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# Present Fishery Status of the Most Common Species in Bardawil Lagoon, Egypt; Based on Maximum Sustainable Yield Estimation

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## ABSTRACT

Bardawil lagoon is one of the northern lakes in Egypt and has an exceptional significance where it is the least polluted wetland in Egypt and represents one of the least polluted lagoons in the whole Mediterranean region. The catch in Bardawil lagoon is composed of a high-valued fish species like grey mullet, soles, seabass, seabream, eel, meager and grouper. The lagoon covered a total surface area of about 650 Km$^2$ and employing more than 4,000 fishermen. In 2022, 4283 tons were landed from the lagoon, achieving more than 350 million Egyptian pounds. A number of fishing methods are used in the lagoon including trammel nets (Dabba), veranda nets (El-Bouss), lines (sinnar), dubdeiba, crab nets, and dahbana nets. The fishery statistics (catch and effort data) are necessary in the stock assessment studies, as they constitute the basic input for the surplus production models SPMs which established to determine the equilibrium or sustainable yield that may be harvested from a fishery for a given level of effort. The present work was undertaken to evaluate the fishery status of Bardawil lagoon fishery as well as to estimate the maximum sustainable yield for four commercial stocks; soles, grey mullet, crabs and shrimp. The study will help fishery managers develop and implement the fisheries regulations in the lagoon.

## INTRODUCTION

Egyptian fisheries (comprises the management, catching, processing, marketing of fish stocks) and aquaculture (the farming of fish) afford a significant source of food, employment, income and recreation for the Egyptian people. Millions of Egyptians rely on fish and fisheries for their incomes and livelihoods **(Mehanna, 2020, 2021, 2025)**. Bardawil lagoon (Fig. 1) is one of the northern lakes in Egypt, and it is a main source of native and commercial fishes in North Sinai. It plays a crucial role in the fish production in Egypt, where it yields very economically key species of fishes and crustaecean such as grey mullet, soles, seabass, seabream, eel, meager, crabs, shrimp and grouper. Bardawil lagoon is a shallow hyper-saline lagoon that extends to about 85km length with a maximum width of 22km, and ranges in depth from 0.3 to 3m. Bardawil lagoon is the least polluted wetland in Egypt and is considered one of the least polluted in the whole Mediterranean area with a total surface area of about 650Km$^2$ and hiring more than 4,000 fishermen. The fishery in Bardawil lagoon is seasonal generally from early April to the end of December; all fishing operations are forbidden in winter, from January to the end of March. These actions were decided to protect the seabream and seabass during their departure from the lagoon for spawning migration. A number of fishing techniques are operated in the lagoon comprising trammel nets (Dabba), veranda (El-Bouss), trawl nets (Kalsa), lines (sinnar), El-Dahbana nets and El-Tair nets **(Farouk, 2014; Salman 2014; Aabed, 2020; Mehanna *et al.*, 2020; Mehanna *et al.*, 2023)**. In 2022, 4283 tons were catched from the lagoon attaining more than 350 million Egyptian pounds **(GAFRD, 2022)**. For the special significance of the lagoon, the government established a development project to enhance the fish production from the lagoon. The project was started in 2024 and has three phases, the first is digging a longitudinal canal parallel to the sand bar of length 73km, the second is digging a number of branching canals of 57km length, while the last is the coast guards canals with a length of 7.5km (Fig. 2).

The fishery statistics (catch and effort data) are crucial in the field of stock assessment science, as it comprises the basic input for the surplus production models, established to evaluate the equilibrium or sustainable harvest that may be yielded from a fishery for a specified level of effort **(Mehanna, 2006a, b)**. An understanding of fishing effort is essential for assessing and managing different fish stocks. Most management actions comprise determining directly or indirectly about the amount of fishing effort (f) that should be applied to the stock to attain a definite amount of catch (C) that is sustainable over time **(Rothchild, 1977)**. Additionally, the most widely used method up-to-date fot approximating the relative abundance of any exploited fish stock is achieved by means of the catch per unit effort (C/f) as an index of relative abundance of fish stocks.

The present paper focused on the impacts of the excessive fishing effort on the lagoon production as well as on the commercial species exploited in the lagoon. Besides, the fishery status of the lagoon and four commercial species was assessed and evaluated to estimate the maximum sustainable yield and the optimum fishing effort that ensure the sustainability of lagoon production.

