Original Research Article

Maximum sustainable yield estimates from Lake Nasser fisheries, Egypt with special reference to Nile tilapia *Oreochromis niloticus* using ASPIC software

Abstract

The lakes' fisheries play an important role in the Egyptian economy. Egyptian lakes face many challenges such as over-fishing, illegal and destructive fishing methods, human activities and pollution which affected the fish production from it. The lakes' contribution to the Egyptian fish production decreased from about 50% in 80's to the only 10% during 2017. Lake Nasser, as one of the largest artificial lakes in the world, plays a significant role in Egyptian fisheries. Its mean annual fish production is about 28,000 ton, this constituted 18% of the total fish harvested from Egyptian lakes. The catch and effort data over 15 years were collected from the lake and analyzed to assess its status and to summerize the main problems facing its development and management. Maximum Sustainable Yield of Nasser lake with special reference to the Nile tilapia, the main species in the lake, is estimated based on catch and effort data from 2003 to 2017. The computer software packages of ASPIC had been used. The surplus production model of Schaefer was applied in this study. The obtained results proved the over exploitation situation for the lake fishery and to achieve the sustainability many applicable measures are recommended.

Key words: Nasser lake; Nile tilapia; catch per unit effort; surplus production models, maximum sustainable yield

1. Introduction

The assessment of the state of fishery resources, maximum fleet size and potential fishing effort to exploit resources on a sustainable level is essential for appropriate planning and development of the fisheries sector (Sathianandan et al., 2008). Sustainable fishery implies that the number or weight of a fish species that can be harvested from its stocks should be below the maximum sustainable yield (MSY) without affecting its abundance for a longer period of time (Hilborn and Walters, 1992). Schaefer and Fox surplus production models are frequently used to calculate the MSY for fisheries (Prager, 1994). These models are much popular (Quinn and Deriso, 1999) for stock assessment of tropical fisheries since major inputs for these models are catch and effort data.

The Egyptian fish production comes from two main resources; Wild or natural resources and artificial or aquaculture. The annual fish production from these resources showed a great fluctuation during the last 40 years (Fig. 1). During 80's, marine fisheries constituted about 20% from total fish production of Egypt while the lakes formed about 52%, Nile represented 11% and aquaculture production was about 17%. In 90's, the fish production from the different resources was 24% for marine fisheries, 42% for lakes, 13% for Nile and 21% for aquaculture. During the period from 2000 through 2009, the marine fisheries contributed 13% from total Egyptian fish production, lakes production was decreased to 19% while Nile production was 11% and aquaculture production increased to 52% of the total fish yield in Egypt. More recent in the period from 2010 to 2017, the marine fisheries showed a serious decline where it formed only 7% of the total fish production in Egypt. The same trend was observed for lakes (12%) and Nile (5%) while the contribution of the aquaculture sector to the Egyptian fish production greatly increased to reach 76% of the total production. The following of catch and effort statistics showed that there is a steady decrease in fish abundance and annual fish production harvested from the natural resources of Egypt. This can be attributed to a number of factors, such as over-fishing, using illegal and destructive fishing methods, habitat degradation, increasing tourism and industrial expansion, climate change and pollution (Mehanna et al., 2005; Mehanna and El-Gammal, 2007; Mehanna and Mohamed, 2018; Mehanna, 2019 & 2020).

As one of the largest man-made freshwater lakes in the world, Lake Nasser (Fig. 2) extends to about 550 km length with dendritic side areas named khors which are highly productive in fisheries. The mean annual fish production from the lake was about 30 thousand ton which constituted about 17.9% of the total production from Egyptian lakes (Fig. 3) during the period from 1986 to 2017. Lake Nasser came in the third degree after Lake Manzalah (35.72%) and Lake Borollus (30.68%), followed by Lake Edku (4.92%), Lake Mariut (3.38%), Lake Bardawil (1.9%), Lake Timsah and Bitter lakes (1.85%), Lake Qarun (1.24%), Wadi El-Raiyan lakes (1.17%) then Tushka (0.87%), water bodies in new valley (0.33) and finally Lake Porfouad (0.06%).

Few studies were found about the ecology, biology and limnology of the lake but very little stock assessment and fisheries management work had been undertaken in Lake Nasser: Latif (1973, 1974 and 1984); El-Gammal (1995); Rashid (1995); Mekkawy (1998); Khalifa et al. (2000); Adam (2004); Mehanna (2007); Habib et al. (2014). The present study analyzed the data concerning catch, effort and catch per unit of fishing effort in lake Nasser to estimate the maximum sustainable yield (MSY) and the optimum level of fishing effort (f_{opt}) in order to assess the fishery status of the lake with special reference to the main fish stock in the lake, Nile tilapia. The study proposed some regulations for managing the lake fishery resource and the Nile tilapia. The study aimed also at comparing the present status of lake fisheries with those recorded in the previous studies.

2. Material and methods

2.1 Study area

Lake Nasser (Fig. 2) is a vast artificial lake in southern Egypt and northern Sudan. Strictly, "Lake Nasser" refers only to the much larger portion of the lake that is in Egyptian territory (83% of the total), with the Sudanese preferring to call their smaller body of water Lake Nubia. The lake is some 550 km long and 35 km across at its widest point. In places, the lake can reach a depth of 600 feet (182.9 m) but its mean depth is 82.6 feet (25.2 m). It covers a total surface area of 5,250 Km^2 and has a storage capacity of some 157 billion m^3 of water. The long reservoir has 100 side arms called khors, more on the eastern shore than on the western shore (Encyclopedia, 2004). The Egyptian portion is 324 km long and has a shoreline of 7,844 km. About thirty-five species of fish, as well as Nile River crocodiles, are found in the lake. Lake Nasser has arguably the best freshwater fishing in the world for both Nile perch and tigerfish. There are also several species of catfish and tilapias inhabit the lake.

