Lake Nasser–Nubia

Gamal M. El-Shabrawy

Abstract The construction of the Aswan High Dam created one of the largest man-made lakes in Africa, extending for 500 km south of the dam. The major portion lies in Egypt (Lake Nasser); the Sudanese part is known as Lake Nubia. Accumulation of water, primarily aimed at generating hydroelectric power and irrigation, started in 1964. The average annual discharge of the Nile is ca 84×10^9 m^3. With its storage capacity of ca 160×10^9 m^3 the reservoir is therefore worth almost 2 years of river discharge. Of this, by an agreement dating to 1959, the annual share of Egypt at a water level of 180 m asl is 55×10^9 m^3, that of Sudan 18×10^9 m^3. More than 70% of the sediment of the River Nile is deposited near Wadi Halfa. Fluctuations of physical and chemical variables, phytoplankton, macro-phytes, zooplankton, macrobenthos and fish are discussed. To fill the hitherto empty pelagic niche and exploit this area of the lake efficiently, the introduction of a pelagic planktivore fish could be considered. A brief overview is provided of the positive and negative consequences of the dam's construction, at a local and at a planetary scale.

1 Introduction

The Aswan High Dam started impounding in 1964 and was officially inaugurated in 1970 (Ahmed, 1999). Its construction resulted in the creation of the longest man-made lake in the world, extending in Egypt for about 300 km as Lake Nasser and for 180 km further south in Sudan as Lake Nubia (Fig. 1). The southern two thirds of Lake Nubia are narrow, due to the presence of a gorge region, about 135 km in length. The remaining part, from Amka to the High Dam, is much wider. The lake is divided into three sections (Latif, 1984): a riverine section, with all-year riverine characteristics, comprised of the southern part of Lake Nubia from the southern

G.M. El-Shabrawy (✉)
National Institute of Oceanography and Fisheries, Fish Research Station,
El-Khanater El-Kharia, Cairo, Egypt
e-mail: Elshabrawy_gamal@yahoo.com

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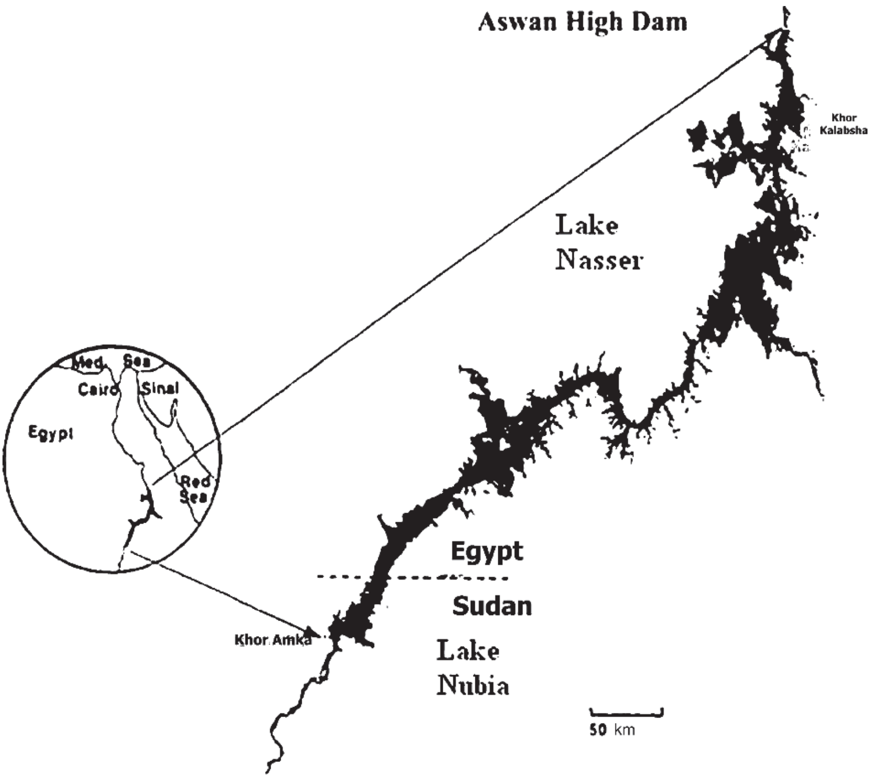

Fig. 1 Map of the High Dam Lake: Lake Nasser–Nubia (after Smith, 1990, with permission from Springer)

end to Daweishat. The semi-riverine section, with riverine characteristics during the flood season and lacustrine conditions during the rest of the year, comprises the north part of Lake Nubia and the south part of Lake Nasser. It extends from Daweishat to Amada/Toshka. The lacustrine section extends from Amada–Toshka to the dam.

2 Lake Morphology (Table 1a)

Lake Nasser (22° 31′–23° 45′ N and 31°30′–33°15′ E) reached its operating level of 175 m asl in 1975, with a total amount of 121×10^9 m^3 of stored water. Of this, 31.6×10^9 m^3 are dead storage (water below the level of the sluices). The deepest zone is situated between 85 and 150 m asl. The central part is a river-lake: the current at the southern end of the Nubian region reaches 100–150 cm s^{-1}. This speed gradually drops to 10–20 cm s^{-1}, and in Lake Nasser it is 0–3 cm s^{-1}. The mean depth of the central part gradually increases from 10 m at the southern end to 70 m in the north.

Table 1a Morphometric features of Lakes Nasser and Nubia at the 160 m and 180 m levels

Parameter		Lake Nasser 160 m	Lake Nasser 180 m	Lake Nubia 160 m	Lake Nubia 180 m
Length	(km)	292	292	128	190
Shoreline length	(km)	5400	7800	647	1406
Surface area	(km^2)	2585	5238	472	978
Volume	(km^3)	55.6	132.5	10.3	24.4
Mean width	(km)	8.9	18	3.7	5.2
Mean depth	(m)	21	25	20	26
Maximum depth	(m)	110	130	110	130

The bulk of the water masses coming from the south flows through the central part, which holds about half the volume of the lake (Entz, 1976).

Lake Nasser has a number of side extensions known as khors. Their mean length increases from south to north owing to the northwardly declining ancient riverbed (Entz, 1973). All khors have a “U” shape in cross section, with a flat sandy central belt. There are 100 important khors in Lakes Nasser and Nubia combined. Their total length when the lake is full is nearly 3,000 km and their total surface area is 4,900 km^2 (79% of total lake surface). In volume, they contain 86.4 km^3 water (55% of total lake volume). Some khors represent auxiliary, semi-isolated lakes. Khors Allaqi, Kalabsha and Toshka are the largest (for more information about the so-called Toshka lakes, see El-Shabrawy & Dumont, 2009). They have a sandy bottom, while others like Korosko and El-Sadake are steep, relatively narrow and have a rocky bottom (Latif, 1984). The Lake Nubia region (20° 27′–22° 00′ N and 30° 35′–31° 14′ E) is situated in the contact zone of two geological formations. The Nile Valley north of the Second Cataract belongs to the Mesozoic Nubia Sandstone while south of the Second Cataract it is part of the ancient Basement Complex (Barbour, 1961). Alluvial silty loam or clay terraces form a strip along the lakeshore, varying from a few metres to about 2 km in width. Siltation has been confined to Lake Nubia, and particularly heavy siltation occurs in the area between 360 and 430 km south of the dam (Abu Zaid, 1987).

3 Water Levels

The operation policy of the reservoir is based on dividing Lake Nasser storage into six zones, illustrated in Fig. 2. The dead storage zone, that receives sediments during the flood period, has a top elevation of 147 m with total volume of about 31×10^9 m^3. This zone releases no flow, regardless of the downstream requirements. The live storage zone, which amounts to 90×10^9 m^3 includes the buffer zone and the conservation zone. The buffer zone lies between elevation 147 and

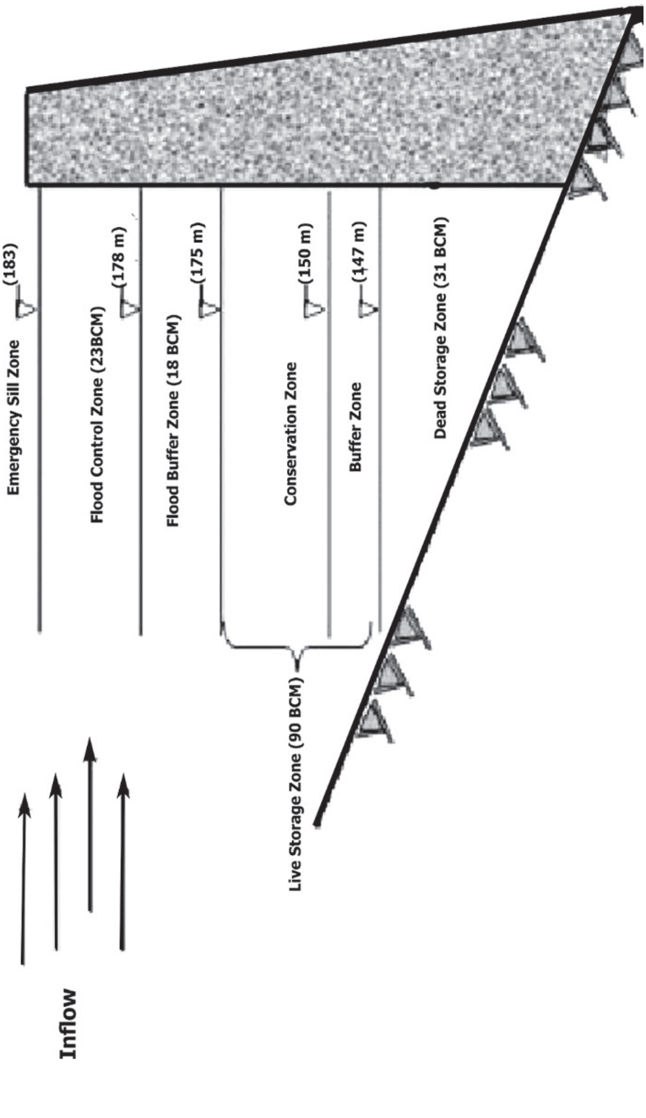

Fig. 2 Inflow as the main component for different operation zones of AHD reservoir (after El-Shafie, 2007, with permission from Springer)

