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Fisheries management based on gear selectivity of a tropical reservoir, Lake Nasser, Egypt

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ABSTRACT

Lake Nasser, a large man-made tropical reservoir, is located in the southern part of Egypt. The lakes' fisheries have undergone a steady decrease during the last 10 years obscuring its potential for sustainability. Fisheries assessment study based on the fishing activities is essential to attain reliable information for construction a management plan to achieve rational and sustainable exploitation. Spatial and landing site surveys were conducted during the period from 2016 to 2017. More than 300 random fishing boats were examined to investigate their fishing gears characteristics, species composition, mean trophic level and catch per unit effort. More than 13,000 fish specimens from the catch were sampled and investigated for the gear selectivity study. The results indicate that trammel nets, gill nets and long-lines are the main fishing methods used. Thirty-four fish species were recorded in the lake, 6 of them were dominant, namely; *Oreochromis niloticus*, *Sarothrodon galilaeus*, *Coptodon zillii*, *Lates niloticus*, *Alestes baramoze* and *Hydrocynus vittitus*. The lake exhibits spatial variations in its productivity as the southern part is more productive. The time series of size and CPUE showed a high exploitation rate for the most important commercial fish species in the lake by the fishing gears used. Measures for fishery management based on gear selectivity are suggested for sustainability.

Introduction

Besides using the water in reservoirs for irrigation or hydropower purposes, some fishing activities take place in these water-bodies (Béné et al., 2009). The Aswan High Dam Reservoir extends for 500 km along the Nile River and covers an area of 6,000 km^2; of which the northern two-thirds is in Egypt (Lake Nasser) and one-third is in Sudan (Lake Nubia). According to the General Authority of Fisheries Resource Development (GAFRD, 2018), Lake Nasser's catch decreased from about 37,700 in 2009 to be 18,400 MT in 2016. As well, about 14,000 fishers using 3100 fishing boats work in Lake Nasser (Halls et al., 2015).

Although 75 known fish species have been recorded from the Nile system (Bishai & Khalil, 1997), the fisheries of Lake Nasser depend on only a limited number of species. It was reported that there are only six species which have an economic value, namely; *Oreochromis niloticus*, *Sarothrodon galilaeus*, *Coptodon zillii*, *Lates niloticus*, *Alestes dentex* and *Hydrocynus forskalii* (El-Haweet et al., 2008). Fisheries research in Lake Nasser has largely focused on the biology of some species (Abdel-Azim, 1974, 1982; El-Etriby, 1982; Latif & Khallaf, 1974, 1987; Massoud et al., 1985; Rashid, 1977; Tharwat et al., 1994). While, some researches had focused on the fish stock assessment (Entz & Latif, 1974; Ahmed, 1998; Mekkawy, 1998; Khalifa et al., 2000; Adam, 2004; El-Haweet et al., 2008). Understanding of the fishing gear selectivity is important for fisheries management because gears influence the catch composition and the size of the target species (McClanahan & Mangi, 2004). Moreover, information about the gear selectivity in Lake Nasser is required for construction the fisheries management plan for sustainable exploitation of its' resources.

Material and methods

Area of study: Lake Nasser is the northern part of the Aswan High Dam (AHD) reservoir. It is located about 1000 km south of Cairo; 22°25′N and 31°45′E. The lake extends to about 300 km long with an average width of 20 km. The long reservoir has numerous

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dendritic inlets called khors, its long shoreline is affected by the amount of annual flood. Only three official landing sites (fishing ports) are recognized on the lake; Aswan, Garf-Hussein and Abu Simbel. The catch is collected from the remote fishing grounds and is transferred to landing sites by carrier boats. In the present study, the lake was divided into three sub-areas; northern, middle and southern. Each sub-area is represented by two khors (one in the east and the other in the west). The northern sub-area is represented by khor Rahma and khor Ghazal; the middle sub-area is represented by khor Allaqi and khor Sokkar, and the southern sub-area is represented by khor Hamido and khor Toushka (Fig. 1).