The fishing boats which made of wood, fiber and steel were from 4 to 9 m in length and from one to three m in width according to the type of fishing gear used. Most of the fishing boats are equipped by engines of 9 – 25 hp. The majority of the boats are of two or three fishermen, sometimes we can see one or four fishermen per boat but this was very rare. A number of fishing methods were operated inside the lake: floating gill nets (sakarota), trammel nets (duk), sunken gill nets (kobok), beach seines (gorrafa) and long-lines (sinnar and haddaf). The most common gears are gill nets and trammel nets. Over 15000 fishermen are working in the lake and totally depend on the fishing to support their livelihood.

2.2 Data collection

Fisheries data were obtained from different sources (database, literature and unpublished data). Data concerning total catch, different species catch and fishing effort carried out into Lake Nasser represented by the number of fishing boats during the period from 1980 to 1990 were obtained from Rashid (1995) and Mekkawy (1998), these data was completed to 1993 from El-Gammal (1995) while those of the period from 1994 to 2017 were obtained from the annual reports of General Authority for Fish Resources Development (GAFRD). Catches by species were obtained from Rashid (1995) and GAFRD while the catch composition was recorded through field trips to the lake. The catch composition was recorded during the field trips to the lake during the period from 2015 to 2017.

The collected data were analyzed to estimate the catch per unit of fishing effort (CPUE) which was considered as a function of stock biomass.

2.3 Modeling

The logistic surplus production model of Schaefer (1954 &1957) as implemented in ASPIC 5 computer program of Prager (2004) was applied to assess the fishery status of

Lake Nasser. The maximum sustainable yield (MSY) and the optimum level of fishing effort (f_{opt}) were estimated according to the following equation:

$dB_t/dt = rB_t – r/K * B_t^2$

where B_t is the biomass of the stock at time t, K is the carrying capacity of the habitat where the stock lives and r is the intrinsic rate of growth of the stock.

Schaefer's model has K = -a/b, B_{MSY} (the equilibrium biomass for MSY) = K/2, MSY = aK/4 and f_{MSY} = a/2

The ASPIC is based on the non-equilibrium surplus production model. This software has two types of surplus production models Logistic (Schaefer) and Fox (special case of GENFIT). The key output parameters are: ratio of starting biomass over carrying capacity (B_1/K), MSY, catchability coefficient (q), carrying capacity (K), optimum fishing effort (f_{MSY}) and coefficient of determination (R^2). These all parameters are the key parameters for fish stock assessment. ASPIC needs an input value of initial proportion (IP, ratio of starting biomass over carrying capacity B_1/K). When the IP is near zero which indicates that the data started from a virgin population and when it is near 1 then it means the data started from the serious exploitation population. Initial proportion determines the progressive fishery data series. Sometime starting biomass if fixed at $B_1 = C_1/ (qE_1)$ where C = catch, q = catchability and E = fishing efforts. In present study our data have starting catch of 31.3 thousand ton which roughly 80% of the maximum catch of 37.7 thousand ton, therefore we have used an IP value of 0.8.

3. **Results**

3.1 Catch composition

The most dominant fish species group in the catch were tilapia (Family: Cichlidae), Nile perch (Family: Latidae), tigerfish and Raya (Family: Alestiidae), Catfish (Families: Bagridae, Clariidae, Mochokidae and Schilbeidae) and Nile carp (Family: Cyprinidae). During 2017, tilapia species formed 54% of the total catch of the lake, Nile Perch (*Lates niloticus*) was 15.3% of the total landings, the characins *Alestes* spp. and *Hydrocynus* spp. were 17.4% and 5.8% respectively.

3.2 Catch statistics

The annual total fish production from Lake Nasser during the period from 1991 to 2017 was given in Figure (4). The total catch of the lake fluctuated between a maximum value of 53.8 thousand ton during 1998 and a minimum of 16.8 thousand ton during 2000 with a mean of 30.4 thousand ton, while the total catch of tilapia was varied from a maximum of 29.4 thousand ton during 1991 to a minimum value of 6.5 thousand ton during 1999 with an average of 17.1 thousand ton (Fig. 5). It was noticed that there is a decreasing trend in the total landing of the lake indicating the decline of the stocks inhabiting the lake.

3.3 Fishing effort

The unit of fishing effort during the period of study was used as the number of fishing boats where it was the only available fishing effort unit. The number of fishing boats was varied from a maximum of 3751 boat during 2017 to a minimum of 1555 boat during 2000 with a mean of 3100 boat (Fig. 6).

3.4 Catch per unit of fishing effort

The total catch per unit of fishing effort was estimated as ton per fishing boat. The total CPUE varied between a maximum of 13.7 ton/boat/year during 1999 and a minimum of 5.3 ton/boat/year during 2016 and 2017 with a mean of 8.2 ton/boat/year. After the fishing season 1999, a noticeable decrease in the CPUE was recorded, reversing the fish abundance in the lake during the last five years (Fig. 7). On the other hand, the Nile tilapia CPUE varied between a maximum of 10.3 ton/boat/year during 1991 and a minimum of 1.9 ton/boat/year during 2013 with a mean of 5.0 ton/boat/year (Fig. 7).

