies dealing with dynamics and management of *C. sapidus* in the Egyptian waters. This work is the first so far to provide biological parameters and population dynamics required for managing the *C. sapidus* stock in Bardawil lagoon.

MATERIALS AND METHODS

A total of 1960 crabs (906 males and 1054 females) were obtained between May 2016 and December 2018 (except the closing months during this period) from the commercial landings of Bardawil lagoon. Sexes were separated externally and their carapace length (CL) and width (CW) to the nearest mm, and their body weight (BW) to the nearest 0.1 g, were recorded for each specimen.

The monthly width and length frequencies were grouped in 0.5 cm classes for LFDA (Length Frequency Distribution Analysis).

The relation between both of CW and CL against BW was computed using the formula $BW = a\ CW^b$ and $BW = a\ CL^b$ where a and b were constants.

The relation between the CL and CW was estimated using the following linear equation: CL = a + b CW where a and b are the constants of the relationship.

Growth parameters ($L\infty$ and K), total mortality rate (Z), natural mortality rate (M), length at first capture (L_c) and yield per recruit analysis were estimated for *Callinectes sapidus* using the following methods:

ELEFAN I program to construct the growth curve and estimate the asymptotic carapace length $CL\infty$ and the growth parameter K. The seasonal von Bertalanffy growth model was applied to quantify the growth parameters using Hoenig method using the LFDA (Length Frequency Distribution Analysis) for each sex. The seasonal von Bertalanffy growth function can be expressed as:

$$L_t = L\infty\ (1 - e^{[-k\ (t-to)\ +\ (ck/2\pi)\ \sin 2\pi\ (t-ts)\ -\ (CK/2\pi)\ \sin 2\pi\ (to-ts)]})$$

where $L\infty$ is the asymptotic carapace length that crabs can grow, K is the annual growth coefficient (y^{-1}), t_0 is the age at length zero, ts is the time of the year when the growth rate is highest and C is the amplitude of the seasonality factor, which ranges between 0 and 1 (i.e. for values of C close to 0 no seasonality occurs, for values close to 1 the amplitude is maximal). The ELEFAN routine estimates only two of the three growth parameters ($L\infty$ and K), thus t_0 was computed by the empirical function of Pauly (1983) for growth fitting: Log ($-t_0$) = -0.3922 – 0.2752 Log CL∞ - 1.038 Log K

- Wetherall (1986) plot to estimate L∞ and Z/K.
- Longevity was calculated from $t_{max} \approx 3/K$ (Pauly, 1980).
- Jones and Van Zalinge (1981) (Analysis of the cumulative catch curve) and Pauly (1983) (Analysis of the length converted catch curve) methods to estimate total mortality coefficient Z. Also, an estimate of Z was derived from Wetherall (1986) plot.
- Alverson & Carney (1975), Pauly (1980) and Lorenzen (1996) formulae to estimate natural mortality coefficient M.
- Catch curve analysis (Pauly, 1984) to estimate the length at first capture Lc.
- Yield per recruit Y/R analysis was investigated by applying the model of Beverton and Holt (1957) using Gulland (1969) formula as follows:

$$Y/R = Fe^{-M\,(Tc-Tr)}\, W\infty * [(1/Z) - (3S/(Z + K)) + (3S^2 / (Z + 2K)) - S^3/(Z+3K)]$$

Where $S = e^{-k\,(Tc-to)}$, Tr = age at the recruitment and W∞ = asymptotic body weight. Yield per recruit analysis was applied for sexes combined.

RESULTS AND DISCUSSION

Impact of crab's invasion on Bardawil lagoon

In the past, Bardawil lagoon was produced a high valued fish species mainly seabream, flathead grey mullet and thinlip grey mullet with mean annual landings of 2000 ton. Since early 1990's, catch composition in the lagoon were greatly changed specially since the fishing season 1996. Crustaceans have been recorded in the catch in significant quantities during early 1990's and progressively increased to represent up to 60% of the total yield production of Bardawil Lagoon (GAFRD, 2017). This increasing in crustacean catch negatively impacted the lagoon production from economic fish species (Khalil, 2006, Mehanna, 2006, Mehanna *et al.*, 2010 & 2011; Salman, 2013; Mehanna, 2013) (Fig. 1). In addition, several exotic species have been appeared and established themselves in lagoon ecosystem, e.g. *Terpon puta*, *Siganus rivulatus*, *Hemiramphus far*. Their fisheries are abundance and reveal that they find their suitable ecological niche in the lagoon. Also, *Tilapia zillii* appeared in the commercial catch of the lagoon since 1997. At the beginning, its appearance was confined to winter months from October and thereafter, tilapias' catch increased gradually.