Data and samples collection: Seasonal spatial surveys on the fishing ground and monthly landing sites surveys were conducted during the period from October 2016 to September 2017 to describe the fishing activities, gear types and selectivity in Lake Nasser. A number of 195 commercial fishing boats in the fishing grounds and 101 carrier boats in the landing sites were interviewed in the three sub-areas. Data about fishing gears, boats, fishermen and the fishing grounds were collected. Observed fishes were identified to the species level according to Bishai and Khalil (1997) and the FishBase (Froese & Pauly, 2016). A number of 13,150 fish samples from the dominant species were collected and their lengths and weights were measured. The catch from boats using similar fishing gear were grouped together and averaged, so species composition of each gear was estimated. Fish diversity (***D***) in each gear was calculated using the formula $D = N_k/N_{max}$, where N_k is the number of species in gear ***k*** and N_{max} is the total number of species recorded in the lake; ***D*** is constrained between 0 and 1. The trophic level for each species was estimated based on the diet composition data compiled in FishBase (Froese & Pauly, 2016). For each gear (***k***), the mean trophic level was calculated as: $TL_k = \sum_{i=1}^{m} Y_{ik}\mathrm{TL}/\sum Y_{ik}$, where Y_{ik} is the catch of species **i** in gear ***k*** and ***TL*** is the trophic level of species ***i*** for ***m*** fish species (Pauly et al., 2001).

The total fish collected by carrier boats were divided by the number of fishing days to get the average total catch per day which was divided by the number of active fishing boats to estimate the catch per unit effort as Kg/boat/day. In addition, catch per fisherman per day (kg/fisherman/day) was calculated from the estimated daily catch per boat divided by the number of fishermen on the boat. The annual total catch from the whole lake (C_t) was calculated as a summation of annual catch for each sub-area (C_i), where $C_i = \sum C_{bm}$. and C_{bm} is the catch of each boat for each month. $C_{bm} = C_b \times B_s \times D_s$, where C_b is the daily average catch of one boat, B_s is the number of active fishing boats in area and D_s is the number of active fishing days (Maclaren, 1981).

Results

Fishing boats and fishermen: Three types of boats were found operating in Lake Nasser (woody, steel and fiber), and ranged from 4.5 to 9.0 m in length and 1.0 to 3.0 m in width depending on the type of fishing gear used. More than 90% of the fishing boats were motorized (9.9–25.0 hp). Two or three and rarely one or four fishermen worked in each boat. This variation depended on the fishing gear or the method used. Fishers can be classified into two groups; owners of fishing boats and gears, and hired labor. Owners are the membership of fishers' cooperative associations whose have the fishing right on a certain area of the lake.

Fishing gears and methods: Three main fishing gears and methods were observed during the period of study: trammel nets, gill nets as well as hooks and lines that were categorized by their specifications and target species. Trammel net consists of three layers, two outer layers with large mesh sizes and one inner layer with a smaller mesh size. Two types of trammel nets were used in the lake; a) bolti nets were used to target large-sized *O. niloticus* (>500 g weight) and b) Shabar nets mainly targeted smaller sizes (<500 g weight) tilapia (*S. galilaeus, C. zillii* and *O. niloticus*). Gill nets were mainly used in the sides of the main channel and khors opening. Four types of gill nets could be distinguished; a) meloha (sakarota) nets are floating set gill nets targeting *A. baramoze* and *Hydrocynus vittatus* species, b) kubk nets are set gill nets targeting large-sized *L. niloticus*, c) tasteer nets are small bottom set gill nets mainly targeted *S. galilaeus, C. zillii* and *O. niloticus* and d) nasha nets were occasionally used in the southern sub-area during the daytime targeting small-sized *A. baramoze* and *H. vittatus*. Two types of hooks and lines were used in the lake to catch *L. niloticus* and *Hydrocynus* spp.; a) long-lines (sennar) and b) recreational hand-line (haddaf). Other fishing methods are occasionally used having wire traps (goaby) that targeted tilapia species, spears and fishing rifles targeted large-size fishes (*L. niloticus*, *Mormyrus* spp. and catfishes) and beach seine targeted relatively small-sized tilapia. The main dimensions of fishing gears, boat description, fishermen per boat, fishing ground type, depth and the main target species are described in Table 1.

Species composition: Thirty-four fish species (12 families) were recorded in the lake (Table 2). In the present study, fishermen mainly targeted 6 fish species, namely; *O. niloticus, S. galilaeus, L.*

Fig. 1. Map of Egypt and Lake Nasser shows the landing sites (blue) and fisheries data sampling (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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Table 1
Description of Fishing nets, boats, ground and target species in Lake Nasser (2016–2017).