3.5 Surplus production models

The MSY values and other parameters estimated indicate that the ASPIC package is not sensible with IP values. The MSY values from Logistic model were slightly higher than the annual catch of the lake and Nile Tilapia, when IP = 0.1 – 0.9 the values ranged between 38 – 50 thousand ton for the lake and between 16 and 21 thousand ton for Nile Tilapia. The R^2 values obtained from the model was above 0.8 showing the better fit of the model to data. From logistic model the MSY estimated value from the lake was 39.6 thousand ton (Fig. 8), fishing effort at MSY (f_{MSY}) was 2276 fishing boat, coefficient of variance (CV) was 1.1, with R^2 = 0.88.

In respect to Nile tilapia fishery, to minimize the bias in the data we use IP = 0.8 because the starting catch was roughly 80% of the maximum catch. The estimated value of MSY from logistic model was 18.1 thousand ton with CV = 0.39. The rate of fishing mortality at MSY (F_{MSY}) and stock biomass giving MSY (B_{MSY}) were 0.7 and 26 thousand ton respectively.

4. Discussion

Tilapia (Family: Cichlidae) were the main component of the lake Nasser catch forming more than the half of the catch during 2017. Besides, a number of freshwater species were recorded; Nile perch, tigerfish and Raya, Catfish and Nile carp. The unsorted fish species and those of lesser importance were grouped as "others". The most common families recorded in the others group are Mormyridae, Tetrodontidae, Malapteruridae and Claroteidae.

In 80's tilapia constituted about 89% of the total catch of the lake, this catch decreased to about 50% of the total fish production during the period from 1991-00. The cyprinids *Labeo* spp. and *Barbus bynni* formed 3.3% while the characins *Alestes* spp. and *Hydrocynus* spp. were 7.4%, and *Lates niloticus* and catfishes were 7% of the total landings. During the period from 1999 to 2016, tilapia constituted about 63% of the total catch of the lake. The cyprinids *Labeo* spp. and *Barbus bynni* as well as catfishes and bagrid fishes, the characins *Alestes* spp. and *Hydrocynus* spp not recorded in the statistics of GAFRD during this period but observed during the field trips. Nile Perch or Samoos, *Lates niloticus* were 12.6% of the total landings.

During 2017, tilapia species formed 54% of the total catch of the lake, Nile Perch (*Lates niloticus*) was 15.3% of the total landings, the characins *Alestes* spp. and *Hydrocynus* spp. were 17.4% and 5.8% respectively. Unfortunately the statistics of GAFRD failed to record the catch of the other commercial species like the cyprinids *Labeo* spp., *Barbus* spp., *Synodontis* spp., *Bagrus* spp., *Clarias* spp., *Schilbe* spp., *Mormyrus* spp., *Tetradon* spp., *Chrysichthys* spp. and *Malapterurus* spp. Besides, many species of lesser important or appear in small quantities were recorded and identified during the field trips. Tilapia species were identified into four species, *Oreochromis niloticus, Sarotherodon galilaeus, Tilapia zilli* and *Oreochromis aureus* from which the Nile tilapia *O. niloticus* constitute the mainstay of the lake's catch (≈39% of the total landing and ≈81% of the tilapia landing).

It is worth mentioning that, the fishery statistics recording system made by GAFRD miss the accuracy, where the catch by species not sorted or recorded and when it found it was not represent the catch composition of the lake. So, the unsorted group constitutes more than 30% of the total annual landings in the lake as well as a number of species not recorded at all.

The catch per unit of fishing effort gives the first sight about the relative abundance of the different fish stocks and consequently the status of the fishery. The total catch of the lake Nasser per unit of fishing effort was estimated as ton per fishing boat. The total CPUE fluctuated from year to year with a maximum value of 13.7 ton/boat/year during 1999 and a minimum of 5.3 ton/boat/year during 2016 and 2017. It is obvious that a decreasing in the CPUE was recorded, reversing the fish abundance in the lake during the last five years (2013-2017). On the other hand, a serious decline in the Nile tilapia CPUE was noticed during the last seven years (2011 to 2017).

The surplus production models had been developed to determine the equilibrium or sustainable yield that may be harvested from a fishery for a given level of effort. They provide a first assumption about the fishery and detect the preliminary status of it. A large family of surplus production models exists now but all of them are similar to the classical Schaefer and Fox models. The effort and catch per unit of fishing effort statistics are essential as they constitute the basic input for the surplus production models.

The non-equilibrium surplus production model of Schaefer (Logistic) has been estimated from ASPIC package. The MSY values and other parameters estimated indicate that the ASPIC package is not sensible with IP values. The results of model revealed that, the present level of fishing effort should be reduced by about 39.3% to obtain MSY. The maximum catch recorded in the lake was 53.8 thousand ton in 1998 which greater than the estimated MSY in an indication for the over exploitation of the lake.

The target control is more conservative than threshold, and defines a desired rate of fishing and acceptable levels of stock biomass. So, the use of 2/3 f_{MSY} as a target reference point is safer than the use of the limiting or threshold reference point (f_{MSY}). The 2/3 f_{MSY} (the fishing at effort level which allow about 80% of the MSY to be harvested with a significant reduced risk) was estimated as 1517 boat. To achieve this level of fishing effort, the current effort must be reduced by about 59.5%.

For the Nile Tilapia, the number of fishing boats must be reduced by about 43.6% to obtain the MSY and to reduce the risk on Nile tilapia stock at lake Nasser, 2/3 f_{MSY} should be applied and the current effort should be reduced by 62.4%.

