The Fayum Depression and Its Lakes

Gamal M. El-Shabrawy and Henri J. Dumont

Abstract The Fayum is a depression below sea level, formed by wind erosion 1.8 million years ago, covering ca 12,000 km². It consists of two lacustrine complexes, Birket Qarun and the two artificial Wadi el-Rayan lakes. Lake Qarun is a saline remnant of the historical freshwater Lake Moeris. It used to be supplied by Nile water between its formation (about 1980 BC) and the Ptolemaic period (323–246 BC). The lake is no longer connected to the Nile and needs to be supplied with pumped water that evaporates in its basin. Consequently, the lake showed a strong increase in salinity, especially during the twentieth century. It evolved from a brackish to a hypersaline state, with incisive repercussions on all biota. In Wadi el-Rayan area, two successive lakes, separated by a waterfall, were created as a reservoir for drainage wastewater. These lakes currently exceed the capacity of Lake Qarun. The physical and chemical variables, phytoplankton, zooplankton, macrobenthos and fish of the two lake complexes are discussed. Among other things, it is argued that the rapid change in salinity of Lake Qarun excludes the presence of endemic species in its fauna.

1 Introduction

The Fayum (also written as Faiyum), a natural depression extending over 12,000 km², was formed by wind erosion ca 1.8 million year ago (Ball, 1939). It is situated ca 100 km southwest of Cairo, and separated from the Nile by a 25 km strip of desert. It is bounded by sandy hills, broken in the south, where a carrier canal (Bahr Yousef) enters the depression. This is its only source of water. The systems of irrigation and drainage are different from those of the Nile Valley. Terraced lands

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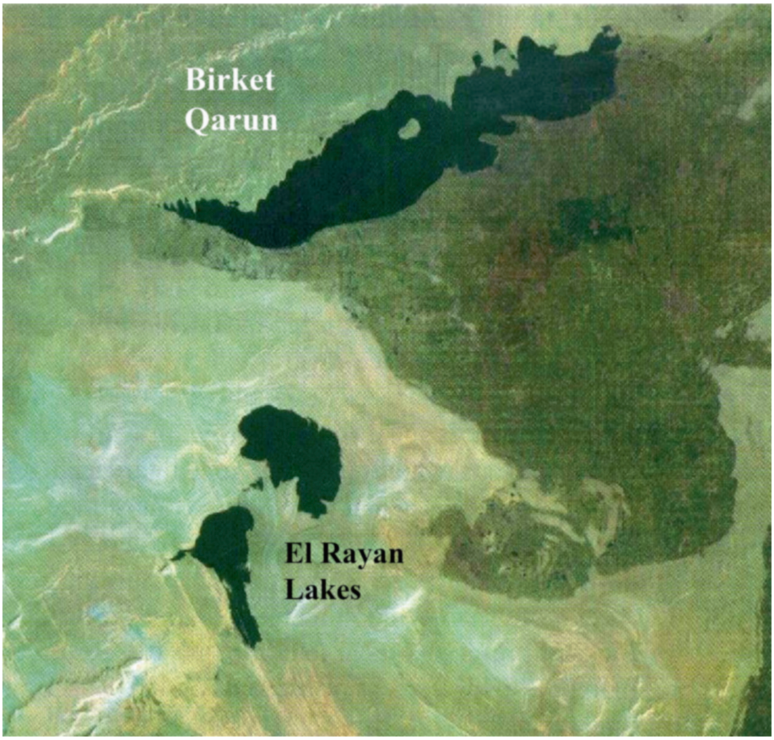

Fig. 1 Map of the Fayum province with its two lakes (Qarun and Wadi El Rayan). Source: (http://www.freesearch.co.uk/out?t = i&dest = http%3A%2F%2Fwww.utlcairo.org%2Fturismo%2Fturismo_fayoum.htm)

allow the use of masonry weirs for the distribution of irrigation water, instead of the regulators and pipe intakes of the Nile valley. One standard Fayum type of weir is used and Lake Qarun collects agricultural drainage water through two drains. Since 1973, about 30% of this water has been diverted to a second depression, Wadi El Rayan, south-west of the Fayum (Figs 1 and 2).

2 Lake (Birket) Qarun

Lake Qarun (29.48° N, 30.29° E) is located ca 43 m below sea level, in the northern Fayum (Figs 1 and 2). Documentary records for this lake began when Herodotos visited Egypt around 450 BC (Brown, 1892). He saw a large water expanse, Lake Moeris, assumed artificial, 50 fathoms deep, and maintained by a seasonal supply of Nile water. In the late nineteenth and early twentieth centuries (Ball, 1939), archaeologists showed that the modern lake is the shrunken remnant of this Lake Moeris. Lake Qarun is currently saline (see below), turbid (Secchi disc transparency <40 cm), and without surface outflow. It covers an area of 235 km^2, has an

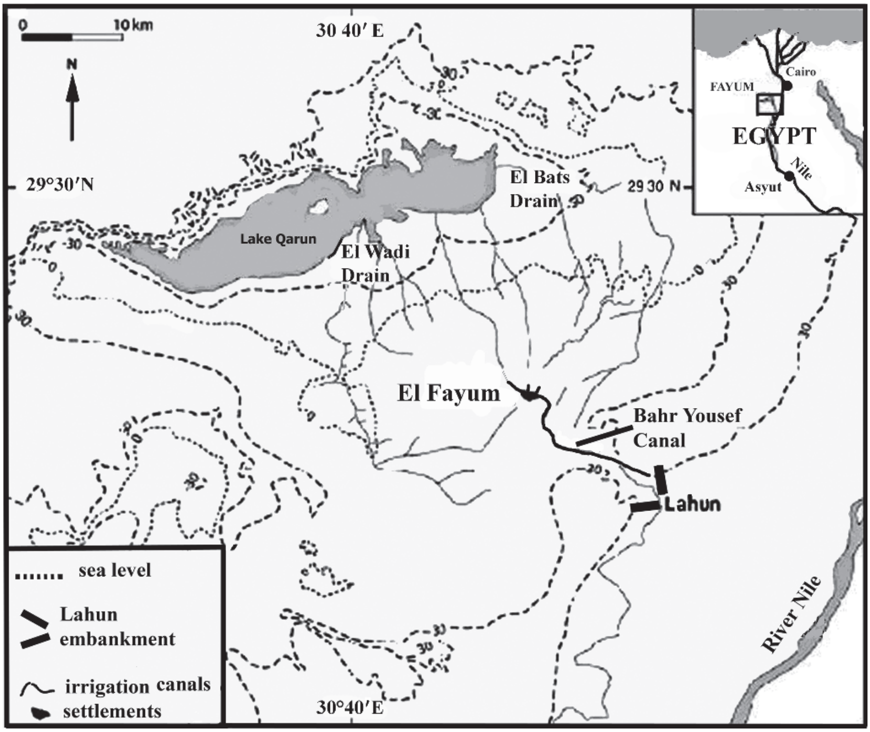

Fig. 2 Map of the Fayum Depression showing the surface hydrology including Bahr Yusef, irrigation canals, drains, and Lake Qarun (after Flower et al., 2006, with permission from Springer)

elongated rectangular shape, and stretches for 40 km from east to west. Average depth is 4 m, with the main western basin deeper than the eastern (maximum 8.8 m) (El-Wakeel, 1963). The lake is one of Egypt's prime sites for migratory and waterbirds. Kittlitz's plover, Kentish Plover, Collared Pratincole and Little Tern breed and Great Crested Grebes and Black-necked Grebes spend winter here. Fayum City, the principal town in the region, is a distribution centre from which a network of canals and pumping stations deliver water to the agricultural regions around it (Brown, 1892; Hewison, 2001). Agricultural returns and excess water are passed to Lake Qarun by two principal 'drains': the El Bats Drain, flowing into the lake's east end and the El Wadi Drain entering the western basin (Fig. 1). The water in these drains is fresh (El-Sayed & Guindy, 1999) but contaminated by agro-chemicals. About 360×10^6 m^3 of water annually enter the lake, carrying an average of 430,000 t of salts (Meshal, 1973). There is less incoming drainage than loss by evaporation. Consequently, salinity increases with time, reaching 45.31‰ in 1996 (Anonymous, 1997). Water level typically varies by less than 1 m annually and temperature changes seasonally between about 33°C and 15°C (Ball, 1939; El-Sayed & Guindy, 1999). Physical and chemical variables have been documented by Lucas (1906), Abu-Samra (1934), Ball (1939), Naguib (1958), Meshal (1973), Ishak & Abdel-Malek (1980), Abd Ellah (1999), Elewa et al. (2001), Mansour et al. (2001) & Ali (2002). Bacteria were studied by Sabae (1993, 1996), Sabae & Rabeh (2000), Sabae & Ali (2004). Wimpenny & Titterington (1936), Girgis (1959), Bolous (1960), Khalil (1978), Shaaban et al. (1985), Abdel-Malek & Ishak (1980), Abdel-Moniem (1991), Gad (1992), Ahmed (1994), Abdel-Moniem (2001a, b). El-Shabrawy (2001a), Mansour & Sidky (2003), El-Shabrawy & Belmonte (2004), Fathi & Flower (2005) & Mageed (2005) investigated the plankton. Abdel-Malek & Ishak (1980) & Fishar (1993, 2000), El-Shabrawy (2001b), & Flower et al. (2006) studied the benthic fauna. Lake fisheries were addressed by Wimpenny & Faouzi (1935), Faouzi (1936), Wimpenny (1936), El-Zarka (1963), El-Zarka & El-Sedafy (1967), Bolous & Ashour (1973), Boraey (1974), Kirollus (1977), Abdel-Malek (1980, 1982), Ishak et al. (1982), Swielum (1989), Mosaad (1990), Shafik (1991), Yacoub (1994), Gabr (1998) & El-Shabrawy & Fishar (1999).