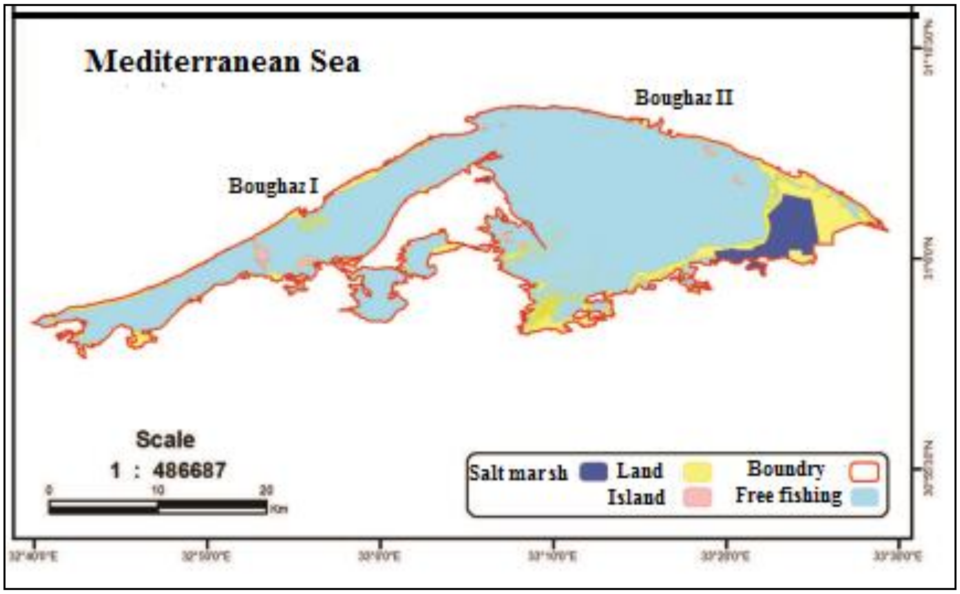



**Fig. 1.** Bardawil lagoon

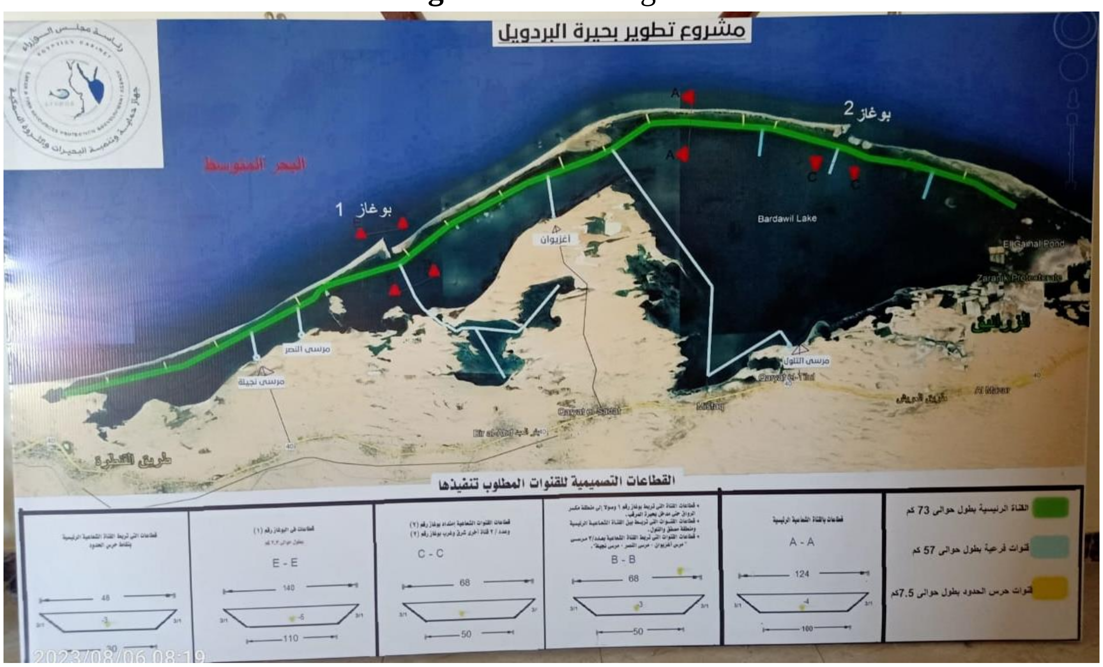



**Fig. 2.** Development project stages for Bardawil lagoon development **(source: LFRPDA office in Bir Elabd)**

## MATERIALS AND METHODS

### 1. Collection of fishery statistics

Records regarding the monthly and annual catch statistics of different fish species and fishing effort in Bardawil lagoon were acquired from the General authority for Fish Resources Development Office in Bir El-Abd, North Sinai. Annual statistical books from

2003 to 2022 (**GAFRD, 2003-2022**) were also used to obtain the fishery statistics for the years 2003 to 2022.

**2. Catch per unit fishing effort**

The number of fishing boats were used as fishing effort unit after the standardization of different segments of the fleet. The method suggested by **Robson (1966)** and discussed by **Gulland (1983)** was used to standardize the fishing effort. The dabba boats unit was chosen as a standard fishing effort unit, and the number of all other fishing boats have been transformed into equivalent standard units. The collected catch and estimated effort data were analyzed to calculate the catch per unit of fishing effort (CPUE) which was considered as a function of stock biomass and indication for the relative abundance of stocks.

**3. Description of method**

A time series of catches can be viewed as a sequence of yields produced by the available biomass with a given productivity. Typical production models, such as the one by **Schaefer (1954)**, use time series of catch and abundance to estimate productivity. Maximum sustainable yield (MSY) and the corresponding level of fishing effort $f_{MSY}$ are estimated for the total lagoon production and three of the commercial species; soles, grey mullet and crabs. CMSY estimates biomass, exploitation rate, MSY and related fisheries reference points from catch data and resilience of the species. A Bayesian statespace implementation of the Schaefer model (BSM) is developed, where r, k and MSY are predicted from catch and abundance data. The basic biomass dynamics are governed by Equation 1:

$$B_{t+1} = B_t + r\,(1 - B_t/K)\,B_t - C_t$$

where $B_{t+1}$ is the exploited biomass in the subsequent year t+1; $B_t$ is the current biomass, and $C_t$ is the catch in year t. To account for depensation or reduced recruitment at severely depleted stock sizes, such as predicted by all common stock–recruitment functions **(Beverton & Holt, 1957; Ricker, 1975; Barrowman & Myers, 2000)**, a linear decline of surplus production, which is a function of recruitment, somatic growth and natural mortality **(Schnute & Richards, 2001)**, is incorporated if biomass falls below ¼ k (Equation 2).

$$B_{t+1} = B_t + 4\,B_t/K\,r(1 - B_t/K)\,B_t - Ct \quad Bt/K < 0.25$$

The term 4 Bt/k assumes a linear decline of recruitment below half of the biomass that is capable of producing MSY.