These results are come in accordance with the previous studies. El-Gammal (1995), based on surplus production models, found that the species exploited in Lake Nasser were over-exploited and the fishing effort must be reduced by about 51% (mean number of fishing boats in the period of his study 80-93 was 1712 boat). Mekkawy (1998), based on analytical models, concluded that *Oreochromis niloticus* and *Sarotherodon galilaeus* at Lake Nasser during 66-92, were suffering from growth-overfishing and suggested that the used mesh sizes should be increased. Mehanna (2006) based on the catch and effort data from 1980 to 2003 concluded that the fish stocks in lake Nasser are overexploited and need urgent regulatory measurements to enhance these stocks. Because of no action was taken to conserve the fish stocks in the lake, El-Far et al. (2018) came to the same conclusion and suggested the same recommendations that given in the all previous studies since 70's (Latif and Rashid, 1971; Bazigos. 1972; Latif, 1973, 1974 & 1984; Abdel-Azim, 1974; Ryder and

Henderson, 1975; Latif and Khallaf, 1976; Elewa, 1987; Yamaguchi et al., 1990; Agaypi, 1992; Rashid, 1995; El-Gammal, 1995; Mekkawy, 1998; Khalifa et al., 2000; Bishai et al., 2000; Adam, 2004; Mehanna, 2007).

5. Conclusion and recommendations

It could be concluded that the Nasser lake fishery is over exploited as the MSY estimated for the lake and Nile Tilapia was less than the Maximum catch recorded. Many challenges are responsible for this situation such as the high fishing pressure, illegal size nets, illegal fishing practices, poor postharvest handling which affected the fish quality and the fishermen's income and lack of information on fishery status in terms of biological, ecological, hydrological, social and economic policy. Another important issue is the fishery statistics recording system as there are many non-official points for landing of catches rather than the official ones and a considerable part of the catch didn't have any records as well as the persons in charge not qualified to identify the species and therefore most fish species caught from the lake are given under "others". Besides, the lack of co-ordination between the responsible authorities, the unclear division of responsibilities and the conflicts between different institutions. So, it could be suggested the current regulations enforcement (closed season for one month, minimum legal size and legal mesh size). Control fishing effort, mesh size of nets, control gear types used and prohibition the destructive ones. Increase the closed season to two or three months each year or closed the spawning and nursery grounds temporary. All stakeholders (government, administrative authorities, scientists and fishermen communities) should be involved in the management plan. Make an accurate data base about lake's fishery envolving good records for fishery statistics to facilitate the evaluation and managing this valuable fish resource. Provide the basic services for fishermen like social and health insurance as well as aware them about the importance of regulatory measures applied. Beside the fishing pressure, fish production from Lake Nasser is influenced by environmental, hydrological and physical characteristics so the future studies should give a full picture about all these characteristics in the lake. Encourage the researchers to continue the study using the analytical models to assess and manage the different fish stocks in the lake. Finally, improve the sharing of responsibilities and improve coordination between the responsible authorities and organizations to insure the quality of the Lake management plan.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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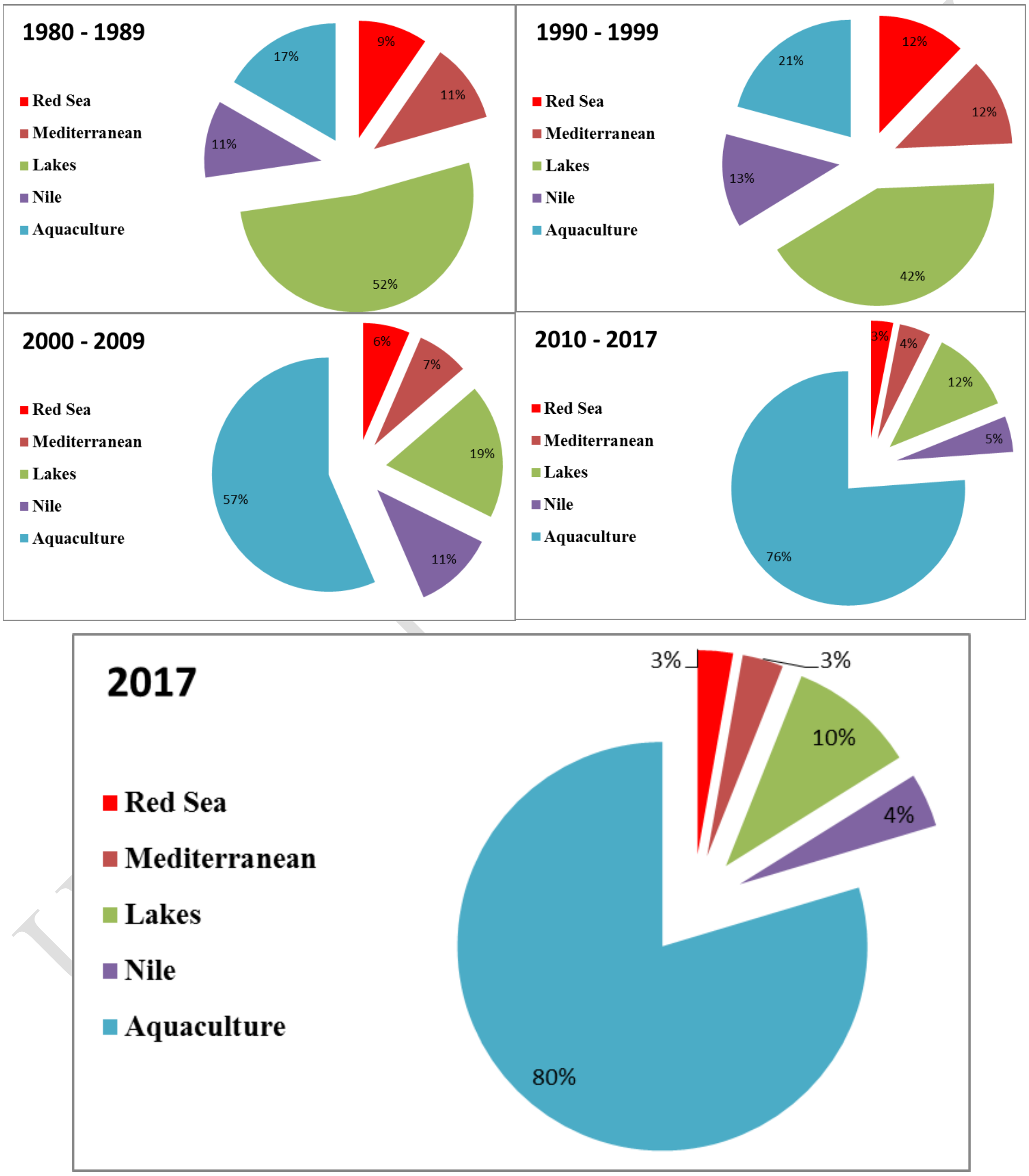