The dramatic change in catch composition during this period indicated the presence of several driving factors which alter the ecological condition of the lagoon as well as biological balance. This serious change in catch composition can be attributed to a number of factors: the change in the ecological conditions of the lagoon, uncontrolled fish exporting policy and the overexploitation since late 80's till now. These factors lead to the decreasing of sea bream and sea bass production (Mehanna, 2006; Mehanna and El-Aiatt, 2011; Mehanna *et al.*, 2011; Mehanna, 2013).

Callinectes sapidus is native to the Western Atlantic, It was introduced in Europe (Denmark, Netherlands, and adjacent North Sea, France, Gulf of Genoa); northern Adriatic; Aegean, western Black, and eastern Mediterranean Seas. It has also been introduced to Japan. It is now rather abundant in parts of the northern and eastern Mediterranean Sea and Japan (Tureli, 1999; Tureli and Yesilyurt, 2014; Tureli *et al.*, 2016). Blue crab has become established as a non-native species in the

Mediterranean basin (Holthuis, 1961). Holthuis and Gottlieb (1955) suggested that *C. sapidus* was transported to the Mediterranean in ship's ballast tanks. The blue crab was first recorded in the Egyptian waters of Mediterranean Sea in the 1940's (Banoub, 1963).

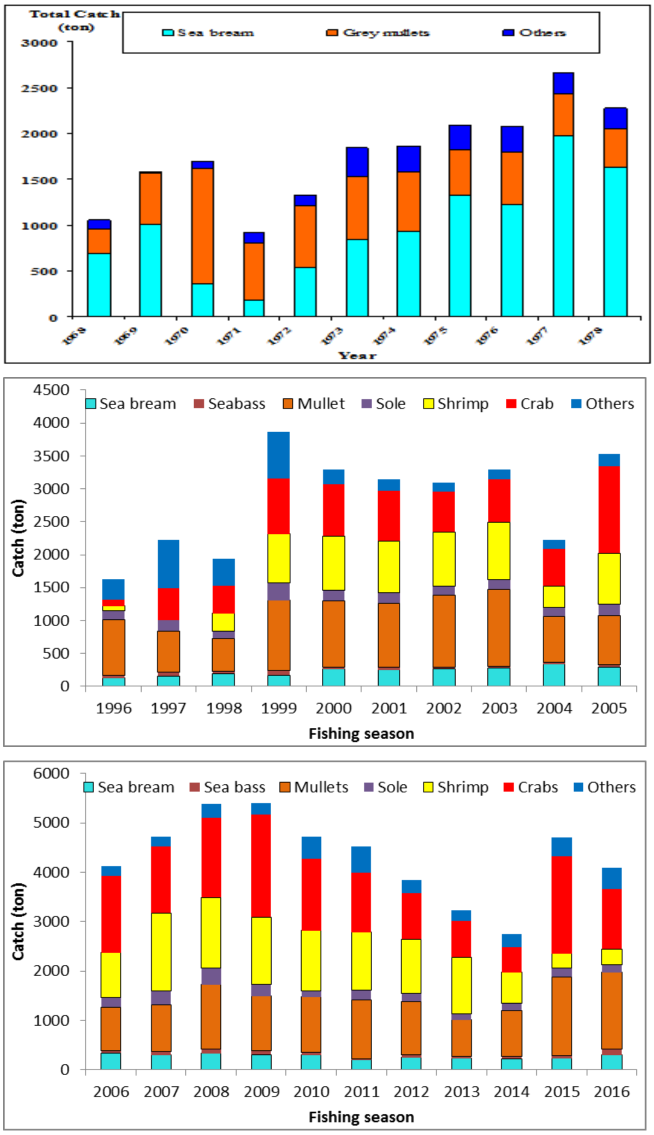

Fig. 1: Catch trends and catch composition changing during different periods of times

Subsequently, it has been reported in coastal waters off Italy (Giordani-soika, 1951, as *Neptunus pelagicus*), Israel (Holthuis and Gottlieb, 1955), Greece (Kinzelbach, 1965), and Turkey (Kocataş and Katağan, 1983). Most recently, it has been reported in the Bay of Biscay, along the northwest coast of Spain (Cabal *et al.*, 2006) and Sacca di Goro lagoon, the northern part of Italy (Manfrin *et al*., 2015).