## RESULTS AND DISCUSSION

### 1. Catch composition

The Bardawil lagoon catch consisted mainly of high-value saltwater fish species like grey mullet (family Mugilidae) which constitutes the majority of lagoon catch with a contribution of 26% of the total catch during the period from 2003 to 2022 (Fig. 3). The gilthead sea bream *Sparus aurata* (family Sparidae) constituted about 10.4%, while soles *Solea solea* and *S. aegyptiaca* (family Soleidae) formed 4.3%, *Dicentrarchus labrax* and *D. punctatus* (family Moronidae) constituted 2.5%, *Argyrosomus regius* (family Sciaenidae) forming 0.44% and *Epinephelus aenus* (family Serranidae) (0.17%). Additionally, crustaceans were represented in the catch by shrimp mainly *Metapenaeus stebbingi* (19.1%) and crabs mainly *Portunus pelagicus* and *Callinectus sapidus* (30.2%) (Fig. 3). In addition, the "others" group that contains the unsorted species or those of lesser importance. This group contains *Anguilla anguilla* (Anguillidae); *Terapon puta* (Terapontidae); *Siganus* spp. (Siganidae); *Hemiramphus far* (Hemiramphidae); *Tylosurus* spp. (Belonidae), *Crenidens crenidens* (Sparidae), *Atherina boyeri* (Atherinidae) and *Tilapia zillii* (Cichlidae). Generally, the catch composition fluctuated from year to year with the dominance of crustacean species (shrimp and crab) from 2003 till 2022 (Fig. 3).

It is worth mentioning that, the catch composition of the lagoon was altered during the last 35 years. During the last years, crustaceans (shrimp and crab) landings have annually increased to a great extent in Bardawil lagoon, reaching about 50 percent of the total catch, affecting the catch of other economic fish species like sea bream and sea bass **(Tom *et al.*, 1984**; **Mehanna, 2006a, b; Mehanna, 2013; Mehanna *et al.*, 2020; Mehanna *et al.*, 2023)**.

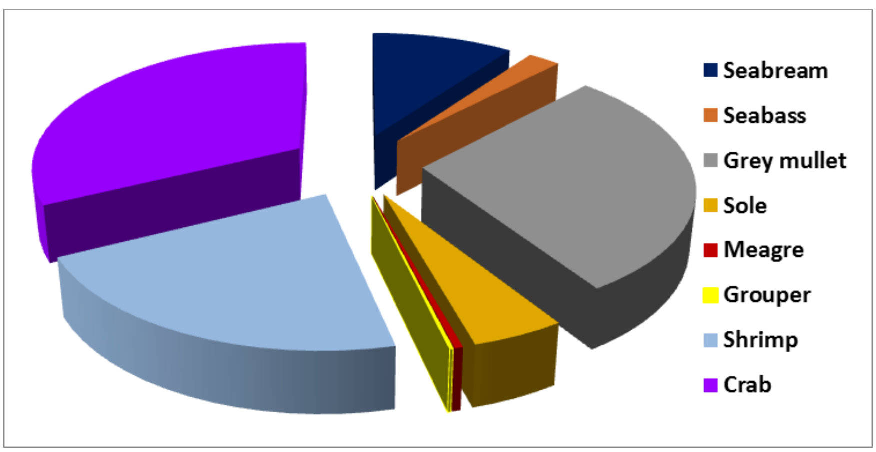



**Fig. 3.** Catch composition (%) in Bardawil lagoon during 2003-2022

## 2. Catch statistics of the studied groups

The annual total fish production from Bardawil lagoon during the period from 2003 to 2022 (Fig. 4) fluctuated between a minimum of 2758 tons during 2014 and a maximum value of 5410 tons during 2009, with a mean value of 3720 tons after excluding the 2020 catch (1592 tons), because the fishing in this year extended for two months only for security reasons in this area. Although the total catch in Bardawil lagoon showed an improvement in the last two years (2021 and 2022), a decreasing trend was observed for the total catch.

The grey mullet species (*Mugil cephalus*, *Liza ramada*, *Liza aurata*, *Chelon labrosus*) fluctuated between a minimum of 733 tons (2013) and a maximum of 1590 tons (2015), with a mean of 1003.7 tons.

Soles (4.3% of the total catch) varied between a minimum of 107 tons in 2017 and a maximum of 343 tons in 2008, with a mean of 165.2 tons.

Crab kept their contribution to the lagoon catch by 30.2% and fluctuated between 519 tons in 2014 and 2071 tons in 2009, with a mean of 1118 tons, while shrimp contribution declined to only 19.1% of the lagoon catch and varied between 43.9 tons in 2018 and 1569 tons in 2007, with a mean of 728.2 tons (Fig. 5).

Generally, a decreasing trend was detected in the annual total fish production from Bardawil lagoon during the period from 2003 to 2022 (Fig. 4). The same trend was also observed for the grey mullet, soles, shrimp and crab (Fig. 5).