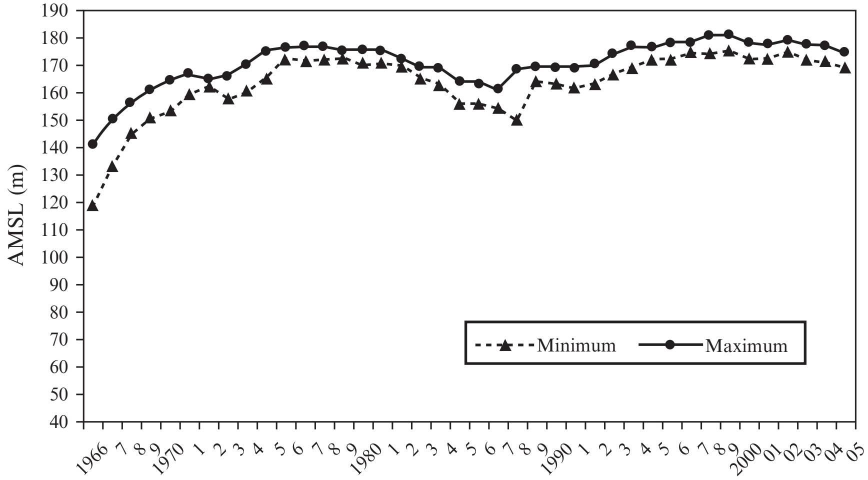

Fig. 3 Yearly amplitude of water level fluctuation in the period from 1966 to 2005 (original data from Nile Research Institute, reproduced with permission)

150 m while the conservation zone lies between 150 and 175 m. An additional storage volume of 40 × 10^9 m^3 is available for high flood waters. It is between elevation of 175 and 182 m, and brings the total lake volume up to 160 × 10^9 m^3. Within the live storage zone, the dam operators make their releases meet downstream requirements, although the total annual release should not normally exceed Egypt's agreed quota (55.5 × 10^9 m^3). The remaining storage is divided into a flood buffer and a flood control zone. Although the emergency spill zone is designed to have a crest level of 178 m, reservoir releases are such that the water elevation does not exceed 175 m at the end of a hydrologic year (31 July). As shown in Fig. 1, the level of 178 m is separating the flood buffer zone from the flood control zone at which any accumulated volume has to be spilled (Abu Zeid & Abdel Daym, 1990; Sadek et al., 1997; Fahmy, 2001). The water level of the lake changes between months and years, depending on the rates of inflow and outflow. The highest levels reached were in November 1996 and December 1997 at 179 m asl, and the lowest occurred in 1988 at 151 m. Figure 3 shows the water levels of the High Dam from 1966 to 2001.

4 Transparency

Transparency is affected by the turbidity caused by silt and clay (allochtonous inorganic materials) of riverine origin. It is particularly strong in the flood season. Secchi disc transparency reveals differences in turbidity between the three sections (Fig. 4). During floods (August–October), inorganic turbidity is high in the riverine

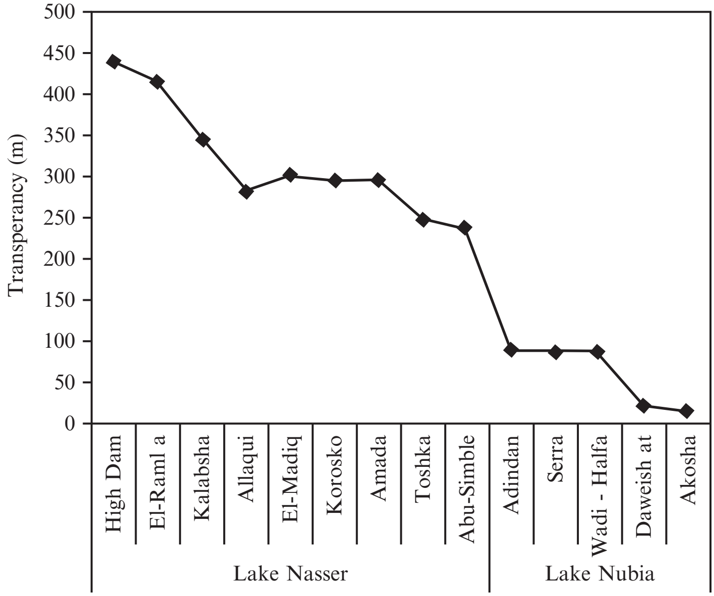

Fig. 4 Secchi disk transparency (cm) at some stations on Lakes Nasser and Nubia (orig.)

and semi-riverine sections. Transparency drops to 15–8 cm at Melik El-Nasser and to 7 cm at Daweishat and Akasha. At the southern end of Lake Nasser, transparency varies between 50 and 100 cm. In the northern part, it is usually higher because of the absence of silt and may reach 300–400 cm. Seasonal fluctuations in turbidity are also observed. Near the High Dam, autochthonous organic turbidity caused by phytoplankton blooms (mainly blue-green algae) reduces Secchi disc transparency to less than 50–100 cm in spring and early summer. In autumn and winter, phytoplankton density diminishes and transparency increases. The transparency in the khors is normally slightly lower than in adjacent open water areas due to suspended organic material. The khors of the southern section, especially those with a wide entrance, are highly affected by turbid floodwater.

5 Water Temperature (Table 1b)

Lake Nasser, situated on the eastern side of the Sahara, has a hot climate with water temperature higher at the southern than at the northern end during all seasons. The highest water temperature, 34.1°C, was recorded at Abou Simbel in summer; the lowest, 16.2°C, at the High Dam in winter. This amplitude of variation is close to that of the Sahelian Lake Chad (18–32°C) (Umeham, 1989). Abd Ellah et al. (2000) mentioned that, due to mixing, the vertical water temperature gradient in

Table 1b Physical–chemical characteristics of Lake Nubia (summarized from Abu Gideiri & Ali, 1980)

	1971/1972	1973/1974	1975/1976	1979
Characteristics	Oct.–Sept.	Oct.–June	Oct.–Sept.	May–Dec.
Air temperature, range (°C)[a]	15.8–31.5	13.7–34.7	15.1–32–9	18.3–34.3
Water temperature, range (°C)	15.3–27.7	15.7–30.3	16.3–29.9	20.8–28.8
Secchi (cm)	25.5–226.7	32.3–166.3	29–271.5	60–120
Diss. oxygen (mg l^{-1})	8–9.7	6.3–10	7–9	7.5–9.2
Free CO_2 (mg l^{-1})	1–2	–	0–1.2	–
pH	8.4–8.9	8.45–9.0	6.8–8.3	8.6–8.8
Total alkalinity (mg l^{-1})	86.7–123.3	90–130	76.7–110.8	58.8–124.2
Nitrate (mg l^{-1})	0.02–3.7	–	0.85–2.11	–
Nitrite (mg l^{-1})	–	–	0.01–1.01	–
Orthophosphate (mg l^{-1})	0.02–0.6	0.12–1.2	0.11–0.69	0.04–0.47
Sulphate (mg l^{-1})	3–15	–	4.5–17.8	8–13.3
Chloride (mg l^{-1})	–	12.5–20	–	–

[a]At sampling time.

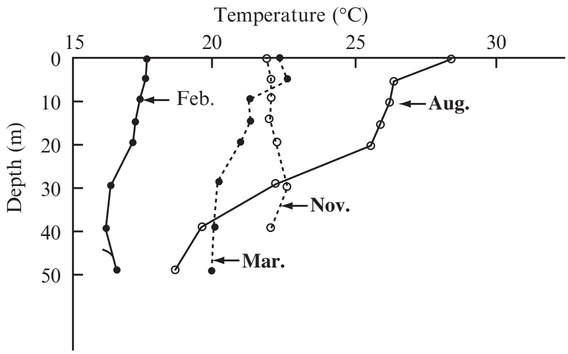

Fig. 5 Vertical (m) variation in water temperature (°C) along the main channel during winter, spring, summer, and autumn (after Goma & Abdel-Rahman, 1992) (reproduced with permission of EEAA Biodiversity Unit, Egypt)

winter 1993 was weak. Surface water temperature ranged from 17°C in the south to 19°C in the middle (Fig. 3). In spring, surface warming caused the development of a negative water temperature gradient, with indications of a thermocline developing: water temperature was 20°C at the surface, decreasing to 16°C near the bottom. In summer, thermal stratification was at a maximum. Surface water temperature reached 28°C, decreasing to <18°C near the bottom. In autumn, surface cooling and vertical convection created a surface isothermal layer (20 m) with a temperature of about 27°C, overlying a stratified layer similar to that in summer. During the next winter 1994, water temperature was similar at all depths (20–21°C) (Fig. 5). In general, vertical temperature gradient was dependent on season, time of day, climatic condition, and inflow from the south. The middle part of the lake usually had a higher water temperature throughout the year, due to a slower flow of water.