Fishing gear or method	Local name	Gear Dimensions			Boat Description		No. of Fishers	Fishing Ground (type and depth)	Target species
		Length (m)	Height (m)	Mesh size (mm)	Length (m)	Engine (hp)			
Trammel net	*Bolti nets*	50–300	1.8–3.0	59–127 (125–167)	4.5–6	9.9–15 (paddle)	2	sandy-muddy from 5 to 15 m	*O. niloticus*
	Shabar nets	20–300	1.5–2.0	45–59 (83–143)	4.5–6	15 (paddle)	2	sandy-rocky up to 7 m	*S. galilaeus*
Gill net	*Meloha nets*	500–3000	6.0–7.0	28–59	6.5–9.5	15–25	3	sandy-rocky more than 7.0 m	*Alestes* spp. *Hydrocynus* spp.
	Kubk nets	750–4000	3.0–4.0	80–143	5.5–8.5	15	2–4	sandy-rocky from 6 to 20 m	*L. niloticus*
	Tasteer nets	200–750	3.0–4.0	50–59	5.0–6.5	9.9–15	2–3	sandy-muddy from 3 to 8 m	*S. galilaeus*
	Nasha nets	30–100	2.0–3.0	23–29	5.5–6.5	9.9–15	3	sandy-rocky from 3 to 5 m	*Alestes* spp. *Hydrocynus* spp.
Hooks and lines	*Sennar*	12J-shape hooks per line (60 m)			5.0–6.5	15 (paddles)	2–3	sandy-rocky up to 10 m	*L. niloticus*
	Haddaf	6 threads with lures			6.5–9.0	15–25	2	sandy-rocky up to 30 m	*L. niloticus Hydrocynus* spp.

*The mesh size of the outer layer of trammel nets between brackets.

Table 2
Families and species recorded in Lake Nasser catch during 2016–2017.

Family	Species
Alestidae	*Alestes baramoze* (Joannis, 1835), *Alestes dentex* (Linnaeus, 1758), *Brycinus nurse* (Rüppell, 1832), *Hydrocynus forskalii* (Cuvier, 1819), *Hydrocynus vittatus* (Castelnau, 1861).
Bagridae	*Bagrus bayad* (Forsskål, 1775), *Bagrus docmak* (Forsskål, 1775)
Cichlidae	*Oreochromis aureus* (Steindachner, 1864), *Oreochromis niloticus* (Linnaeus, 1758), *Saroththerodon galilaeus* (Linnaeus, 1758), *Coptodon zillii* (Gervais, 1848)
Clariidae	*Clarias gariepinus* (Burchell, 1822), *Heterobranchus bidorsalis* (Geoffroy Saint-Hilaire, 1809), *Heterobranchus longifilis* (Valenciennes, 1840)
Claroteidae	*Auchenoglanis biscutatus* (Geoffroy Saint-Hilaire, 1809), *Chrysichthys auratus* (Geoffroy Saint-Hilaire, 1809), *Chrysichthys rueppelli* (Boulenger, 1907)
Cyprinidae	*Barbus bynni* (Forsskål, 1775), *Labeo coubei* (Rüppell, 1832), *Labeo horie* (Heckel, 1847), *Labeo niloticus* (Linnaeus, 1758)
Latidae	*Lates niloticus* (Linnaeus, 1758)
Malapteruridae	*Malapterurus electicus* (Gmelin, 1789)
Mochokidae	*Synodontis batensoda* (Rüppell, 1832), *Synodontis clarias* (Linnaeus, 1758), *Synodontis membranaceus* (Geoffroy Saint-Hilaire, 1809), *Synodontis schall* (Bloch & Schneider, 1801), *Synodontis serratus* (Rüppell, 1829)
Mormyridae	*Mormyrus caschive* (Linnaeus, 1758), *Mormyrus kannume* (Forsskål, 1775)
Schilbeidae	*Schilbe mystus* (Linnaeus, 1758), *Schilbe niloticus* (Rüppell, 1832), *Schilbe uranoscopus* (Rüppell, 1829)
Tetrodontidae	*Tetrodon linneatus* (Linnaeus, 1758)

niloticus, H. vittatus A. baramoze and *C. zillii*. Fig. 2 indicates that bolti nets were the most selective targeting particular species (*O. niloticus* = 62.8%) followed by sennar (*L. niloticus* = 53.2%), tasteer nets (*S. galilaeus* and *C. zillii* = 48.3%), meloha nets (*H. vittatus* and *A. baramoze* = 47.6%) and kubk nets (*L. niloticus* = 43.9%).