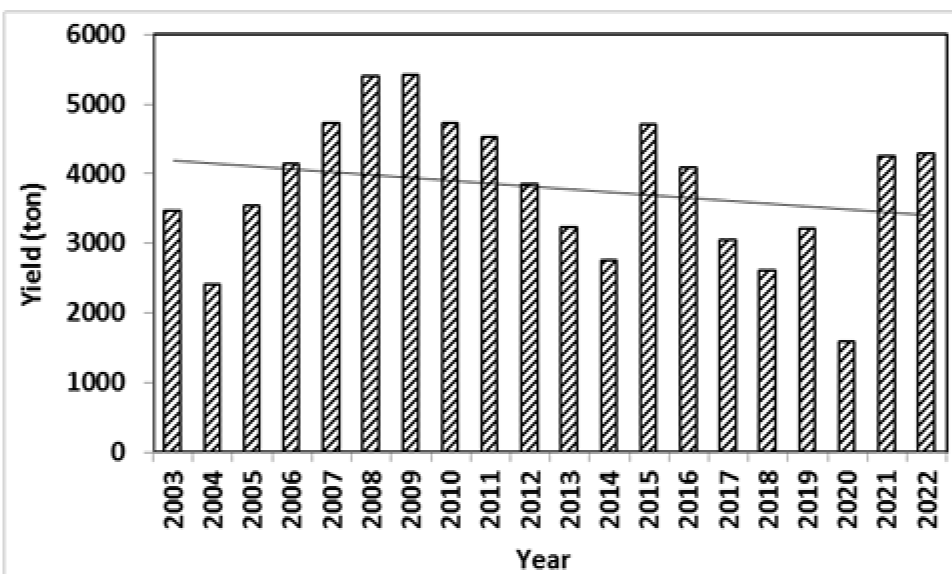
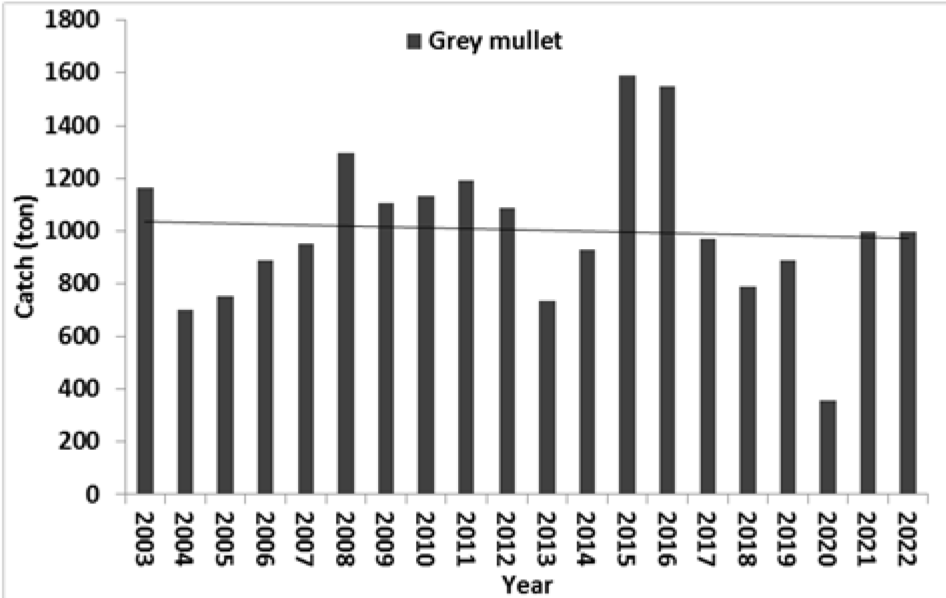
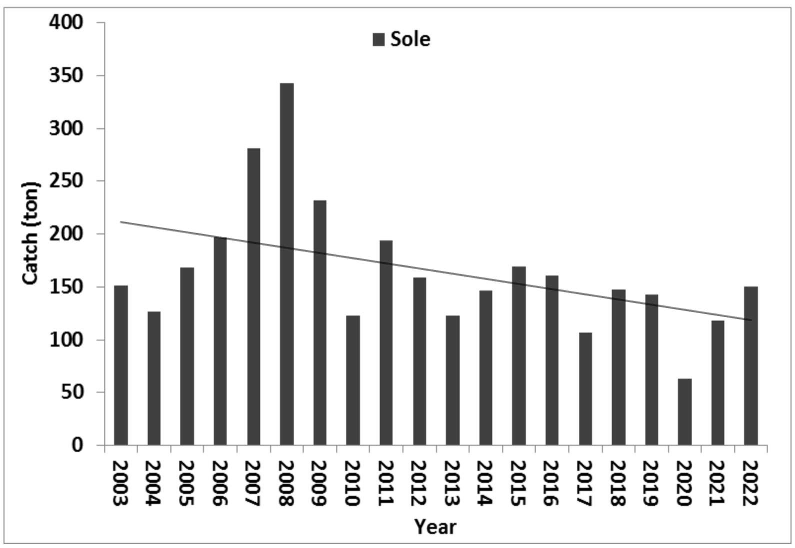



**Fig. 4.** Catch trend of Bardawil lagoon fishery from 2003 to 2022


Grey mullet
Catch (ton)
Year
0
200
400
600
800
1000
1200
1400
1600
1800
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022


Sole
Catch (ton)
Year
0
50
100
150
200
250
300
350
400
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
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2018
2019
2020
2021
2022