For some stations of Lake Nubia, water temperatures in the uppermost 15 m in August 1976 are given in Table 1b. In the riverine section of Lake Nubia, stratified conditions did not occur due to mixing (Ali, 1984).

6 Dissolved Oxygen

The lake water is well oxygenated during winter and spring (average 11.1 and 13.5 mg l^{-1}, respectively), while in summer and autumn lower average values, around 7 mg l^{-1}, occur. Elewa (1978), Latif (1984) and Abdel Moniem (1995) pointed out that thermal stratification coincides with the formation of an oxygenated epilimnion and oxygen-free hypolimnion. The oxygenated epilimnion becomes deeper southwards. The depth of the oxygenated layer was only 8–10 m in the north compared with 20 m at Adindan (Latif, 1984) (Fig. 6).

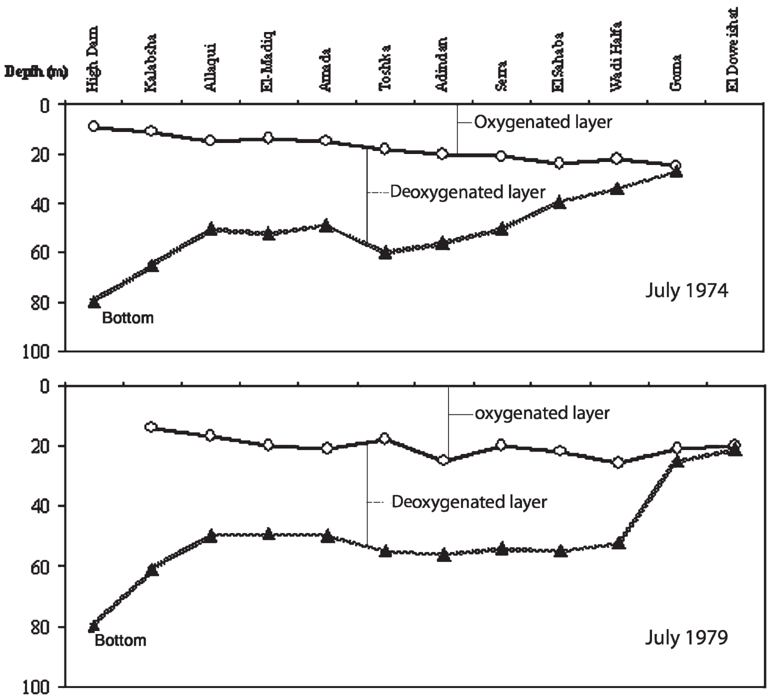

Fig. 6 Depth of oxygenated and non-oxygenated layers along the main channel of Lakes Nasser and Nubia in July 1974 and 1979 (Elewa, 1980) (reproduced with permission of EEAA Biodiversity Unit, Egypt)

7 Hydrogen Ion Concentration

pH is neutral to alkaline (7.2 and 9.5), and decreases with depth, except at Akasha in Lake Nubia, where it slightly increases (Abdel-Moniem, 1995; Rashid, 1995; Yousry, 2003). It ranges between 6.8 and 8.9 in lake Nubia (Abu-Gideiri & Ali, 1975).

8 Major Ions

Sulphate ranges from 5 to 15 mg l^{-1} and remained relatively constant before 1972 and 1975–1976 (Latif, 1984). Shoreit et al. (1992) pointed out that sulphate decreases with depth and fluctuates between 12 mg l^{-1} at the surface and 3.0 mg l^{-1} at the bottom. Abdel-Moniem (1995) recorded values ranging from 0.90 to 9.86 mg l^{-1} with an average 1.63 mg l^{-1} near the bottom during summer. Yousry (2003) recorded a range of 3.83–7.59 mg l^{-1}. Low sulphate at the bottom was attributed to low oxygen content leading to sulphate-reducing bacterial activity.

The concentration of Ca^{2+} and Mg^{2+} was 25–26 and 10–11 mg l^{-1}, respectively (Entz, 1972). Ca^{2+} increases from north to south, similar to the trend in CO_3^{2-}, indicating that it mainly occurs as carbonate. A seasonal variation was observed, with a minimum of 18.3 mg l^{-1} in spring and a maximum of 23.9 mg l^{-1} in autumn, while Mg^{2+} ranged between 7.73 and 10.3 mg l^{-1} (Yousry, 2003). Latif and Elewa (1980) pointed out concentrations of Na^{+} and K^{+} of 6.2–27.8 and 1.9–8.0 mg l^{-1}, during 1974–1976. Much lower concentrations of Na^{+} were recorded in 1993 (Abdel-Moniem, 1995) in the main channel of the lake, 0.89–3.15 mg l^{-1}, with annual average 1.62 mg l^{-1}, while K^{+} varied between 2.13 and 5.08 mg l^{-1}, with annual average 4.03 mg l^{-1}.

9 Nutrients

9.1 Nitrite–Nitrogen (NO_2–N)

Latif and Elewa (1980), Rabeh et al. (1999) and Goma (2000) recorded the range of nitrite–nitrogen as 5–180, 0.0–7.1 and 3.0–68.4 µg l^{-1}. Abu-Gideiri and Ali (1975) mentioned nitrite concentrations from 10–101 µg l^{-1} in Lake Nubia.

9.2 Nitrate–Nitrogen (NO_3–N)

Latif and Elewa (1980) found that nitrate–nitrogen fluctuated between 0.5 and 3.0 mgl^{-1}. Recent studies show NO_3–N concentrations between 0.1 and 6 mg l^{-1} (Goma, 2000), 4.6–742.2 (Toulibah et al., 2000) and 250–1900 µg l^{-1} (Yousry, 2003) in Lake Nasser and 20–2110 µg l^{-1} in Lake Nubia (Abu-Gideiri & Ali, 1975).

9.3 Orthophosphate (PO_4)

Orthophosphate ranges between 70 and 460 µg l^{-1} and is higher at the bottom than at the surface (Latif & Elewa, 1977). In early years, higher phosphate values were recorded (20–2000 µg l^{-1}) (Entz, 1972). In recent years, the range fluctuated from 5.5 to 27.7 µg l^{-1} (Toulibah et al., 2000), 40–90 (Yousry, 2003) and 50–530 (Soltan et al., 2005). Abu-Gideiri and Ali (1975) mentioned organic-phosphate concentrations of 20–690 µg l^{-1} in Lake Nubia.

10 Heavy Metals

The ranges of Fe, Mn, Zn and Cu in lake sediment were 236–259, 95–138, 1.5–2.1 and 6.5–12.0 mg kg^{-1}, respectively, with order Fe > Mn > Zn > Cu in 1977 (Elewa, 1980), while the ranges in 1988 were 4.02–8.71%, 485–1,305, 77–432 and 56–81 ppm for Fe, Mn, Zn and Cu, respectively (Elewa et al., 1990). Soltan et al. (2005) mentioned that a relatively high Fe concentration (0.20–0.24 mg l^{-1}) at the north end of the lake might originate from surrounding rocks. Concentrations of Pb and Cd in lake water (range 0.0003–0.0100; 0.0005–0.0040 mg l^{-1}, respectively), may be derived from the use of phosphate fertilizer in shore cultivation and gasoline leaks from fishery boats. Relatively high Zn and Cu concentrations suggest that these contaminants are generated from fishing boats, discharges of ships, and erosion of igneous rocks. However, the concentration of all metals is below the maximum permissible value set by the Environmental Protection Agency and Egyptian Chemical Standards.

11 Bacteria

Total bacteria in the main channel of Lake Nasser peaked at 731×10^5 ind ml^{-1} in spring. High temperature helps proliferation of bacteria and phytoplankton, which produce dissolved organic matter, used in bacterial reproduction (Rabeh et al., 1999; Rabeh, 2009). The standing crop of total bacteria in the largest khors varied from 0.12×10^5 cells ml^{-1} at Khor Korosko in autumn to 933×10^5 cells ml^{-1} at Khor Allaqi in spring. Comparing the results obtained by Elewa and Azazy (1986) in 1974–1984 with those recorded in 1996 (Rabeh et al., 1999), a more than 100 fold increase in total bacterial counts was observed at all sites.

12 Phytoplankton

The phytoplankton community increases southwards from 3.4×10^6 algal units l^{-1} at El-Birba to 15.3×10^6 algal units l^{-1} at Adindan (Bishai et al., 2000). Diversity increases from 27 (Samaan, 1971) to 84 species (Abdel Moniem, 1995). Chlorophyceae, Cyanophyceae, Bacillariophyceae, Dinophyceae and Euglenophyceae are represented. Numerically, Bacillariophyceae, (about half of the total) and Cyanophyceae are the main component, with Dinophyceae, Chlorophyceae and Euglenophyceae frequent or rare (Zaghloul, 1985; Mohammed et al., 1989; Abdel Moniem, 1995; Habib, 2000). *Melosira* sp. (contributing up to 99%), besides *Synedra* and *Nitzschia* spp. are abundant (Zaghloul, 1985; Habib, 2000). Abdel Moniem (1995) pointed out that diatoms in the main channel are mainly represented by *Aulacoseira granulata*, *Melosira nyassensis* and *Cyclotella ocellata*. Cyanophyceae contributed 47% to total phytoplankton numbers, with *Microcystis aeruginosa*, *Planktolyngbya limnetica* and *Oscillatoria limnetica* dominant.