Figure 1: Catch percentage from different fishery resources in Egypt from 80's to 2017

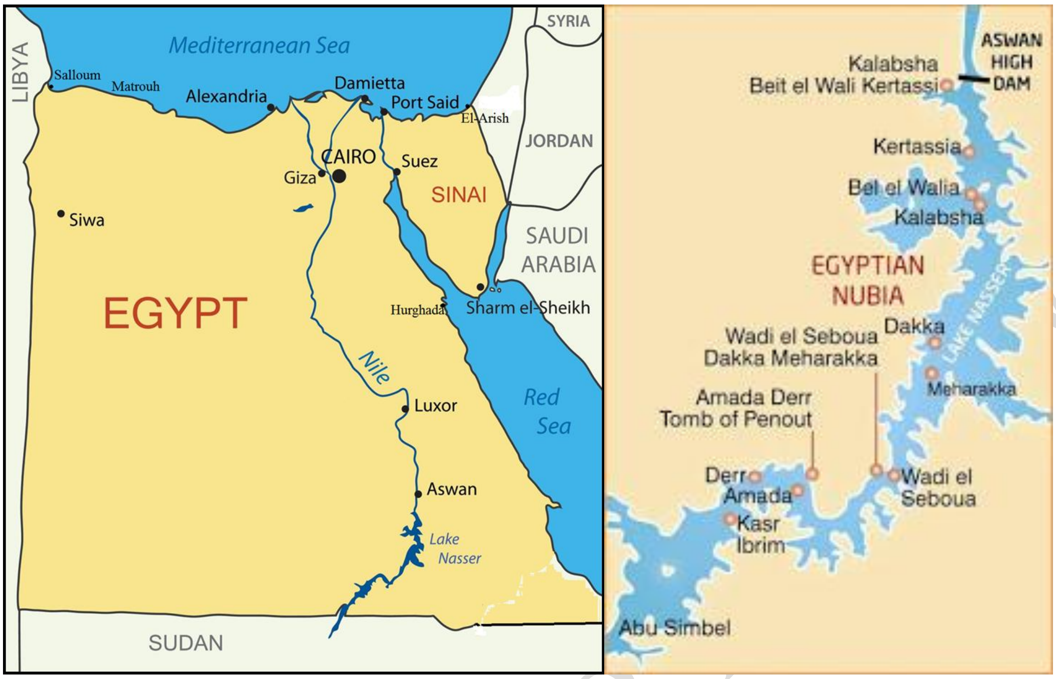


Figure 2: Lake Nasser

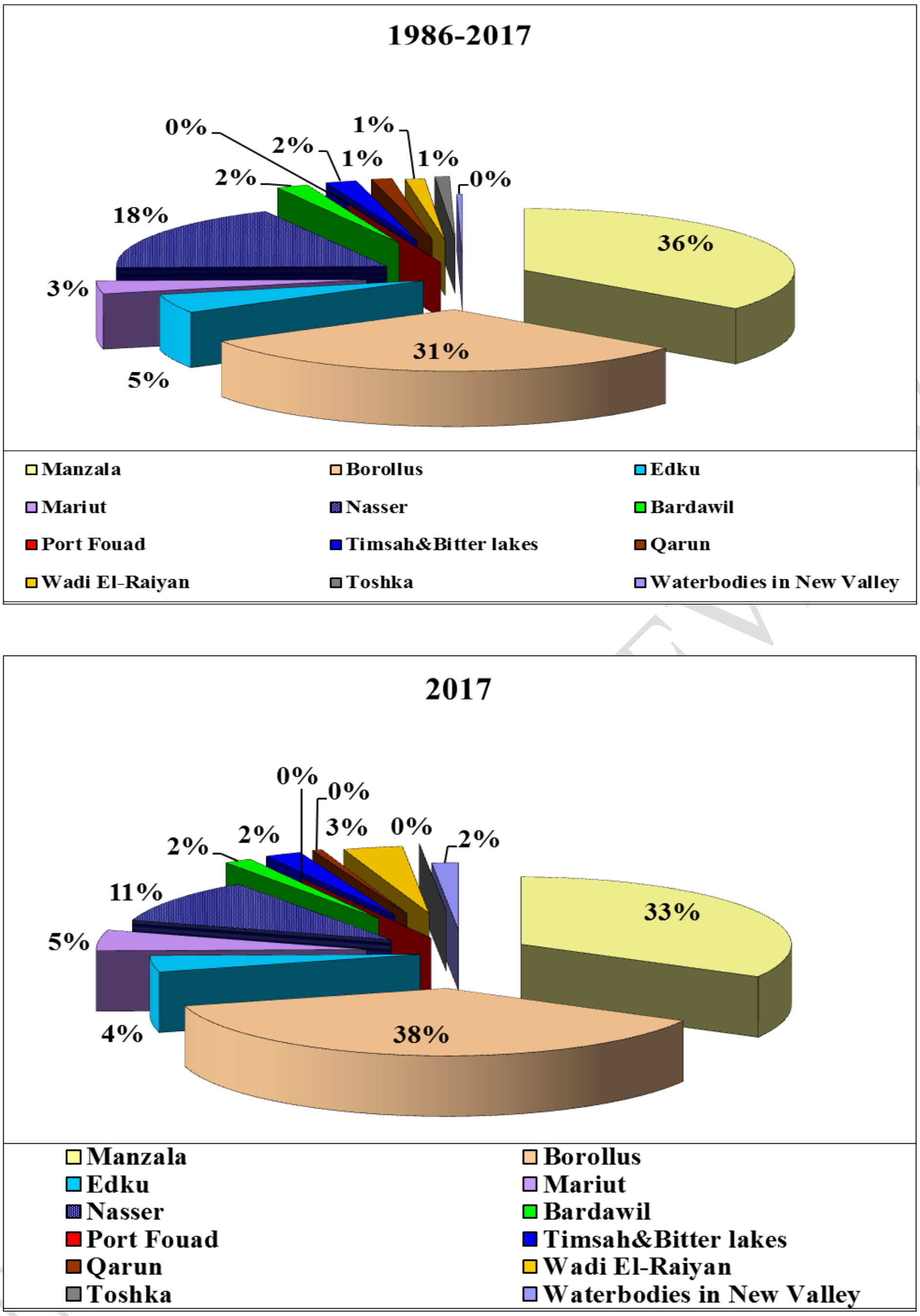