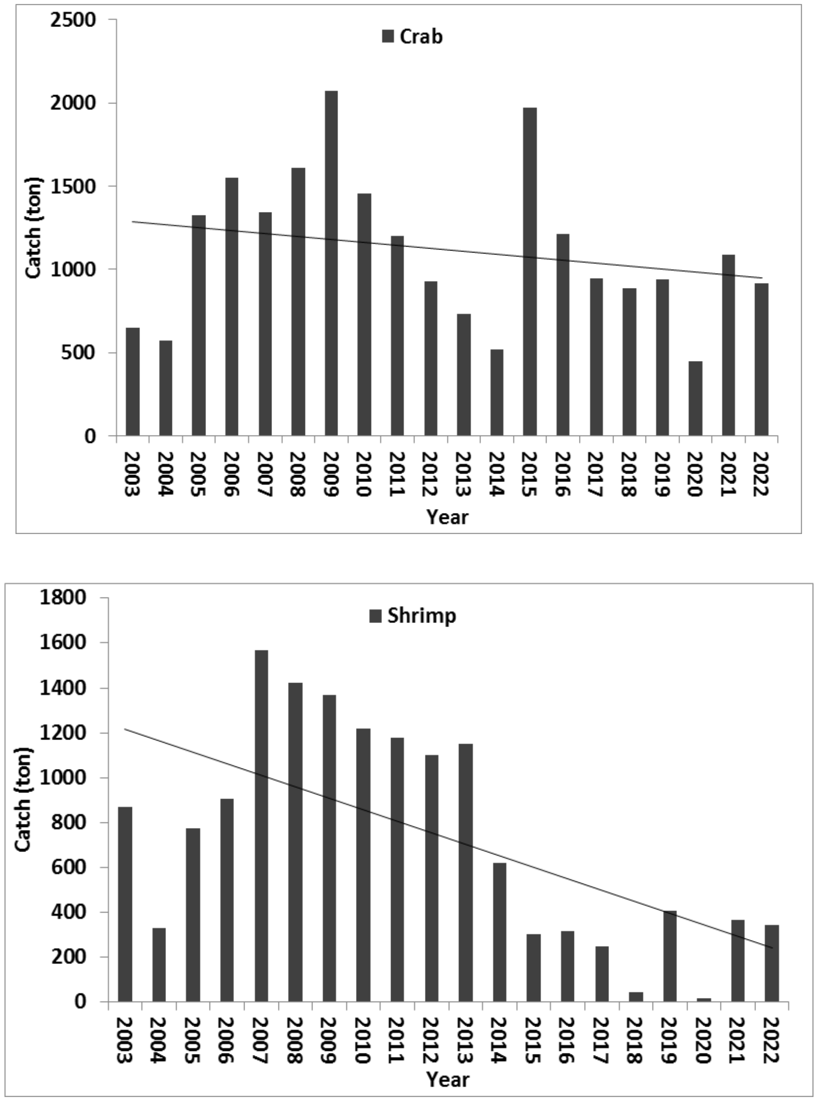



**Fig. 5.** Catch trend of four commercial species (ton) in Bardawil lagoon during 2003 to 2022

### 3. Fishing effort and catch per unit effort CPUE

Catch, effort, and CPUE are key indicators to assess the fishery stock status. Catchability coefficient (q) constitutes the ratio between fishing mortality and fishing efforts, so-called the efficiency of fishing gears. The q was also essential where catch and effort data were used as a critical component for the study of the fish population dynamics. The q could be affected by the variability of the temporal and spatial distribution of the fish stock and fishing fleets **(Hoggarth *et al.*, 2006)**.

The available fishing effort data in this study were the number of fishing boats. The fishing boats operating in Bardawil lagoon are wooden small boats of about 6- 7m in length and 1.8m as an average width, and motorized by outboards of 8 to 10hp (majority are 9.9hp) for Dabba fishing method and by outboards of 15-30hp for El-Bouss fishing techniques. The number of fishing boats during the last 20 fishing seasons fluctuated between 1120 and 1150 boats working with Dabba and varied between 84 and 108 working with El-Bouss fishing method. The average number of fishermen was three persons for each Dabba boat, while the number varied between 14 and 20 persons for each unit Bouss fishing technique (four boats: two motorized and two un-motorized).

The catch per unit fishing effort has been extensively used to measure changes in the abundance of fish population. The catch per unit fishing effort gives the first sight about the relative abundance of the different fish stocks and consequently the status of the fishery **(Mehanna & El-Gammal, 2007; Mehanna & Haggag, 2010; Mehanna *et al.*, 2019a, b)**. After excluding the year 2020, the total CPUE of standardized fishing technique during 2003 and 2022 (Fig. 6) fluctuated between a minimum of 1.86 ton / fishing boat during 2004 to a maximum of 4.31 ton / fishing boat during 2009 with an average of 2.97. Generally, there is a decreasing trend in the relative abundance CPUE of different fish and crustacean species in the lagoon.

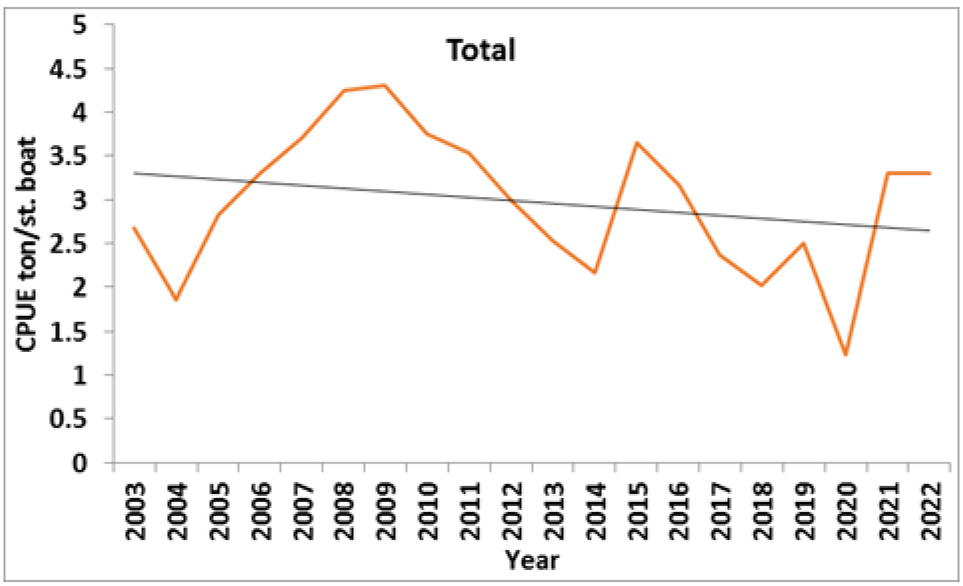
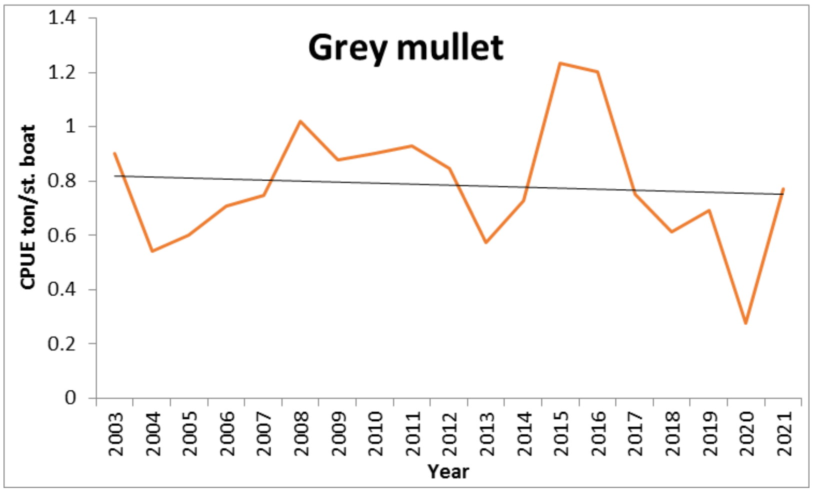