2.1 The Egyptian Company for Salts and Minerals (EMISAL)

The Egyptian Company for Salts and Minerals (EMISAL) operates on the south coast of the lake. Here, a zone known as Batnat Abu Ksah has been cut off from the lake and divided into a series of evaporation ponds, to concentrate lake water to at least 10 times its original salinity. The main product of the EMISAL is sodium sulphate. The amount of water pumped from the lake to the ponds of plant has increased from about 7.5×10^6 m^3 in 1986 to 20×10^6 m^3 in 1997 (Abd Ellah, 1999).

2.2 Historical Review

The Fayum depression was artificially connected with the Nile under the reign of pharaoh Amenehat I (1980–1970 BC). The digging of the Hawara canal, now Bahr Yousef, was one of the great Nile projects of the ancient Egyptians (Fig. 1). In the flooded valley, Lake Moeris formed, with an area of about 724 km^2 and a mean depth of 80 m (Ball, 1939). The Lahun Embankment, constructed during the reign of Ptolemy I and II (323–246 BC), diverted the annual influx of Nile water. Lake Qarun thereby dropped to 5 m below sea level and the newly exposed land was colonized by Macedonian soldiers (Ball, 1939; Shafei, 1940). The lake continued to shrink during the Roman period (35 BC–AD 385), and declined from −7 m in the second century AD to −17 m or lower in the third century AD (Ball, 1939). Under Mohamed Ali (1805–1848), it dropped to −40 m (Shafei, 1940). The lowest level, −46 m, was recorded in 1932–1933 (Shafei, 1940). While climate was undoubtedly a factor regulating lake volume and water quality in the past, human interventions now determine its hydrology. Since the engineering feats of the ancient Egyptians, hydrologic modifications have continued (see Rivlin, 1961; Shahin, 1985) but after the completion of the Aswan High Dam in the mid-1960s, Nile floods ceased to affect the Fayum. Sediment records confirm these environmental changes. The high levels of the mid-Holocene lake are reflected in freshwater diatom deposits immediately north-east of the modern lake (Aleem, 1958; Przybylowska-Lange, 1976; Zalat, 1991). Diatom analysis of two shallow-water (3–4 m depth) cores indicate that salinity also fluctuated in the past (Müeller-Wilmes, 1988). The vegetational history of the Fayum is not well known, although classical accounts attest to the fertility of the region; 2,000 years ago, Strabo (in Hewison, 2001) listed a variety of fruit and vegetable crops available in the area. Now, much agriculture is given over to cotton, wheat, sugarcane and fodder crops. Earlier pollen analysis of near-shore cores from the east basin revealed a low plant diversity (Mehringer et al., 1979). These pollen diagrams span approximately the last 325 years (dates inferred from exotic pollens and pollen influx calculations) and show a vegetation dominated by ruderals (mainly chenopods). Cereals increase towards the core top, and twentieth century introductions of *Eucalyptus* and *Casuarina* are clearly recorded. Marine dinoflagellate cysts in the core are attributed to a reworking of marine sediments of Eocene age.

2.3 Some Physical Characteristics (Table 1)

The annual average radiation in 1996, ca 148 W m^{-2}, fluctuated from 242 W m^{-2} in summer to 53 W m^{-2} in winter (Anonymous, 1997). Ball (1939) first measured evaporation directly and found an annual average of 177 cm. Gorgy (1959) arrived at an annual average of 185 cm, using the energy budget method. Meshal & Morcos (1981) recorded 190 cm, and Abd Ellah (1999) 174 cm. Relative humidity in the lake area is directly proportional to air pressure and inversely proportional to wind speed. It fluctuates between 40% in May and 59% in December, with annual average 49% (Abd Ellah, 1999). Wind speed is low during winter (2.5 m s^{-1}), and maximum in summer (5.5 m s^{-1}). The dominant direction is north-west; in winter, it changes to north-east.

2.3.1 Water Budget

Meshal and Morcos (1981) calculated the water budget of Lake Qarun from:

$$(I + R + G) - (E + Q) = S \qquad (1)$$

Where the terms are the time average of I = inflow of drainage water, R = rainfall, G = seepage, E = evaporation, O = outflow and S = salinity.

Since the lake has no outflow, Eq. 1 reduces to $(I + R + G) - E = S$ (2)

Table 1 Components in (10^6 m^3) of the water budget and factors (10^6 kg) affecting the salt budget of Lake Qarun (Abd Ellah, 1999)

Months 1996	Water inflow	Water loss	Water pumped to EMISAL	Salt gain through drains	Salt extracted by EMISAL
Jan	8.54	9.173	0.313	30.982	11.714
Feb	27.66	17.395	0.387	58.315	14.356
Mar	30.39	20.067	0.904	55.707	32.981
Apr	34.18	31.427	1.192	57.65	43.017
May	20.86	52.372	2.106	44.801	76.448
Jun	17.48	57.756	2.581	45.645	98.082
Jul	15.34	52.9	3.033	38.262	120.41
Aug	19.56	57.744	2.727	53.066	111.262
Sep	37.28	46.943	2.329	58.936	93.168
Oct	39.72	36.651	2.250	74.036	89.775
Nov	43.71	25.038	0.806	66.714	31.53
Dec	43.38	7.869	0.468	106.783	17.784
Total	338.1	415.335	19.096	690.89	740.527

The monthly net gain or loss shows that there is seepage from the lake during July, August and November and seepage to the lake during the rest of the year. The annual gain through seepage is 65×10^6 m^3. Water level usually rises in spring and drops in late summer and early autumn. The minimum (–44.1 m) is in September, the maximum (–43.4 m) in May. The lake gains water (338×10^6 m^3 y^{-1}) from El-Bats and El-Wadi Drains; losses (415×10^6 m^3 y^{-1}) are by evaporation and by pumping to EMISAL (19×10^6 m^3 y^{-1}). The water budget is negative during 7 months (January–July), and positive during the rest of the year. The net budget is negative by about 96×10^6 m^3 y^{-1} (Table 1).

2.3.2 Salinity and Salt Budget (Table 1)

The agricultural drainage water that reaches the lake has a salinity fluctuating between 1.32–3.46‰ and 1.26–4.14‰. As Lake Qarun is closed, it receives dissolved salts through the drains (690×10^6 kg y^{-1}), but looses some of them to the EMISAL plant (740×10^6 kg y^{-1}). This budget appears negative but the loss of salt is compensated by seepage from cultivated land around the lake (Abd Ellah, op. cit.).

The salinity of the lake has strongly increased in the course of the twentieth century (Fig. 3). In 1906, it was 10.5 g l^{-1}, but already reached 18 g l^{-1} in 1919–1925 (Coastguards Administration). Naguib (1958) mentioned 17.8–25.5 g l^{-1} in 1953–1955. Salinity increased further, to 30.9‰, 38.7‰ and 42.8‰ in the 1971, 1995 and 1999–2000, respectively (Mashal, 1973; Anonymous, 1997; Ali, 2003). This rapid evolution has important consequences for the biota of the lake which, for obvious reasons, cannot contain endemics. Soliman (1989) predicted a further increase in salinity in the twenty-first century, eventually leading to a biologically "dead waterbody". A (temporary?) decrease to 32.4‰ was, however, recorded in 2003 (Sabae & Ali, 2004).