Khors have a higher population density ($3.62–5.23 \times 10^6$ units l^{-1}) than the main channel ($0.93–1.03 \times 10^6$ units l^{-1}), and southern khors are more productive than northern ones (Gaber, 1982). The phytoplankton shows a vertical distribution with highest density at 2–5 m (Gaber, 1982; Toulibah et al., 2000). In 1987–1992, water blooms of *Microcystis aeruginosa* occurred occasionally in the southern region of Lake Nasser. Currently, blooms occur around the year and throughout the lake. The largest bloom was recorded in December 1989, when patches of 125 km in length occurred from El-Sebra to Abou Simbel (Mohamed & Loriya, 2000).

13 Chlorophyll-*a*

The amount of chlorophyll-*a* provides an index of phytoplankton productivity. The southern region of lake shows higher mean annual values (12 mg m^{-3}) than the northern region (8 mg m^{-3}) (Fead, 1980). The vertical distribution of Chl-*a* is maximum at 2–6 m depth (Habib et al., 1996), reaching its highest value (15.1 mg m^{-3}) in spring and lowest in winter (8.85 mg m^{-3}) (Abdel Moniem, 1995). In contrast, Yoursy (2003) recorded a highest value of Chl-*a* (11.07 mg m^{-3}) in winter, and lowest (2.3 mg m^{-3}) in summer. Nanoplankton represents a considerable fraction (53.4–74.4%) (Abdel Moniem, 1995).

14 Primary Productivity

The primary productivity in Lake Nasser shows high epilimnetic values, usually between 15 mg C m^{-3} h^{-1} in winter and 68 mg C m^{-3} h^{-1} in spring (Abdel Moniem, 1995). In1997/98 it reached a maximum of 239 mg C m^{-3} h^{-1} (Toulibah et al., 2000). Habib (2000) mentioned that primary production varied between 0.7 and 23.8 g C m^{-2} day^{-1} with mean around 4 g C m^{-2} day^{-1}. Seasonal variation depended on transparency and chlorophyll-*a* (Habib, 2000). Yoursy (2003) recorded the highest values of net production and photosynthetic activity (7.08 g C m^{-2} $day^{-1}$and 18.9 g O_2 m^{-2} day^{-1}) in summer and the lowest (0.12 g C m^{-2} day^{-1} and 0.33 g O_2 m^{-2} day^{-1}) in autumn.

15 Macrophytes (Table 2)

Rorslett (1989) summarized the changes in vegetation following impoundment as (a) a decline in species richness; (b) a gradual disappearance of the shallow water and mid-depth communities; (c) a conspicuous absence of submerged vascular macrophytes if lake level varies >7 m annually; and (d) an increase in species with strategies of the rudera1 (R) type.

In 1963–1964, Boulos (1966) recorded *Alisma gramineum*, *Damasonium alisma* Mill var. *compactum* Michell, *Potamogeton crispus*, *Potamogeton pectinatus*, *Zannichellia palustris* and *Potamogeton perfoliatus*. In 1972, *Potamogeton pectinatus* (Entz, 1976), and in 1973–1974 *Najas marina* subsp. *armata*, *N. horrida*, *Z. palustris* and *Potamogeton pectinatus* were found (El-Hadidi, 1976; Entz, 1980). In 1981–1982 Springuel (1985) listed *Najas marina* subsp. *armata*, *Najas horrida*, *Potamogeton trichoides*, *P. crispus*, *Zannichellia palustris*, *Vallisneria spiralis* and *Potamogeton lucens* (identified as *P. nodosus*). After the construction of the Aswan High Dam, two euhydrophyte species (*A. gramineum* and *D. alisma*) were lost, but the other four species colonized the lake with varying degrees of success. In 1967, *Vallisneria spiralis* L. was recorded for the first time in Egypt (El-Hadidi, 1968; El-Hadidi & Ghabbour, 1968). In 1978–1986, of eight species recorded (Ali 1987; Springuel & Murphy, 1991), five (*Potamogeton schweinfurthii*, *Najas horrida*,

Table 2 Freshwater macrophyte species recorded in Nasser–Nubia lakes before and after formation of the Aswan High Dam

Species	1963–1964a	1963–1964b	1972–1974	1980–1986	1984–1986	1989–1990	1993–1994
Alisma gramineum	*	*	–	–	–	–	–
Damasonium alisma	*	*	–	–	–	–	–
Potamogeton crispus	*	*	–	*	*	*	*
Potamogeton pectinatus	*	*	*	*	*	–	–
Potamogeton perfoliatus	*	*	–	–	–	–	–
Potamogeton trichoides	–	–	–	*	*	–	–
Potamogeton lucens	–	–	–	–	–	*	*
Potamogeton nodosus	–	–	–	*	–	–	–
Zannichellia palustris	*	*	–	*	*	*	*
Vallisneria spiralis	–	*	*	*	*	*	*
Najas minor	–	–	–	*	–	–	–
Najas horrida	–	–	–	*	*	*	*
Najas marina	–	*	*	*	*	*	*
Nitella hyalina (macroalga)	–	–	–	–	–	*	*
Ceratophyllum demersum	–	–	–	–	–	–	*
Myriophyllum spicatum	–	–	–	–	–	–	*

(*): present; (–): absent. 1963/1964a: after Boulos (1966), 1963/1964b after El-Hadidi (1976), 1972/1974 after Entz (1976), 1980/1986 after Springuel and Murphy (1991), 1984/1986 after Ali (1987), 1989/1991 after Ali (1992), 1993/1994 after Ali (2000).

N. marina subsp. *armata* and *Nitella hyalina*) were new to the area. Ali (2000) recorded a dense cover of two "nuisance species" *Myriophyllum spicatum* L. in Abu Hor and *Ceratophyllum demersum* L. at Aswan port, in addition to *N horrida*, *N. marina intermedia* from the High Dam to Allaqi and *P. schweinfurthii* at Kalabsha (Table 2).

Ali (2006) recorded 61 species along the Lake Nubia shores. Species with high abundance (C) and frequency (F) were *Tamarix nilotica* (Ehrenb.) Bunge (C 5–100%, F 32.5%), *Persicaria lanigera* (R. Br.) Sojak (C 5–100%, F 19.3%), *Persicaria senegalensis* (Mein.) Sojak (C 5–100%, F 10.8%), *Crypsis schoenoides* (L.) Lam. (C 1–90%, F 16.9%), *Eragrostis aegyptiaca* (Willd.) Delile (C 1–90%, F 15.7%), *Glinus lotoides* L. (C 1–80%, F 43.4%), *Portulaca oleracea* L. (C 1–80%, F 12.0%), *Phragmites australis* (Cav.) Trin. Ex Steud. (C 1–70%, F 19.3%), *Hyoscyamus muticus* L. (C 1–60%, F 39.8%), *Crypsis aculeata* (L.) Aiton (C 1–60%, F 13.3%), *Heliotropium supinum* L. (C 1–50%, F 27%), *Cyperus michelianus* (L.) Delile (C 1–40%, F 34%), *Cyperus alopecuroides* Rottb. (C 5–40%, F 12.0%) and *Fimbristylis bisumbellata* (Forssk.) Bubani (C 1–30%, F 25%). *Tamarix nilotica* and *G. lotoides* dominated the Lake Nubia shores from Debeira (338 km south of Aswan High Dam–AHD) to El-Daka (487 km south of AHD). *H. muticus* extended from Debeira (338 km south of AHD) to El-Dewishat (431 km south of AHD). *P. lanigera* was mainly present in the southern section of the lake, from Semna (404 km south of AHD) to Okma (466 km south of AHD).

16 Zooplankton

16.1 Distribution, Seasonal Variation and Standing Crop

Many investigators have studied the distribution and seasonal variation of zooplankton in the lake and its main khors since its early filling (Samaan, 1971; Samaan & Gaber, 1976; Latif, 1984; Zaghloul, 1985; Mageed, 1992, 1995; Iskaros, 1993; Shehata et al., 1998; El-Shabrawy, 2000; El-Shabrawy & Dumont, 2003; Mageed & Heikal, 2006).

Lake Nasser's zooplankton is rich. In 1971 the annual average in the main channel was 21,000 ind m^{-3}, but the khors were nearly twice as rich (46,000 ind m^{-3}) (Samaan, 1971). The standing crop oscillated from 29,000 to 60,000 ind m^{-3} in 1984. A recent study by El-Shabrawy (2000) showed that density in the main channel varied from 25,000 to 120,000 ind m^{-3} and was highest in the upper 10 m (euphotic zone). Peaks occurred between Korosko and Amada (southern area). Time-wise, zooplankton peaked (88,000 ind m^{-3}) in spring, and dropped (32,000 ind m^{-3}) in winter. The population density in khors was higher than in the main channel and the southern khors (Korosko and Toshka) were richer than the northern ones (El-Shabrawy & Dumont, 2003).