Size Composition: Differences in fish size composition were observed for each fishing gear (Fig. 4). Small fish sizes were observed in shabar and nasha nets operated in low water depths (up to 5 m), while fishing gears set in open water (bolti, kubk net and sennar) targeted larger fish sizes. Both *S. galilaeus* and *C. zillii* were mainly caught by shabar nets and their sizes (total length) ranged from 13 to 32 cm and from 12 to 27 cm, respectively (Fig. 3a and b). Small-sized *O. niloticus* (15–29 cm) were caught by shabar nets while large sizes (24–54 cm) were caught by bolti nets (Fig. 3c). On the other hand, small-sized *L. niloticus* (13–38 cm) were targeted by meloha nets set near the shoreline (up to 7 m depth), while kubk nets were used to catch the medium sizes (35–50 cm), and large sizes (45–112 cm) were captured by sennar in open water (Fig. 3d). Furthermore, small-sized *H. vitattus* (22–35 cm) were caught by nasha nets, while medium sizes (29–47 cm) and large sizes (40–77 cm) were caught by kubk nets and sennar, respectively (Fig. 3e). As well, small-sized *A. baramoze* (22–32 cm) were targeted by nasha nets, whereas meloha nets are used to catch the large sizes (35–48 cm) (Fig. 3f).

Diversity and trophic level: Each gear had a relative species diversity in its catch. Sennar mainly attracted low fish diversity per day (D = 0.27). On the other hand, shabar nets had the highest species diversity (D = 0.59) followed by meloha nets (D = 0.56), tasteer nets (D = 0.47), kubk nets (D = 0.41) and bolti nets (D = 0.32). Low mean trophic levels were recorded for fishing gears targeting tilapia species (TL = 2.55 for bolti nets, TL = 2.76 for tasteer nets and TL = 2.96 for shabar nets). Relatively high trophic levels of shabar and tasteer nets referred to the highest species diversity of their catch. Medium trophic levels were recorded for gill (meloha) nets (TL = 3.53) and kubk nets (TL = 3.69), while high trophic level (TL = 4.21) was recorded in sennar.

Catch Per Unit Effort (CPUE): On a daily catch per fishing gear, sennar was noted to be the lowest fishing method in fish number per gear (5 fish) and per fishermen (2 fish). On the other hand, shabar nets had the highest fish numbers per gear (126 fish) and per fisherman (60 fish) per day, followed by tasteer nets, meloha nets, bolti nets and kubk nets (Fig. 4).

According to catch weight per fishing gear, shabar nets were more efficient (36.9 kg/day) followed by tasteer nets (29.1 kg/day), bolti nets (26.2 kg/day), meloha nets (25.7 kg/day), kubk nets (22.7 kg/ day) and finally sennar (13.0 kg/ day). On the other hand, the catch per 50 m net (or 50 hooks) per day was recorded to be 13.7 kg, 8.1 kg, 7.29 kg, 7.3 kg, 2.7 kg and 2.5 kg per day for shabar, sennar, bolti, tasteer, meloha and kubk gears, respectively (Fig. 5a).

Spatially, the southern part of the lake showed a higher catch per boat per day (from 24.6 to 48.5 kg/boat/day) compared to the northern part (from 16.2 to 26.7 kg/boat/day). In general, CPUE showed seasonal differences for the three sub-areas with a higher average value (33.9 kg/boat/day) in spring and a lower average

