1. General introduction

Tropical freshwaters contribute 15 percent of the world's reported capture fishery production from only 0.2 percent of the global aquatic surface area. The relative contribution may be even higher, as less than half of the inland capture production is officially reported (Kolding and van Zwieten, 2006). Most of the small-scale fishers in the world work in inland fisheries (BNP, 2009). Reservoirs are an essential component of most irrigation systems worldwide and, together with those built for flood control and power generation, retain large volumes of water. The total global reservoir area is unknown, but in 2000 the World Commission on Dams counted about 48 000 large dams, 46 percent of them in China, 19 percent in the rest of Asia, 3 percent in Africa (60 percent of which are in South Africa and Zimbabwe), and 2 percent in South America. The 60 000 largest reservoirs in the world – those with a volume of 10 million m^3 or more – are estimated to cover a surface area of 400 000 km^2 and together hold 6 500 km^3 of water (Kolding and van Zwieten, 2006). In addition to their roles in power generation and provision of water for agriculture, industry and homes, most of these reservoirs also play an important role in fish production and contribute significantly to the livelihoods of the communities along their shores. There is increasing recognition that the potential of most reservoir fisheries may greatly exceed current use. Considerable opportunities exist for increasing productivity, provided that environmentally and socially acceptable and sustainable management systems can be adopted.

Reservoirs are created by human activity and therefore host semi-natural ecosystems that can be manipulated in various ways. The productivity of reservoir fisheries can be increased by using a number of approaches that combine better harvesting strategies, fertilization, carefully adapted stock enhancement and aquaculture (Petr, 1994, 1998; Kolding and van Zwieten, 2006). An improved understanding of both biological principles and stakeholder participation is necessary to realize this untapped potential. The natural biophysical constraints of reservoirs define their ecological production processes, and their socio-economic settings shape the possibilities for human enhancement of production. By synthesizing these mechanisms into general principles and predictive indicators, it should be possible to provide various options and scenarios for improved productivity that can be adapted to local cultural and institutional settings.

Different reservoirs have different properties and separate institutions conducting research and management. Seen in isolation, these differences mean that the productivity data of each of these reservoirs may be difficult to interpret and difficult to place in a global context. It may be possible to reveal cross-regional information that otherwise would not be seen – such as where one river basin is fundamentally different from others – by examining the various attributes using a standardized approach. From a comparative angle, it may even be possible to understand why reservoirs from the same area may have different productivity levels.

The present review examines three very different river basins and was undertaken as part of the Improved Fisheries Productivity and Management in Tropical Reservoirs project funded by the CGIAR Challenge Program on Water and Food (www.waterandfood.org). The project focuses on reservoirs in the benchmark basins of the Indus and Ganges Rivers in India and the Nile and Volta Rivers in Africa. In the latter two basins, the project worked essentially on Lake Nasser and Lake Volta. The general objective of the project was to explore and test opportunities for increasing the productivity of these reservoirs with a combination of improved understanding of reservoir environment, introducing better harvesting strategies and adopting carefully selected stock enhancement strategies and/or aquaculture approaches.

Three individual desk reviews were initially prepared covering the Indo-Gangetic Basin (IGB) reservoirs (CIFRI, 2006), Lake Nasser (NIOF-LNDA, 2005) and Lake Volta (WRI, 2006). Each review included in-depth inventories of the history, resources and environments and information on: the geographical, physical, hydrological and chemical features of the basin; limnological characteristics; past, present and potential fishery production; and the socio-economic setting. They also identify gaps in information and provide recommendations for future work.

The primary intention of the present document is to synthesize and standardize the information collated in the three desk reviews with the objective of evaluating the information and summarizing it with reference to general literature and up-to-date knowledge on tropical reservoir fisheries in developing countries (Petr, 1978, 1994; Sugunan, 1995; Kolding, Musando and Songore, 2003; Kolding and van Zwieten, 2006). The three case studies represent quite different scenarios of reservoir fisheries in terms of management and fishing operations, and these differences are analysed and discussed to draw conclusions of general value.

Data and information were collected through individual desk reviews on many aspects of the ecosystems. This information has been condensed in this technical paper with the objective of providing a baseline information framework to assist in describing and analysing the ecological changes that took place after the impoundment of the rivers. The ultimate objective is to explain changes in fish productivity from both bottom-up and top-down processes, i.e. in relation to variations in climate, ecological succession and fishing effort. The information generated by the various sections in the background reviews has been integrated into a consistent framework, which may be useful for management purposes and to assist in adaptive learning. The general principle driving this framework is that: (i) data and information need to be made available in a historical context; and (ii) data from different studies and disciplines need to be organized in time series and preferably visualized in graphical form.

All three reviews show that, while biological data and information are generally available, there has not been sufficient emphasis on synthesizing this information and making it meaningful for management purposes. As a result, large amounts of research data and information have been collected from different sources but have rarely been integrated for systemic understanding. Outputs have only been translated into proposed management actions to a limited degree. The three reviews suffered from the general tendency to isolate and compartmentalize research into separate disciplines, with very limited cross-disciplinary flow of information or recognition as to how the results of various disciplines can be combined into a more comprehensive understanding of the behaviour of populations, communities and ecosystems and the productive activities that depend on them. This tendency severely hampered the analysis presented in this review.

A pragmatic and holistic understanding of reservoir ecosystems is needed in order to guide the choice of indicators and the development of monitoring systems that can inform management. This technical paper presents a basic description and analysis of the main processes taking place in different reservoir environments. The next step would be to devise a hierarchy of indicators describing the different processes taking place. Only when these are seen in combination across sectoral disciplines will it be possible to reach a better understanding of the processes that drive fish stocks, fisheries and reservoir productivity.

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2. Reservoirs in the Indo-Gangetic Basin of India

Courtesy: CIFRI.

2.1 INTRODUCTION

Reservoirs abound in the countries of which the Indus and Ganges Basins form part: Afghanistan, Bangladesh, China, India, Nepal and Pakistan. The Indo-Gangetic reservoirs of India, the focus of this review, alone have an area of 1.16 million ha, which is 36.8 percent of the total reservoir area of India (Sugunan, 1995). Fish productivity is generally considered to depend on morphometric, edaphic and climatic factors, with an emphasis on nutrient availability and primary productivity; oligotrophy is seen as something to be corrected. However, this static approach to reservoir productivity neglects the carrying capacity influenced by changes in water level, other aspects of seasonality, and fishing pressure.

In general, the Indian reservoirs in the IGB for which data are available have extremely low yields in comparison with reservoirs elsewhere in the world (Bandu Amarasinghe and Vijverberg, 2002; De Silva, 2001). The low reservoir productivity has largely been blamed on intense fishing pressure and poor management, but may also reflect the failure of riverine fish communities to adapt to impoundment (Fernando and Holcik, 1991). Two possibilities exist to improve productivity: (i) introducing new species that are adapted to lake conditions; or (ii) stocking. Almost all reservoirs in India are managed by stocking to some degree. Variations in stocking patterns, densities, age at first stocking, species stocked, return rates on stocked material and cost-effectiveness should be included as factors to explain apparent low yield. A more comprehensive understanding of the dynamics of reservoir productivity would entail developing a time series of indicators of system drivers (e.g. water levels or eutrophication), the state of stocks (e.g. production characteristics of stocks including enhancement through stocking), and the fishing pressure (e.g. catch and fishing effort statistics) in relation to the stocking regimes in order to evaluate their effectiveness (Jul-Larsen *et al*., 2003; Kolding and van Zwieten, 2006).

There are insufficient data to carry out such a full analysis here, as only limited data and information are available on stocking in India. In the following sections, the data that are available are reviewed and discussed. An important data source is Sugunan (1995). An additional data set comprising often incomplete information on catch, stocking (including species composition) and fishing methods and social information has recently become available on 691 reservoirs in Bihar (18 reservoirs), Haryana (23), Himachal Pradesh (5), Jammu and Kashmir (2), Jharkhand (141), Madhya Pradesh (50), Punjab (13), Rajasthan (398), Uttar Pradesh (33) and West Bengal (8). This data set forms the basis of the discussion in Section 2.5, including quantitative information on stocking practices in relation to production (CIFRI, 2005a).

Before this discussion, Section 2.2 outlines the general physical and demographic geography of the Indian part of the IGB. Section 2.3 then describes the various fish production systems. Physicochemical and productivity constraints are described in Section 2.4.

Following the discussion in Section 2.5, Section 2.6 describes fish and fishery production characteristics. Management and socio-economic arrangements are described in Section 2.7, followed by some recommendations in Section 2.8.

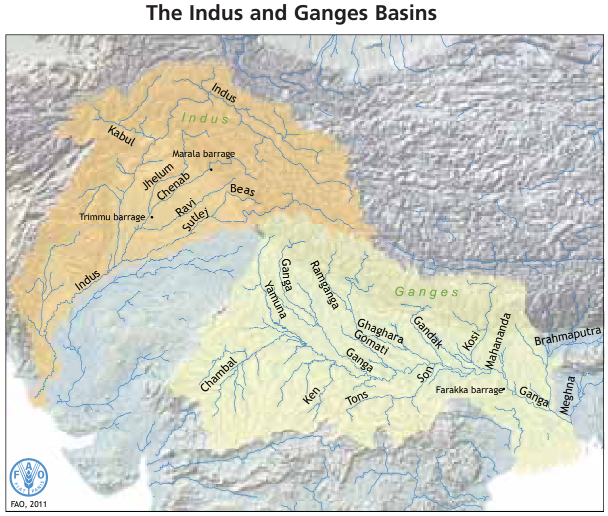
2.2 DESCRIPTION OF THE AREA

2.2.1 Geography

The IGB refers to the Indus and Ganges Basins (Figure 1). The Indus Basin covers an area of 1 165 500 km^2 in Afghanistan, Tibet Autonomous Region of China, India and Pakistan. The drainage area in India is 321 289 km^2 – in the States of Jammu and Kashmir (193 762 km^2); Himachal Pradesh (51 356 km^2); Punjab (50 304 km^2); Rajasthan (15 814 km^2); Haryana (9 939 km^2); and the Union Territory of Chandigarh (114 km^2). The Ganges Basin lies in Bangladesh, China, India and Nepal and has a total area of 1 086 000 km^2.

The IGB falls into three physiographic regions: mountain areas, plains and deltas. The mountain areas consist of the southern slopes of the Hindu Kush and the Himalayas. The upper part of the Indus Basin in Jammu and Kashmir and Himachal Pradesh is mostly mountain ranges and narrow valleys. The Indo-Gangetic Plains are fairly uniform, with elevations of 150 m on the Ganges Plain and 300 m on the Punjab Plain, although local geomorphologic variations are significant. The delta regions consist of the Indus Delta in Pakistan and the Ganga–Brahmaputra–Meghna Delta area in Bangladesh and India.

FIGURE 1
The Indus and Ganges Basins



Source: FAO 2011.

2.2.2 Main rivers in the Indo-Gangetic Basin

The Indus River originates in Tibet Autonomous Region of China at 5 182 m above sea level and flows for 2 880 km to the Arabian Sea. The length of the river in India is 1 114 km. The upper Indus catchment contains some of the largest glaciers in the world outside the polar regions. The glacial area of the upper Indus catchment is about 2 250 km^2 and provides most of the river flow in summer. The Kabul River, which is mainly snowfed, originates at the Unai Pass of the southern Hindu Kush at 3 000 m. It drains eastern Afghanistan and then enters Pakistan just north of the Khyber Pass. The Jhelum River rises in Kashmir at a much lower elevation than the source of the Indus River and falls much less rapidly than the Indus River after entering Pakistani territory. The Chenab River originates in Himachal Pradesh in India at 4 900 m. It flows through Jammu in the Indian part of Kashmir and enters Pakistani territory upstream of the Marala Barrage. The Jhelum River joins the Chenab River at the Trimmu Barrage.

The Ganga River (known as the Ganga-Padma River in Bangladesh) begins in the central Himalayas and flows 2 500 km to the Bay of Bengal. The Ganges Basin has a plain 200–300 km wide, which is bordered by mountains and highlands on three sides. Many tributaries and distributaries join and flow from the Ganga to drain the northern part of India and most of Bangladesh. The largest tributaries of the Ganga are the Ghaghara and Yamuna Rivers. Other important rivers that merge with the Ganga River are: the Son River, which originates in the hills of Madhya Pradesh; the Gomati River, which flows past Lucknow; and the Chambal River. The Yamuna River flows to the west and south of the Ganges River and joins it almost halfway along its course. The Yamuna River receives a number of central Indian rivers. To the north of the Ganga, the large tributaries are the Ramganga, Gomati, Ghaghara, Gandak, Kosi and Mahananda Rivers. Beyond the Mahananda River, the Ganga River enters its own delta, formed by its distributaries, and then merges into the combined delta of the Ganga, Brahmaputra and Meghna Rivers.

2.2.3 Climate

Annual rainfall in the Indo-Gangetic Plains varies from less than 400 mm in western Pakistan to over 1 600 mm in eastern India and in Bangladesh (White and Rodriguez-Aguilar, 2001). The plains in the middle Ganges Basin receive 800–1 200 mm/year of rain, and those in the upper Ganges Basin as well as the Indus Valley receive 400–800 mm/year. Annual rainfall is less than 500 mm in western Rajasthan and adjoining parts of Haryana and Punjab, while the annual rainfall in Bangladesh ranges from 1 500 to 4 000 mm. The monsoon brings wet summers but very little rain the rest of the year. Heavy monsoon showers begin in the south of India and part of southeast Bangladesh at the beginning of June and gradually spread inland. In about ten days, the whole lower Ganges Basin receives heavy showers. In the middle Ganges Basin, the onset of the summer monsoon is in the middle of June, while in the upper Ganges Basin and the Indus Valley heavy rains begin towards the end of June.

In the lower Ganges Basin, three seasons generally are recognized: monsoon (June–October), winter (November–February) and summer (March–May). While the monsoon months are remarkably wet, the winter months are very dry. Rainfall in these four months averages only about 100 mm. Winter rain in the Ganges Basin is due to the retreat of the southwest monsoon, which is gradual in the upper basin and Indus Valley. By early September, the monsoon season is over in the Delhi area of the upper Ganges Basin and by late September it is over even in Patna, in the middle basin. While the last of the southwest (summer) monsoon is still bringing showers to the lower basin, the drier northeast (winter) monsoons begin to blow in the upper basin and Indus Valley. By the middle of October, the lower basin is subject to dry continental air and the summer monsoon rains have ceased.