16.2 Zooplankton Composition

The assemblage consists of Copepoda, Cladocera, and Rotifera, besides Protozoa and meroplankton (Table 3). Copepoda dominate, forming more than 65% by numbers (Fig. 2). They are represented by two carnivorous cyclopoida (*Thermocyclops neglectus* and *Mesocyclops ogunnus*) and one herbivorous Calanoid (*Thermodiaptomus galebi*). Cladocera come next in abundance, with a percentage around 20% and 10 species, while rotifera are less abundant, but show the highest diversity (16 species). *Thermocyclops neglectus* and *Mesocyclops ogunnus* constitute around 18% by numbers; *Tropodiaptomus processifer*, *T. kraepelini*, *T. asimi*, *Thermodiaptomus galebi*, and *T. syngenes* 16%; *Moina dubia* 15%; *Daphnia barbata*, *D. lumholtzi*, *Ceriodaphnia cornuta* 13%; *Bosmina longirostris* 8%, Nauplius larvae and crustacean eggs 7%, 5.5% and 4.4%, respectively. *Brachionus calyciflorus*, *B. angularis* and *B. caudatus* form 4%; Chironomids 3.6%; *Keratella tropica* and *K. cochlearis* 2.9%; other occasional organisms, finally, 2.7% (Abu Gideiri & Ali, 1975).

Table 3 Zooplankton species recorded from Lake Nasser at different time periods

	1981	1989–1990	1993–1994	1996–1998	2003
Protozoa					
Arcella discoides (Ehrb.)	–	–	*	*	–
Centropyxis aculeata (Ehrb.)	–	–	*	*	–
Epistylis bimarginata (Nenninger)	–	–	*	–	–
Euplotes patella (Müller)	–	–	*	–	–
Rotifera					
Anuraeopsis fissa (Gosse)	–	–	*	*	–
Ascomorpha ecaudis (Perty)	–	–	*	–	–
Asplanchna girodi (de Guerne)	–	–	–	*	–
Brachionus angularis (Gosse)	*	*	*	*	–
Brachionus calyciflorus (Pallas)	*	*	*	*	*
Brachionus caudatus (Barrois & Daday)	*	*	*	–	–
Brachionus falcatus (Zacharias)	–	*	*	*	*
Brachionus patulus (Müller)	–	–	*	*	*
Brachionus plicatilis (Müller)	–	*	*	–	–
Conochilus hippocrepis (Schank)	–	–	*	–	–
Conochillus unicornis (Rousslet)	–	–	*	–	*
Euchlanis dilatata (Ehrb.)	–	*	*	*	–
Filinia opoliensis (Zacharias)	–	*	*	*	*
Filinia longiseta (Ehrb.)	*	*	*	*	–
Hexarthra mira (Hudson)	–	*	*	*	–
Keratella cochlearis (Gosse)	*	*	*	*	*
Keratella quadrata(Müller)	–	–	*	–	*
Keratella tropica (Apstein)	*	*	*	*	*
Lecane arcula (Harring)	–	–	–	*	–

(continued)

Table 3 (continued)

	1981	1989–1990	1993–1994	1996–1998	2003
Lecane bulla (Gosse)	*	*	*	*	–
Lecane closterocerca (Schmarda)	–	–	–	*	–
Lecane luna (Müller)	*	*	*	*	–
Lecane lunaris (Ehrb.)	–	*	*	*	–
Polyarthra vulgaris (Carlin)	–	*	–	*	*
Pompholyx complanata (Gosse)	–	–	*	–	–
Proalides sp.	–	–	–	*	–
Scaridium longicaudum (Müller)	–	*	–	–	–
Trichocerca similis (Wierzejski)	–	*	*	*	*
Trichocerca porcellus (Gosse)	–	–	*	–	–
Trichocerca pusilla (Lauterborn)	–	–	*	*	–
Trichocerca longiseta (Schrank)	*	–	–	*	*
Testudinella patina (Hermann)	–	–	*	–	–
Copepoda					
Thermodiaptomus galebi (Barrois)	*	*	*	*	*
Thermocyclops neglectus (Sars)	*	*	*	*	*
Mesocyclops ogunnus (Onabamiro)	*	*	*	*	*
Ergasilus sieboldi (Nordmann)	*	–	–	–	–
Halicyclops magniceps (Lilljeborg)	*	–	–	–	–
Cladocera					
Alona rectangula (Sars)	–	–	–	*	*
Alona intermedia (Sars)	–	*	–	–	–
Alona affinis (Leydig)	*		–	–	–
Macrothrix laticornis (Jurine)	–	*	–	*	–
Bosmina longirostris (Müller)	–	–	–	*	*
Chydorus sphaericus (Müller)	–	–	*	*	*
Ceriodaphnia quadrangula (Müller)	–	*	–	*	–
Ceriodaphnia dubia (Richard)	–	–	–	*	*
Ceriodaphnia cornuta (Sars)	*	*	*	–	*
Daphnia barbata (Weltner)	*	*	–	*	*
Daphnia longispina (Müller)	–	–	*	*	*
Diaphanosoma excisum (Sars)	*	*	*	*	*
Diaphanosoma mongolianum (Ueno)	–	–	–	*	–
Simocephalus vetulus (Müller)	–	–	–	*	*

1981: after Zaghloul, 1985, 1998–1990: after Abdel-Mageed, 1992, 1993–1994: after Abdel-Mageed, 1995, 1996–1998: after El-Shabrawy, 2000 and El-Shabrawy and Dumont, 2003, 2003: after Mageed and Hekal, 2006.

16.3 Zooplankton Biomass

In the coastal area of the main channel and main khors, copepoda constituted 53% of zooplankton biomass (280–1,050 mg g^{-1}). Cladocera occupied the second position (27–46%). Regarding seasonal variation of biomass, spring had the highest value (690 mg m^{-3}), and winter the lowest (360 mg m^{-3}).

16.4 Vertical Distribution

In the main channel, *Keratella cochlearis*, *Proalides* sp. (Rotifera), *Bosmina longirostris*, *Ceriodaphnia dubia* (Cladocera) and all Copepoda except *Mesocyclops ogunnus* migrate over ca 20 m. The highest density occurs between 10 and 15 m, and almost all Cladocera disappear below 15–20 m in summer, due to a lack of oxygen.

16.5 Zooplankton Production

No work has been done on zooplankton production in Lake Nasser, except for the study of El-Shabrawy & Dumont (2003), which estimated production (P) from biomass (B), using the IBP regression equation for mixed crustacean lake zooplankton ($P = 9.097\ B^{1.237}$), after Morgan (1980). Such an estimation is rough, but detailed measurements of the production of most cladoceran and copepods species that live in Lake Nasser have been carried out in Lake Chad (Lévêque & Saint-Jean, 1983). They were strongly temperature-dependent. Daily P/B values varied by factors 2.5–7 across species, seasons and lake temperature. Taking average zooplankton dry weight across the top 10 m of Lake Nasser at 5 g m^{-2} yr^{-1}, a yearly usable production of the order 50 t km^{-2} yr^{-1} is found. This is remarkably close to the production of Lake Chad, estimated at 43 t km^{-2} yr^{-1} by Lévêque & Saint-Jean (1983). Extrapolating, total annual production for the whole lake will be around 25×10^4 t. Assuming an efficiency of 10% (Lauzanne, 1983), zooplankton converted to fish biomass should suffice to produce 25,000 t of fish.

17 Macrobenthos (Table 4)

The importance of benthos lies in its position as secondary producer. Fish biomass and yield strongly correlate with macroinvertebrate biomass or production. Lentic fish obtain most of their energy from the benthos (Wissmar & Wetzel, 1987). Entz (1978) stated that before construction of the high dam, mollusca (bivalve) were ubiquitous but died out during stagnation owing to depletion of oxygen. *Tubifex* sp. was abundant, while chironomids were rare in the old river bed of the lake. Other investigations were carried out later (Anon, 1979; Iskaros 1988–1993; Fishar, 1995). El-Shabrawy & Abd El-Regal (1999) mentioned that the main channel harbored little diversity; only nine species of Arthropoda, Annelida and Mollusca were recorded. The southern part showed the highest density, with a peak of 2,920 org m^{-2} at Toshka in winter, mainly *Limnodrilus hoffmeisteri and L. udekemianus*. Kalabsha had the lowest density (150 org m^{-2}) in summer. Annelids therefore contributed ca 80% to total numbers and biomass. The highest density occurred in the south (Toshka & Abu Simbel), with a peak of 1,800 org m^{-2} in winter, while Kalabsha was the poorest site. *Branchiura sowerbyi* was rare and absent from several stations along the main