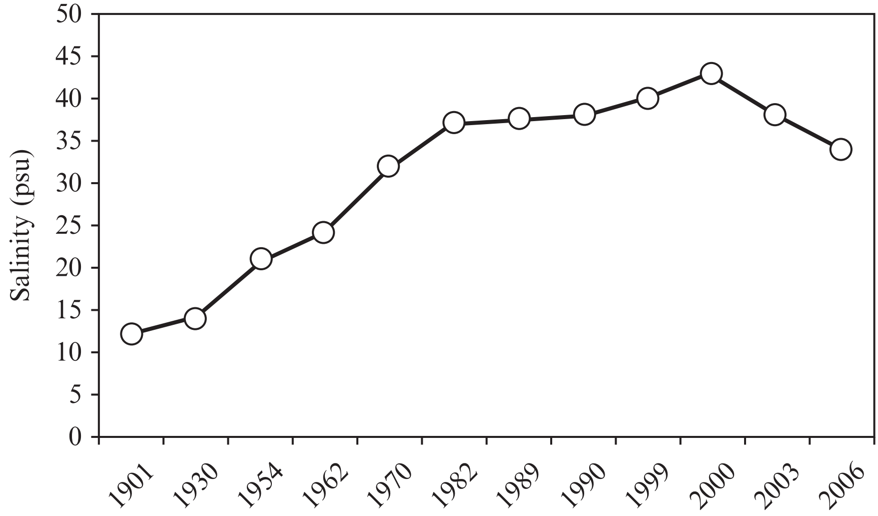

Fig. 3 Average salinity fluctuation in Lake Qarun from 1901 to 2006 (original)

2.3.3 Temperature

Surface water temperature is minimum (15°C) in winter (December and January), while a maximum of 33°C occurs in summer (July and August).

2.3.4 pH and Nutrients (Table 2)

pH fluctuated around 8 during 1974–77, slightly increased in 1994–95 and reached 8.8 in 1999–2000. Table 2 shows some of the nutrient chemistry of the lake. There was an increase in Nitrate and Nitrite from 35 and 0.16 $\mu g\ l^{-1}$ in 1953–1955, to 94 and 14 $\mu g\ l^{-1}$ in 2003. Orthophosphate increased from 0.4 $\mu g\ l^{-1}$ in 1953–1955 to 60 $\mu g\ l^{-1}$ in 2003.

2.4 Bacterial Indices of Sewage Pollution

The distribution of coliform Bacteria shows that the eastern region is more polluted than the west. The highest bacterial counts occur in the drains (Sabae, 1993; Sabae & Rabeh, 2000).

2.5 Phytoplankton

Bacillariophyceae, Dinophyceae, Cyanophyceae, Chlorophyceae, Euglenophyceae and Cryptophyceae occur. Phytoplankton seasonality varies between years. In 1989,

Table 2 Physical and chemical Features of Lake Qarun in different periods

Variables		1953–1955	1995	1999–2000	2003
Water temperature	°C	25.15 (16.4–32)	24.9 (17.7–31)	23.26 (14.4–32.6)	22.9 (13.2–31.4)
Secchi-depth	Cm	*	54 (44.3–94)	59.86 (25–110)	55 (35–80)
Salinity	‰	21.94 (17.9–25.4)	38.7 (36.5–42.7)	42.86 (38.38–49.07)	32.4 (29.7–37.2)
Dissolved Oxygen	mg l^{-1}	*	6.89 (4.25–11.1)	7.99 (4.8–12)	7.9 (4–14)
Chemical Oxygen Demand	mg l^{-1}	*	14.9 (6.2–21.1)	28.1 (13–43.2)	20.9 (12.8–24.58)
Biological Oxygen Demand	mg l^{-1}	*	4.7 (1.9–10.43)	6.9 (1.47–11.4)	5.9 (2.7–13.9)
pH		8.12 (7.98–8.25)	8.4 (8–8.71)	8.2 (7.3–8.8)	8.4 (7.7–8.9)
Carbonate	mg l^{-1}	34.89 (22.4–60.5)	89.6 (65.7–118.7)	65.38 (6.6–125.4)	27.8 (5–75)
Bicarbonate	mg l^{-1}	164.36 (142.3–186.8)	191.2 (129.4–284)	330.2 (198.8–391.6)	190.84 (100–268)
Sodium	mg l^{-1}	*	3880	9880 (8130–13700)	9064 (7357–10511)
Potassium	mg l^{-1}	*	440	460 (381–606)	363 (280–486)
Calcium	mg l^{-1}	*	2331 (1619–3669)	595.9 (432–810)	611 (360–882)
Magnesium	mg l^{-1}	*	5505 (4718–5983)	1589 (1211–1982)	1886 (1348–2340)
Nitrite	µg l^{-1}	0.16 (0.04–0.31)	4.46 (2.61–13.2)	8.15 (1.1–43.1)	13.7 (1.2–51.8)
Nitrate	µg l^{-1}	34.84 (36.83–55.92)	61.2 (27.4–222.7)	66.1 (20.2–664.5)	93.9 (59–776)
Ammonia	mg l^{-1}	*	0 .05 (0.02–0.25)	0.36 (0.08–1.1)	0.15 (0.03–0.68)
Total nitrogen	mg l^{-1}	*	7.5 (2.38–14.28)	*	*
Orthophosphate	µg l^{-1}	0.38 (0–0.8)	25.6 (12.3–63.6)	55.23 (37.8–83.5)	59.5 (21–152)
Total phosphorus	µg l^{-1}	*	120 (84.1–25)	181.9 (122.4–291.5)	367.7 (175–775)
Silica	mg l^{-1}	*	6.7 (3.35–10.7)		6.16 (1.3–11.8)

* Not available.

1953–1955 after Nagiub (1958); 1995 after Anonymous (1997); 1999–2000 after Ali (2002); 2003 after Sabae and Ali (2004).

algae peaked in summer (1,100 × 10^3 cells l^{-1}), dropping to a minimum in spring (200 × 10^3 cells l^{-1}) (Abdel-Moniem, 1991). During 1993–1996, peaks were in spring (1994 and 1996) and in summer (1993–1995) (Anonymous, 1997). Diatoms were dominant, followed by dinoflagellates and blue–green algae. A major peak in August 2001 was attributed to the genus *Cyclotella* (Fathy & Flower, 2005). The species in Lake Qarun are partly freshwater and partly of saline and brackish-water. Although the lake is now strongly saline, many species are still of fresh-water (e.g. blue-greens, *Scenedesmus, Ankistrodesmus*). Some enter the lake with drainage water (e.g. *Aulacoseira granulata*) (Abdel-Moniem, 2001), some indicate brackish conditions (e.g. *Cyclotella caspia*), and some are marine (El-Wakeel & Dowidar, 1969), introduced with mullet fry. The diversity dropped from 119 and 101 species in 1989 and 1996 (Abdel-Moniem, 1991; Anonymous, 1997) to 50 and 49 species in 1999 and 2001 (Fathy & Flower, 2005; Abdel-Moniem, 2001b).

Abdel-Moniem (2001a) measured ^{14}C uptake in relation with physical and chemical variates. Primary productivity was highest during the hot period and the eastern part of the lake was more productive than the western one.

2.6 Zooplankton (Table 3)

In 1931, Wimpenney & Titterington (1936) recorded a brackish-water assemblage, dominated by *Arctodiaptomus salinus* (Copepoda) and *Moina salina* (Cladocera). The later increase in salinity eradicated these species. Grigis (1959) and Naguib (1961) noticed their demise, the marine neritic copepod *Paracartia latisetosa* replacing them. El-Maghraby and Dowidar (1969), Khalil (1978), Abdel Malek and Ishak (1980) and Ahmed (1994) observed how after 1928 the lake gradually became monopolized by marine zooplankters, imported with marine fish fry. The standing crop reached an annual average of 30,000 ind m^{-3} in 1974–1977 with Copepoda dominant, followed by meroplankton larvae and by Rotifera. It increased to 1,600 × 10^4 ind m^{-3} in 1989, mainly due to Protozoa but Rotifera and Copepoda also increased, to 247,000 and 109,000 ind m^{-3}. Winter was the peak period; lowest density occurred in summer (1989). The standing crop of total zooplankton decreased in 1994–1995 (average 356,000 ind m^{-3}) with Rotifera now contributing more than 70% to the total and summer the most productive season. Seven species were identified, but the saline-water *Brachionus* cf. *rotundiformis* monopolized the community (more than 90% of the total, up to half a million individuals per cubic meter). *Synchaeta* spp. were second in rank, with 6–8% of the stock (El-Shabrawy, 2001a). *Paracartia latisetosa* was the only calanoid and the dominant species of the mesozooplankton. Other copepods were *Canuella* sp. (a harpacticoid), and *Apocyclops panamensis* (a cyclopoid). Copepod nauplii were the most abundant items, contributing up to 80% of total Copepoda (El-Shabrawy & Belmonte, 2004).