The Ganges–Brahmaputra Delta has a typical monsoon climate, warm and dry from March to May, rainy from June to October, and cool from November to February. The mean annual rainfall is 2 000 mm, of which about 70 percent occurs in the monsoon season. Rainfall generally varies from northwest to southeast, increasing from a mean annual rainfall of 1 500 mm in the northeast to 2 900 mm in the southeastern corner (Anon., 2004). Potential evapotranspiration rates are about 1 500 mm, exceeding the rainfall rates from November to May. The relative humidity is high, varying from 70 percent in March to 89 percent in July. The area experiences moderate to long periods of sunshine, commonly exceeding 8.5 hours/day outside the monsoon season. The mean annual temperature is 26 °C with peaks of more than 30 °C in May. Winter temperatures can fall to 10 °C in January. The southern region of the area, and in particular the southeastern coastline, is vulnerable to cyclones in the monsoon season. Storm surges can dramatically raise the water level by up to 4 m above tidal and seasonal levels. The southwest coastline is protected to some extent by the dampening effects of the Sundarbans wetlands.

2.2.4 Soils

The Indo-Gangetic alluvial plains are considered among the world's most extensive fluvial plains. They came into existence with the collision of Indian and Eurasian tectonic plates during the middle Miocene (Anon., 2004). The basin is still tectonically active.

The major source of sediment is the large river system of the Indo-Gangetic Plains. These plains extend over an area 1 600 km long and 320 km wide, including the arid and semi-arid environment in Rajasthan and Punjab, and humid and peri-humid deltaic plains in Bengal. The alluvium varies in texture from sandy to clayey, calcareous to non-calcareous, and acidic to alkaline. In Bangladesh, most of the area is covered by alluvial soils, followed by black soils, peat and marshy soils. Only a few pockets of sulphate acid soils are seen near the mouth of the Ganga River (Anon., 2004).

Most of the Indian area of the IGB is poor in available nitrogen (N) (Anon., 2004). Parts of Punjab, Haryana and Uttar Pradesh are in the medium range. Only a small area of Himachal Pradesh has high levels of available N. Available phosphorus (P) is medium in most districts. High P soils are rare in the Indian portion of the IGB. Available potassium (K) in most districts ranges between high and medium levels. Recent alluvial zones are low in available K.

The Indo-Gangetic Plains are undergoing a gradual transition in climate, physiography, natural vegetation and cropping systems. Land use in this region has undergone a remarkable change in the past 40–50 years. Grazing land has reduced as land has been used for other uses, in particular agriculture. As a result, the availability of manure for maintaining soil health, especially soil organic matter, has diminished. Biological activity has gradually been impaired to the extent of reducing the efficiency of applied inputs. Soil carbonate carbon in the soils of the Indo-Gangetic Plains is 0.13 and 4.61 petagrams (10^9 t) in the upper layers 30 cm and 150 cm deep, respectively (Anon., 2004).

2.2.5 Land use and water extraction

A study covering 133 021 million ha, or 63 percent of the IGB, found that 46.6 percent of the area is cultivated, of which 24.9 percent (33.08 million ha) is irrigated – 26.6 percent by canals and the remainder with groundwater – indicating the large volume of water extraction from the rivers for food production (Thenkabail, Schull and Turra, 2005). Some 3.05 million ha of wetlands in the Himalayas (32.5 percent) and the plains (67.5 percent) are used for flooded irrigation, and 0.67 million ha of floodplains in the plains are classified as grass and shrubs. The total area covered by rivers, lakes, marshes, estuaries and other wetlands is 1.34 million ha (1 percent). Of the 1.15 million ha of other wetlands, only 7.6 percent is considered to have natural vegetation. The remainder is used for agriculture.

Water withdrawal poses a serious threat to the IGB in India. Barrages control all of the tributaries to the Ganga River and divert about 60 percent of river flow to large irrigation works (Gopal, 2004; Shah *et al*., 2009). The flow of the Ganga River into Bangladesh has more than 30 upstream water diversions. From the largest, the Farraka Barrage, 18 km from the border with Bangladesh, the average monthly discharge of the Ganga River is 316 m^3/s. The Indus River is sensitive to climate change, as Himalayan glaciers provide 70–80 percent of its water, the highest proportion of any river in Asia and double the proportion that glaciers provide to the Ganges River (30–40 percent). The Indus Basin is already suffering from severe water scarcity owing to overextraction for agriculture causing saltwater intrusion in the delta. Damming and water extraction have severe consequences for riverine biodiversity (Dudgeon, 2000).

2.2.6 Demography and labour

Of the four riparian countries (excluding Afghanistan), India has by far the largest population, followed by Pakistan, Bangladesh and Nepal (Table 1). Bangladesh has the highest population density (1 024 people/km^2), followed by India (347), Pakistan (183) and Nepal (165). Pakistan has the fastest growing population in the basin, with an annual rate of 2.4 percent, followed by Nepal (2.3 percent), Bangladesh (1.7 percent) and India (1.5 percent). In all four countries, rural populations are growing more slowly than national populations, which points to a population explosion in urban areas, particularly in large metropolitan centres.

The populations of the basin countries are largely rural: Nepal (88 percent), Bangladesh (74 percent), India (72 percent), and Pakistan (65 percent). Pakistan and Nepal have the largest percentage of population aged 0–14 years (41 percent) and India has the lowest (33 percent). The major portion of the population falls into the working age bracket of 15–64 years in all countries – highest in India (62 percent) and lowest in Nepal and Pakistan (55 percent). High population growth rates in all countries remain a challenge to food security and poverty alleviation. Limited information is available on the number of people who depend on fishing in the rivers and reservoirs of the IGB (Anon., 2006). Estimates indicate that about 300 000 people are engaged in fisheries and associated activities in the IGB.

TABLE 1

Size and composition of the agricultural labour force in Indo-Gangetic countries

	Total population (2001)	Labour force		Employed in agriculture[1]		Employment in agriculture
		Total (2001)	Average annual growth rate (1980–1999)	Male	Female	
	(million)	(million)	(%)	(% of male employment)	(% of female employment)	(% of total employment)[1]
Bangladesh	133.35	70.79	2.6	52.1	48.1	63.2
India	1 032.40	460.53	2.0	na	na	66.2
Nepal	23.59	10.98	2.3	na	na	78.5
Pakistan	141.45	53.48	2.8	41.0	66.3	47.3

na = not available.
[1] Latest year available.
Sources: World Bank, 2000; World Bank, 2001, 2003.

2.3 FISHERY RESOURCES AND PRODUCTION SYSTEMS

2.3.1 Rivers

The Indus and Ganga Rivers (Table 2) originate in the Himalayas to traverse the great alluvial Indo-Gangetic Plains. They are snowfed and rainfed rivers that are characterized by complicated flood regimes and seasonal variations in volume of flow (Sinha and Katiha, 2002).

The Ganga River system has a combined length of 12 500 km and a catchment area of 97.6 million ha. Its tributary rivers are spread over most of the north Indian states (except the hill states) to extend up to West Bengal through Bihar.

Commercial fishing is virtually absent in the upland waters of the Ganga River system, mostly because of inaccessibility. The stretch of the Ganga River from Haridwar to Lalgola is recognized as one of the richest capture fisheries in India, producing highly prized major carps, hilsa (*Tenualosa ilisha*) and catfishes. Mid-September to June are peak months for fishing.

The main stem of the Indus River and its tributaries in the States of Kashmir, Himachal Pradesh and Punjab also support important fisheries. In the upper river, the fishery targets mainly mahseer (*Tor* spp.), snow trout (*Schizothorax* spp.), other cyprinids and exotic trouts. In the lower reaches, the Beas and Sutlej Rivers contain commercially exploitable stocks of indigenous carps and catfishes.

TABLE 2
River stretches in Indo-Gangetic Basin states in India

River system	Main rivers	Approximate length (km)	States
Ganges	Ganga	2 525	Uttar Pradesh, Bihar, Jharkhand, West Bengal
	Ramganga	569	Uttar Pradesh
	Gomati	940	Uttar Pradesh
	Gharghara	1 080	Uttar Pradesh, Bihar
	Gandak	300	Bihar
	Kosi	492	Bihar
	Yamuna	1 376	Punjab, Haryana, Delhi, Uttar Pradesh
	Chambal	1 080	Madhya Pradesh, Uttar Pradesh, Rajasthan
	Tons	264	Uttar Pradesh
	Son	784	Uttar Pradesh
	Ken	360	Madhya Pradesh
Indus	Jhelum	400	Jammu and Kashmir
	Chenab	330	Jammu and Kashmir, Himachal Pradesh
	Beas	460	Himachal Pradesh, Punjab
	Sutlej	1 370	Himachal Pradesh, Punjab
	Ravi	720	Jammu and Kashmir, Himachal Pradesh, Punjab

Source: DAHDF, 2005.

2.3.2 Floodplain wetlands

The Indo-Gangetic river systems, particularly those in Uttar Pradesh, Bihar and West Bengal, have extensive floodplains punctuated with oxbow lakes, known locally as *mauns*, *beels*, *chaurs* and *jheels*. These are shallow, nutrient-rich waterbodies formed by changes in the course of the river. Some of these retain connection with the main river, at least in wet seasons (Sinha, 1997). Many of these waterbodies in West Bengal and Assam are adapted as stocked fisheries and have significant potential for further development (Table 3). In addition to food fish, the rivers produce a wide variety of ornamental fish species. The Himalayan region also offers opportunities for developing sport fishing. Some waterbodies in the basin are ecologically sensitive and recognized as internationally important under the Ramsar Convention, but continue to function as capture fisheries.

The annual fish yield in floodplains may vary from 50 to 400 kg/ha (CIFRI, 2005b). Most of the rural population fish either full-time professionally, seasonally or for subsistence. For full-time fishers, conflict over water resources can be intense during the dry season, when water is required for irrigation. Flood control, drainage and irrigation schemes may obstruct the lateral migration of rheophilic species and the passive drift of larvae from the main channel to modified floodplains. The decrease in flow has reduced the available major carp habitats in the Ganges Basin in Bangladesh (Ali, 1991). The lower water flow, especially during the dry season and in hill regions such as the Barind Tract, causes drought and the drying of ponds as groundwater levels drop. Modifications to hydrological regimes, damming and extreme water extraction for irrigation cause reductions in catch per unit area and in fish biodiversity. Both habitat restoration and fish enhancement are important to sustain these floodplain fisheries (Craig *et al*., 2004).

TABLE 3
Potential for enhancing fish production in floodplain wetlands of Indo-Gangetic India

Region	Area	Yield		Potential increase in yield
		Existing	Potential	
	('000 ha)	('000 tonnes)		(%)
West Bengal	42.5	9.56	53.15	456
Bihar	40.0	4.80	30.00	525
Uttar Pradesh	152.0	22.80	114.00	400
Total Indo-Gangetic Basin	234.5	37.16	197.15	431
Total India	353.7	50.65	307.93	508

Source: CIFRI, 2005b (modified).

2.3.3 Estuaries

The IGB open estuarine system includes the Hoogly–Matlah estuarine system in the vicinity of Kolkata in India (Table 4). Annual landings from Gangetic Sundarbans of the Hoogly–Matlah estuaries have exceeded 10 000 tonnes, with an average yield that varies between 45 and 75 kg/ha. Some of the most common fishes in Indian mangrove waters are species of *Liza*, *Mugil*, *Lates*, *Polynemus*, *Sciaena*, *Setipinna*, *Pangasius*, *Tenualosa* (*Hilsa ilisha*) and *Atroplus*. The hilsa fishery in Bangladesh is of great importance, accounting for 20 percent of national fish production (Blaber *et al*., 1998). The construction of the Farakka Barrage in 1975 to divert water from the Ganges River to the Hoogly Canal had a positive impact on the estuarine fisheries of the Hoogly–Matlah system (see Table 4). However, the barrage is perceived to have had a severely negative impact on the hilsa fishery in the Bangladeshi part of the Ganga River, although the data to support this claim are weak (Payne *et al*., 2004). The estuary is also recognized as an excellent source of naturally occurring fish and prawn seed. The Hoogly–Matlah system is under threat from pollution because of its proximity to a major urban and industrial centre.

TABLE 4
Major estuaries of the Indo-Gangetic Basin in India

Estuarine system	Estimated area (ha)	Yield (tonnes)
Hoogly–Matlah estuarine system	234 000	20 000[1]
		72 098[2]
Wetlands of West Bengal		
Freshwater	na	10–14
Saline	33 000	≈37 500
Mangroves	356 500	na

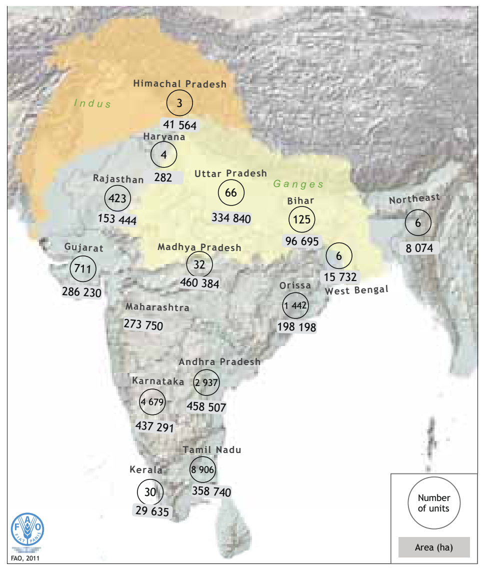
[1] Before the Farakka Barrage project.
[2] After the Farakka Barrage project.
na = not available.
Sources: Sinha, 1997 (modified); Jha *et al.*, 2008.

2.3.4 Reservoirs

The Government of India has defined reservoirs as "man-made impoundments (of more than 10 ha) created by the obstruction of the surface flow by dams of any description on a river, stream or any water course" (Sugunan, 1995). In the IGB, the States of Madhya Pradesh and Uttar Pradesh have the largest area of reservoirs (Figure 2).