Table 4 Macrobenthos species recorded in Lake Nasser by different authors

Taxa and species	Entz, 1976	Entz, 1978	Latif, 1984	Elewa, 1987	Lskaros, 1988, 1993	Fishar, 1995	El-Shabrawy and Abd El-Regal, 1999
Cnidaria							
Hydra vulgaris Pallas						*	*
Aquatic insects							
Chironomus larvae	*	*	*	*	*	*	*
Nymphs of Odonata					*	*	*
Nymphs of Ephemeroptera						*	*
Nymphs of Trichoptera				*		*	
Nymphs of Hemiptera			*			*	*
Nymphs of Coleoptera						*	*
Crustacea							
Caridina nilotica (P. Roux)		*	*		*		
Potamonautes niloticus (Edwards)			*				*
Stenocypris malcolmsoni (Baird)						*	*
Annelida							
Branchiura sowerbyi (Beddard)				*	*		
Limnodrilus hoffmeisteri (Claparéde)				*	*		
Limnodrilus udekemianus (Claparéde)				*	*		
Tubifex sp.	*	*					
Helobdella conifera (Moore)					*	*	*
Mollusca							
Bellamya unicolor (Olivier)					*	*	*
Biomphalaria alexandrina (Ehrb.)					*		
Bulinus truncatus (Audouin)				*	*	*	*
Bulinus forskalii (Ehrb.)					*		
Cleopatra bulimoides (Olivier)				*	*	*	*
Gabbiella senariensis (Kuster)					*		
Helisoma duryi (Wetherbg)					*		
Lanistes carinatus (Olivier)					*	*	*
Lymnaea natalensis (Krauss)					*		
Melanoides tuberculata (Müller)				*	*	*	*
Physa acuta (Draparnaud)				*	*	*	*
Pila ovata (Olivier)					*		
Theodoxus niloticus (Reeve)					*	*	*
Valvata nilotica (Jickeli)				*	*	*	*
Gyraulus ehrenbergi (Beck)					*	*	*
Corbicula consobrina (Cailliaud)			*	*	*	*	*
Pisidium pirothi (Jickeli)				*	*	*	*

channel. Arthropods, represented by *Chironomus* larvae, formed about 10% of total benthos numbers and biomass. They were totally absent during summer and autumn and reached a standing crop of up to 300 org m^{-2} during spring and winter. Compared with the main channel, the macrobenthos in the littoral was highly diverse: 21 species were recorded. Arthropods were numerically dominant, constituting about half of the numbers, followed by Annelida and Mollusca (41% and 12%). The total biomass of these groups was the reverse of its numbers: Mollusca contributed the major part of biomass (54%), followed by Annelida and Arthropoda (25% and 21% respectively). *Chironomus* larvae and *Caridina nilotica* were the dominant arthropods at the majority of stations, while other arthropods were scarce (Fishar, 2000) (Table 4).

18 Long-Term Changes

The low standing crop of benthos at the beginning of impoundment (Latif et al., 1979), increased gradually with the rise in water level. The standing crop dropped to a minimum in 1988, and increased again during the following years, due to a drop in lake level resulting from a major drought lasting until 1988. According to the classification of MacLachlan (1974), three stages can be differentiated in the formation of the macrobenthos of Lake Nasser. The first stage (filling phase) covered the early years of impoundment (1966–1978) and was characterized by a mass development of chironomids and oligochaetes (*Tubifex* spp.) able to utilize organic matter and live under anoxic conditions. Some workers (Entz, 1978; Latif, 1984) found the freshwater crab, *Potamonautes niloticus*, the prawn *Caridina nilotica*, and some snails (including *Bulinus truncatus*) in the littoral zone. These species are riverine and most of them died at the end of this stage. The second stage (post-filling phase) covered the next 10 years (1979–1989) and was characterized by an increase in standing crop and in species diversity owing to an increase in organic matter, dissolved oxygen (DO) and surface area of the lake. The standing stock of benthic animals was reduced at the end of this stage due to a decrease in water level resulting from the African drought (Elewa, 1987; Iskaros, 1988). The third stage (equilibrium phase) from about 1990 until the present has been characterized by a further increase in diversity of species, and fluctuations in the number of individuals. The community of the benthos in Lake Nasser is now beginning to stabilize (Table 4).

19 Fish

19.1 Fish Diversity

The 57 species recorded since 1964 (Table 5) belong to 16 families (Latif, 1974). Some, like *Protopterus aethiopicus* and *Polypterus bichir*, are extremely rare. In the course of impoundment, some species became less and others more common. For example,

Table 5 Fishes recorded in Lake Nasser (after Latif, 1974)

Species	Local Name	Species	Local Name
Protopterus aethiopicus	Dabib El-Hout	*Clarias anguillaris*	Hout, Karmout
Polypterus bichir	Abu-Bichir	*Clarias gariepinus*	Hout, Karmout
Mormyrops anguilloides	Gamhour	*Heterobranchus longifilis*	Hout, Karmout
Petrocephalus bane	Gelmaya, Arminya	*Heterobranchus bidorsalis*	Hout, Karmout
Pollimyrus isidori	Anooma	*Schilbe* (Eutropius) *niloticus*	Schilba
Gnathonemus cyprinoides	Um-Shafika	*Schilbe* (Schilbe) *mystus*	Schilba
Mormyrus kannume	Um-Bowez	*Schilbe* (Schilbe) *uranoscopus*	Schilba-Arabi
Mormyrus caschive	Boweza	*Siluranodon auritus*	Schilba
Hyperopisus bebe	Kalamya-Babeh	*Bagrus bajad*	Bayad
Gymnarchus niloticus	Rayah Niliah	*Bagrus docmak*	Docmack
Hydrocynus forskalii	Kalb El-Samak	*Chrysichthys auratus*	Gurgar
Hydrocynus vittatus	Kalb El-Samak	*Chrysichthys rueppelli*	Gurgar Schami
Hydrocynus brevis	Kalb El-Samak	*Clarotes laticeps*	Abu-Meseka
Alestes dentex	Rayah	*Auchenoglanis biscutatus*	Halouf
Alestes baremoze	Rayah	*Auchenoglanis occidentalis*	Halouf
Brycinus nurse	Sardina	*Synodontis schall*	Schall
Distichodus niloticus	Lessan El-Bagar	*Synodontis serratus*	Schall
Citharinus citharus	Kamara	*Synodontis clarias*	Schall
Citharinus latus	Kamara	*Mochocus niloticus*	Mekawkas Nili
Chelaethiops bibie	Bebe	*Chiloglanis niloticus*	Kiloglans
Labeo victorianus	Lebeis Hagari	*Malapterurus electricus*	Rahaad
Labeo niloticus	Lebeis Nili (abyad)	*Sarotherodon galilaeus*	Bolti Galili
Labeo coubie	Lebeis Aswad	*Oreochromis niloticus*	Bolti Nili
Labeo horie	Lebeis Aswad	*Oreochromis aureus**	Bolti Azrak
Garra dembeensis	Abu-Kors	*Tilapia zillii*	Bolti Akhadar
Barbus bynni	Benni	*Lates niloticus*	Samous, Ishr-ayad
Barbus werneri	Benni	*Tetraodon lineatus*	Fahaka
Barbus anema	Benni		
Barbus perince	Benni		
Barbus neglectus	Benni		
Raiamas loati	Morgan loti		
Leptocypris niloticus	Bebee–Margan Nili		

Chelaethiops bibie and *Leptocypris* (*Barilius*) *niloticus* were common in the southern region in 1970, but at present are infrequent. Latif (1974) found that *Eutropius niloticus*, *Schilbe uranoscopus*, *S. mystes*, *Alestes dentex*, *A. baremoze*, *Mormyrus*, *Labeo* spp. and *Barbus* spp. were more frequent in Lake Nubia than in Lake Nasser. The reverse is true for *Sarotherodon galilaeus*, *Oreochromis niloticus*, *Hydrocynus forskalii*, *Brycinus nurse* and *Bagrus* spp. Again *Schilbe* spp. are more frequent in the southern part of Lake

Nubia except during the flood, when they become common in flooded areas. *Alestes baremoze* and *A. dentex* are repelled by these waters and become common in the south, ahead of the flood. However, *A. baremoze* migrates upstream for spawning in Lake Nubia (Rashid, 1977). Similar migration from natural lakes to connecting rivers for spawning has been observed elsewhere (Durand & Loubens, 1971; Hopson, 1972).

Today, *Sarotherodon galilaeus* and *Oreochromis niloticus* represent 90–95% of total fish catch in lake Nasser. The remainder are *Hydrocynus* spp., *Synodontis* spp., *Bagrus* spp., *Lates niloticus* and *Brycinus nurse*. Thus, the species diversity has declined and some species are now restricted to the southern region of the Lake, while others have vanished completely (Khalifa et al., 2000) (Fig. 7).

There are 43 fish species in Lake Nubia (Table 6). The most abundant are the Characidae, Cyprinidae, and Schilbeidae followed by Mochokidae and Centropomidae. In commercial landings, Cichlidae (tilapias) are, again, dominant, but Lates *niloticus* is gaining in importance. *Distichodus*, *Citharinus* and *Bagrus*, which used to form a major part of the commercial fish catches during 1967–1968, almost disappeared. Fish abundance varies temporarily and spatially. For example, the western and southern regions have higher catches than other parts of the lake (Abu Gideiri & Ali, 1975). *Bagrus* and *Synodontis* are abundant during March–May. *Lates* and the *Labeo*'s increase in abundance with the flood during August and September. *Barbus bynni* shows highest catches during January, and in May–June (Fig. 8). In 1985, 26 species belonging to ten families were recorded. Compared with previous studies some species that were commercially important during the early years of the lake are now negligible (*Distichodus*, *Citharinus*, *Bagrus*). The species widely distributed in the lake are *Labeo niloticus*, *Lates niloticus*, *Sarotherodon niloticus*, *Hydrocynus forskallii*, *Alestes baremose* and *Eutropius niloticus*. Their highest production occurs during February–May and July–September.

19.2 Fish Production

Since the early days of impoundment, fish landings from the lake have contributed significantly to total annual fish production of Egypt. They have fluctuated between 34,000 t during 1982, and 13,900 t in 1999 (Fig. 7).