C. sapidus along with *Portunus pelagicus* were established as invasive species in Bardawil lagoon with considerable amounts in early 1990's (GAFRD, 1992). Throughout the period from 1987 to 1995, the landings of the crab progressively increased from 19.7 to 491.7 ton. A continuous increase occurred to reach 2071 ton in 2009 and 1973 ton in 2015 (GAFRD, 2017). The crab populations expanded quickly and now support important commercial fisheries in the lagoon (Fig. 2). The expansion of crab in Bardawil lagoon along with the ecological conditions affected greatly the abundance of the commercial finfish in the lagoon.

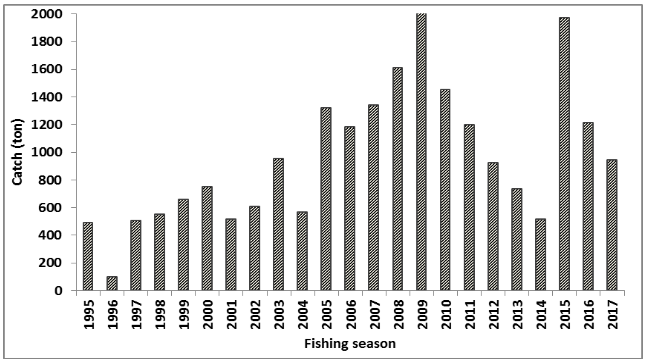

Fig. 2: Crab's catch trends during the last 23 fishing seasons

Carapace length – width relationship

The carapace length (CL) of *C. sapidus* was plotted against the carapace width (CW) to estimate the CL – CW relationship (Fig. 3).