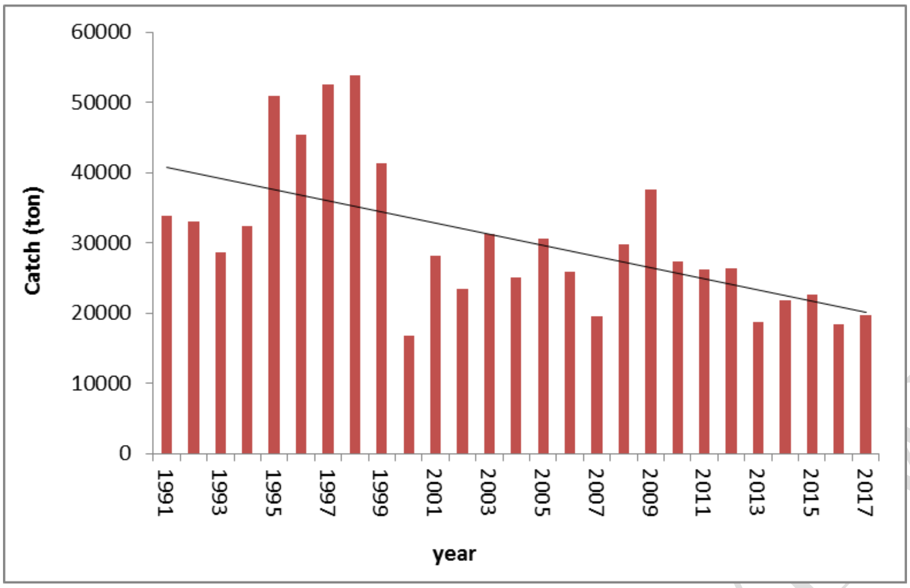


Figure 3: Percentage of fish production from the Egyptian lakes



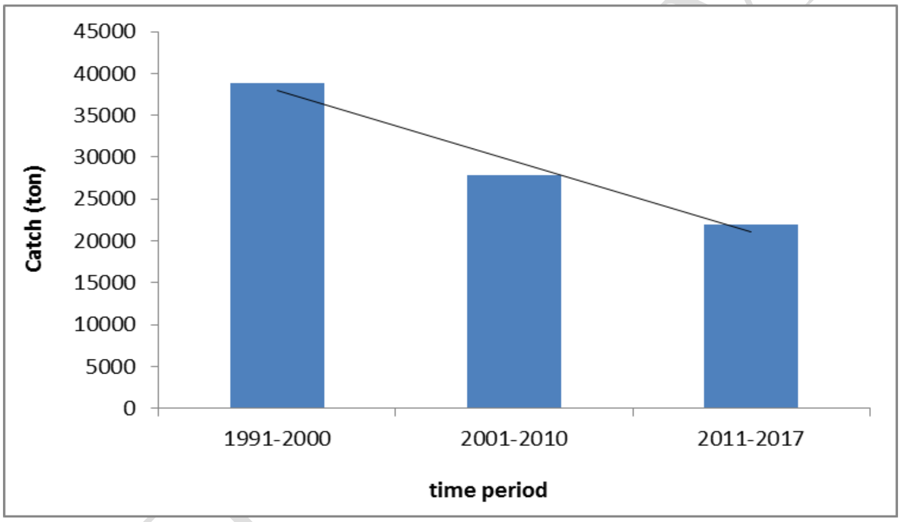
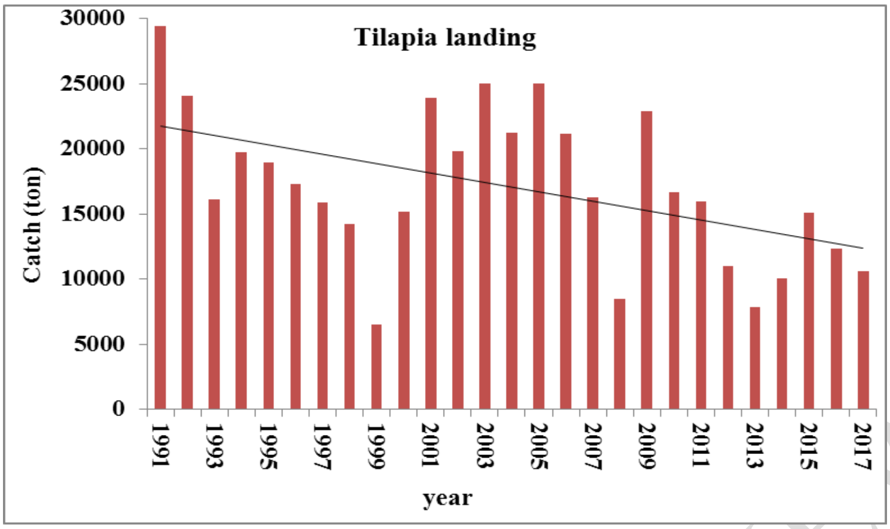