In spite of the rising salinity, zooplankton species richness increased from 20 species in 1974–1977 to ca 30 in 1999–2000 and 2003 (Table 3). El-Shabrawy & Taha (1999) found that zooplankton grazing regulated phytoplankton biomass in

Table 3 List of Zooplankton species recorded from Lake Qarun

Species	1974/1977	1989	1994/1995	1999/2000	2003
Protista					
Xystonellopsis sp.	–	–	–	*	–
Tintinnopsis strigosa Meunier	*	*	*	*	*
Tintinnopsis amphora Kofoid & Camp.	*	*	*	*	–
Tintinnopsis campanula Ehr.	*	*	–	–	–
Tintinnopsis cylindrica (Daday)	*	*	*	–	–
Tintinnopsis lobiancoi (Daday)	*	*	–	–	–
Favella azorica Cleve	–	*	*	*	*
Favella ehrenbergi Clap & Lach.	*	*	*	*	*
Favella helgolandica (Brandt)	–	*	*	*	–
Favella panamensis Kof. & Camp.	–	–	*	*	*
Favella infundibulum Kof. & Camp.	–	*	*	–	–
Helicostamella subulata Ehr.	–	*	*	*	*
Leprotintinnicus botincus Nord.	–	*	*	*	*
Globigerina inflata d'Orbigny	*	*	*	*	*
Textularia sp.	*	*	*	*	*
Unidentified ciliophore	–	*	*	*	*
Euplotes vannus Müller	–	–	–	*	*
Rotifera					
Brachionus plicatilis Müller	*	*	–	–	–
Brachionus cf. *rotundiformis* Tschugunoff	–	–	*	*	–
Synchaeta sp.	*	*	*	*	*
Synchaeta cf *kitina*	–	*	*	*	*
Colurella adriatica Hauer	–	*	*	*	*
Notholca salina Focke	–	*	*	*	*
Lecane closterocerca (Schmarda)	*	*	*	*	*
Lecane bulla Gosse	–	*	*	*	*
Keratella tropica Apstein	*	*	*	–	*
Copepoda					
Nauplius larvae	*	*	*	*	*
Calanoid copepodids	*	*	*	*	*
Cyclopoid copepodids	*	*	*	*	*
Paracartia latisetosa Kiritchag.	*	*	*	*	*
Apocyclops panamensis (Marsh)	–		*	*	*
Mesochra heldti Monard	*	*	–	–	*
Canuella sp.		–	*	*	–
Meroplankton					
Cirriped larvae	*	*	*	*	*
Polychaete larvae	*	*	*	*	*
Mollusc larvae	*	*	*	*	*

1974–1977 after Abdel Malek and Ishak (1980); 1989 after Ahmed (1994); 1994–1995 and 1999–2000 after El-Shabrawy (2001a) and 2003 after Mageed (2005).

summer, when *Brachionus* cf *rotundiformis* was predominant, but not in winter and spring, when nauplii (Copepoda) and *Tintinnopsis* spp. (Protozoa) were abundant.

2.7 Benthos (Table 4)

The benthos transforms organic sediment to biomass and contributes to the nutrition of fish. According to Naguib (1961), three molluscan species (*Cardium* sp., *Mactra* sp. and *Pirenella* sp.) originally dominated the bottom fauna, but later, Fishar (1993) found Crustacea had become the dominant group. Specific macrobenthic species were studied by Khalil, 1978; El-Gaid, 1980; Hussien and Salem, 1981; Holdish and Tolba, 1983 and Tolba and Hijji, 1994. Regarding long-term changes in macrobenthos community structure, Abdel Malek & Ishak (1980) recorded 12 macrobenthic species in 1974–1975. Mollusca were the major component (93%) of biomass, *Cerastoderma glaucum* alone contributing ca 70%. Around 1989, a collapse occurred, with depletion in standing crop and biomass, from 425 g dry wt m^{-2} to 80 g fresh wt m^{-2}. The sea anemone *Apitasiogeton pellucidus* first appeared, at a density of 95 ind m^{-2} and Arthropoda and Annelida were represented by 6 and 2 species, respectively. The benthos had a density of 13,400 ind m^{-2}, weighed 104 g fresh wt m^{-2} in 1994–1995 but sharply decreased to 7,300 m^{-2}, weighing 84 g fresh wt m^{-2} in 1999–2000 (Table 4). *Polydora hoplura*, *Ficopomatus enigmaticus* (Polychaeta), and *Bulla ampulla* (Mollusca) were newly recorded. The macrobenthos continued to show a decrease in standing crop (6,000 ind m^{-2}), and only 40 g fresh wt m^{-2} in 2006 (El-Shabrawy & Kalifa 2007).

2.8 Status of the Fishery

Since the lake was originally of freshwater, its fisheries were Nilotic. In the first decades of twentieth century it was famous for the large quantities of *Lates niloticus* and *Oreochromis niloticus* produced (Faouzi, 1936). The salinity increase that followed gradually eliminated all species except *Tilapia* and *Anguilla*. Faouzi (1938) mentioned that *Tilapia zillii* was the only species that had not suffered, while El-Zarka (1961) stated that *Tilapia nilotica* could still be found in small numbers in the 1950s.

Because of this disappearance of its original fish fauna, the commercial catch dropped from 4,000 t in 1920 to 1–2,000 t in subsequent years, affecting the livelihood of the fishing community around the lake. Accordingly, the necessity arose to stock the lake with species tolerant of high salinity. Fish and crustaceans of marine origin i.e. Mullet (*Mugil cephalus*, *Liza ramada, L. saliens, L. aurata*), *Atherina mochon*, *Anguilla vulgaris*, *Solea aegyptiaca* and prawn were chosen. Some of the introduced species such as *L. saliens*, *S. aegyptiaca* and prawn succeeded in spawning, but others (*M. cephalus, L. ramada* and *L. aurata*) were unable to do so

Table 4 Macrobenthos abundance (ind m^{-2}) and biomass (g fresh wt m^{-2}) in Birket Qarun

	1974–1977		1989		1993		1994		1995		1999–2000		2006	
Years	**no#**	**wt**	**no**	**wt**	**no**	**wt**	**no**	**wt**	**no**	**wt**	**no**	**wt**	**no**	**wt**
Coelenterata														
Apitasiogeton pellucidus Holl.			93	1.02	356	2.22	388	2.44	229	1.68	159	1.6	100	1.23
Obelia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal			**93**	**1.02**	**356**	**2.22**	**388**	**2.44**	**229**	**1.68**	**159**	**1.6**	**100**	**1.23**
Arthropoda														
Corophium sp.		0	952	1.43	982	0.86	956	0.75	944	0.67	279	0.07	182	0.29
Cyprideis torosa Jones		19.65	0	0	67	0.03	13,200	1.67	9,087	1.19	6,192	0.82	5,382	0.63
Balanus pallidus Darwin		0	213	24.2	120	24.02	206	31.97	208	44.11	17	6.62	34	3.15
Brachynotus sexdentatus Risso		0	1	2.65	2	0.61	2	2.1	7	2.01	21	14.44	2	0.53
Sphaeroma pulchellum (Colosi)		0	*	*	0	0	0	0	0	0	0	0	0	0
Sphaeroma serratum Fabricius		0	3	0.03	27	0.19	6	0.32	12	0.16	3	0.32	12	0.46
Orchestia platensis Kroyer		*	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus aequicauda Mart.		2.82	2	0.02	5	0.02	3	0.01	5	0.02	2	0.05	5	0.03
Chironomid larvae			0	0	9	0.19	0	0	1	0	4	0.02	13	0.14
Subtotal		**22.47**	**1171**	**28.33**	**1,212**	**25.92**	**14,373**	**36.82**	**10,264**	**48.16**	**6,518**	**22.34**	**5,629**	**5.2**
Annelida														
Nereis succinea (Frey & Leuck.)		4.25	202	8.69	216	11.98	185	8.22	121	4.07	37	4.03	88	1.62
Polydora ligni Webster		0	114	0.63	165	0.18	181	0.26	339	0.44	0	0	0	0
Polydora hoplura Clapar.		0	0	0	0	0	0	0	0	0	237	0.59	108	0.13
Ficopomatus enigmaticus Fauv.		0	0	0	0	0	0	0	0	0	136	2.65	61	0.99
Tubificidae		0	0	0	0	0	53	0.03	110	0.19	76	0.5	38	0.03
Subtotal		**4.25**	**316**	**9.32**	**381**	**12.16**	**419**	**8.51**	**570**	**4.7**	**486**	**7.77**	**296**	**2.76**
Mollusca														
Cerastoderma glaucum Poiret		288.5	41	24.86	42	34.22	36	15.96	62	47.07	31	26.24	77	16.95
Venerupsis aurea Gmelin		33	49	14.96	6	1.37	12	7.28	51	31.22	29	23.13	53	11.6
Pirenilla conica Blainville		43.25	3	0.09	1	0.11	3	0.5	12	2.45	8	1.19	7	0.42