**Fig. 6.** Total catch per fishing effort (ton/standardized boat) in Bardawil lagoon during 2003 to 2022

The CPUE for the grey mullet, soles, shrimp and crab in Bardawil lagoon showed a decreasing trend in the last 20 (2003-2022) years reflecting the decline of relative abundance of these stocks. Grey mullet catch/effort fluctuated between a maximum value of 1.23 ton/boat during 2015 to a minimum value of 0.28 ton/fishing boat during the fishing season 2020. The CPUE of soles fluctuated between a maximum value of 0.27 ton/boat during 2008 and a minimum value of 0.05 ton/boat during 2020. Shrimp catch per unit effort fluctuated between 1.23 (2007) and 0.01 (2020) ton/boat, while crab catch per unit effort varied from 1.65 (2009) to 0.35 (2020) ton/boat. Seabream catch per unit fishing effort in the lagoon experienced an increase trend, with a very high value at 2021 (0.92 ton/boat) and the same trend was observed for seabass catch, as it recorded 0.18 ton/boat during 2021 (Fig. 7). The decrease of CPUE for total catch and the four commercial species from Bardawil lagoon, indicating the over exploitation situation of the lagoon.



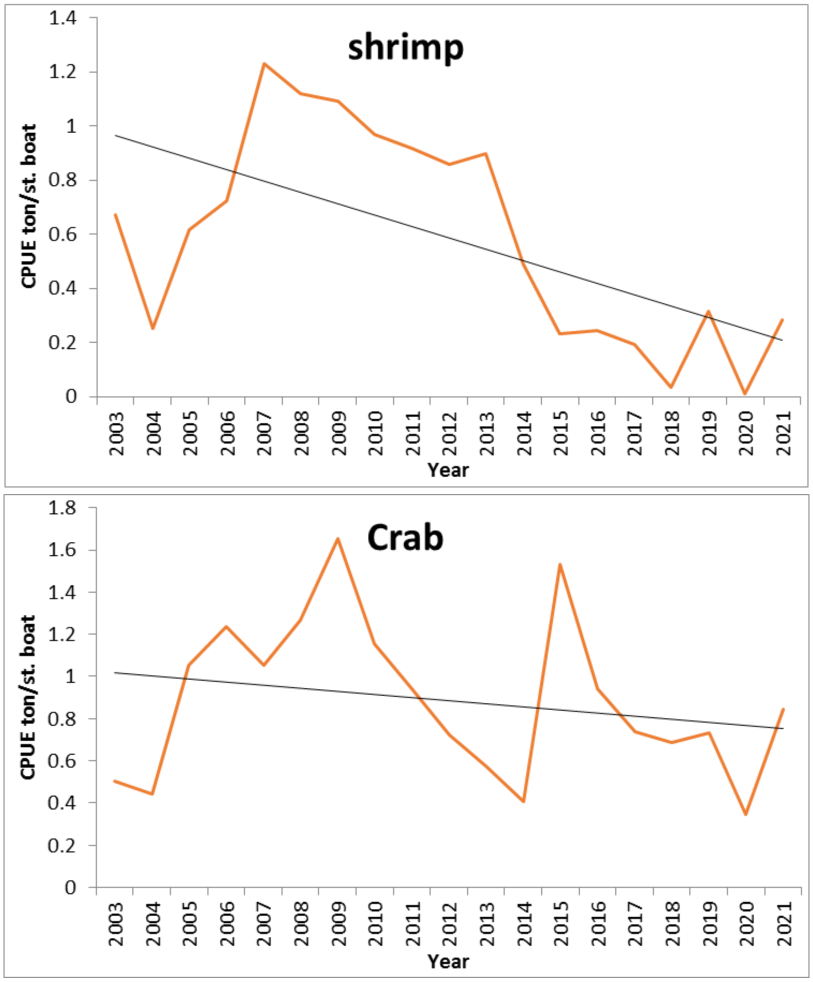




**Fig. 7.** Catch per unit effort of four common species in Bardawil lagoon during 2003-2022

## 4. Surplus production models SPMs

Fisheries reference points are generally used to set management objectives and help track fishery status **(Hoggarth *et al.*, 2006)**. Biological reference points (BRPs) help set sustainable production targets **(Musick & Bonfil, 2004)** and thus may help set the limit of total allowable catch (TAC). Stock assessment, estimation of BRPs, and TAC act as the baseline for conserving fishery resources **(Hilborn & Walters, 1992)**. Maximum sustainable yield (MSY) is a frequently used reference point for fisheries management.

A Bayesian state-space implementation of the **Schaefer (1954)** production model (BSM) was used in the presence of catch and catch per unit effort (CPUE) data. In this study, where data scarcity is an obstacle to estimating reference points, SPMs will be a great help for management authorities to use in the decision-making process and acknowledged for its best performance for data-limited stock assessment **(Rosenberg *et al.*, 2014)**.