19.3 Fishing Gear

Three main kinds of fishing gear are used: the sinking gill net (kobak), the floating gill net (sakorata) and the trammel net (duk). Longlines (sharak) and cast nets (toraha) are used less frequently. Sinking gill nets and trammel nets are used along the shore at depths of up to 10–15 m. The former are usually operated overnight. When the weather and water conditions are favorable, sinking gill nets are used in the open waters of the Khors and to some extent in the main channel. The predominant fish

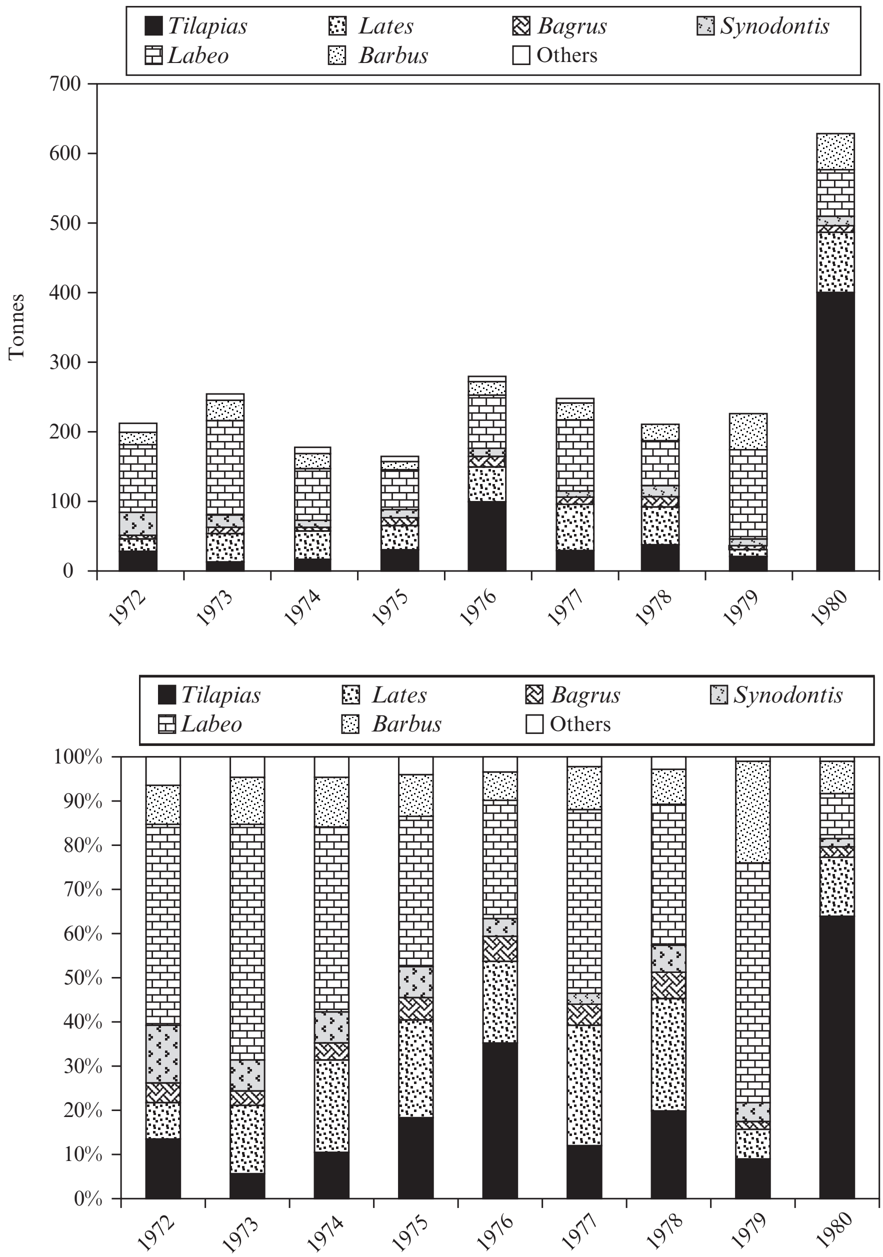

Fig. 7 Evolution of fish landings and percentage composition of the commercial catches in Lake Nasser (orig.)

Table 6 Fish species found in Lake Nubia from 1967 to 1979

Fish species	1967–1968	1971–1972	1973–1974	1975–1976	1979
Protopterus aethiopicus	*				
Heterotis niloticus	*				
Polypterus spp.	*				
Hyperopisus bebe	*	*		*	*
Mormyrus kannume	*	*	*	*	
M. cashive		*			
Mormyrops anguloides	*	*	*	*	
Petrocephalus bane	*	*			
Marcucenius spp.	*				
Gnathonemus cyprinoides	*	*			
Hydrocynus forskalii	*	*	*	*	*
*Alestes dente**	*	*	*	*	*
A. baremose	*	*	*	*	*
A. nurse	*	*	*	*	*
Distichodus niloticus	*	*	*	*	*
D. rostratus	*				
D. engycephalus	*				
Citharinus citharus	*	*		*	
Labeo coubie	*	*	*	*	*
L. niloticus	*	*	*	*	*
L. horie	*			*	*
Barbus bynnie	*	*	*	*	*
Bagrus bayad	*	*	*	*	*
B. docmak	*	*	*	*	*
Clarotes laticeps	*			*	
Auchenoglanis occidentalis	*				
Auchenoglanis spp.	*				
Chrysichthys auratus	*			*	
Clarias lazera	*	*			
C. angularis		*			
Heterobranchus bidorsalis	*				
Synodontis schall	*	*	*	*	*
S. serratus	*	*	*	*	*
S. batensoda	*	*	*		*
S. khartoumensis	*				
Sarotherodon galilaeus					*
Oreochromis niloticus	*		*	*	*
Malapterurus electricus	*				
Lates niloticus	*	*	*	*	*
Eutropius niloticus	*	*		*	*
Schilbe uranoscopus	*	*		*	*
S. mystus	*	*			
Tetraodon fahaka	*	*	*		

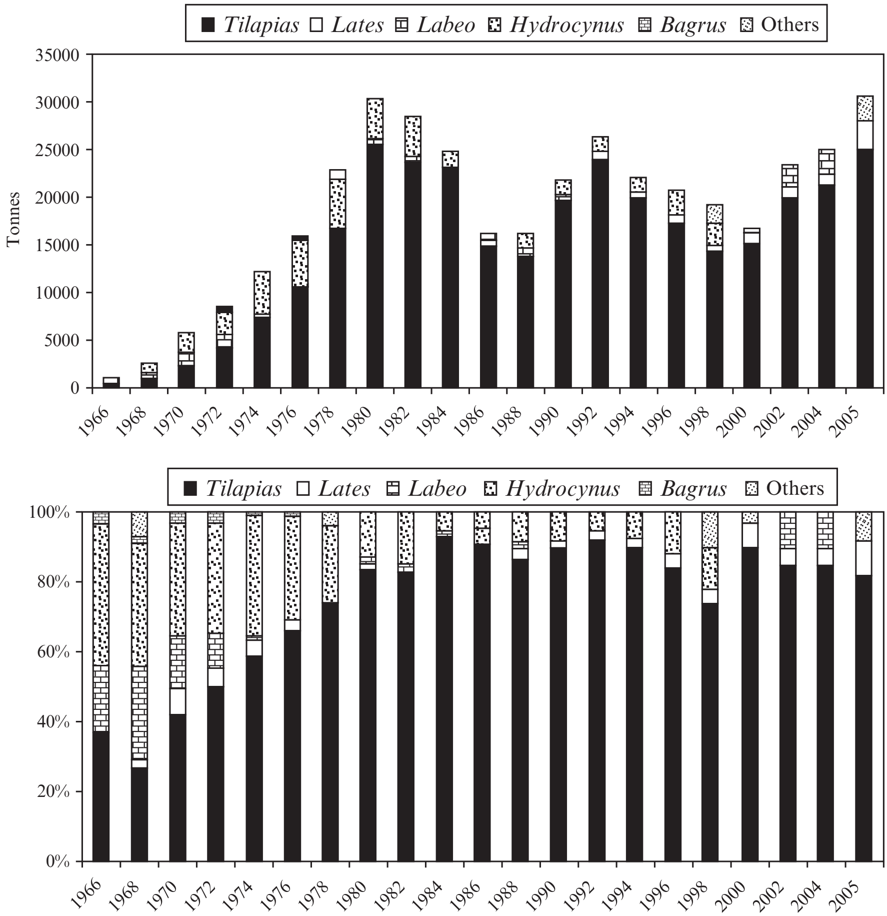

Fig. 8 Evolution of fish landings and percentage composition of the commercial catches in Lake Nubia (modified from Ali, 1984, reproduced with permission of the FAO)

caught in gill nets are *Alestes* spp. and *Hydrocynus* spp. The catch is usually gutted, salted and preserved in tins. Fish species caught in trammel nets are *Oreochromis niloticus*, *Sarotherodon galilaeus*, *Lates niloticus*, *Bagrus bayad*, *B. docmak*, *Mormyrus* spp., *Synodontis* spp. and *Barbus* spp. Tilapias and Nile perch form the bulk of the trammel net catch. The catch is collected by carrier boat. There are about 100 carrier boats each collecting from an assigned area. All of the collected fish, fresh and salted, are landed at the Aswan Fishing Harbour. The landings are sorted. In the case of fresh fish, tilapias and Nile perch are recorded separately (as bolti and samoos, respectively) because they are not difficult to identify, large quantities are landed, and they have a relatively high market value. Minor species, of about the same market value, tend to be combined under one name. Accordingly, the nominal catch statistics do not give an accurate figure of the composition of the landings.