For the purpose of fishery management, reservoirs are classified as small (< 1 000 ha), medium (1 000–5 000 ha) and large (> 5 000 ha), although different states provide slightly different classifications. Their area is estimated at 1 485 557 ha for small, 527 541 ha for medium and 1 140 268 ha for large reservoirs (Sugunan, 1995). The IGB has 1.16 million ha of reservoirs, or 36.8 percent of the total reservoir area of India (Table 5). Small reservoirs account for the largest area (40.6 percent), followed by large (33.0 percent) and medium (26.4 percent) reservoirs. The largest number of reservoirs are small (> 566) followed by medium (> 80) and large (26) reservoirs. Most of the small reservoirs are less than 500 ha, while many of the reservoirs in the medium category measure 1 000–2 000 ha. Although these reservoirs were built primarily for irrigation, soil conservation, flood control, domestic water supply and electricity generation, they also form important inland fisheries with substantial potential to increase output through improved management.

FIGURE 2
Distribution of reservoirs in all size categories in India



Source: Modified from Sugunan (1995).
Note: The Northeast corresponds to the states: Arunachal Pradesh, Assam, Nagaland, Meghalaya, Manipur,Tripura and Mizoram.

TABLE 5
Distribution of reservoirs larger than 10 ha in the Indo-Gangetic Basin in India by state and area

Region	Reservoir area							
	Small		Medium		Large		Total	
	Area	% of area in India	Area	% of area in India	Area	% of area in India	Area	% of area in India
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Jammu and Kashmir	na	na	1 000	0.19	8 700	0.76	9 700	0.31
Himachal Pradesh	200	0.01	na	na	41 364	3.63	41 564	1.32
Haryana	837	0.06	na	na	na	na	837	0.03
Punjab and Chandigarh	832	0.06	3 535	0.67	na	na	4 367	0.14
Rajasthan	54 231	3.65	49 827	9.45	49 386	4.33	153 444	4.87
Uttar Pradesh	218 651	14.72	44 993	8.53	71 196	6.24	334 840	10.62
Madhya Pradesh	172 575	11.62	169 502	32.13	118 307	10.38	460 384	14.60
Bihar	12 461	0.84	12 523	2.37	71 711	6.29	96 695	3.07
Jharkhand	10 444	0.70	11 958	2.27	5 957	0.52	28 359	0.90
West Bengal	451	0.03	13 148	2.49	15 600	1.37	29 199	0.93
Total IGB states	470 682	31.68	306 486	58.10	382 221	33.52	1 159 389	36.77
Total India	1 485 557		527 541		1 140 268		3 153 366	

Note: IGB = Indo-Gangetic Basin.
na = not available.
Sources: DAHDF (2005) and the Department of Fisheries of Jammu and Kashmir, Himachal Pradesh, Haryana, Punjab and Chandigarh, Rajasthan, Uttar Pradesh, Madhya Pradesh, Bihar, Jharkhand and West Bengal.

2.3.5 Aquaculture

Inland aquaculture is distributed over almost all Indian states and in the IGB in particular (Table 6). Aquaculture ponds cover more than 0.86 million ha and are mostly concentrated in West Bengal (278 000 ha), Rajasthan (180 000 ha) and Uttar Pradesh (162 000 ha). States in the IGB account for more than 30 percent of aquaculture area in the country. The highest annual productivity is in Punjab, at 4 085 kg/ha, followed by Haryana at 3 501 kg/ha. The annual national productivity average in ponds supported by the Fish Farmers Development Agency (FFDA) – a government body set up to advance the use of improved aquaculture technology – increased from 50 kg/ha in 1974–75 to about 2 389 kg/ha in the 1990s, which is above the national average of 2 135 kg/ha (Anon., 1996).

TABLE 6
Aquaculture area and production in the Indo-Gangetic Basin in India, by state and area

Region	Total area	Area covered by FFDA	Area covered by FFDA	Production by area covered by FFDA	Annual yield
	('000 ha)	('000 ha)	(%)	(tonnes)	(kg/ha)
Bihar	95	22.31	23.48	47 527	2 130
Haryana	100	18.57	18.57	65 005	3 501
Himachal Pradesh	1	0.26	26.00	658	2 502
Jammu and Kashmir	17	1.56	9.18	2 022	1 300
Madhya Pradesh	119	54.96	46.18	86 292	1 570
Punjab	70	12.15	7.357	49 628	4 085
Rajasthan	180	4.17	2.32	7 211	1 730
Uttar Pradesh	162	69.21	42.72	138 410	2 000
West Bengal	276	98.78	35.79	296 349	3 000
Total for IGB states	867	321.81	37.12	768 800	2 389
Percentage of India total	30.40	75.67		84.67	
Total India	2 852	425.26	14.91	908 023	2 135

Notes: FFDA = Fish Farmers Development Agency; IGB = Indo-Gangetic Basin.
Source: DAHDF, 2005.

2.4 MORPHOMETRIC, EDAPHIC, CLIMATIC AND HYDROLOGICAL FEATURES OF IGB RESERVOIRS

Large reservoirs in India are estimated to have an annual production potential of 65–190 kg/ha, medium-sized reservoirs 145–215 kg/ha and small reservoirs 285–545 kg/ha based on hydrochemical factors and primary productivity (Sugunan, 1995). Factors that constrain productivity in reservoirs can be summed up as morphometric (area, depth and shoreline), edaphic and climatic. These factors affect energy and nutrient dynamics and biotic interactions. A number of morphometric indices – the shoreline development index, volume development index (mean depth over maximum depth), catchment-to-reservoir area ratio, flushing rate (Sugunan, 2000) and relative lake-level fluctuation (RLLF)[1] (Jul-Larsen *et al.*, 2003) – have been proposed to relate productivity to these constraints. However, limited information is available at present for most of the IGB, and more reliable estimates of reservoir productivity are thus difficult to obtain.

Mean depth (volume over area) (Table 7) is indicative of the extent of the euphotic littoral zone (Rawson, 1952; Hayes, 1957). Bottom water in reservoirs more than 18 m deep sometimes serves as a nutrient sink (Rawson, 1955), as seen in some deep reservoirs of India. Hydel reservoirs on mountain slopes with steep basin walls are considered biological deserts. Nevertheless, deep reservoirs such as Bargi (14 m) in Madhya Pradesh, Chamera (43.5 m) and Govindsagar (55 m) in Himachal Pradesh, Rihand (22.8 m) in Uttar Pradesh and Badua (14.5 m) in Bihar are relatively productive

[1] A drawdown ratio, defined as the area of maximum extent over the area at minimum extent (information that exists for many reservoirs), would probably serve the same purpose. This requires further examination.

owing to other favourable factors (Das, 2001). Most small or medium-sized IGB reservoirs have low mean depths of 4–7 m and are thus expected to have higher potential for fish production.

TABLE 7
Morphometric and hydrological features of Indo-Gangetic Basin reservoirs

Indo-Gangetic Basin states	Reservoir area	Number	Mean depth	Elevation	Catchment area	Volume development index	Total inflow
	(ha)		(m)	(m)	(km²)		(billion m³)
Jammu and Kashmir	na	na	25	na	na	na	na
Himachal Pradesh	900–15 000	3	20–55	440–899.2	4 725–56 980	na	na
Punjab	46–280	na	4–10	na	6.1–56.1	na	na
Haryana	na	4	3.4–5.0	na	11.4–11.9	na	na
Rajasthan	165–1 554	423	1.7–7.7	na	35–27 840	na	na
Uttar Pradesh	17.5–30 149	66	3–22.8	119–268	32.4–13 344	na	na
Madhya Pradesh	77–66 000	32	3.4–14.0	348.7–488.3	8.3–23 025	0.5–1.7	27.7–7 800
Bihar and Jharkhand	21–3 733	125+	5.2–14.6	na	29–6 120	0.7–1.4	na
West Bengal	na	6	3.2–11.0	na	na	na	na

na = not available.
Sources: CIFRI, 1981, 2003a, 2003b, 2004a, 2004b, 2004c, 2004d and 2007; Sugunan, 1995.

The shore development index indicates the shoreline's degree of irregularity (Das, 2001). High values in this index indicate higher productivity. Reservoirs with dendritic shorelines offer many sheltered bays and coves and are likely to be relatively productive because of their extensive littoral areas. The shoreline development indexes of the Tilaiya (9.12) and Konar (8.78) reservoirs are moderate and accompanied by moderate-to-rich planktonic communities.

The volume development index (Table 7) denotes the depth of the reservoir in relation to the nature of the reservoir wall (Hutchinson, 1957). If the value is > 1, the reservoir is cup-shaped with less littoral area, and a value < 1 means the reservoir is saucer shaped and more productive. The volume development indices of many of the small and medium-sized reservoirs of Bihar, Jharkhand, Madhya Pradesh, Punjab, Rajasthan and Uttar Pradesh are less than one and so predict moderate productivity.

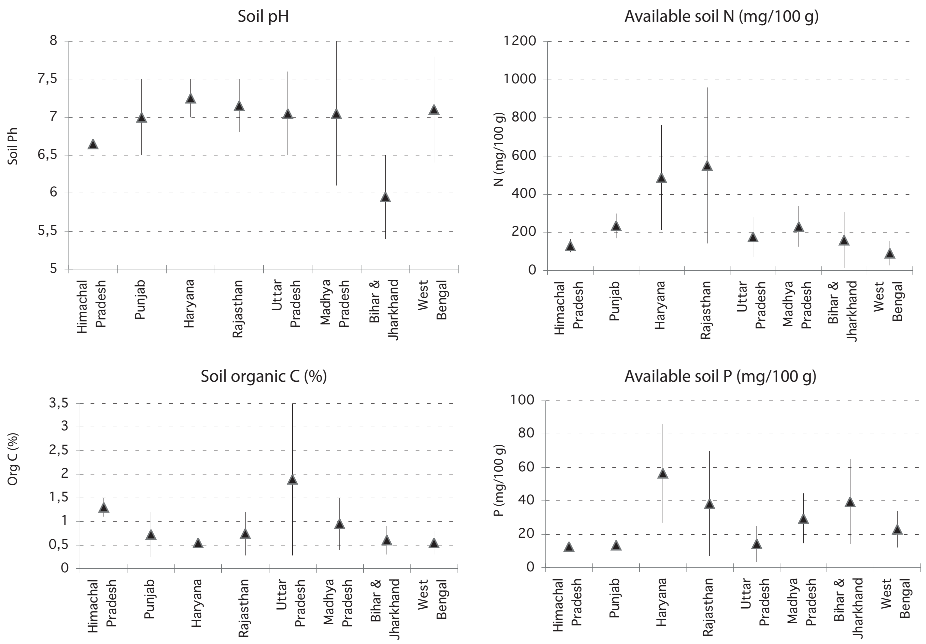
Edaphic factors are dynamically linked to soil condition, land-use patterns and precipitation in the catchment. The Indus Basin is less fertile than the Ganges Basin. The Ganges Basin is covered mostly with intensely cultivated agricultural lands under moderate-to-high rainfall of 250–4 000 mm. In contrast, the upper Indus Basin is a glacial landscape with comparatively little rainfall of 100–750 mm.

The dominant soils in the Ganges Basin have high K content and moderate N and P content, while Indus Basin soils are generally poorer, with low-to-moderate N and P content in Punjab, Haryana and Himachal Pradesh (Figure 3). The soils in the IGB are mostly neutral to moderately alkaline, although moderately acidic soil is observed around some of reservoirs in Bihar and Jharkhand (Figure 3), probably related to the forest cover. Specific conductivity in IGB reservoir soils is moderate.

The fertility of soils throughout the IGB is generally correlated with the increasing application of inorganic fertilizers in agriculture. In Indian reservoirs, the quality of water in reservoirs is closely correlated to the catchment area (Natarajan, 1976).

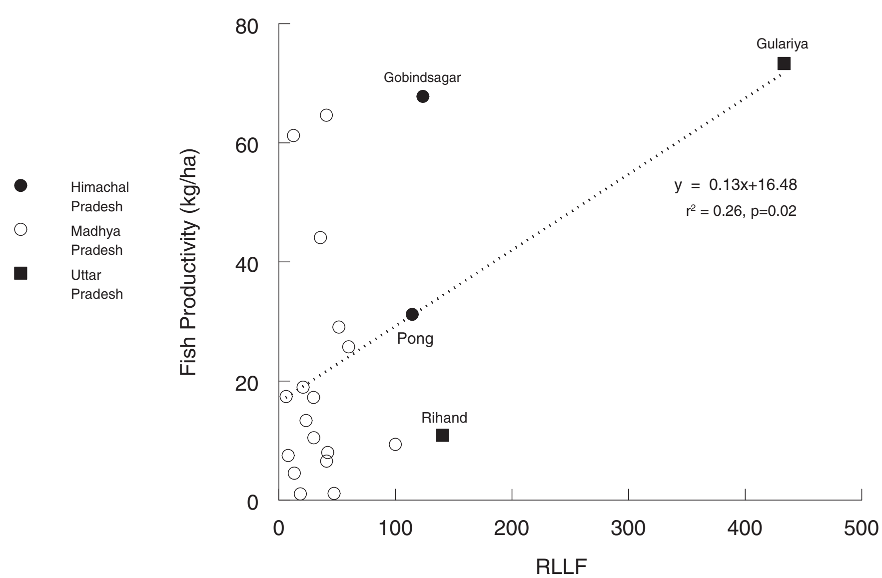
Flushing rate (inflow over storage capacity) regulates both the degree and regime of nutrient loading (Vollenweider, 1969). High flushing rates preclude fertilization as a management strategy, as nutrient inputs are rapidly removed downstream. Flushing rates are high in the reservoirs of Bihar, Himachal Pradesh, Jharkhand and West Bengal; moderate in Madhya Pradesh; and low in Rajasthan. Relative change in water level over the year may be more important in determining fertility than the total amount of water received. The RLLF index relates the change in water level with the mean depth (Jul-Larsen *et al.*, 2003; Kolding and van Zwieten, 2006). In the analysis of IGB reservoirs, however, the significant relation between RLLF and fish productivity depends entirely on the outlier of the Gulariya reservoir (Figure 4). This is a small reservoir in Uttar Pradesh that covers 300 ha when full, shrinking to 6.7 ha during the summer and drying completely in extreme summers.

FIGURE 3
Basic sediment characteristics in reservoirs of the Indo-Gangetic Basin in India



Sources: CIFRI, 1981, 2003a, 2003b, 2004a, 2004b, 2004c, 2004d and 2007; Sugunan, 1995.