The surplus production model of Schaefer was applied for total catch and for the commercial species; grey mullet, sole, shrimp and crabs in the lagoon (Figs. 8, 9). The widely used and accepted target BRP for fisheries management is the maximum sustainable yield (MSY) **(Mohsin *et al.*, 2017; Karim *et al.*, 2018; Zhang *et al.*, 2018; Ji *et al.*, 2019)**. In this study, the estimated MSY was 13590 tons for the total fishery from Bardawil lagoon which was greatly higher than the catch in the last year (4283 tons in 2022), This MSY can be achieved at fishing effort of 692 standardized fishing boat compared to 1294 boat in 2022. This means that the current number of fishing boats is very high than that which produced the MSY and should be decreased by 46.5%; this decrease in fishing effort (decrease of production costs) will be accompanied with the increase of catch by about 217.2% (increase of net profits and achieve the sustainability).

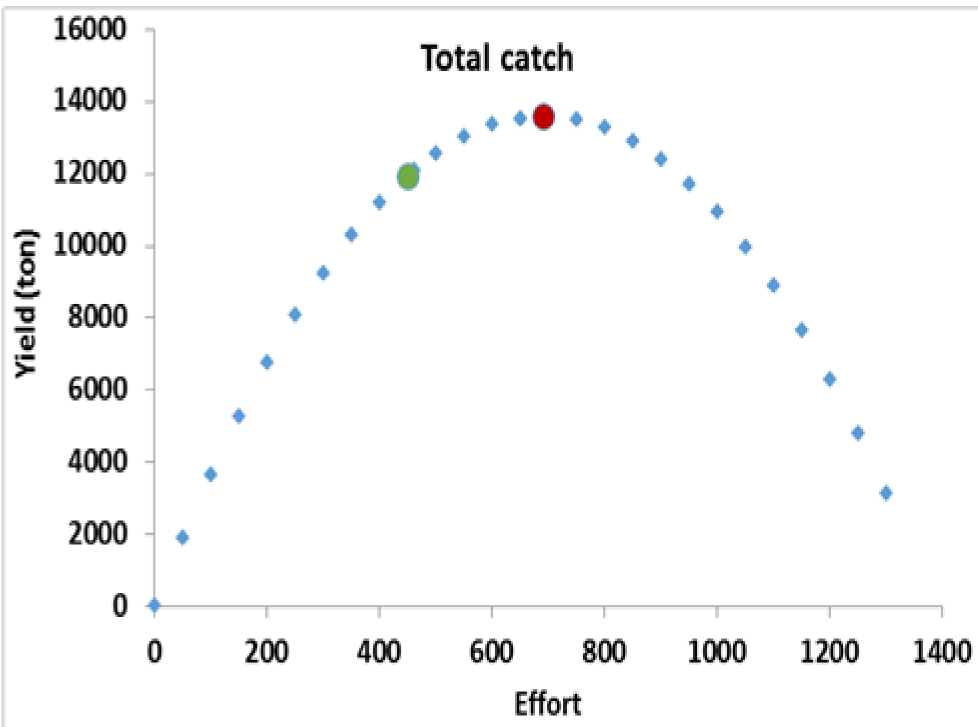
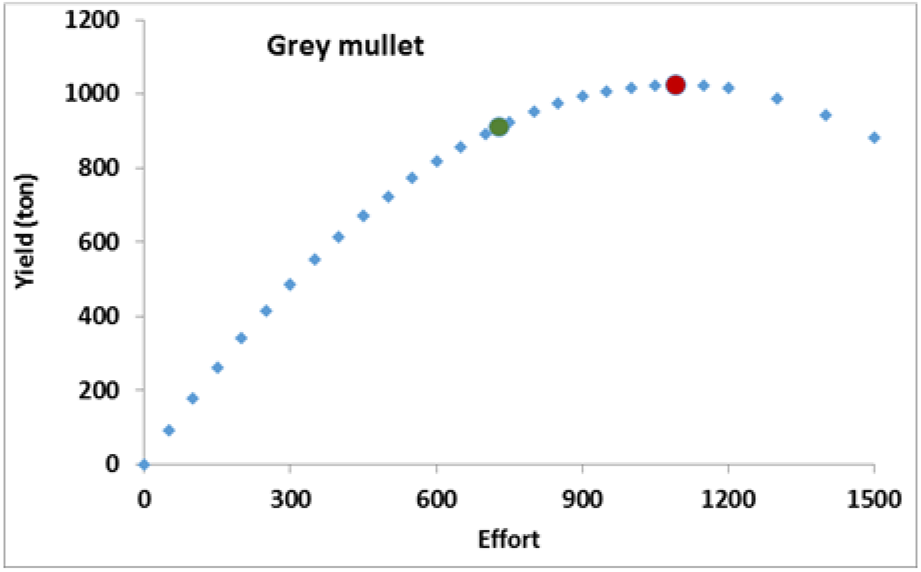
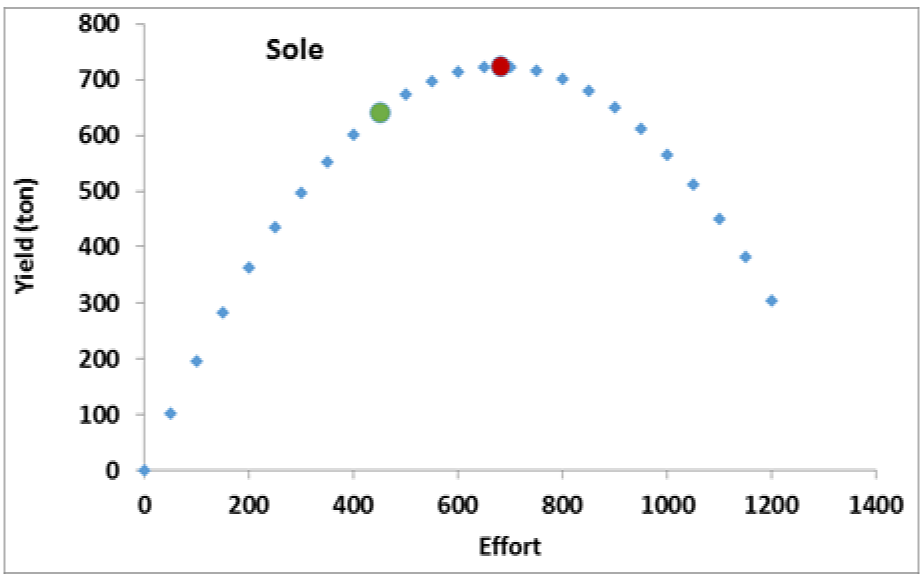



**Fig. 8.** Surplus production model of Bardawil lagoon fishery with the target reference points

The same outputs were observed for the most important species in the lagoon: grey mullet, soles, shrimp and crabs.