Fig. 4: Annual total catch (ton) of lake Nasser and the trend of catch during the period from 1991 to 2017



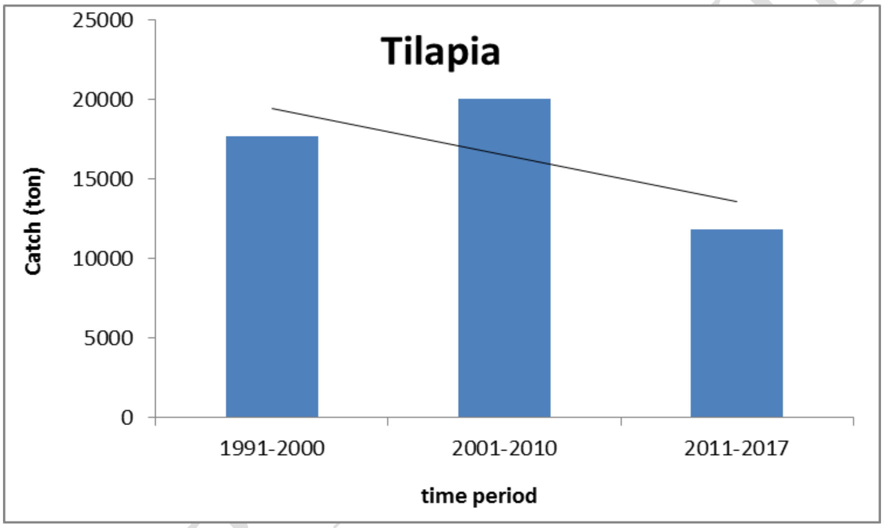


Figure 5: Annual tilapia catch (ton) from lake Nasser and its trend during the period from 1991 to 2017