Nassarius sp		0	3	2.44	1	0.68	0	0	0	0	0	0	5	0.39
Semisalsa sp		21.63	0	0	0	0	298	1.07	112	0.34	49	0.24	15	0.05
Bula ampula Linnaeus		0	0	0	0	0	0	0	0	0	2	1.35	18	2.24
Melanoides tuberculata Müller		*	0	0	0	0	0	0	0	0	0	0	0	0
Physa acuta Draparnaud		*	0	0	0	0	0	0	0	0	0	0	0	0
Cleopatra bulimoides Olivier		*	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal		**386.38**	**96**	**42.35**	**50**	**36.38**	**349**	**24.81**	**237**	**81.08**	**119**	**52.15**	**175**	**31.64**
Total	**1989**	**413.1**	**1,676**	**81.02**	**1,999**	**76.68**	**15,529**	**72.58**	**11300**	**135.62**	**7,282**	**83.86**	**6,199**	**40.83**

#: recorded as total only. *: recorded qualitatively. 1974–1977, after (Abdel Malek & Ishak, 1980); 1993, after (Fishar, 1993); 1993 after (Anonymous, 1997); 1994–1995–1999–2000 (El-Shabrawy, 2001b) and 2006 (El-Shabrawy unpublished).

and have been continuously transplanted since 1928. About two million fry were annually released during 1928–1964 (El-Zarka & Kamel, 1965). These numbers reached 55 million between 1971 and 1978 and more than 100 million fry in recent years (Anonymous, 1997). Mullet first appeared in the commercial catch in 1929 and 1930; after 1934, they started to play a major part in the fisheries. During 1961/1962, when mullet landings were first compiled separately for the different species, it was found that *M. saliens* constituted about 13% of total production, and *M. capito* and *M. cephalus* 5% (El-Zarka, 1963b). To date, the issue of mullet spawning in the lake has remained disputed.

Soles were first introduced in 1938, and again in 1943, 1945 and 1948. A total of 1,603 specimens ranging in length from 7 to 10 cm, collected from the Maadia district of the Mediterranean Sea, were released to the lake. The first record of soles, 38 kg, in the commercial catch was in 1938. In 1943, sole catch rose to 1.5 t and soles successfully spawned in the lake (El-Zarka, 1963a). During subsequent years, the increase of the annual catch was partly due to in-lake production but also to improved skills of fishermen in catching them. From 1961 to 1966, sole fisheries constituted about 33% of total yield (El-Zarka, 1968). During the 1970s, and until 1978, their production ranked at the top, contributing half of lake fisheries (Bishai & Kirollus, 1989).

From 1977 to 1979, about two million sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) fry, and about three million shrimp seed were released to the lake. Shrimp taxa included *Panaeus japonicus*, *P. semisulcatus*, *P. latisulcatus*, *Metapenaeus stebbingi* and *Metapenaeopsis philipii*. In subsequent years, they successfully acclimated to the lake. In 1987/1988, shrimp production reached ca 500 t, 45% of total lake yield. Unfortunately, shrimp fishing had a destructive effect on fish stocks because shrimp nets catch also fish fry and fingerlings.

Fishing in Lake Qarun involves 550 wooden boats and about 4,000 fishermen. Fish is landed in 11 sites along the southern coast. Fishing is closed in June and July each year, as a regulatory measure to maintain tilapias. The main fishing gear used is trammel gill nets. Their height and construction depends upon the target species. Beach seines are used for catching shrimp. The net is 5.4 m in depth and about 25 m long. Traps and hooks are used for catching *Tilapia zillii*.

2.9 Fish Landings

Total annual fish catch is shown in Fig. 4. There was a drop from ca 2,000 t in 1970–1972 to 600 t in 1993–1998. Sole contributed half of the total during 1970–1973, with annual yield ca 1,000 t. This decreased to a minimum of 11.4 t in 1989/1990. The contribution of tilapias evolved from 20% in 1970–1973 to a maximum of 73% in 1980–1981. Their annual catch represented ca 50% of the total in 1994–1998, with yield around 300 t. Mullet dropped from 580 t in 1970–1972 to 157 t in 1997–1998. The maximal catch of prawn was in 1982–1983 and 1988–1989 with 334 and 326 t, respectively. In recent years, only 3 and 23 t were caught

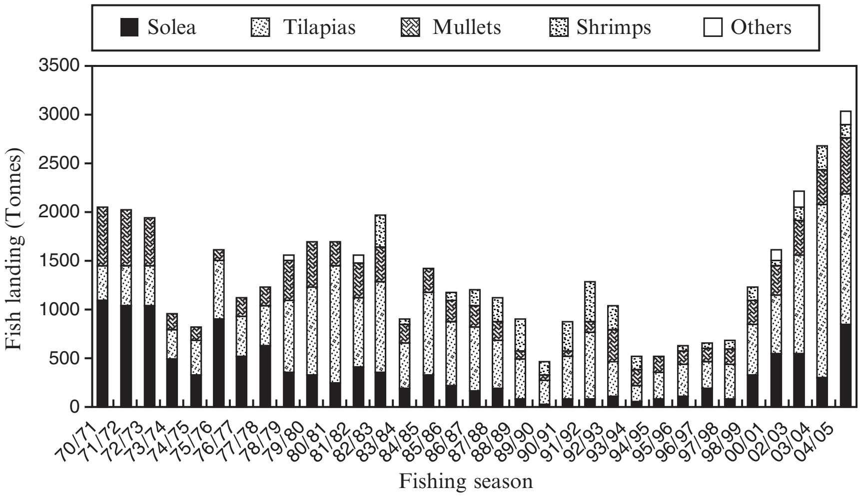

Fig. 4 Evolution of fish landings and percentage composition of the commercial catches in Lake Qarun (original)

during 1994/1995 and 1996/1997, respectively. To compensate this severe drop in lake fisheries, marine fish should be introduced that exploit benthic fauna such as *Balanus*, sea anemones, crabs and mollusks. In the long run, as salinity reaches 60‰, *Artemia salina* will take over, and its cysts may become harvestable.

Fishing in Lake Qarun contributes only 1% to inland fisheries of Egypt, but it is the most important source of fish (65%) in Fayum province. Besides, its luxury fishes (mullet, sea bream and sea bass) are sought-after dishes in the surrounding resorts. Thus, the community around the lake is depending strongly on its fisheries.

3 Wadi El Rayan

Wadi El Rayan (703 km^2, 28° 15′–29° 17′ N) is an uninhabited depression in Egypt's Western Desert, situated southwest of Cairo, at 60 m below sea level. Unlike most desert regions, it has a high biological diversity. The major habitat-types in the depression are sabkhas, sand flats, sand dunes, wetlands (man-made lakes), springs (three natural El Rayan springs, located below Minqar El Rayan at a site known as Oyun El Rayan or spring area, with water believed to flow from Nubian sandstone strata) (Serag et al., 2003).

3.1 Wadi El Rayan Lakes

Wadi El Rayan holds two lakes, connected by a channel (Fig. 1). The upper lake has an area of 50.9 km^2 and the lower of 62.0 km^2. They lie between 30° 20′–30°

25′ E and 29° 05′–29° 20′ N. The connecting area holds permanent shallow water with emergent aquatic macrophytes, forming a swamp. The upper lake is surrounded by dense vegetation and has a maximum depth of 25 m (Saleh, 1984). The lower lake is changing all the time, newly flooded areas continuously being added in the southwest. Its maximum depth is 33 m. The Wadi El Rayan lakes receive water through the El-Wadi Drain, with discharges 11 × 10^6 m^3 in January and 24 ×10^6 m^3 in November, totaling 220 ×10^6 m^3 y^{-1} (Abd Ellah, 1999). Inflow to the second lake varies from 3.6 × 10^6 m^3 in July to 17 × 10^6 m^3 in March, with a total of 127 × 10^6 m^3 y^{-1}. The lakes vary in physical and chemical characters. The upper one is less saline (1.4–1.5 g l^{-1}) than the second (4.5–6.1 g l^{-1}) and its salinity increases from north to south. Nutrients are higher in the upper than in the lower lake (Aboul-ela & Khalil, 1988; Saleh et al., 1988; Anonymous, 1998; Konsowa & Abd Ellah, 2002a, b). The formation and evolution of the lakes since 1973 is illustrated in Fig. 5.