FIGURE 4
Relation between fish productivity and the relative lake-level fluctuation index



Note: RLLF = % average annual drawdown over mean depth in 21 reservoirs in the Indo-Gangetic Basin.
Sources: CIFRI, 2003a, 2003b and 2007; Sugunan, 1995.

Water transparency is affected by the monsoon when the higher inflows are loaded with dissolved and suspended organic and inorganic matter. In Madhya Pradesh, in particular, turbidity is generally high and can strongly affect the composition of algal communities, depending on the strength of the monsoon (Ramakrishniah and Sarkar, 1982). In contrast, reservoirs in rocky and gravelly catchments such as those in Himachal Pradesh, Jammu and Kashmir, and Jharkhand are more stable and transparent, although Secchi disc depth rarely reaches more than 2 m (Unni, 1985).

Seasonal variation of water temperature in IGB reservoirs ranges from 2–4 °C during the post-monsoon and pre-monsoon seasons, and diurnal variation is 10–12 °C (Das, 2001). In the western, central and eastern parts of the IGB, the temperature difference between the top and bottom of reservoirs averages 1–2 °C, with little or no stable thermal stratification, even in deeper reservoirs such as Bargi reservoir, which has a maximum depth of 59 m. However, thermal stratification does occur in some northern Indian reservoirs. Getalsund reservoir in Bihar has a thermocline between 7 m (25.3 °C) and 12 m (20.8 °C) with a stable hypolimnion below 12 m (Pal, 1979). Konar reservoir has a metalimnion at 3–9 m depth, with a temperature drop of 0.7–1.1 °C/m (Sarkar, 1979). Rihand reservoir has a metalimnion at 4–13 m depth, with a temperature difference of 8.5–10 °C in May (Desai and Singh, 1979). A very strong and well-defined thermocline has been observed in Govindsagar reservoir (Sarkar, Govind and Natarajan, 1977). Transient thermal stratification as a result of low wind speed with a fall in metalimnion temperature of less than 1 °C has been reported for the upper peninsular reservoirs of south Bihar, Gujarat and Madhya Pradesh and is a phenomenon that has been observed in many tropical lakes (Lewis, 1973; Taylor and Gebre-Mariam, 1989). Thermal stratification and the presence of an oxycline are both related to reservoir fertility, with more productive reservoirs showing sharper oxygen depletion in the tropholytic zone. In less productive water, as in Konar, Tilaiya and Rihand reservoirs, the oxygen curve is orthograde.

2.5 CHEMICAL AND BIOLOGICAL FEATURES OF IGB RESERVOIRS

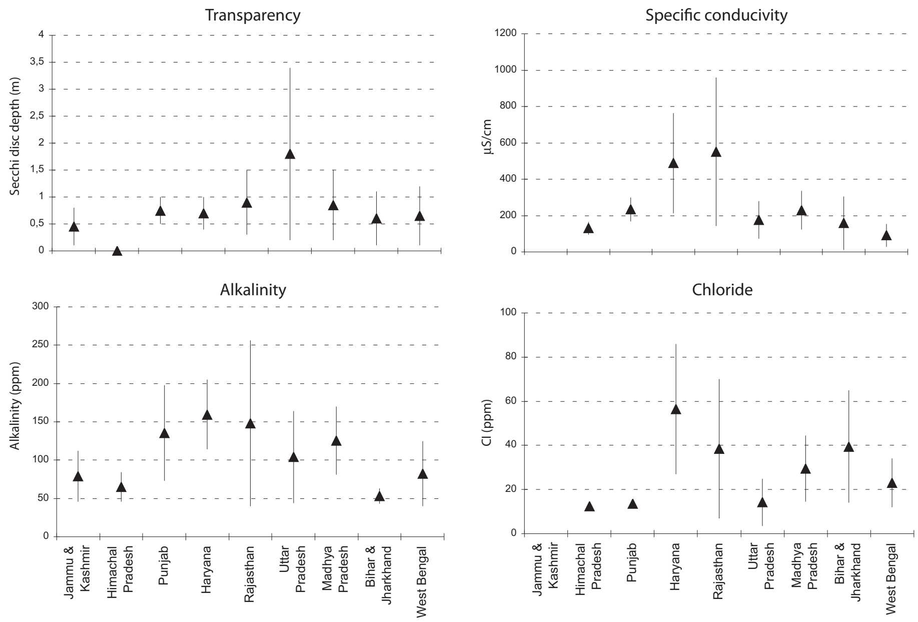
In most reservoirs in IGB states, conductivity ranges from 100 to 300 µS/cm, with some higher values in reservoirs in Rajasthan and Haryana. The average chloride content in IGB reservoirs is in the range of 7–30 mg/litre, the normal range of freshwater, with higher values sometimes recorded during pre-monsoon months in some reservoirs of Haryana and Rajasthan. Most of the reservoirs have moderate total alkalinity in the range of 40–205 mg/litre, again reflecting the moderate primary productivity of these reservoirs (Figure 5). The low values of total alkalinity in Bihar and Jharkhand reservoirs are due to acidic, lateritic soils in dry forest areas. In general, total alkalinity is higher during pre-monsoon periods, with a substantial decrease with dilution in the following monsoon period. Some reservoirs in Bihar, Jharkhand and Madhya Pradesh have low total hardness of 23–68 mg/litre, but all are still in the range of calcium and magnesium concentrations required for productive waters (> 20 mg/litre).

In Indian reservoirs, available N (in the form of nitrate and nitrogen dioxide) and P are very low (Figure 6), except during the period around the monsoons, when high temperatures increase the rate of microbial decomposition and runoff from agricultural land increases sediment and nutrient loading. During most of the year, available phosphate rarely exceeds 0.1 mg/litre. In general, silicate content is moderate in most of the reservoirs of the IGB (Figure 6), although some reservoirs in Jharkhand and Rajasthan show higher values (Das, 2001).

Gross primary productivity is shown in Figure 7. In most IGB reservoirs, green and blue-green algae, most notably *Microcystis*, form the bulk of phytoplankton communities, followed by diatoms (CIFRI, 2007; Sugunan, 1995). In Gobindsagar, which is a productive reservoir, *Ceratium* sp. is dominant over *Microcystis.* Reservoirs in Rajasthan, with scanty rainfall and poor flushing, favour macrophytes, and no blooms of *Microcystis* are recorded. Plankton usually exhibits two peaks in a year, a distinct winter pulse attributed to higher nutrient-rich monsoon inflow and a summer pulse of lower magnitude. Copepods are important elements of the zooplankton followed by cladocerans, rotifers and protozoans (CIFRI, 2007; Sugunan, 1995).

FIGURE 5

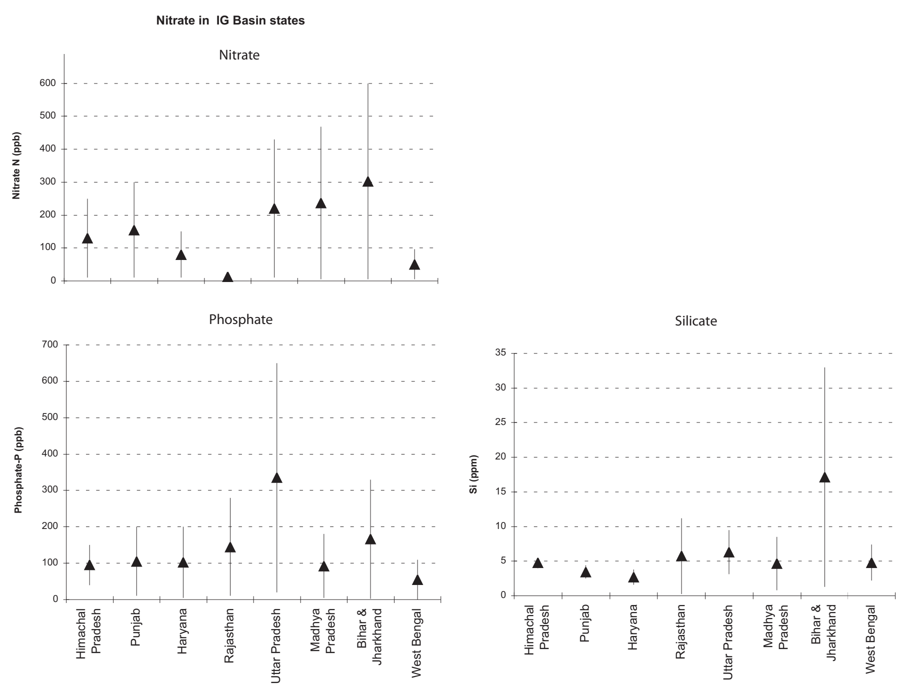
Physicochemical characteristics of water in reservoirs of the Indo-Gangetic Basin in India



Sources: CIFRI, 1981, 2003a, 2003b, 2004a, 2004b, 2004c, 2004d and 2007; Sugunan, 1995.

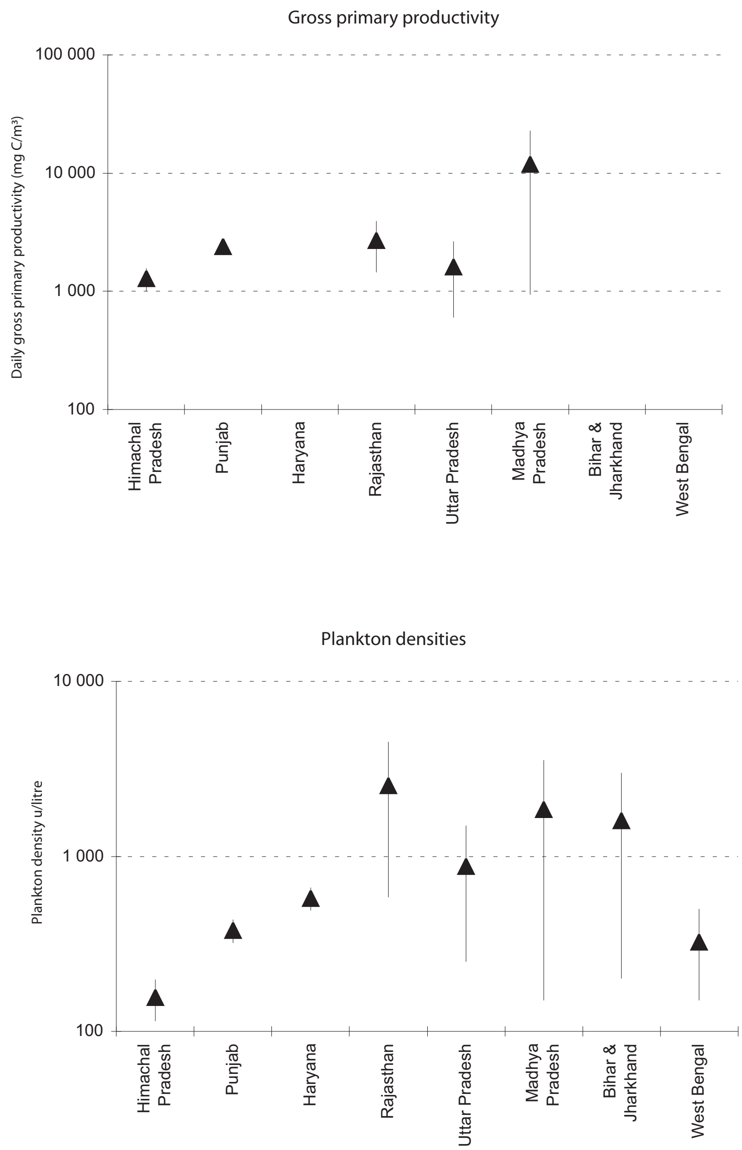
FIGURE 6

Basic nutrients in the Indo-Gangetic reservoirs of India



Sources: CIFRI, 1981, 2003a, 2003b, 2004a, 2004b, 2004c, 2004d and 2007; Sugunan, 1995.

FIGURE 7
Gross primary production in IGB reservoirs and zooplankton and phytoplankton densities, as recorded in some Indo-Gangetic Basin reservoirs



Sources: CIFRI, 1981, 2003a, 2003b, 2004a, 2004b, 2004c, 2004d and 2007.

2.6 FISH AND FISHERIES IN RESERVOIRS

2.6.1 Fish production

Fish production in IGB reservoirs is dominated by about 30 species (Table 8). In the upper part of the basin, these include mahseers (*Tor* spp.), snow trouts (*Schizothorax* spp.) and other cyprinids. In the middle and lower reaches, major carps such as *Catla catla* and *Labeo* species predominate.

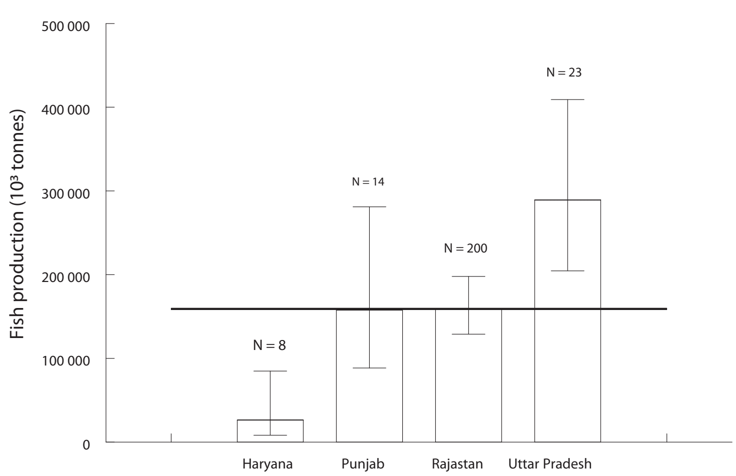
TABLE 8
Major fish species found in reservoirs of the Indo-Gangetic Basin

System	Ganges (reservoirs)		Indus (Gobindsagar reservoir)	
Reaches	**Upper**	**Middle/Lower**	**Upper**	**Middle/Lower**
Species	Mahseers: *Tor putitora* *Tor tor* Snow trout: *Schizothorax plagiostomus* Medium carps: *Labeo dero* *Labeo pangusia* Goonch: *Bagarius bagarius*	Major carps: *Catla catla* *Labeo rohita* *Cirrhinus cirrhosus* *Labeo calbasu* Minor carps: *Labeo gonius* *Labeo bata* *Labeo boga* *Labeo boggut* *Puntius sarana* *Chagunius chagunio* Catfishes: *Wallago attu* *Silonia silondia* *Pangasius pangasius* *Rita rita* *Aorichthys aor* *Aorichthys seenghala* Smaller catfishes: *Clupisoma garua* *Eutropiichthys vacha* *Mystus cavasius* *Ompok bimaculatus*	Mahseers: *Tor putitora* Snow trout: *Schizothorax plagiostomus* Major carps: *Crossocheilus latius* *Labeo calbasu* Medium carps: *Labeo dero* *Labeo bata* Snakeheads: *Channa marulius* *Channa striatus* *Channa punctatus* Catfishes: *Aorichthys seenghala* *Wallago attu* Others: *Heteropneustes fossilis* *Nemacheilus* sp. *Mastacembelus armatus* *Glyptothorax* sp.	Salmonids *Salmo trutta* Snow trout: *Schizothorax plagiostomus* Major carps: *Crossocheilus latius* *Cyprinus carpio* var. *specularis* *Catla catla* *Labeo rohita* *Labeo calbasu* *Cirrhinus cirrhosus* *Hypophthalmichthys molitrix* Medium carps: *Labeo dero* *Labeo dyocheilus* *Labeo bata* Catfishes: *Aorichthys seenghala* Smaller catfishes: *Clupisoma montana* *Mystus bleekeri* Others: *Garra gotyla* *Mastacembelus armatus*

Source: Sugunan, 1995.