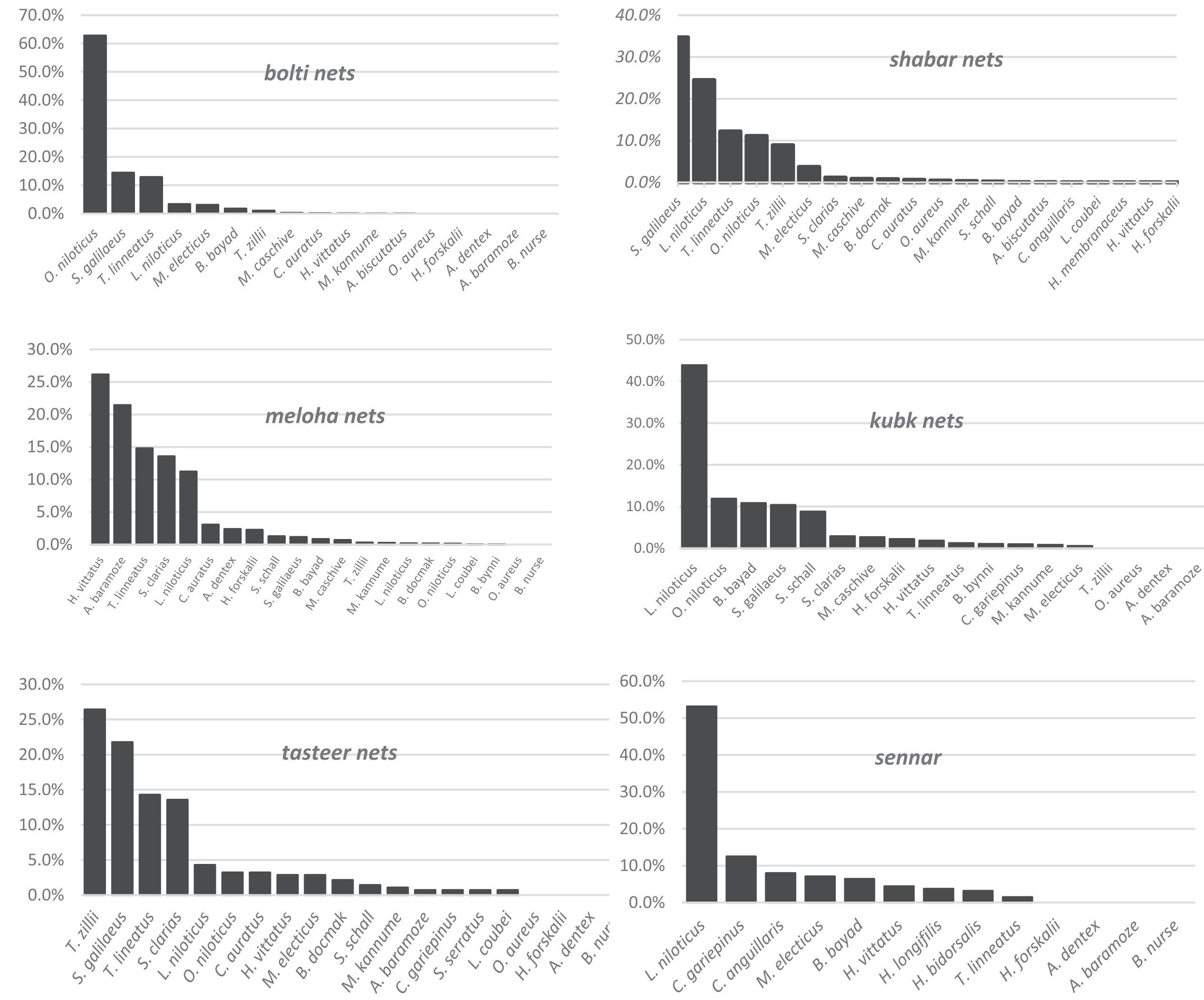

Fig. 2. Species composition of most fishing gears used in Lake Nasser during 2016–2017.

value (23.7 kg/boat/day) in winter. The highest value for CPUE (48.5 kg/boat/day) was recorded in the southern sub-area during summer. While, the lowest value (16.2 kg/boat/day) was recorded in the northern sub-area during autumn (Fig. 5b).

Fish landing: Total fish landed in Lake Nasser was estimated to be about 24.5 thousand MT during the period from October 2016 to September 2017. Catches were composed of *O. niloticus* (34.8%), *S. galilaeus* (31.2%), *Hydrocynus* species (mainly *H. vitattus*) (8.9%), *C. zillii* (8.7%), *L. niloticus* (7.4%), *Alestes* species (mainly *A. baramoze*) (6.3%), *C. auratus* (1.0%). Other species contributed less than 1.0% of the total fish landed. It is worth noting that not all the species or sizes were reported, as some species such as *T. lineatus* (about 2.73 thousand MT) were completely discarded and others like *Synodontis* species (about 1.13 thousand MT) were partially discarded.

Discussion

More than 90 percent of the world's capture fishers work in small-scale fisheries providing many local communities in the developing world with a source of food security and livelihoods (FAO, 2015). Maximizing profits, food security and ensuring sustainable catches are the main purpose of fisheries management (King, 2007). Lake Nasser fishery sector employs more than 14 thousand fishers and provides more than 20 thousand MT of fishes for the Egyptian people. However, the Lake Nasser fisheries production has been gradually decreased over the last 10 years. Reduction of the lake production appears to be affected by the water levels driven by climate variation and water management as well as the fishing pressure (Agaypi, 2000; El-Haweet et al., 2008; Van Zweiten et al., 2011; Halls, 2015). Monitoring the effect of fishing pressure on the exploited fish population in Lake Nasser is essential for resources development and sustainability.