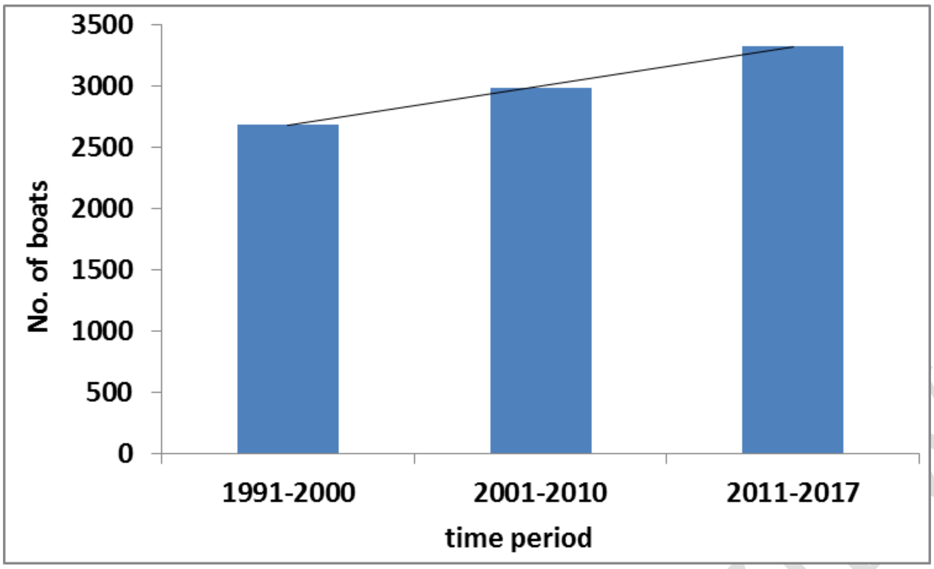


Figure 6: Fishing effort increasing trend during the period from 1981 to 2017

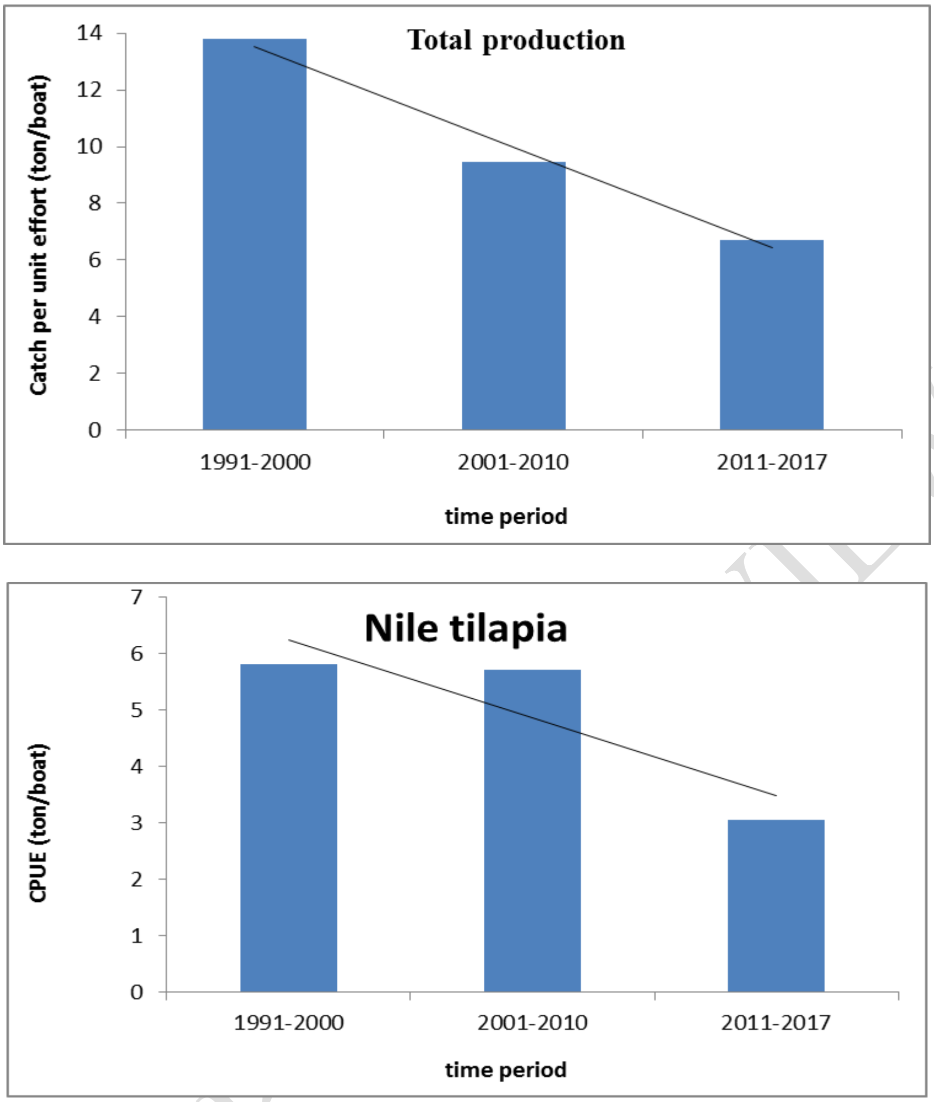


Figure 7: CPUE (ton/boat) for total and Nile tilapia during the period from 1991 to 2017

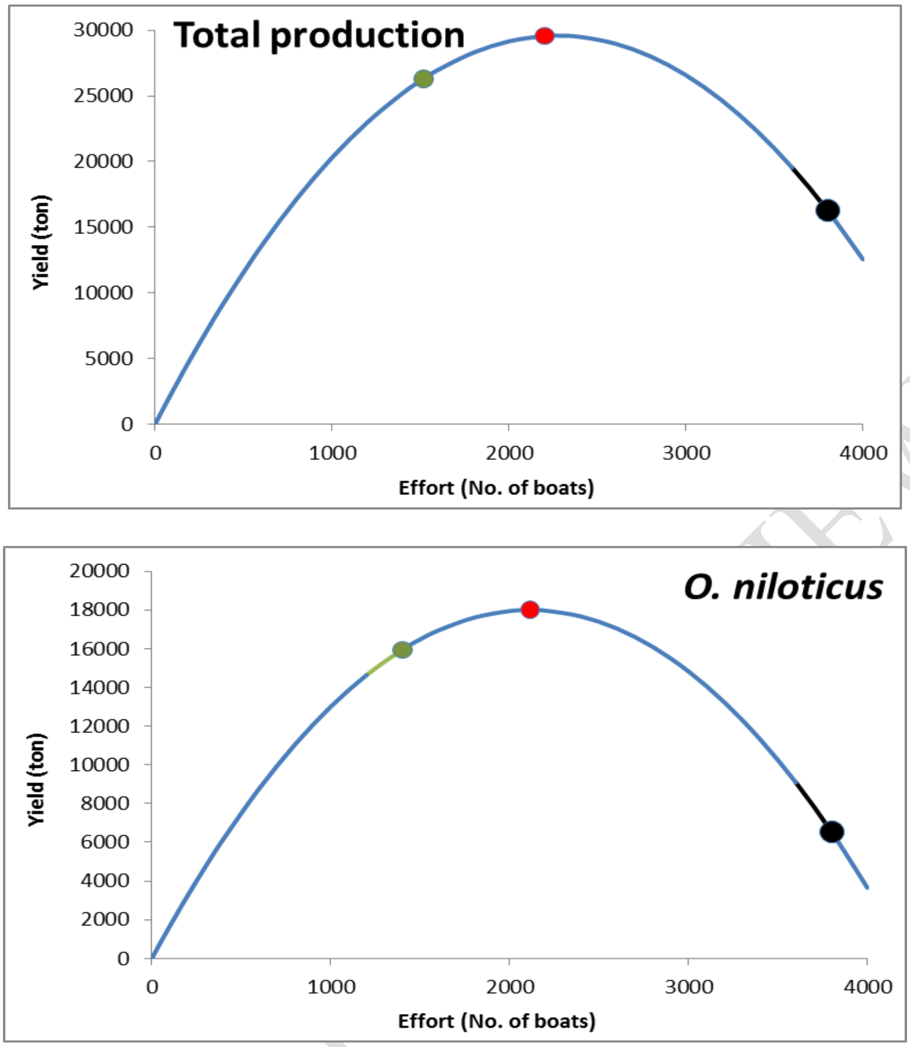


Figure 8: Yield curve of Nile tilapia with f_{max} as limited reference point (Red), 2/3 f_{max} as target reference point (green) and the current situation (black).