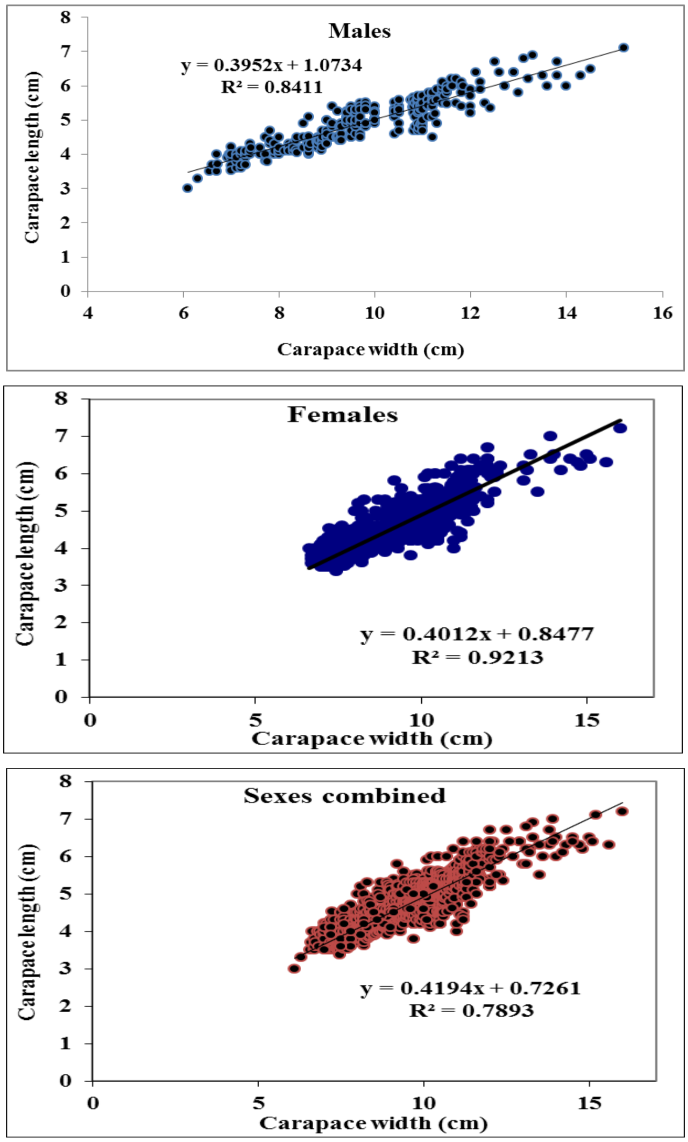

Fig. 3: Carapace length CL-Carapace width CW relationship of *Callinectes sapidus*

The CL varied from 3.0 to 7.1 cm for males and from 3.6 to 7.5 cm for females while the CW varied from 6.3 to 15.2 cm for males and from 6.7 to 16.3 cm for females. The obtained equations were:
Males: CL = 1.0734 + 0.3952 CW (r^2 = 0.84)
Females: CL = 0.8477 + 0.4012 CW (r^2 = 0.92)
Combined sexes: CL = 0.7261 + 0.4194 CW (r = 0.79)

Carapace length and width - body weight relationship

Length-weight relationship (LWR) and its parameters 'a' and 'b' are of great importance in fishery biology and practical stock assessment of aquatic species (Gulland, 1983; Enin, 1994; Stergiou and Moutopoulos, 2001). LWR can also be useful in studies of rate of feeding, metamorphosis, gonad development, maturity and well being of the fish population (Le Cren, 1951; Bolger and Connolly, 1989). The carapace length of *C. sapidus* in Bardawil lagoon was ranged between 3.0 and 7.1 cm (6.3-15.2 cm CW) with weights varying from 15 to 225 g for males, while the carapace length was varied from 3.5 and 7.5 cm (with weights, ranging from 18.0 and 225 g for females (Fig. 4).

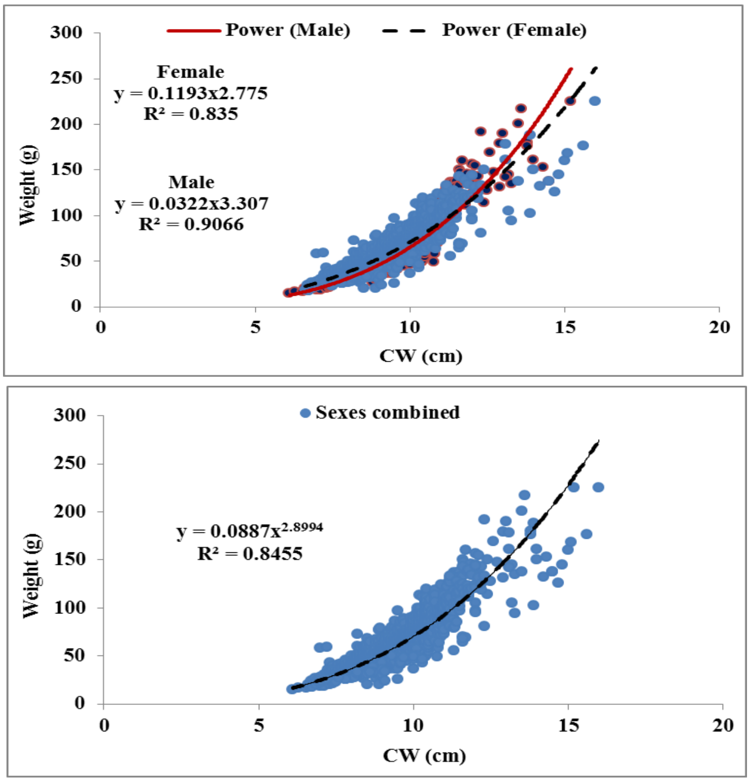

Fig. 4: Carapace width CW- weight relationship of *Callinectes sapidus*

The obtained carapace width - weight equations were:
Males: W = 0.0322 $CW^{3.307}$ (r^2 = 0.91)
Females: W = 0.1193 $CW^{2.775}$ (r^2 = 0.84)
And carapace width – weight equations (Fig. 5) were:
Males: W = 0.1962 $CL^{3.5844}$ (r^2 = 0.77)
Females: W = 1.0329 $CL^{2.6407}$ (r^2 = 0.72)