Over the 13 years from 1990 to 2003, freshwater fish production in Indian states located in the IGB increased from 0.92 million tonnes to 2.08 million tonnes (Figure 8). The share of the IGB in total fish production in India increased from 24 percent in 1990 to 33 percent in 2003. West Bengal produces over 56 percent of fish production in the basin, followed by Bihar with 13 percent, Uttar Pradesh 12 percent, Madhya Pradesh 7 percent and other states combined 12 percent. The highest percentage growth in fish production was recorded in Punjab, where it reached 83 000 tonnes in 2003, up from 11 000 tonnes in 1990 (DAHDF, 2005).

FIGURE 8
Fish production in Indo-Gangetic Basin states



Source: DAHDF, 2005.

The average yield of IGB reservoirs is 18 kg/ha (Sinha and Katiha, 2002) (Table 9). Small reservoirs produce 30 kg/ha, medium-sized 13 kg/ha and large 9 kg/ha. In the case of small reservoirs, notable yields are achieved in Madhya Pradesh (47 kg/ha) and Rajasthan (46 kg/ha). The productivity of medium-sized reservoirs is comparatively high in Rajasthan at 24 kg/ha. Comparatively high fish yields from large reservoirs are achieved in Madhya Pradesh (40 kg/ha) and Himachal Pradesh (36 kg/ha) (Sinha and Katiha, 2002) (Tables 9 and 10).

Catch per unit area generally decreases significantly with increased reservoir area (Figures 9 and 10). For comparisons, therefore, it is necessary to standardize the area based on log-log regressions of yield and reservoir area to correct for reservoir size (Kolding and van Zwieten, 2006; van Densen *et al.*, 1999). From this, a hypothetical 1 000 ha reservoir would yield an extremely low 0.56 kg/ha in Bihar and 14.8 kg/ha in the three Pradesh states (Figure 10, top). All reservoirs gave an annual yield of 36 kg/ha (Figure 10, bottom) (CIFRI, 2006a). By comparison, hypothetical 1 000 ha lakes in the Philippines gave an annual yield of 365 kg/ha, Sri Lankan reservoirs 239 kg/ha, Chinese reservoirs 79 kg/ha, Thai reservoirs 74 kg/ha and Indonesian reservoirs 65 kg/ha (van Densen *et al.*, 1999). Similar regressions for Latin American reservoirs gave annual yields in Cuba of 144 kg/ha and in Mexico of 234 kg/ha; while a hypothetical African lake of 1 000 ha would produce 316 kg/ha.

TABLE 9
Fish yield in reservoirs of Indo-Gangetic Basin states in India, by reservoir size

Region	Yield (kg/ha)			
	Small	Medium	Large	Average
Madhya Pradesh	47.26	12.02	14.53	13.68
Bihar	3.91	1.90	0.11	0.05
Uttar Pradesh	14.60	7.17	1.07	4.68
Rajasthan	46.43	24.47	5.30	24.89
Himachal Pradesh	na	na	35.55	35.55
Total for IGB states	29.75	12.80	9.23	18.32
Total for India	49.90	12.30	11.43	20.13

na = not available.
Source: Sinha and Katiha, 2002 (modified).

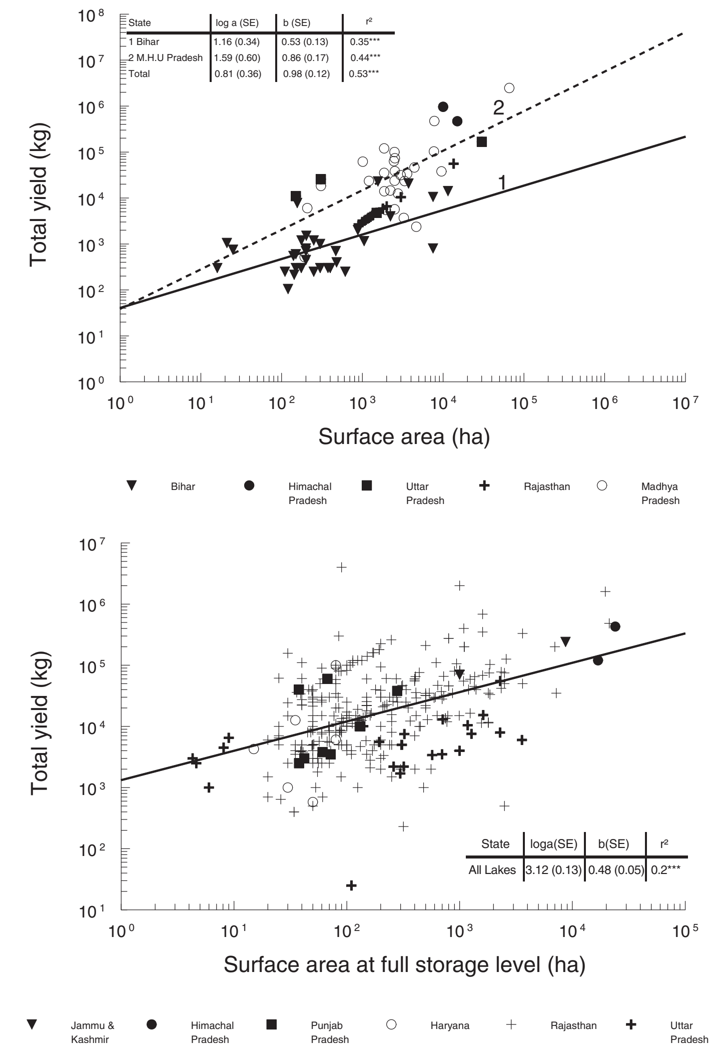
TABLE 10
Fish production potential based on morpho-edaphic characteristics and actual catch in Indo-Gangetic Basin reservoirs

Indo-Gangetic Basin states	Annual fish production potential	Annual catch
	(kg/ha)	
Jammu and Kashmir	60	15–25
Himachal Pradesh	56	25
Punjab	57–100	14–70
Haryana	153–360	80–100
Rajasthan	178–478	41–365
Uttar Pradesh	85–127	5–14
Madhya Pradesh	70–545	18–63
Bihar and Jharkhand	80–325	2–8
West Bengal	75–300	15–60

Sources: Sugunan, 1995; CIFRI, 1981, 2003a, 2003b, 2004a, 2004b, 2004c, 2004d and 2007.

FIGURE 9

Plot of yield on surface area for reservoirs for Indo-Gangetic Basin states in India



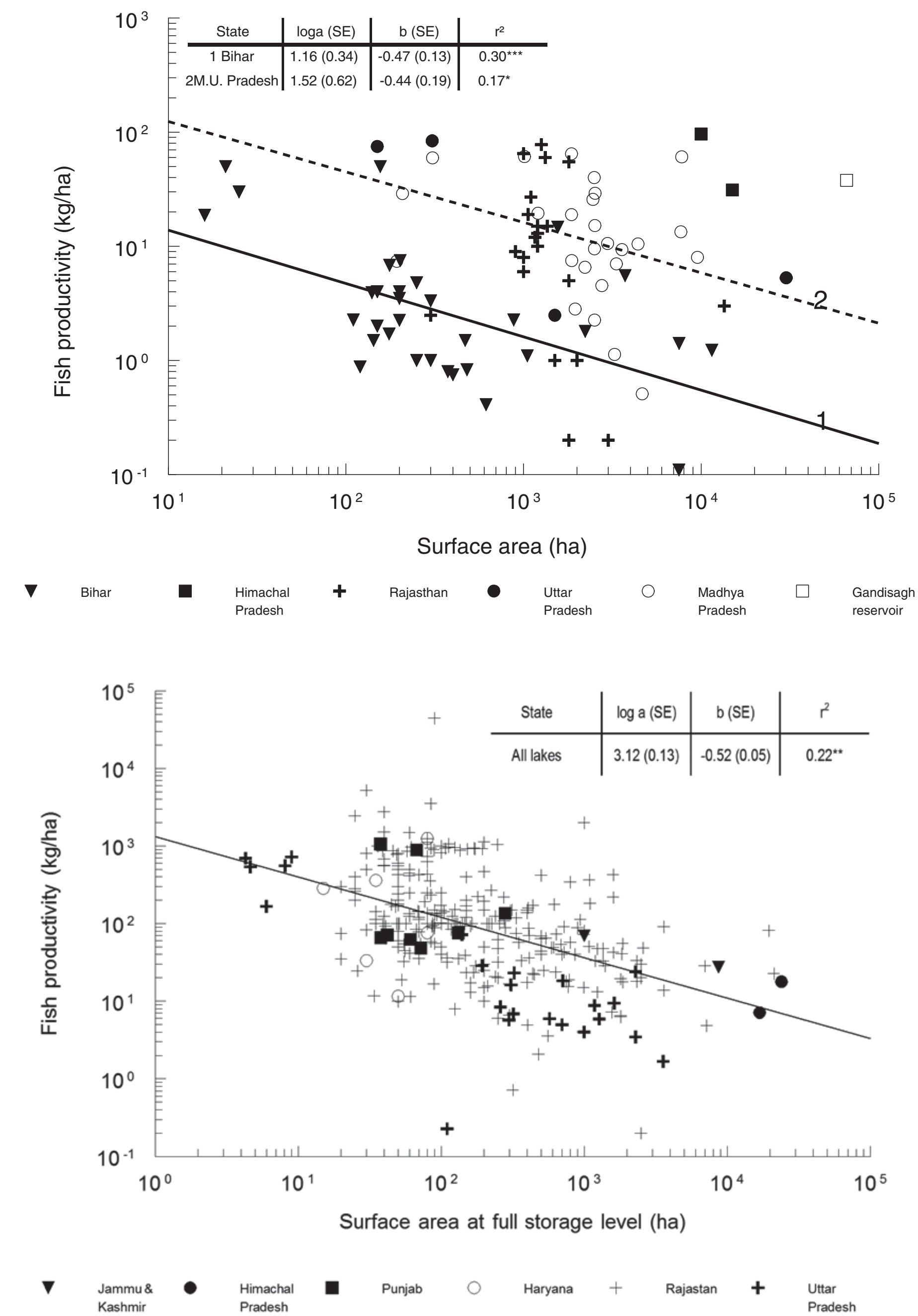
Notes:
Top graph: Madhya Pradesh (27 reservoirs), Rajasthan (20), Uttar Pradesh (4), Himachal Pradesh (2) and Bihar (33). Bottom graph: Jammu and Kashmir (2), Himachal Pradesh (2), Punjab (8), Haryana (6), Rajasthan (279) and Uttar Pradesh (23).
All regressions are according to the following: $\log_{10} Y_{ij} = \log_{10} a + b.^{10}\log S_i + \varepsilon_{ij}$, where Y_{ij} = total yield in kilograms, S_i = area in hectares, ε_{ij} = residual error, log *a* = intercept and *b* = slope, r^2 = proportion of explained variation, ***=p<0.001, SE = standard error. Rajasthan data from Sugunan (1995) were not used in the regression as they appear to be calculated through a model.
Sources: Sugunan, 1995; CIFRI, 2006b.

Although the arithmetic mean productivity of the 98 IGB reservoirs for which catch data were available for this review is relatively high at 66.5 kg/ha (Figure 11), the distribution is highly skewed, so a better descriptor of actual catch would be the median of 4.2 kg/ha or the geometric mean of 5.2 kg/ha. Even compared with the 20 kg/ha average yield of Indian reservoirs (Table 9), this productivity seems far below potential. Even a moderate increase of 100 kg/ha for small reservoirs and 50 kg/ha for medium-sized and large ones would provide an additional 170 000 tonnes of fish (Sugunan, 1995). The low productivity of Indian reservoirs is thought to be caused mainly by a management system that fails to consider reservoir ecology and trophic dynamics. It also results from inadequate stocking, badly selected species for stocking (Jayasinghe, Amarasinghe and De Silva, 2006), stocking material below a reasonable length and "irrational" exploitation. A subset of 67 reservoirs for which the catch, fishing effort, area and species composition of the catch are known, was used for subsequent analysis

(CIFRI, 2006b). The median depth of these reservoirs was 5 m. Three reservoirs had a mean depth greater than 100 m, and 90 percent had a mean depth of less than 15 m.