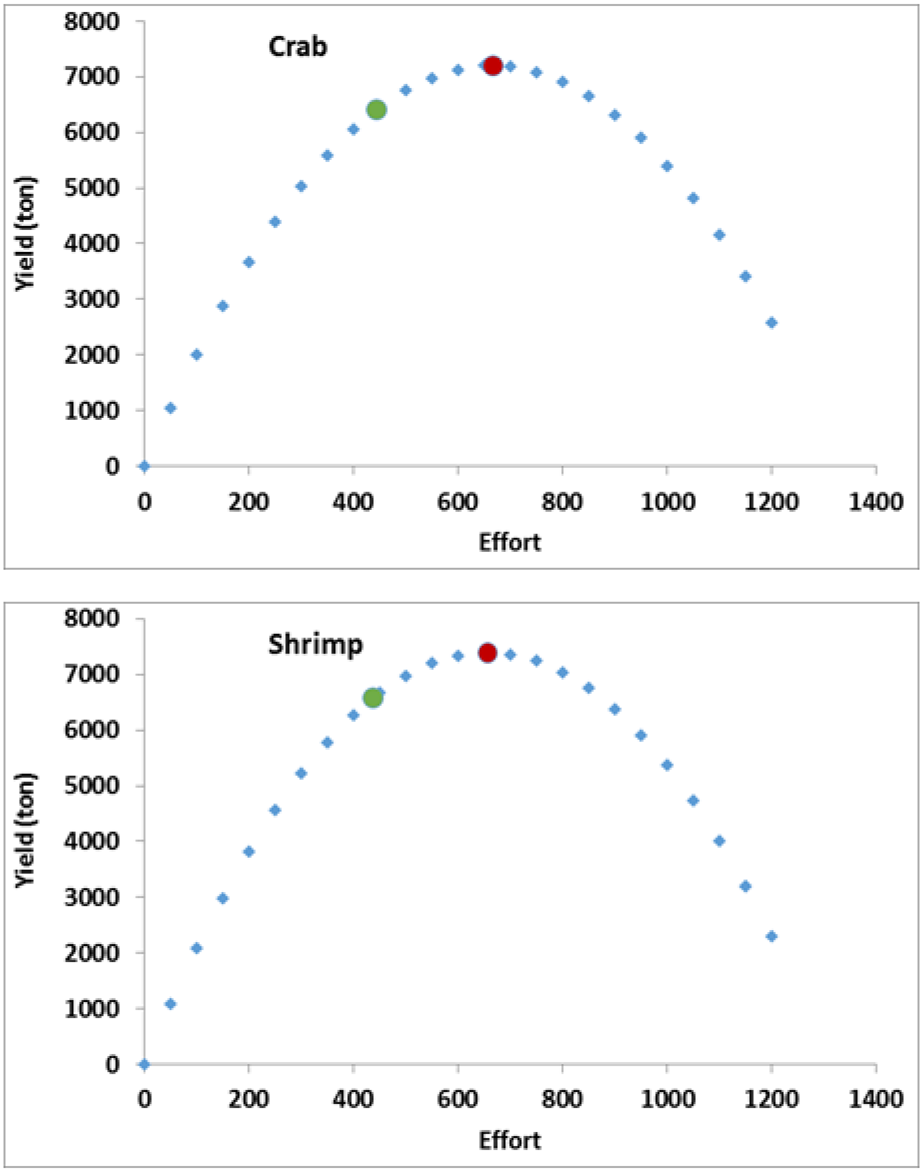



**Fig. 9.** Surplus production model of commercial species in Bardawil lagoon with the target reference points

These results are in agreement with all the previous studies dealing with the dynamics and fishery status of fish stocks in Bardawil lagoon. All previous studies reported for these species indicating the overexploitation situation due to the small mesh sizes used in Bardawil lagoon **(Mehanna, 2007; Mehanna & Haggag, 2007, 2011; Salem & El-Aiatt, 2012; Mehanna & Hegazi, 2013; Salman, 2014; Aabed, 2020; Mehanna *et al.*, 2020; Mehanna *et al.*, 2023)**.

## CONCLUSION

The present study focused on the evaluation of fishery status in Bardawil lagoon and how the fishing effort and gear design and size affected the yield of this fishery. The results indicated that the Bardawil fisheries are overexploited and the gear used are illegal with small mesh and hook sizes. Generally, commercial fish species showed a decline trend in their catches with years, being caught very young without reaching maturation. The current results are beneficial for fisheries managers, ecologists and biologists as it may help in resource conservation of commercial fisheries in Bardawil lagoon. It could be recommended that the recording system in the lagoon should be improved and the new technologies should be applied to make a reliable and correct data base for catch and effort statistics. Furthermore, avoiding catching non-target species and reducing the catch of young fishes and juveniles should be controlled. In addition, detailed evaluation of all fishing gears in Bardawil lagoon should be done, in addition to modifying the gear selectivity to reduce the by-catch. Finally, fishing effort in the lagoon should be decreased and controlled.

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