Passive nets, trammel nets, gill nets and long-lines are the dominant fishing gears used in Lake Nasser. In general, passive gears are selective for certain species and sizes of fish. Consequently, commercial fishers apply their knowledge of gear selectivity to enhance the efficiency of catching the targeted species at specific sizes (Hubert et al., 2012). Controlling passive gears effort is easy and is generally expressed in terms of a "standard set" with net specification and time interval needed for management objectives (Cochrane, 2002; Gerow, 2007; Parkinson et al., 1988). The present investigation revealed that the number of species in the catch of Lake Nasser (34 species) is higher than that recorded in down Nile River (29 species) in Egypt (Shalloof & El-Far, 2010) and in the upper part of the river (23 species) in Sudan (Mohammed, 2012). This may be referred to the wide flooded shallow water areas which are available in the lake for spawning and feeding activities of various fish species (Bishai et al., 2000). On the other hand, the

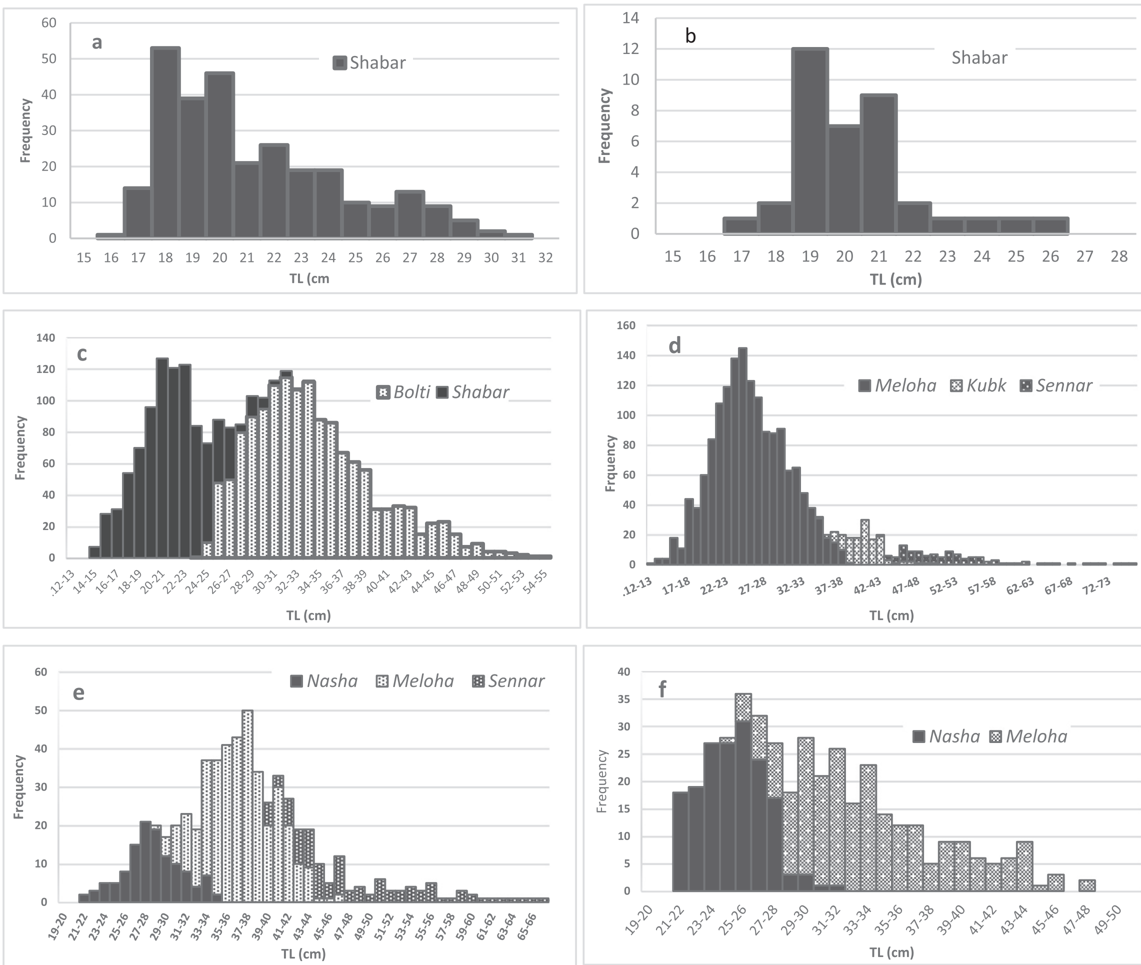

Fig. 3. Length frequencies of fish species according to different fishing gear used in Lake Nasser (a; *S. galilaeus*, b; *C. zillii*, c; *O. niloticus*, d; *L. niloticus*, e; *H. vitattus* and f; *A. baramoze*).