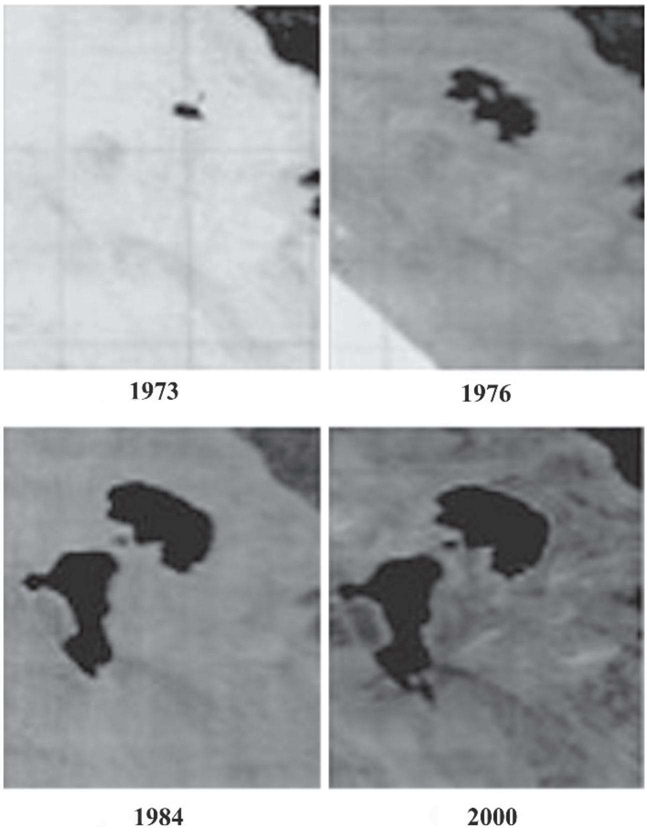

Fig. 5 Progressive formation of Wadi El Rayan lakes (from IUCN, 2001, with permission of Biodiversity Unit, EEAA, Egypt)

3.2 Climate

The climate of Wadi El Rayan is typically Saharan, hot and dry with scanty winter rain and abundant sunshine throughout the year (Smith, 1984).

Absolute maximum and minimum air temperatures, 48.5°C and 1.2°C, were recorded in June and January, respectively. The mean amplitude of diurnal fluctuations is 14.2°C in winter and 17°C in summer. Mean water temperature is minimum (16.5°C) in winter and maximum (31.1°C) in summer.

The minimum evaporation rate (3.18 cm $month^{-1}$) was measured in autumn, the maximum (25.67 cm $month^{-1}$) in summer (Maiyza et al., 1999). Overall, the aridity index (P/E + P), where P is annual rainfall (Precipitation) and E is annual evaporation, lies between 0.03 and 0.02 mm, characteristic of a hyper-arid region.

The incident light showed a visible maximum during spring (649 W m^{-2}) began to decrease gradually until reached a minimum value of 241 watt m^{-2} at the end of autumn.

Light winds blow most of the year from the North (north-west to north-east). Wind speed maxima and minima of 5.3 and 2.5 m s^{-1} occur in summer and winter.

Relative humidity is directly proportional with air pressure and inversely proportional with wind speed at Wadi El Rayan. It varies from 37% and 58% in June and November.

3.3 Water Budget of the Lakes

Between the beginning of the water storage project and the present, there have been no systematic measurements of the fluctuation of the water level in the lakes or of their volume and surface area. Therefore the assumption of a constancy of the water volumes (570×10^6 m^3 for the upper lake; 615×10^6 m^3 for the lower lake: Abd Ellah, 1999) is not based on actual values. Recently, millions of cubic meters of waters were forced from the southern basin of the upper lake to reclaim huge areas southwest of the lower lake. This land reclamation resulted in a reduction in volume and surface area, especially of the lower lake. The total inflow of El-Wadi drain to the upper lake is 220×10^6 m^3 y^{-1}, while annual discharge to the second lake is 127×10^6 m^3 y^{-1}. The net water budget for the upper lake used to have a positive value of 13×10^6 m^3 y^{-1}, for the lower lake 39×10^6 m^3 y^{-1}. These values recently became negative.

3.4 Salinity

The salinity of the upper lake (less than 2 psu) increases southward, due to the diluting effect of drainage water in the north (Abd Ellah, 1999). The continuous inflow of brackish water (gain of salt) from El-Wadi Drain and outflow through the connecting channel (loss of salt) keeps salinity constant or at least slows down salinisation (Table 5). Salinity is obviously higher in the lower than in the upper

Table 5 Physical and chemical characteristics of Wadi el-Rayan lakes at different times

	1989		1996		2001		2003
	Upper lake	Lower lake	Upper lake	Lower lake	Upper lake	Lower lake	Upper lake
Water temperature °C	14.9: 31.5	13: 30.5	12.4: 29.1	12.7: 28.7	14: 31	13.4: 31.6	14.6: 31.4
Secchi-depth cm	80: 220	130: 210	150: 190	230: 400	40: 220	200: 500	80: 200
Salinity ‰	0.7: 2.9	2.1: 3.1	08: 02.8	3.7: 5.1	1.1: 1.6	3.4: 6.2	1.1: 1.7
Dissolved Oxygen mg l^{-1}	7.46: 10.3	7.2: 9.13	9.1: 12.4	8.3: 11.1	*	*	7.7: 14.2
Chemical Oxygen Demand mg l^{-1}	1.5: 7.7	1.6: 5.5	*	*	*	*	12.3: 17.6
Biological Oxygen Demand mg l^{-1}	*	*	*	*	*	*	1.6: 5.8
pH	7.4: 9.8	8.2: 9.3	8.1: 8.5	8.2: 8.4	*	*	7.9: 8.9
Carbonate mg l^{-1}	20: 50.3	26.4: 35.5	37.3: 47.8	43.8: 60.5	15: 47	29.7: 52.9	7.6: 12.1
Bicarbonate mg l^{-1}	110: 208	127: 150	159: 176	163: 174	176: 240	145: 169	168: 240
Sodium mg l^{-1}	*	*	*	*	225: 417	1314: 1641	122: 386
Potassium mg l^{-1}	*	*	*	*	*	*	2.9: 15
Calcium mg l^{-1}	*	*	*	*	*	*	40: 68
Magnesium mg l^{-1}	*	*	*	*	*	*	51: 117
Nitrite µg l^{-1}	0.0: 101	0.0: 31	1.1: 11.7	0.6: 1.2	14: 48	2.8:26	3.7: 80
Nitrate µg l^{-1}	24: 418	29: 268	26.7: 124.9	30.1: 42.9	138: 420	193: 386	28.3: 750
Ammonia µg l^{-1}	53: 1378	50: 78	35.3: 140	34.5: 94.9	32: 219	21.7: 112.3	117: 645
Orthophosphate µg l^{-1}	16.2: 130	4.1: 87.2	1.8: 30.6	5.2: 18.6	4.2: 35.3	8.4: 30.6	22.1: 200
Total phosphorus µg l^{-1}	*	*	*	*	*	*	126: 440
Silica mg l^{-1}	8.4: 29.6	7.9: 21.8	*	*	*	*	1.4: 10.5

*Not available.

1989: after Konsowa (1991); 1996: after Taha and Abdel-Moniem (1999); 2001 after Konsowa and Abd Ellah (2003a, b) and 2003 after Soliman (2006).

lake. Since they are closed basins, salinity undergoes an increase in space and time toward the south, reaching more than 10 psu in the lower lake in 2006. The rate of increase reflects discharge from the upper lake, and evaporation. Because discharge has decreased during recent years, the rise of salinity has become faster.

3.5 Transparency

Transparency is always lower in the upper than the lower lake. The vegetation in the connecting channel reduces the suspended material and consequently increases transparency in the lower lake.

3.6 Chemistry

Bicarbonate exceeds carbonate (Table 6), and Sodium is higher than Potassium but all gradually increase southwards in both lakes. The lakes can be classified as hard water (total alkalinity > 250 mg l^{-1}) and is highly productive (Konsowa & Abd Ellah, 2002a). Nutrient concentrations are considerably higher in the upper than in the lower lake.

The springs are below detectable limits for heavy metals and arsenic (Table 6) but are higher in Calcium and Magnesium than the lakes. Nickel, Arsenic, Zinc, Chromium, Barium, Manganese, and Iron were detected in all samples from the lakes; Selenium, Cadmium, and Molybdenum only in few. Generally, concentrations increased from the drain to the southern part of the upper lake and in the lower lake. Relatively high concentrations of chloride and bromide occur in spring water. They also increase from the upper to the lower lake, due to evaporative concentration. The amounts of phosphate and nitrate, 1.3 and 6.9 mg l^{-1}, are surprisingly low, compared to a maximum of 987 mg l^{-1} for sulphate (Saleh et al., 2000).