In Bardawil lagoon, blue crab showed positive allometric growth for males and negative allometric growth for females for length and width-weight relationship. For sexes combined, the growth pattern was found to be negative allometric for both carapace width and length (Fig. 5). The previous available studies gave also the similar results (Stickney, 1972; Atar and Secer, 2003; Gokce *et al.*, 2006; Sumer *et al.*, 2013), others reported the different results (Gokce *et al.*, 2006; Stickney, 1972). The parameters of length-weight relationships may be affected by various factors, such as time of years, temperature, food, environmental conditions, stomach fullness, differences in age, stage of maturity and sex (Bagenal and Tesch, 1978; Pauly, 1984).

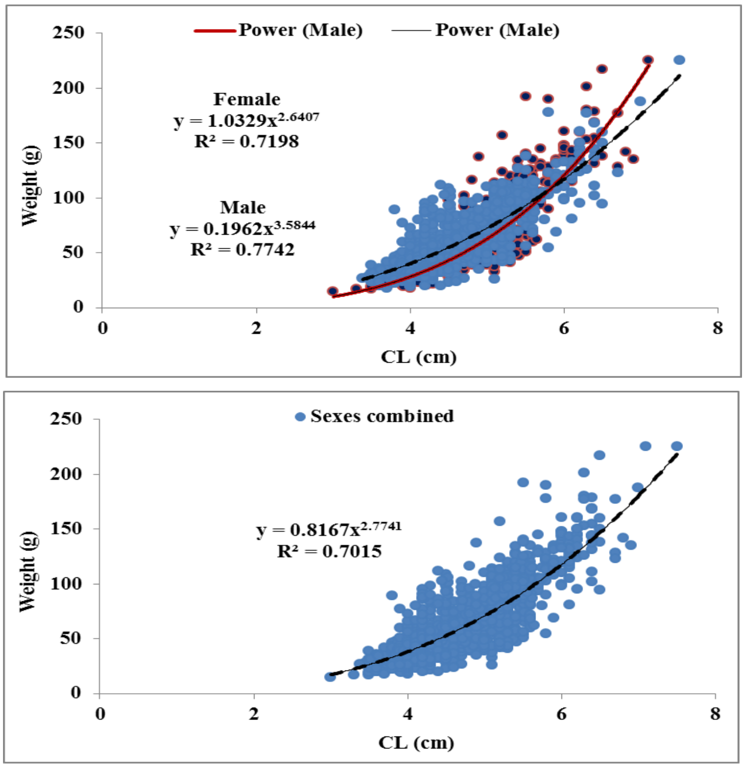

Fig. 5: Carapace length CL - weight relationship of *Callinectes sapidus*

Growth parameters and maximum age

Wetherall (1986) method gave CL∞ estimates at 9.71, 10.11 and 9.96 cm for males, females and sexes combined respectively. These values were then applied to a von Bertalanffy plot to estimate the growth parameter K. The respective values of K were 1.53, 1.45 and 1.42 y^{-1}. ELEFAN I program (Pauly, 1987) gave L∞ = 9.59 cm and K= 1.59 y^{-1} for males, L∞ = 9.98 cm and K= 1.51 y^{-1} for females and 10.22 and K = 1.38 y^{-1} for combined sexes. The estimates of age at length zero t_o are -0.14, -0.15 and -0.15 year for males, females and sexes combined respectively. Females have higher CL∞ and slightly lower K value than males. The values of estimated growth parameters (K and L∞) of *C. sapidus* from Bardawil lagoon indicate the short longevity and fast growth rate of this species. Potential lifespan was estimated to be 1.96, 2.07 and 2.11 years for males, females and sexes combined respectively. The available studies that considered longevities of 3 to 8 years (Fogarty and Lipcius, 2007), Rugolo *et al.* (1997&1998) and Miller and Houde (1999) investigated estimates of longevity ranging from 4 to 8 yrs for Chesapeake Bay. Kahn and Helser (2005) mentioned that the most likely maximum life span in Delaware Bay is 3 yrs. It would appear that the most likely range for blue crab longevity is 2 to 6 yrs depending on location, maximum size and other ecological factors (Fogarty and Lipcius, 2007).