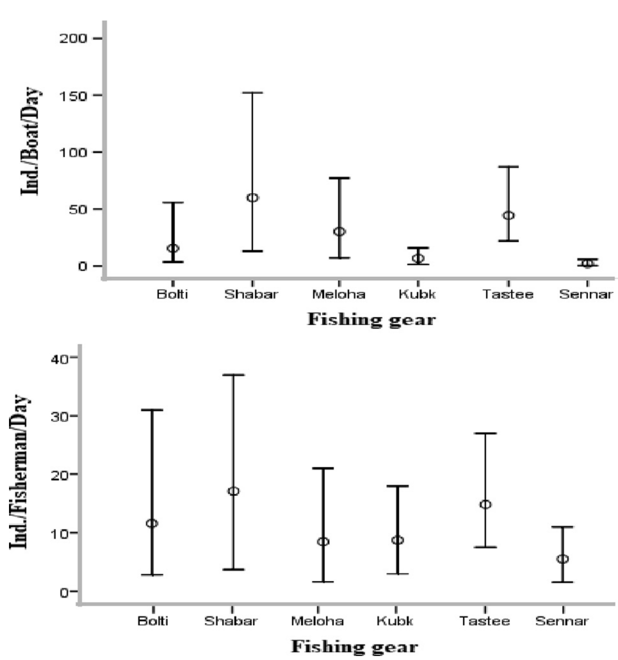

Fig. 4. Catch per unit effort (no. of fish/ boat/ day and no. of fish/ fisher/ day) in Lake Nasser.

species diversity in Lake Nasser is lower than that early recorded in the River Nile system, 75 species (Bishai & Khalil, 1997). This may be due to the change from riverine to a lacustrine condition during the formation of the lake (Béné & Russell, 2007). The current results showed a decreasing in the size composition of the commercial fish species compared to those reported by Latif and Khallaf (1987), Adam (2004) and El-Haweet et al. (2008) and also a decreasing of the catch per boat per day in comparison with the results obtained by Khalifa et al. (2000) and Adam (2004). Furthermore, Van Zwieten et al. (2011) and Halls et al. (2015) reported overfishing in Lake Nasser fisheries which could be used as indicators to describe the fisheries status of Lake Nasser (Christensen, 2005).

The present study indicates that fishing pressure using current fishing gears may be an important cause of the perceived decline in the catch among different species. Throughout the world, most of catches have shown a drift towards the smaller species and sizes indicating that the fish populations are being exploited at non-sustainable levels in the long term (Welcomme, 2001). Results of the present study revealed that the gears operating in shallow waters (shabar, tasteer and bolti nets) were higher in fish diversity and catch per net unit with lower trophic levels than that operating in open waters (kubk, meloha nets and sennar). This is probably because of the nutrients abundance in shallow water areas (Ali et al., 2007; El-Shabrawy, 2009; Hussian et al., 2015; Khalifa et al., 2015; Abdel-Karim & Mahmoud, 2016). In the present study, most commercial fish species in Lake Nasser were caught by differ-