FIGURE 10

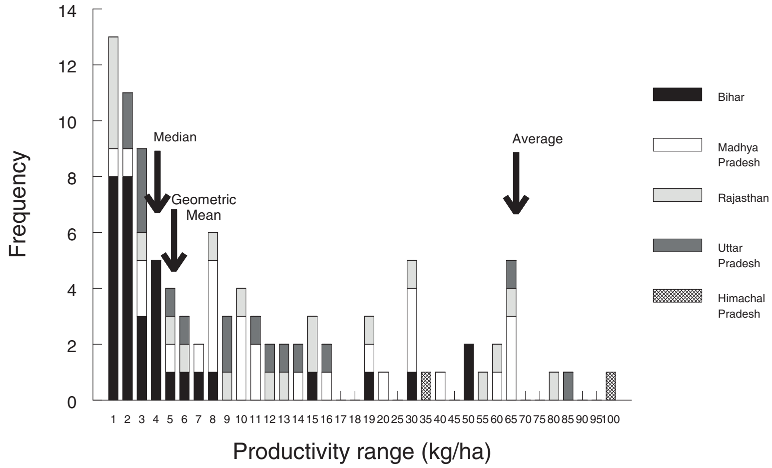
Plot of fish productivity on surface area for reservoirs for Indo-Gangetic Basin states in India



Notes: Madhya Pradesh (27 reservoirs), Rajasthan (20), Uttar Pradesh (4), Himachal Pradesh (2) and Bihar (33), and (bottom) Jammu and Kashmir (2), Himachal Pradesh (2), Punjab (8), Haryana (6), Rajasthan (279) and Uttar Pradesh (23). Regressions are according to: $^{10}\log FP_{ij} = {}^{10}\log a + b\ {}^{10}\log S_i + \varepsilon_{ij}$, where FP_{ij} = fish productivity (kg/ha), S_j= area (ha), log a = intercept and b = slope, ε_{ij} = residual error. SE = the standard error, r^2 = proportion of explained variation, ***=p<0.001. No regression was made for the reservoirs in Rajasthan as the data appear to be calculated through a model and not based in observations. The Gandisaghar reservoir and the reservoirs in Himachal Pradesh were excluded from the regression.

Sources: Sugunan, 1995; CIFRI, 2006b.

FIGURE 11
Distribution of estimated productivity in 98 Indo-Gangetic reservoirs in India



Note: Average = arithmetic mean. *Source:* Sugunan, 1995.

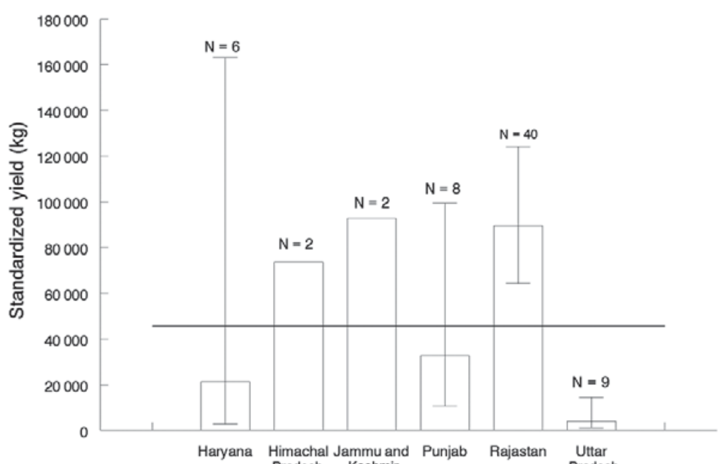
Total production and production by species in reservoirs can be compared directly by standardizing them by surface area. Regression analysis of the $\log_{10}$ transformed total yield against the $\log_{10}$ transformed surface area was significant ($p < 0.001$, $n = 67$, $r^2 = 0.17$) and gave as intercept $a = 3.38$ and a slope of $b = 0.411$. The total catch was standardized to surface area as follows:

$$C_{st} = C \cdot \left(\frac{\overline{area}}{area}\right)^b$$

where C_{st} = standardized yield, C = actual yield, $\overline{area}$ = the average area of 67 IGB reservoirs at full storage level of 1 296 ha, *area* = the actual area of the reservoir at full storage level, and b as calculated. In this way, the standardized yield is independent of the surface area of the reservoir.

Average standardized yields from reservoirs in Haryana, Punjab and Uttar Pradesh were all lower than average, although with a wide range in yields in Haryana and Punjab. Only the yields from Uttar Pradesh reservoirs, at 7 261 kg, were both low and less variable. Standardized yields from reservoirs in Rajasthan averaged 164 865 kg, which was significantly higher than the overall mean yield (Figure 12).

FIGURE 12
Standardized catches from the Indo-Gangetic Basin reservoirs in selected states, showing the geometric mean and 95 percent confidence limits.

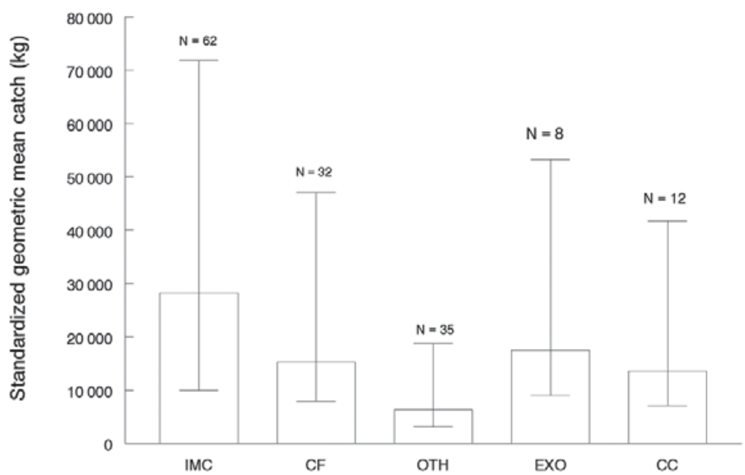


Notes: N = number of reservoirs included in the analysis. The horizontal line is the geometric mean catch over all reservoirs (25 491 kg).

With a standardized average yield of 52 tonnes, Indian major carps generate the highest yield and are caught in almost all reservoirs. In half of the reservoirs, about 28 tonnes of catfishes and 11 tonnes of other species (minor carps and minnows) are caught annually. Exotics are caught in eight reservoirs, averaging 31 tonnes and an average of 26 tonnes of *Cyprinus carpio* are caught in 12 reservoirs (Figure 13). Indian major carps are the most important species in Haryana, Punjab, Rajasthan and Uttar Pradesh. Catfishes are important in Himachal Pradesh, Rajasthan and Uttar Pradesh. In the few reservoirs in Himachal Pradesh and Jammu and Kashmir included in the data set, exotics are an important part of the catch (Figure 14).

FIGURE 13

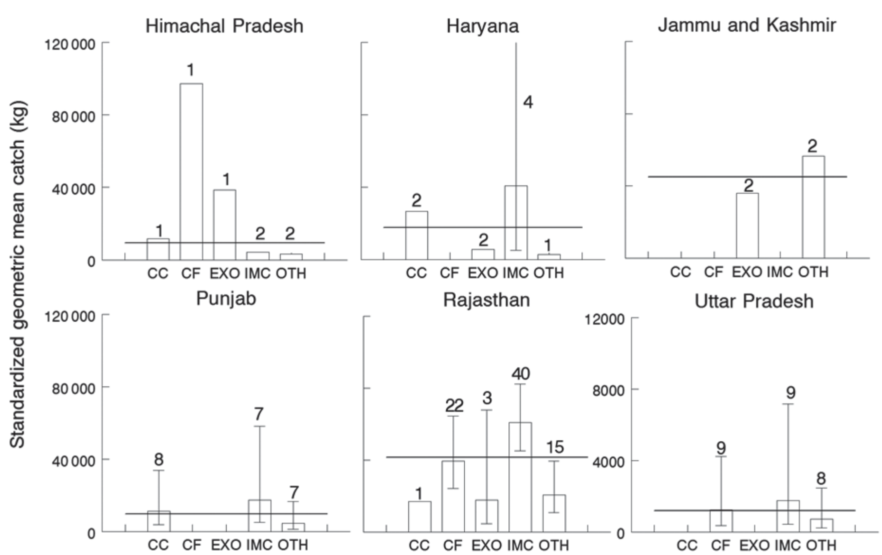
Standardized catch of main species from 67 reservoirs of the Indo-Gangetic Basin, showing the geometric mean standardized yield and the 95 percent confidence limits



Note: CC = *Cyprinus carpio,* CF = catfishes, EXO = exotic, IMC = Indian major carps, N = number of reservoirs, OTH = other (not including mahseer).

FIGURE 14

Standardized catch of main species in 67 reservoirs by state, showing the geometric mean standardized yield and the 95 percent confidence limits



Note: CC = *Cyprinus carpio,* CF = catfishes, EXO = exotic, IMC = Indian major carps, N = number of reservoirs, OTH = other (not including mahseer).

2.6.2 Fishing practices

Reservoirs are mostly fished with nylon twine gillnets, installed at or near the surface because the use of bottom-set nets is constrained by large numbers of submerged trees and other obstacles. The standard gillnet is 40–300 mm stretched mesh, 50 m long and 2 m deep with a head rope, floats and foot rope, with or without sinkers. The most common type is the Rangoon net, an entangling gillnet operated without a foot rope. Another entangling net used in reservoirs is *uduvalai*, which has a reduced fishing height and is usually operated in shallow marginal areas to catch small fish. Drag nets (beach seines or *mahajal* in Uttar Pradesh and Madhya Pradesh) are used in many reservoirs. Other fishing gear include cast nets, scoop nets, longlines, handlines, pole and line and traps, but the catch from them is insignificant compared with that of gillnets and seines. Information on fishing methods was available for 414 of the 609 reservoirs for which data were available in Haryana (23), Himachal Pradesh (5), Jammu and Kashmir (2), Punjab (13), Rajasthan (400) and Uttar Pradesh (166). Of these, 96 percent were fished with drag nets, 92 percent with gillnets, 89 percent with cast nets, 53 percent with hooks and hook and line, and 2 percent with traps.

In most Indian reservoirs, fishing is not very remunerative and no boats are used – the fishers depending entirely on makeshift rafts fabricated out of old tyres, logs, used cans and anything else that floats. Flat-bottomed, locally made boats ranging in length from 3 to 7 m are used in Kyrdemkulai, Hirakud, Malampuzha, Gobindsagar, Gandhisagar and Rihand reservoirs. A flat-bottomed plank canoe 2–3 m in length is the most popular fishing craft at Gandhisagar. At the same reservoir, repatriates from Bangladesh use a Bengal-type dinghy, which is 5–7 m in length and can be rigged with sails. Reservoir fishers, in general, are too poor to invest in boats, and what boats there are have in many cases been purchased with subsidies from the government or funding agencies. Mechanized boats are not used in reservoir fishing to any appreciable extent.

2.6.3 Fishing effort

Limited information is available on fishing effort in IGB reservoirs, whether expressed as numbers of fishers, boats or gear. Effort is often regulated through licensing, royalties or crop-sharing systems but differs from state to state and includes open-access systems as well. A data-collection methodology to obtain catch statistics through a stratified random system was developed and implemented for the whole of India in the period 1971–1985, but has been discontinued in many states. Some data are available for some reservoirs (Figure 15), but they do not include changes in fishing effort over time, precluding analysis of the impacts of fishing effort on fish communities or of the dynamics of fishing effort in relation to changes in reservoir productivity.

Fisher density decreases as reservoir area increases (Figure 15). As the level of fishing technology is generally low fishers may keep to the shore and avoid deeper areas. The focus on benthic cyprinid species would result in such fishing patterns, in which case shoreline length would be a better indicator of fisher density.

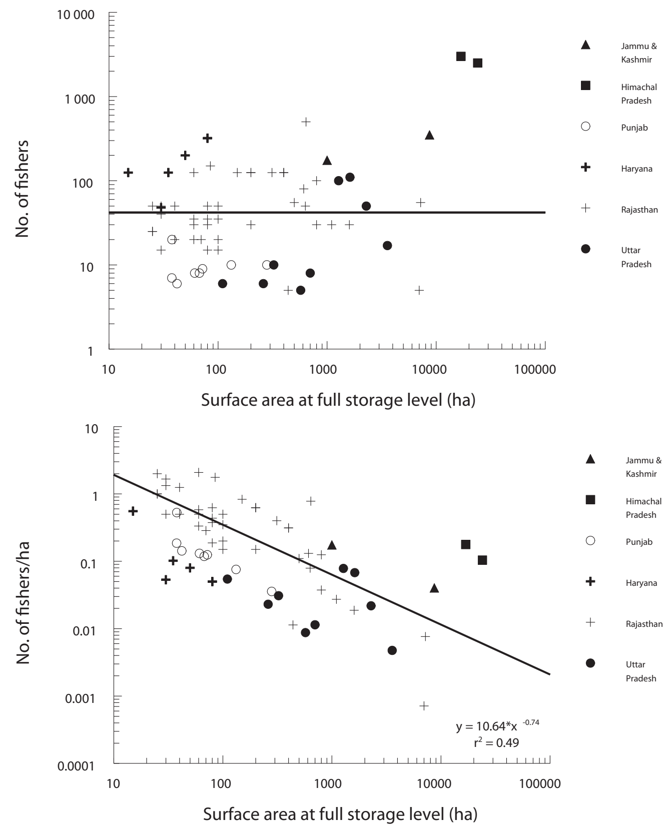
Yield per hectare increases with the density of fishers (Figure 16). However, the marginal returns per fisher fall at higher total yields owing to the increase in fisher density.

Yield is expected to maximize with increased fishing effort. However, no time series of yield and effort is available. As a proxy, the standardized yield (i.e. any relation that does not involve reservoir area) over 67 reservoirs was used and related to the number of fishers per reservoir. Again, no relation between yield and effort was found (Figure 17). Catch rates decrease with increasing effort by almost the inverse of the fishing effort. Catch rates for reservoirs with up to 100 fishers range from 100 kg to 25 tonnes/year, with a median of 2.5 tonnes/year. This is very low in comparison with almost any other freshwater fishery in the world. Reservoirs with more than 100 fishers have a median average catch rate of 0.43 tonnes/year per fisher, or about 1.5 kg/day for 250 fishing days.

Although the data should be treated with caution because it is not clear how reliable they are, this suggests that effort is determined by factors other than total yield, area and reservoir productivity. It could also mean that catch rates are not a driving factor in the distribution of fishing effort. Further, no redistribution of fishing effort to reservoirs with higher productivity seems to take place.