19.4 Introduction of Alien Fish

The fish diversity of Lake Nasser has declined over time, and lacks a true pelagic planktivore. The lake seems to have a vacant ecological niche (pelagic area) that could be exploited by the introduction a pelagic planktivore (clupeid or cyprinid). Such species exist in the River Niger, in Lake Chad and in the large, ancient lakes of east Africa. The Lake Tanganyika clupeid, *Limnothrissa miodon* has been successfully introduced into Lake Kariba, on the border between Zambia and Zimbabwe, to fill the empty pelagic niche (Begg, 1976). A commercial fishery with 26,000 t yr^{-1} developed (Sanyanga et al., 1992) and employs about 3,000 people. The stomach content of *Limnothrissa miodon* (locally known as Kapenta) contains crustacean zooplankton, rotifers and phytoplankton. Cladocera and copepods are its main food items.

Other pelagic cyprinids, like *Engraulicypris sardella*, support productive fisheries in Lake Victoria and Malawi, and are equally good candidates for an introduction. The primary and zooplankton production of Lake Nasser indicates that the predicted yield of its fish landings is about 89,000 yr^{-1}, while recorded landings from Lake Nasser have never exceeded 34,000. The introduction of either of both pelagic planktivorous species could therefore more than double the lake's production (Fig. 7)

20 Impacts of the AHD

The Aswan High Dam has had a tremendous impact on Egyptian life, agriculture, and environment. However, the real question is not whether the Egyptians should have built the AHD or not – for Egypt realistically had no choice – but what steps could have been taken to reduce the adverse environmental impacts to a minimum. Here follows a brief overview of the major effects, positive and negative, of the high dam.

20.1 Positive Impacts

The dam has supported a high population growth rate in Egypt, because it prompted an expansion to agriculture, energy production, and manufacturing. One of the positive effects was that it allowed agriculture to move from basin irrigation to year-round irrigation, so crops could now be produced also during the dry months. And since the fear of flooding no longer existed, farmers were able to work in the fields year-round. The High Dam created a 30% increase in cultivable land in Egypt, and raised the water table in the Sahara. AHD also benefited industry by providing cheap electric power and it supplied even the most remote Nilotic villages with electricity. Lake Nasser became an important fishing site, supplying food and livelihood for the population around it.

Over the last 100 years the average discharge at Aswan has fluctuated around 90 km^3 yr^{-1}, while discharge to the Mediterranean fell from ca 32 km^3 yr^{-1} (before construction of the Aswan High Dam; Osman, 1999) to only ca 4.5 km^3 yr^{-1} (Kempe, 1989). The agricultural sector is the largest user and consumer of water in Egypt, its share being 82% of the gross demand for water. The total volume diverted to agriculture, including conveyance, distribution and application losses, is estimated at ca 55.2 km^3 yr^{-1}. The municipal water demand is currently in the order of 4.5 km^3 yr^{-1}, and is expected to increase significantly due to population growth. Industrial water demand is estimated at 7.6 km^3 yr^{-1}, of which only 0.79 km^3 yr^{-1} is lost to evaporation during industrial processes, while the rest returns to the system in a polluted form (EEAA, 2005).

Until the 1980's, the Aswan High Dam provided half of Egypt's Electricity. The power generating capacity of the Dam is 2.1 gigawatt (GW), produced by 12 Hydro-Generators, each rated at 175 MW. Egypt currently has a total installed generating capacity of 16.6 gigawatt (GW) compared to 3.8 GW in 1976, thus the percentage contribution by the dam has decreased from ca 50% to less than 13%. This percentage will continue to decrease as more thermal power plants are added. Total capacity is expected to be 26 GW by 2010 (http://www.mbarron.net/Nile/envir_nf.html).

In 1946, before the construction of AHD (Aswan High Dam), the yearly flood damaged about 70,000 feddan (ca 30,000 ha) while after its construction it protected about 100,000 feddan from such damages. It also provided protection from damage by high floods in 1975, 1988 and it saved Egypt from drought in 1972/1973, 1979/1980, 1987/1988 (Afifi, 1993).

The HAD also achieved the planned expansions of the agricultural domain, as shown in Fig. 9.

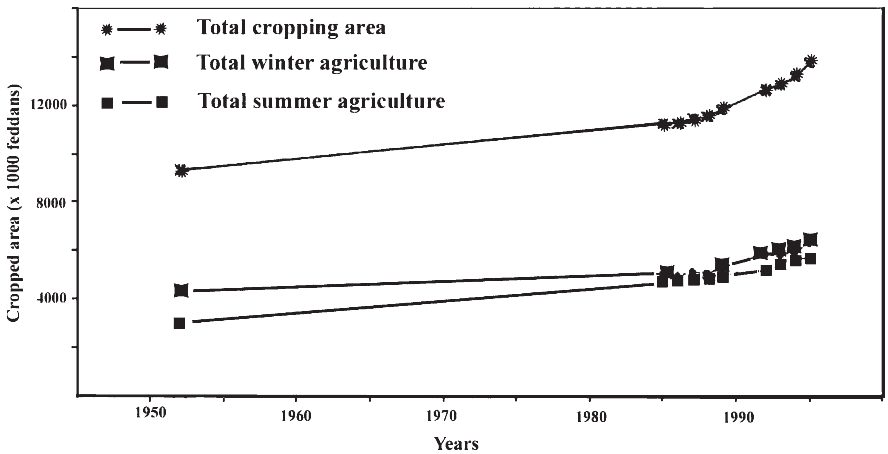

Fig. 9 Development of agriculture in Egypt from 1952 to 1995 (after Moussa et al., 2001, modified)

20.2 Negative Impacts

In the 1970s, the Aswan High Dam became a global symbol of environmental and social problems caused by large-scale development projects. The AHD impacts touch upon a wide spectrum of life aspects, including a change in water quality, as the maximum water release through the AHD is about a quarter of the former flood and is practically silt-free. Bed and bank erosion occurred in the downstream reaches of the Nile, caused by a change in river water levels and flow velocities, and the promontories of the delta started to erode instead of progressing into the sea (see Hamza, 2009).

Siltation of Lake Nasser There was a huge loss of fertility as a result of the creation of Lake Nasser. Fertile silt, henceforth captured by the dam, impacted the quality of soil downstream. This silt, enriched with organic material picked up *en route* used to sediment on the banks of the Nile and in the delta, creating excellent topsoil. As a result of the silt being captured, farmers now have to use about 10^6 t of artificial fertilizer as a substitute for the nutrients which no longer reach the floodplain.

Salinity and water-logging problems have developed due to the over-irrigation of lands, increases in cropping intensities and expansion of rice and sugar cane cultivation. The horizontal agricultural expansion in sandy or light soils that lie at higher elevation have increased seepage, thus contributing to salinity hazards.

Schistosomiasis and the Northward Migration of Malaria Vectors from Sudan Schistosomiasis, also known has bilharzia, is caused by the *Schistosoma* fluke-worm and is transmitted to humans via snails. Urinary schistosomiasis is caused by *S. haematobium*, and intestinal schistosomiasis by *S. mansoni*. Infected snails release the parasites as cercariae larvae, which enter humans spending much time in stagnant water, penetrating through the skin. The creation of the AHD combined with the change of the downstream irrigation from a seasonal to a perennial system has indeed increased the incidence of schistosomiasis (El-Hinnawi, 1980). Intermediate hosts of bilharzia snails (mainly mollusks of the genus *Bulinus*) appeared in the shallow littoral zones of AHD reservoir in great numbers at the end of 1974 (Entz, 1980). The threat was present, but the use of a wide range of control measures since the 1980s (use of molluscicides, introduction of biological control agents…) have prevented the prevalence of both urinary and intestinal bilharzia from reaching epidemic proportions (Jobin, 1999).

Negative effects occurred on the fisheries in the Nile and its coastal lakes, as the migration of certain types of fish were dependent on the arrival of turbid floodwater. As a result, sardines formerly breeding in the Nile estuary have almost disappeared and marine fish that used to seasonally migrate into the delta lakes have been virtually eliminated. Their place has, however, been taken by freshwater fish.

A rise in groundwater levels happened that required a new philosophy of land drainage. With the cessation of the cyclic behavior of groundwater before the AHD (levels rose after a flood wave and gradually sunk afterwards) and the increase in cropping intensities and perennial irrigation, more water seepage occurs that eventually feeds the water table. This has been exacerbated by a lack of effective drainage in some areas of the Nile valley and delta.

A growth of weeds at an epidemic scale in irrigation channels has resulted from the inflow of silt-free water and use of fertilizers in agriculture. This endangered the safety and effectiveness of irrigation and drainage, a significant amount of water was wasted, and water flow through many channels became interrupted.

The clearest losers resulting from the AHD construction have been the 100,000 or more Nubians, half-Egyptian and half-Sudanese, who had to be evacuated from their homes in the valley and were transferred to government-built villages far from the river. The Egyptians settled in eight villages on newly irrigated lands in the Kom Ombo area, 20 km to the north of Aswan. The Sudanese were moved and resettled in the area of Khashm el Girba, in the Upper Atbara valley (Mohieddin, 2000).

Finally, Simpson et al. (1990) state that there is a significant correlation between reservoir water levels and earthquake occurrences. The sheer weight of the water may seismically destabilize the area around it, raising the possibility that the reservoir weight could make underlying faults slip and cause the dam to falter. NASA geophysicists found evidence that large dams cause changes to the earth's rotation, because of the shift of water weight from oceans to reservoirs. Because of the number of dams which have been built, the Earth's daily rotation has apparently sped up by eight-millionths of a second since the 1950s (http://www.arch.mcgill.ca/prof/sijpkes/arch374/winter2001/dbiggs/enviro.html). This is the first time human activity has been shown to have a measurable effect on the Earth's motion.

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