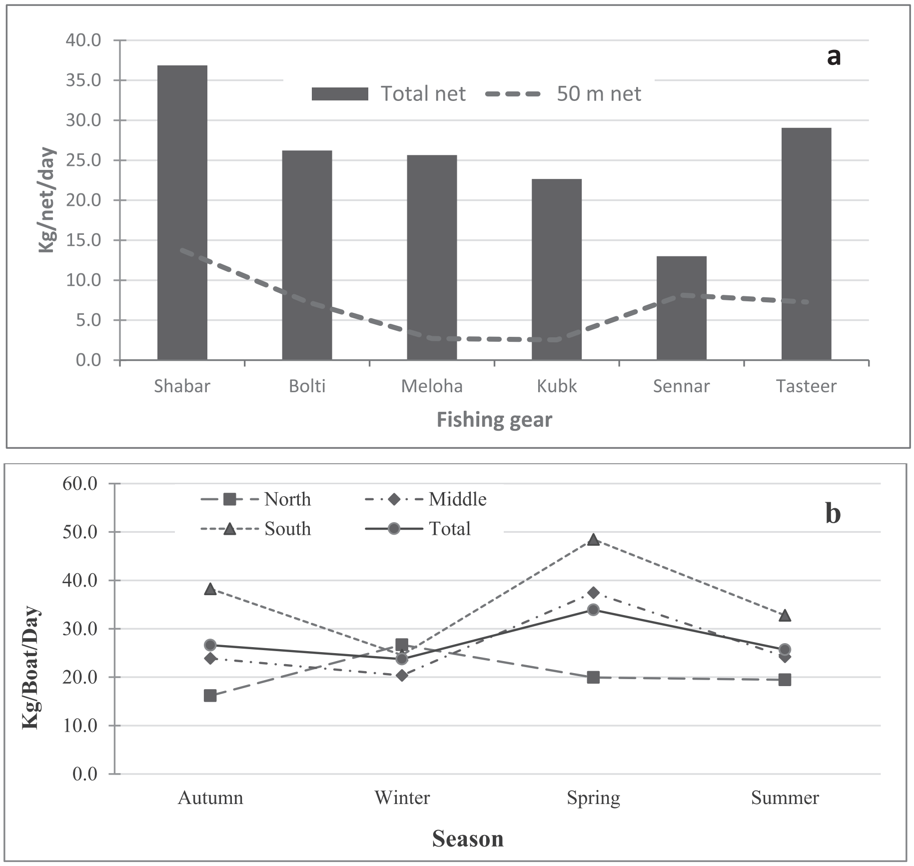

Fig. 5. Catch Per Unit Effort; a) according to fishing gear (kg/ net/ day) and b) according to season (kg/ boat/ day) in different sub-areas.

ent fishing nets at different sizes. Small-sized *O. niloticus* were caught by shabar nets while larger sizes were caught by bolti nets. Small-sized *L. niloticus* were targeted by meloha nets operated in shallow water, medium sizes were caught by kubk nets and large sizes were caught by sennar. Small sizes of *A. baramoze* and *H. vittatus* were caught by nasha nets while large sizes of *A. baramoze* and medium sizes of *H. vittatus* were caught by meloha nets, large-sized *H. vittatus* were caught by sennar. It should be mentioned that shabar, tasteer and nasha nets have illegal mesh sizes (less than 70 mm for trammel and less than 30 mm for floating gill nets). Trammel nets (about 40% of the gears used) and tasteer nets were the dominant gears used in Lake Nasser (Nasr-Allah et al., 2016). These gears remove lower trophic levels (TL <3.0) and often lead to severe damage to the ecosystem (Pitcher, 2000). While, sennar target high trophic levels (TL >4.0). Similar results were reported in the small-scale fisheries of southern Kenya (McClanahan & Mangi, 2004).

Fishing gear's mean trophic may be used as an indicator to measure the impact of fishing on an exploited ecosystem (Pennino et al., 2011). Values of catch per boat per day in the southern part of the lake are mostly higher than those in the northern and middle parts of the lake. Thus, fishes were more abundant in the southern part than in the northern one. It may be because of the epilimnion which is usually shallow in the northern sub-area, while it becomes deeper toward the inflow of Nile floodwater at the south (Abd El-Monem, 2008), similar results were reported (Khalifa et al., 2000; El-Haweet et al., 2007). Mekkawy (1998) and Halls (2015) estimated wide-ranging maximum sustainable yield for Lake Nasser (from <8000 MT to >100,000 MT). This could be due to the unreported catches combined with the artisanal nature of the lake fisheries (Welcomme, 2001).

Conclusion

The decline in Lake Nasser fish production may be related to the fishing practice and the fishing gear used. The present study has demonstrated that small-sized fishes were captured by shabar, tasteer and nasha nets with illegal mesh sizes and meloha nets set near the shore led to overexploitation of the most commercial fish species stocks in the lake. Shabar and tasteer nets were less selective and removed more low trophic levels which may lead to severe damage to the ecosystem. Managing for sustainability and maintenance of trophic levels can be improved by; controlling the fishing practices and effort, employing accurate catch recording methods, determining the trophic levels being captured by various gears and adjusting the mix of gears to maintain the full trophic composition of the fishery to maximize the benefits.

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