FIGURE 15

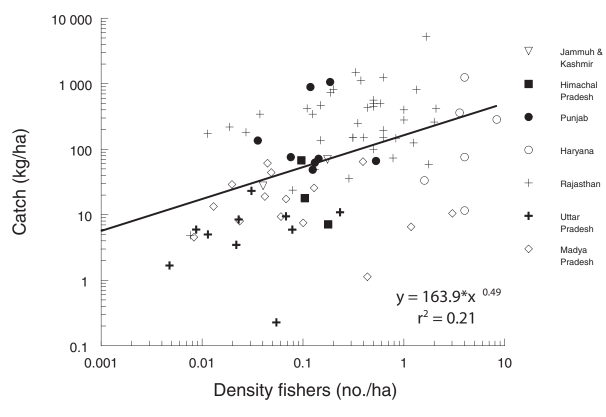
Number and densities of fishers relative to surface area at full storage level of 67 reservoirs in selected Indo-Gangetic Basin states



Notes: No significant relation was found between the two variables. The horizontal line is the geometric mean of all fishers over 67 reservoirs (42). The arithmetic mean = 152 fishers. The regression line is $\log_{10} DF_{ij} = \log_{10} a + b. \log_{10} S_i + \varepsilon_{ij}$, where DF_{ij} = density of fishers, S_i = area, log a = intercept and b = slope. The result is transformed to its corresponding power function, r^2 = proportion of explained variation, $p < 0.001$.

FIGURE 16

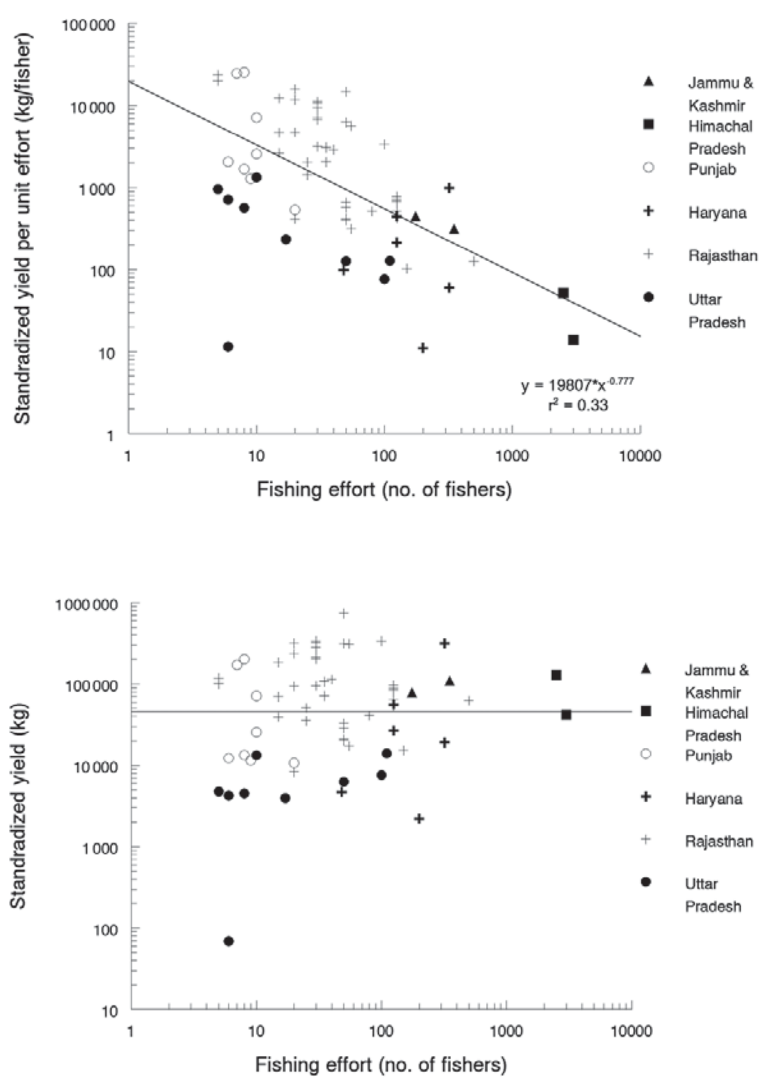
Density of fishers in relation to yield per area or productivity in 84 Indo-Gangetic Basin reservoirs



Source: CIFRI, 2006a.

A possible explanation for the extremely low production per unit area is overexploitation resulting from high effort relative to the production potential of IGB reservoirs. No information was available on this. Outside the IGB states, for example, in Ukai reservoir which has an area of 36 525 ha, 306 boats with 3 400 gillnets, each measuring 50 m, operated from 1982/83 to 1985/86. In a fishing year of 260 days, 1 836 fishers netted 174 tonnes of fish, or less than 0.1 tonnes per fisher per year. This amounts to 400 g of fish per fisher per day. The 520 fishers at Nagarjunasagar reservoir were slightly better off, as they shared a catch of 170 tonnes, or 0.3 tonnes per fisher per year. In lower Aliyar, 17 tonnes of fish were harvested by 14 fishers, which amounted to about 1.2 tonnes per fisher per year. After meeting the royalty obligations of the fishing permit, each fisher could take home only Rs1 000–1 400 (US$20–30) per year. In contrast, the 80 fishers at Bhavanisagar reservoir shared 150–300 tonnes of fish, or 2–4 tonnes per fisher per year, earning each fisher an annual income of Rs8 175 (about US$1 600) (Paul and Sugunan, 1983).

FIGURE 17
Standardized yield and standardized yield per fisher



Notes: Weight corrected for lake area; mean = 24 700 kg.

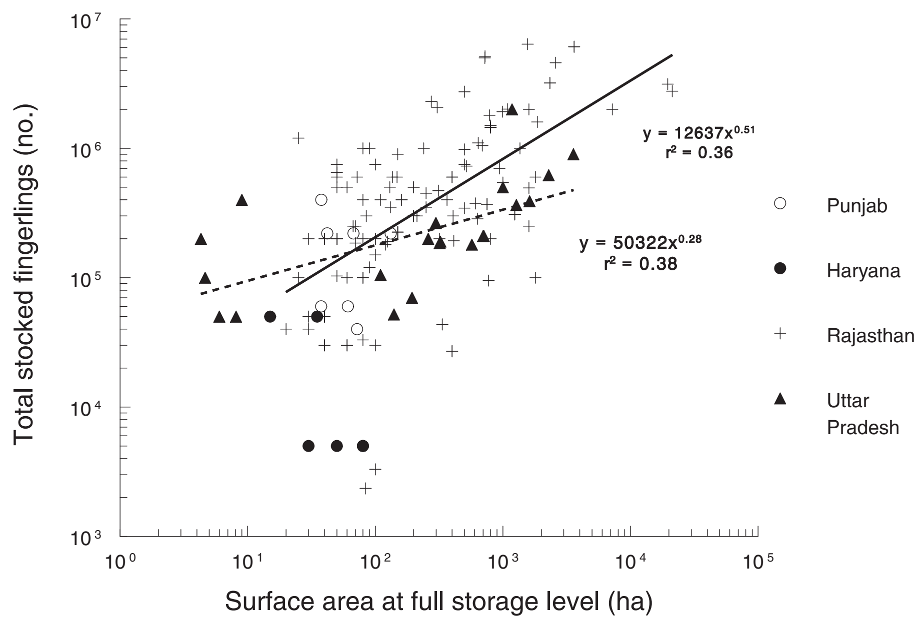
2.7 MANAGEMENT PRACTICES

2.7.1 Stocking and technical management

Various fisheries management measures are implemented in the numerous reservoirs of the country, including the selection of species for stocking, stocking rate and the introduction of exotic species. The Indian major carps *Catla catla*, *Labeo rohita* and *Cirrhinus cirrhosus* are stocked at a rate of 300–1 000 fish of length 100–120 mm per hectare. The growing period in the reservoir varies according to the recapture rate of stocked fish. Stocking increases the fish yield in reservoirs by many times. Feeding and fertilization are not practised in any reservoir.

In the Ganges system, the formation of reservoirs has adversely affected indigenous stocks of the mahseers, snow trouts, *Labeo dero* and *L. dyocheilus* in Himalayan streams. In some instances, mahseer and snow trout breeding and nursery habitats are protected. Sugunan (1995) assessed the impact of stocking on fish production and indigenous fauna diversity. Table 11 summarizes aspects of reservoir fisheries and management for a selection of those important reservoirs. The stocking rate increases proportionately with the reservoir surface area in Rajasthan and Uttar Pradesh, but no relation was found in Haryana, and stocking rates appear to decrease with increasing reservoir area in Haryana. In Rajasthan and Uttar Pradesh, stocking rates also increase with the square root of the reservoir area, indicating that smaller reservoirs have relatively higher stocking rates per unit area (Figure 18).

FIGURE 18
Number of stocked fingerlings related to surface area



Note: Significant correlation in Rajasthan (unbroken line, $p < 0.001$) and Uttar Pradesh ($p < 0.01$) (broken line).

Fisheries were developed in most reservoirs only after construction and there were no provisions for facilitating fisheries or management during their planning. Even simple measures such as removing trees and other obstacles were generally not implemented (Katiha, 1994). An important constraint on reservoir productivity is the absence of fish species that are adapted to the reservoir environment. The fish naturally present when a dam is built, being primarily riverine species, may not be able to adapt very well to the highly variable water levels, the often stratified temperature and oxygen regimes and the generally lacustrine food webs of reservoir environments (Fernando and Holcik, 1991). Therefore, largely for economic and consumer-preference reasons, Indian reservoirs have been stocked with valuable Indo-Gangetic carps for many

TABLE 11
Fishery description, productivity, and management in selected reservoirs in the Indo-Gangetic Basin

State	Reservoir	Area (ha)	Species (% in catch)	Productivity	Management	Reference
Jammu and Kashmir	Salal	1 000	*Tor putitora, Schizothorax* sp., *Cyprinus carpio, Crossocheilus* sp., *Labeo* spp., *Mystus* spp., *Nemacheilus* sp., *Glyptothorax* sp.		Stocking of *T. putitora* fingerlings	Angchook and Dogra, 2006
	Ranjit Sagar	8 700	*T. putitora* (40%), *C. carpio* (35%), *Labeo* spp. (19%), miscellaneous (6%)		Stocking of IMC	Angchook and Dogra, 2006
Himachal Pradesh	Gobindsagar	16 867	*Hypophthalmichthys molitrix* (80%)	17 kg/ha (1975), 96.4 kg/ha (1992/93)	Cage rearing of seed and stocking of IMC	Sugunan, 1995
	Pong	24 629	*Aorichthys seenghala* (275 tonnes, 57% of catch in 2000), *Labeo rohita*, *Labeo calbasu*, *T. putitora*, *C. carpio*	53 kg/ha (1987)	Stocking of common carp and IMC	CIFRI, 2007
	Chamera	900	*C. carpio*, *T. putitora*	24.7 kg/ha (1994)	Introduction of common carp & mahseer, protection of breeding grounds, ban on brood and juvenile fishing, prohibition of small-mesh nets	CIFRI, 2003b
	Pandoh	200	*Salmo trutta fario*, *Labeo dero*, *Labeo dyocheilus*, *T. putitora*		Stocking of common carp	Sugunan, 1995
Punjab	Several reservoirs		*C. carpio*, *Ctenopharyngodon idella*, *L. rohita*, *Cirrhinus cirrhosus*, *Labeo calbasu*, *Schizothorax plagiostomus*, *H. molitrix*, *T. putitora*, *L. dero*, *Labeo bata*, *Clupisoma garua* and *Puntius* spp.	10–70 kg/ha		CIFRI, 2004c
Rajasthan	Several reservoirs	407–3 618	Major carps, minor carps, catfishes	7.0–46.9 tonnes/year (14.9–172.3 kg/ha) in 1997–2002	Enhancement through stocking	CIFRI, 2001 and 2004d
	Ramgargh	1 260	*C. cirrhosus* (33%), *Catla catla* (15%), *L. rohita* (14%), plus *Notopterus notopterus*, *L. bata*, *Puntius sarana*	18–141 (average 77.8) kg/ha in 1969–1985	Stocking of IMC	Jhingran, 1989
	Jaisamand	7 286	*L. rohita*, *C. cirrhosus*, *A. seenghala*, *Labeo fimbriatus*	47.2–88.8 kg/ha in 1970–72	Intensive stocking of IMC to bring down tilapia population	Jhingran, 1989
Uttar Pradesh	Rihand	46 538	*C. catla* (73–99% in 1971–1980	25–329 tonnes/year, maximum 11 kg/ha, potential of 40 kg/ha	Stocking of IMC (catla, rohu & mrigal) for stock diversification. Regular monitoring of fish yield & fishing effort. Mesh regulation and closed fishing season	CIFRI, 1981, Sugunan, 1995

Note: IMC = Indian major carps (*Catla catla*, *Labeo rohita*, *Cirrhinus cirrhosus* and *Labeo calbasu*); local major = large catfish; local minor = small carps and small catfish.