Mortality and exploitation rates

The mean value of the total mortality coefficient (Z) estimated from three different methods was 5.19, 6.21 and 6.35 y^{-1} for males, females and sexes combined respectively. While the geometric mean of natural mortality coefficient (M) for males, females and sexes combined was 2.31, 2.51 and 2.57 y^{-1} respectively, and the respective values of fishing mortality coefficient (F) were 2.88, 3.70 and 3.78 y^{-1}. Accordingly, the exploitation rate (E) was computed as 0.55, 0.60 and 0.59 for males, females and sexes combined respectively.

In the present study, the high values of M were correlated with the high K values of *C. sapidus*. Beverton and Holt (1957&1959) found that the fast growing fish and crustacean species of high K- values have high values of natural mortality. The M/K ratio for males, females and sexes combined of *C. sapidus* from Bardawil lagoon were in the range of 1.5 - 2.5 given by Beverton and Holt (1959). Gulland (1971) reported that the optimum exploitation rate of any exploited stock is about 0.5, so the high values of the present exploitation rate and fishing mortality revealed an excessive fishing effort exerted into the blue crab fishery in the Bardawil lagoon.

Length at first capture (L_c)

The carapace length at first capture (the length at which 50% of the crabs are vulnerable to capture) was estimated as a component of the length converted catch curve analysis. The values of CL_c obtained were 4.33, 4.56 and 4.48 cm for males, females and sexes combined respectively.

Yield per recruit analysis

Based on the obtained results (Fig. 6), a higher catch of crabs could be achieved with the increase of fishing effort along the Bardawil lagoon. Under the present conditions of the lagoon, such an increase in fishing effort may not adversely affect the stock of crabs but will affect the other commercial stocks of finfish in the lagoon. So, it could be said that, presently, the stock of blue crab is underexploited and one possible management policy towards obtaining better catches might be to suggest a specific fishing method for crabs with suitable mesh sizes to conserve the young stages.

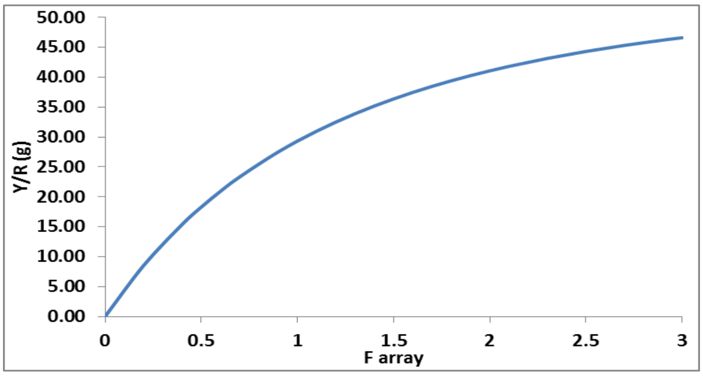

Fig. 6: Yield per recruit analysis of *Callinectes sapidus* from Bardawil lagoon

CONCLUSION

In conclusion, the results of this study show that blue crab fishery in Bardawil lagoon appears to be exploited under its optimum level and there is a scope for a considerable extension of the fishery. But any recommendation to increase the effort in a multi-species fishery should consider all the components of that fishery. Also, before any advice to increase the fishing effort, more precise assessment would be required and a sampling programme for the commercial landings should be established to provide total catches by size groups. Also, an investigation for the impact of the fishery independent factors like predation and other changes in environmental parameters on the growth and recruitment should be done. Finally, improving the catch statistics recording system to cover all species caught from Bardawil lagoon should be considered. Catch and effort data needs to be evaluated for quantity and quality. Currently, effort information is unreliable and attempts should be made to gather appropriate information to measure effective effort in the lagoon fishery. The unreported and unregulated harvest of blue crab and all species exploited in Bardawil lagoon, should also be controlled. Further research must to be conducted to determine the full dynamics of blue crab in the Bardawil lagoon and its relation with other trophic levels in the lagoon.

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