3.7 Phytoplankton

Konsowa (1996) found 96 taxa of phytoplankton. Cyanobacteria, represented by 21 species, were dominant. They showed a gradual decrease in density southwards in the lower lake. Konsowa and Abd Ellah (2003a) mentioned four classes, Cyanobacteria (16 species), Chlorophyceae (25 species), Bacillariophyceae (21 species) and Dinophyceae (3 species) in the upper lake. Cyanobacteria abound (70%), with the colonial *Microcystis aeruginosa* and *Microcystis flos-aquae* or the filamentous *Planktolyngbya limnetica* dominant. The colonial form blooms in mid-winter (January); the filamentous type in August. *Oocystis parva*, *Scenedesmus quadricauda* are the abundant Chlorophyceae, while *Cyclotella glomerata*, *Cyclotella*

Table 6 Concentration of Elements and Inorganic Anions in Wadi el-Rayan Lakes and Springs

Location		El-Wadi Drain	Upper Lake	Lower Lake	First spring	Second spring	Third spring
Cobalt	mg l^{-1}	1.24 ± 0.02	1.27 ± 0.03	1.25 ± 0.02	nd	nd	nd
Lead	µg l^{-1}	12 ± 0.05	6.2 ± 0.01	4.2 ± 0.02	nd	nd	nd
Sulfur	mg l^{-1}	75.0 ± 3	143 ± 9	412 ± 29	183 ± 6	163 ± 4	126 ± 2
Chromium	µg l^{-1}	122 ± 1	123 ± 1	90 ± 3	nd	nd	nd
Selenium	µg l^{-1}	62 ± 1	80 ± 2	72 ± 3	nd	nd	nd
Cadmium	µg l^{-1}	nd	nd	61 ± 2	nd	nd	nd
Arsenic	µg l^{-1}	144 ± 6	164 ± 4	23 ± 1	nd	nd	nd
Molybdenum	µg l^{-1}	nd	nd	12 ± 0.2	nd	nd	nd
Sodium	mg l^{-1}	210 ± 3.5	420 ± 8.9	1410 ± 89	1060 ± 29	1240 ± 88	920 ± 23
Potassium	mg l^{-1}	1.3 ± 0.1	9.9 ± 0.1	48.9 ± 5.3	21.7 ± 3.2	29.2 ± 3.8	19.1 ± 1.3
Calcium	mg l^{-1}	53.8 ± 1.5	46.9 ± 0.9	96.2 ± 3.1	136 ± 8.2	158 ± 9.2	119 ± 2.3
Zinc	mg l^{-1}	6.9 ± 0.2	12.6 ± 0.4	29.2 ± 1.3	26.5 ± 1.1	27.2 ± 0.8	21.5 ± 0.6
Barium	µg l^{-1}	nd	nd	122 ± 0.05	22 ± 0.02	41 ± 0.03	54 ± 0.02
Magnesium	mg l^{-1}	99.0 ± 2.2	56.4 ± 2.3	153 ± 12	139 ± 19	124 ± 22	103 ± 16
Iron	mg l^{-1}	1.29 ± 0.1	1.34 ± 0.1	1.31 ± 0.4	1.24 ± 0.3	1.31 ± 0.2	1.30 ± 0.1
Nickel	mg l^{-1}	1.15 ± 0.10	0.41 ± 0.06	0.48 ± 0.5	nd	nd	nd
Chloride	mg l^{-1}	144 ± 3.9	362 ± 5.3	1730 ± 25	1860 ± 41	2120 ± 77	1400 ± 18
Bromide	mg l^{-1}	nd	nd	12.9 ± 2.8	140 ± 27	23.2 ± 6.7	20.5 ± 5.2
Nitrite	mg l^{-1}	6.74 ± 0.94	2.62 ± 0.18	0.82 ± 0.08	0.79 ± 0.07	6.92 ± 1.2	nd
Phosphate	mg l^{-1}	nd	nd	nd	0.65 ± 0.04	1.33 ± 0.08	nd
Sulfate	mg l^{-1}	162 ± 4.9	334 ± 1.1	970 ± 10	425 ± 12	428 ± 15	303 ± 2.5

After Saleh et al. (2000); Konsowa (1991); nd = no data.

meneghiniana and *Nitzschia amphibiana* are the leading diatoms. According to Konsowa and Abd Ellah (2003b) phytoplankton standing crop in the lower lake (avr. $1{,}450 \times 10^4$ l^{-1}) is much lower than in the upper lake (ca $8{,}580 \times 10^4$ l^{-1}). Cyanophyceae, mainly represented by *Planktolyngbya limnetica*, *Merismopedia tenuissima* and *Gomphosphaeria aponiana* are prevalent (70%), abundant during late spring (May), but disappearing in November. The green algae rank second (26%), dominated by *Planktonema spp., Crucigenia quadrata* and *Oocystis parva* in January-March. Bacillariophyceae constituted 9%, with *Melosira granulata, Nitzchia* spp. and *Cyclotella glomerata* the leader species.

3.8 Primary Productivity

The upper lake is more productive than the lower (588 vs. 391 mg C^{-2} h^{-1}). In the upper lake, a positive relation between temperature and primary productivity (r = .89) has been attributed to the stimulatory effect of temperature on photosynthesis. In the lower lake, a positive relation has been observed between primary productivity and PO_4-P concentration such that nutrient availability seems more important than temperature (Taha & Abdel-Moniem, 1999).

3.9 Zooplankton

A total of 46 zooplankton species have been reported from the upper lake. Autumn is their season of highest abundance, spring of the poorest. Rotifera dominate (60% of total density), mainly with the genera *Keratella* and *Trichocerca*. Six species of Copepoda reach a maximum in autumn. *Thermocyclops neglectus*, *Thermodiaptomus galebi* and *Megacyclops viridis* abound. Among 11 species of Cladocera, *Diaphanosoma mongolianum*, *Bosmina longirostris* and *Daphnia longispina* are common; the others are sporadic (El-Shabrawy, 1993). El-Shabrawy (1996) listed 30 zooplankton species in the lower lake; Rotifera were abundant (65% of total zooplankton). *Hexarthra* and *Brachionus* appear in high density in spring and summer, gradually increasing southward. Copepoda contribute about 25%, but gradually decrease in density southward. *Thermodiaptomus galebi* is abundant; while *Mesocyclops ogunnus*, *Nitokra lacustris* and *Onychocamptus mohamed* are sporadic. *Diaphanosoma mongolianum* monopolizes the cladoceran fraction in spring. Rotifers respond more quickly to environmental changes than crustaceans and are sensitive indicators of changes in water quality (Pejler, 1983). In Wadi EI-Rayan area, temperature, turbidity, water flow and salinity control the rotifer community. Carlin (1943) showed a correlation between the occurrence of various rotifer species and temperature. In Wadi EI-Rayan some species indeed prefer warm water, others do not (El-Shabrawy, 1999). For example, *Brachionus plicatilis* is rare during winter but peaks in summer in the lower lake; *Hexarthra* *oxyuris* blooms in the lower and upper lakes in summer; *Keratella quadrata* and *Brachionus calyciflorus*, finally, become abundant during winter. Chlorosity boosts the abundance of some species and the decline of others. *Brachionus quadridentatus*, *Lecane leontina* and *Keratella cochlearis* were recorded in EI-Wadi drain, at low chlorosity. *Brachionus* cf *plicatilis* and *Hexarthra oxyuris,* in contrast, abound in the tail of the second lake, where chlorosity is high (El-Shabrawy op. cit.). It is worth mentioning that marine species such as *Podon polyphemoides* and polychaete larvae started to appear in the lower lake in 2006, concurrent with a rise in salinity to 12‰.

The average zooplankton in the upper lake is more than four times that of the lower one (106,700 and 22,900 ind m^{-3}, biomass 1,625 and 290 mg m^{-3}). Zooplankton therefore adds 60 and 10 mg C m^{-3} to the organic carbon pool of the upper and lower lakes (Mageed, 2004). The food selectivity of *Oreochromis niloticus, O. aureus* and *Sarotherodon galilaeus* for zooplankton was towards cladocerans. That of *T. zillii* was towards *Keratella quadrata* (SI = + 0.81). The dominant items in the guts of *Mugil cephalus, Liza ramada* and *Lates niloticus* were crustaceans, particularly *Thermodiaptomus galebi* (SI = + 0.73, + 0.89 and + 0.95).

3.10 Macrobenthos

The first survey of Wadi El Rayan macrobenthos was conducted by Khalil (1984). He mentioned 10 species, with *Physa acuta*, *Melanoides tuberculata* and *Gammarus* sp. dominant. Fouda and Saleh (1988) found that the coarse sand bottom of Wadi El Rayan supports a poor fauna in terms of number of species and individuals. Mollusca (six gastropod and two bivalve species) were most abundant. El-Shabrawy (1993) mentioned 14 species, with *Echinogammarus veneris*, *Palaemon elegans*, *Chironomus* larvae, *Melanoides tuberculata*, *Theodoxus niloticus, Semisalsa* sp. and tubificidae abundant. El-Shabrawy (1996) recorded 11 macrobenthic species from the lower lake, while El-Shabrawy (2007) lifted the total to 23 species in three phyla: six species of Arthropoda, eight Annelida and nine Mollusca. The density of macrobenthos was higher in the upper (960 ind m^{-2}, or 26 g fresh wt m^{-2}) than in the lower lake (350 ind m^{-2}, 7 g fresh wt m^{-2}).

3.10.1 Long-Term Changes of the Macrobenthos

The total macrobenthos in the upper lake decreased from 2690 ind m^{-2} in 1989 to 1820 and 960 ind m^{-2} in 1993 and 2006. The lower lake first increased slightly, from 1500 ind m^{-2} in 1989 to 1890 ind m^{-2} in 1993, but a sharp decrease occurred in 2006 (Fig. 6). Arthropoda followed the trend of total macrobenthos. The upper lake annelids dropped from 950 ind m^{-2} in 1989 to 100 ind m^{-2} in 1993; a slight recovery occurred in 2006 (310 ind m^{-2}). Mollusca in the upper and lower lakes

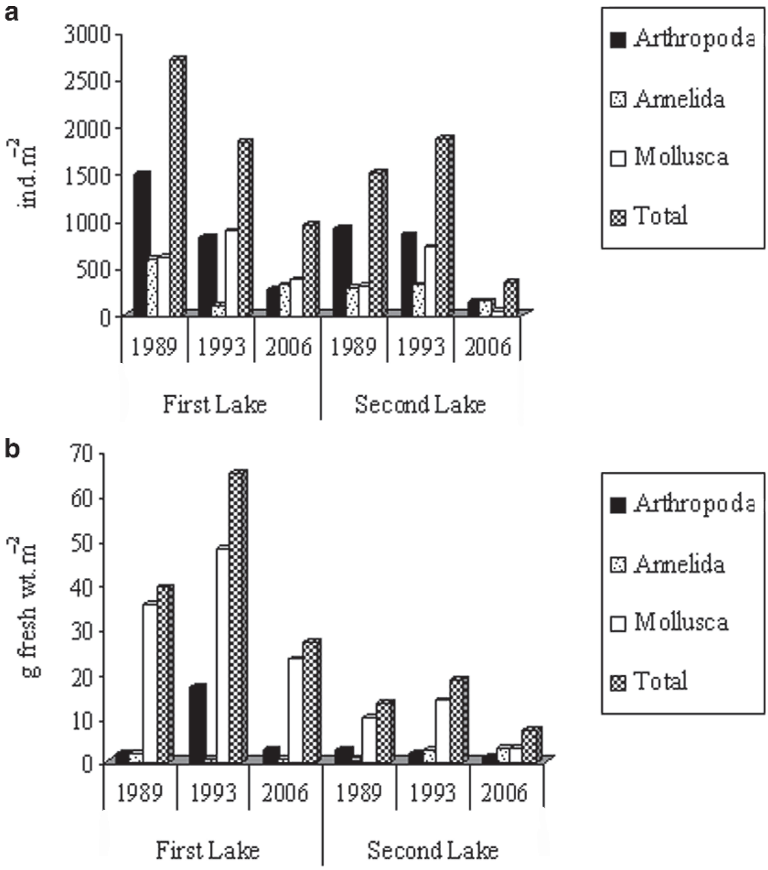

Fig. 6 Changes in macrobenthos community structure in Wadi El Rayan lakes from 1989 to 2006 (original)

increased from 610 and 300 ind m^{-2} in 1989 to 890 and 700 ind m^{-2} in 1993, but collapsed in 2006. Biomass showed a similar trend, except in 1993 when relatively low numbers but with heavy biomass occurred (Fig. 6). Benthic abundance and diversity typically correlate with salinity, dissolved oxygen, depth and sediment type. Seasonal changes are mainly determined by freshwater input (Chainho et al., 2006). An increase in diversity of oceanic species with higher salinity (Lui et al., 2002) and with higher dissolved oxygen have been recorded (Jensen et al., 1985; Dauer et al., 1992; Yap & Nacorda, 1993). In Wadi El Rayan, marine species such as *Hediste diversicolor*, *Nereis succinea* and *Cerastoderma glaucum* populate only the lower lake. The highest standing crop, richness and diversity occur at sites high in oxygen and with plenty of macrophytes (El Shabrawy, in press). Chironomids and *Limnodrilus* spp. are the only macrobenthic species, at deep stations.

3.11 Fisheries in Wadi El Rayan

In the beginning, drainage water carried a freshwater ichthyofauna to the newly formed lake, and some species survived and adapted. They include *Oreochromis niloticus*, *Labeo niloticus*, *Barbus bynni* and *Alestes nurse*. Other species such as *Tilapia zillii*, *Bagrus bayad*, *Bagrus docmak*, *Hydrocyonus forskalii*, *Lates niloticus*, *Schilbe mystus* and *Clarias gariepinus* were present in small numbers (Soliman, 1981). Tilapias, nile perch and *Bagrus spp*. are among the species that became well established. Besides naturally transferred fishes, some euryhaline species (*Mugil cephalus* and *Liza ramada*) were later introduced. Fish fry transplantation started at the beginning of 1978 (Ahmed, 2000).

Fishing activities were first organized in 1980. Between 1976 and 1980, experimental fishing was carried out by fishermen from Lake Qarun. The catch started with 213.5 t in 1976, rising to 295 t in 1979. *Oreochromis niloticus* represented ca 75% of the total (Soliman, 1981). From 1980 to 1982, fishing was managed by a private company. In 1983, the General Authority for Development of Fish Resources (GADFR) took over, with an aim at increasing production. Its policy included fish fry transplantation, limiting fishing season to 7 months, controlling fishing gear, number of boats and fishermen, and establishing a cooperative for each lake.

Fry of *Mugil cephalus* and *Liza ramada* have been introduced to the lake since 1980. The annual number of fry reached 10 millions during 1985. Additionally, 4.5 million of fry of Common carp was introduced in 1984, beside one million of grass carp fry in 1985. Tilapia is represented in the landings by *Oreochromis niloticus*, *Sarotherodon galilaeus*, *Oreochromis aureus* and *Tilapia zillii*. Mullet ranks second to them with about a quarter of the total catch of both lakes combined. *L. ramada* is the most common species now. Nile Perch is worth ca 13% and 5% of the catch of the upper and lower lakes. Carp and Bayad (*Bagrus* spp.) are below 5% (Anonymous, 2003).

The growth of *Oreochromis niloticus* and *Sarotherodon galilaeus* in the upper lake is better than in the lower one; with *Tilapia zillii*, the situation is inverse, while *Oreochromis aureus* and *Liza ramada* grow equally well in both lakes. The exploitation of *Oreochromis niloticus* and *Sarotherodon galilaeus* in the upper lake is higher than in the lower lake. That of *Liza ramada* in the lower lake is higher than in the upper one, and that of *Oreochromis aureus* and *Tilapia zillii* is the same in both lakes. The length at first capture for all species in the upper lake is higher than in the lower lake (Anonymous, op. cit.).

3.11.1 Catch Statistics

Figures 4 and 5 show the annual catch of both lakes by groups of species and the percentage composition of the different groups from 1987/1988 to 2004/2005. Analysis of the catch data shows that the upper lake contributes ca 75%. Catch per unit effort in the upper lake is higher that in the lower lake. The fish stocks in both lakes are overexploited. Application of the Schaefer (1954) model using total catch and fishing effort reveals that the present fishing effort in the upper lake overshoots maximum sustainable yield by 35%. Approximately the same result applies to the lower lake, where fishing effort must be reduced by 26% to achieve sustainable yield.

3.12 Aquaculture

Aquaculture is confined to two large fish farms, covering 10,500 hectares, and 200 fish cages. The first farm of 420 hectares includes 50 concrete ponds (400 m^2 each) and a full complement of feeding ponds, water distribution channels and support infrastructure. Construction work on the second farm started in 1998, and it should enter production soon. In both farms, water is supplied by gravity directly from the waterway between the two lakes, and is returned to it downstream.

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