TABLE 11 (*cont.*)

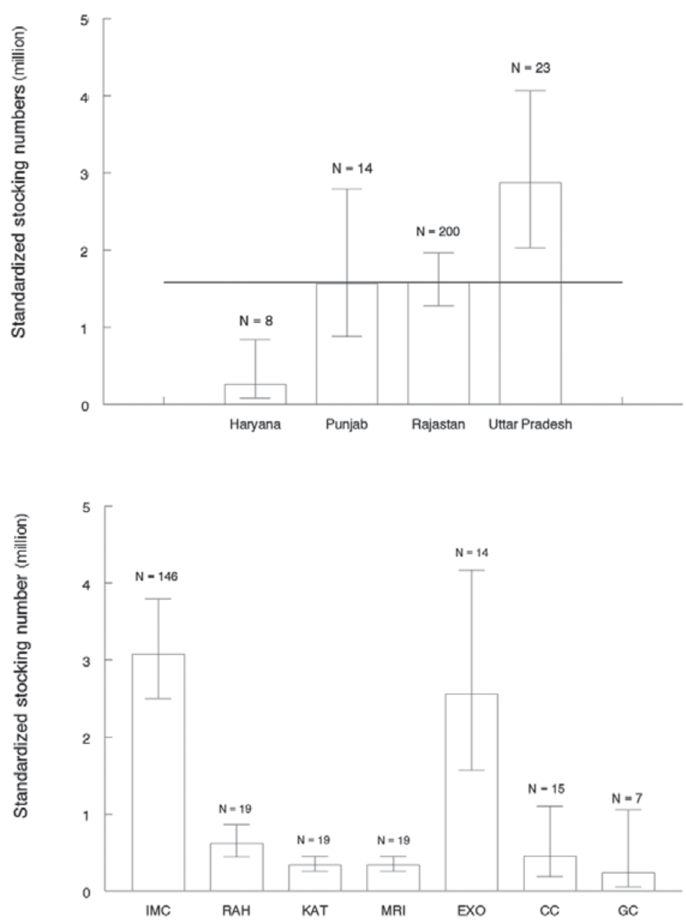
State	Reservoir	Area (ha)	Species (% in catch)	Productivity	Management	Reference
	Gulariya	300	*C. catla*, *L. rohita*, *C. cirrhosus*, *L. calbasu*, minor carps, catfishes	22 tonnes (150 kg/ha), potential 234 kg/ha	Regular stocking of IMC	Sugunan, 1995
	Bachhra	140	Carps, catfishes, minnows	10 tonnes/year (139 kg/ha), potential of 240 kg/ha	Contract commercial fishing through auction	Sugunan, 1995
	Baghla	250	Carps, catfishes, minnows	7 tonnes/year (106 kg/ha), potential of 210 kg/ha	Contract commercial fishing through auction	Sugunan, 1995
	Pahuj	518	IMC, local major, local minor, minnows	64 tonnes/year or 123 kg/ha, potential of 300 kg/ha	Stocking of IMC and continuous follow up of fishery enhancements and institutional interventions	Katiha *et al.*, 2007
Uttaranchal	Baigul	2 995	*Gudusia chapra*, *Labeo gonius*, catfishes, minor carps, (limited amount of major carps)	20 kg/ha	Stocking of IMC	Chauhan, 2007
Madhya Pradesh	Gandhisagar	66 000	*C. catla* (60–70%), *L. rohita*, *C. cirrhosus*	1 676–3 424 tonnes/year (26–52 kg/ha)	Stocking of IMC with greater emphasis on *Catla*. Mesh regulation and strict observance of closed season	Kartha and Rao, 1993
	Halali	7 712	Local minor (36.3%), local major (30.9%), IMC (17.3%): *C. catla* (9.0%), *L. rohita* (6.4%), *C. cirrhosus* (1.9%), minnows (15.5%)	73.5–350.7 tonnes (15–73 kg/ha) average 193.8 tonnes (40 kg/ha) in 1990–2001	Contract and departmental fishing, stocking of IMC	CIFRI, 2003a
	Kerwa	482	IMC, medium-sized carps, small catfishes, minnows, *Tor* spp.	31–72 kg/ha, potential of 545 kg/ha	Stocking and culture of mahseers	CIFRI, 2003a
	Gobindgarh	307	90% of catch is *C. catla*, *L. rohita*, *C. cirrhosus*, *Tor tor*	0.4–26.4 kg/ha (average 15.9 kg/ha)	Stocking of IMC	Srivastava *et al.*, 1985; Sugunan, 1995
	Kulgarhi	193	*C. catla* (75.6%), *C. cirrhosus* (11.5%), *L. rohita* (8.3%), carp hybrids (2.5%)	7.4 kg/ha	Stocking of silver carp (*H. molitrix*)	Dwivedi, Karamchandani & Joshi, 1986
	Dahod	460	IMC, local major, local minor, minnows	25 tonnes/year or 65 kg/ha, potential of 285 kg/ha	Stocking of grass carp (*Ctenopharyngodon idella*) and IMC and regular monitoring and improvement of fishery enhancements and institutional interventions	Vass *et al.*, 2008

Note: IMC = Indian major carps (*Catla catla*, *Labeo rohita*, *Cirrhinus cirrhosus* and *Labeo calbasu*); local major = large catfish; local minor = small carps and small catfish.

decades, and fish production from the reservoirs depends heavily on various types of enhancement.

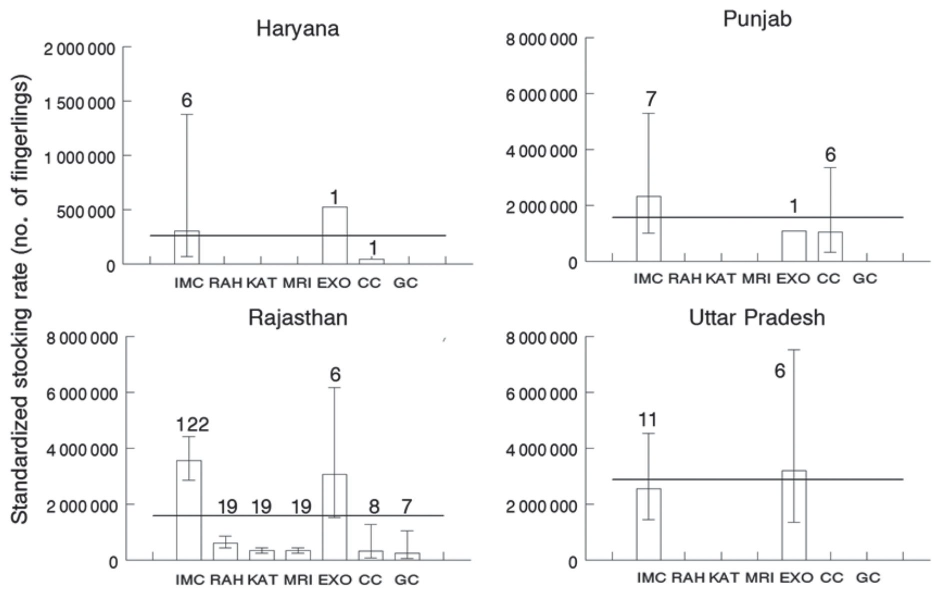
Stocking rates had a significant positive relation to surface area, so these were standardized according to the same equation as for yields (see p. 23). In this case, $a = 4.11$ and $b = 0.58$ ($r^2 = 0.35$, $p < 0.001$) and average area = 1 296 ha to enable direct comparison of stocking rates by species and between states. Stocking rates of all species are about 2 900 000 fingerlings per species, but higher in Uttar Pradesh than in the other states for which information was available (Figures 19 and 20). In Haryana, the geometric mean stocking rate was one-tenth as high. Indian major carps are stocked in 60 percent of the reservoirs examined, with the highest geometric mean stocking rate of about 3 000 000 fingerlings. Common management measures employed elsewhere in the world, such as control of effort, gear restrictions and protected areas, are not commonly seen as options for improving productivity. Indian IGB experience to date suggests that large and medium-sized reservoirs are most productively managed only through stocking and regulating capture fisheries, while production from small reservoirs is easier to maximize through aquaculture (e.g. cages).

FIGURE 19
Standardized stocking rate (number of fingerlings) by state and by species in 245 reservoirs, showing geometric mean and 95 percent confidence interval



Note: EXO = exotics, CC = common carp, GC = grass carp, IMC = Indian major carps, ROH = *Labeo rohita,* KAT = *Catla catla,* MRL = *C. cirrhosus*, N = number of occurrences.

FIGURE 20
Standardized stocking rate in 245 reservoirs by species category and state, showing geometric mean and 95 percent confidence interval



Note: EXO = exotics, CC = common carp, GC = grass carp, IMC = Indian major carps, ROH = *Labeo rohita*, KAT = *Catla catla,* MRI = *Cirrhinus cirrhosus*, N = number of occurrences.

There is a need to dovetail the twin objectives of conservation and yield optimization over the short term in reservoir fishery management. While fishers and fish merchants strive to increase production for economic gain, it is the responsibility of the State to ensure that economic expediency does not cause ecological collapse or loss of important biodiversity (Sugunan, 1995). Managing reservoirs for what are virtually open-access fisheries may be counterproductive from conservation and yield optimization points of view, but this often serves to support the safety net function of small-scale fisheries.

2.7.2 Socio-economic and institutional settings

With very few exceptions, reservoirs in India are public waterbodies owned by government departments, such as those responsible for irrigation and power generation. There is a great deal of variation in the management practices followed by different states, ranging from outright auctioning of licences to almost free fishing. In many cases, the management of fisheries is transferred to the state fisheries department, either by paying a nominal royalty (e.g. Rihand in Uttar Pradesh and Kansbati in West Bengal) or freely (Gobindsagar and Pong Dam in Himachal Pradesh) (Sinha and Katiha, 2002). In some cases, fishing rights are further transferred to another government entity, cooperative or private agency. In particular, public companies have been promoted by many of the states and styled as fishery-development corporations, but these have not functioned effectively (Sugunan, 1995). In some states, such as Madhya Pradesh and Himachal Pradesh, fishery development corporations act as overseeing bodies for the numerous cooperative societies that work in reservoirs and undertake marketing functions to ensure that fishers receive the right price for their catch, often with mixed results. Cooperative societies and state-level fishery-development corporations are also involved in fishing and marketing operations. The nature of their involvement and their role in fishery and market interventions often varies from one reservoir to another within the same state.

Reservoir fishers are among the weakest groups in Indian society and are heavily assisted by the government (Sugunan, 1995). Normally, fisheries departments stock reservoirs free of charge and offer a number of loans and subsidies to fishers for procuring nets and boats. The value of subsidies and the nature and terms of the loans vary from state to state. However, the general intent of the policy is to make fishing virtually open access and to use fisheries to achieve broader social welfare objectives, sometimes to the detriment of the fishery (Katiha, 2002). Free licences are issued to fishers in a number of large reservoirs, although the local assistant director or deputy director determines the number of fishers, sets mesh regulations and controls seasonal closures. In most cases, the department exerts its control over exploitation largely through its role in marketing.

The commercial exploitation systems operated by the different states usually adopt one of the four following options: (i) departmental fishing; (ii) lease by auction; (iii) issuance of licences for fishing; or (iv) royalties or sharecropping. Direct departmental fishing is generally uneconomical and practised in very few reservoirs, except for experimental or exploratory purposes. Among the most important institutional arrangements for exploiting fisheries in reservoirs are various leasing systems based on trends in fish production, income and expenditure of the department, fishers' socio-economic conditions, government policy towards cooperatives and, especially, the status of states' fishery resources. In Madhya Pradesh, Rajasthan and Uttar Pradesh, small reservoirs are leased on an annual basis. In Rajasthan and Uttar Pradesh, small reservoirs are leased every year, medium-sized reservoirs for three years, large reservoirs for five years, and very large reservoirs (> 1 000 ha) for ten years. In Madhya Pradesh, reservoirs smaller than 100 ha are under the management of the local administrative authority (*gram panchayat*); those with areas of 100–1 000 ha are under the Department of Fisheries and those larger than 1 000 ha are under the State Fisheries Corporation.

In general, reservoirs entrusted to state agencies for monitoring and stocking consistently maintain higher yields than those under private control. Fishery cooperatives have been successful when they have engaged expertise to help manage stocking and harvesting. Institutional weaknesses are largely responsible for the lack of reliable fish catch statistics or yield estimates upon which improved reservoir management systems could be based. These weaknesses are, in particular:

- the multiplicity of state agencies involved, many of which have no interest or capacity in data collection or management;
- highly scattered and unorganized market channels, mostly under the control of illegal and often unscrupulous money lenders;
- ineffective cooperatives and local ownership and management schemes;
- diverse licensing, royalty and crop-sharing systems;
- inadequate and poorly trained human resources at all levels.

In India, reservoir fisheries are basically managed following the logic of common property. As in rivers, lakes and seas, biological wealth is considered nature's endowment and the State's intervention in developmental activities should benefit, first and foremost, the poor fishers who toil there. Investments in developing reservoir fisheries are viewed in light of the social benefits that accrue to low-income communities in the form of rehabilitating displaced populations, improving the living conditions of fishers and providing jobs. Although it is possible to link reservoir fishery development with poverty alleviation programmes, limited opportunities exist for creating additional alternative employment around most Indian reservoirs (Paul and Sugunan, 1990) and the progress made so far in this direction is not encouraging.

2.8 PROPOSED ACTION PLAN

Measures suggested for increasing the yield and area of reservoirs under fisheries management are as follows:

- As the real value of the many services provided by reservoirs (e.g. irrigation, livestock, fisheries, electricity, aesthetics) is much higher than the monetary value of its tangible products, reservoir projects should be evaluated through social and cost–benefit analysis instead of simple economic analysis. An appraisal of, and rationalization programme for, the present plethora of state policies concerning ownership, fishing rights, fisheries management, leasing, etc., suggests that it would be an improvement to optimize reservoir fisheries in light of the multistakeholder nature of these assets.
- Appropriate guidelines should be provided on stocking and other management and enhancement measures, as well as infrastructure support to provide the needed quality and quantity of fish seed. Appropriately trained and supported technical assistance is a key aspect of this.
- A fisheries information system is needed, including a catch and effort database to assist in evaluating the effectiveness of measures, including stocking and other enhancement practices.
- Guidelines should be developed for including expected fishery management when planning proposed reservoirs.

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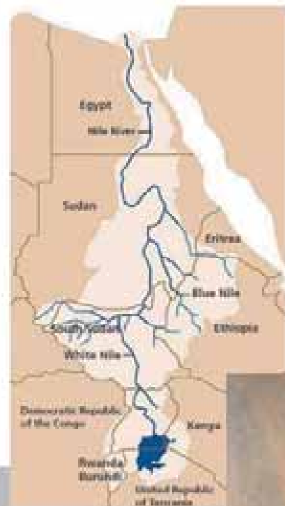
3. Lake Nasser, Egypt



Courtesy: M. Gwyther-Jones (www.flickr.com/photos).

Courtesy: Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center.

3.1 INTRODUCTION TO THE LAKE NASSER REVIEW

Although Lake Nasser reservoir in Egypt is the main focus of this review, the first few sections include information on the Nile Basin's geographic, physical, hydrological and chemical features and limnological characteristics, and discuss present and potential fishery production including aquaculture. The review also discusses the socio-economic setting of the use of the reservoir, identifies gaps in information and provides recommendations for future work. The inventory data contained in this report were collected from primary literature, working reports of the Fishery Management Center and the Lake Nasser Development Authority (LNDA), as well as from government agencies and local fishery cooperatives.[2] The section on primary production is based on Teodoru, Wüest and Wehrli (2006).

[2] Cross-checking information made available in an earlier draft was possible only to a limited extent, as many of the data and literature used were not available to the editors. The reader is referred to various authors of the references cited for further information.

3.2 PHYSICAL FEATURES

3.2.1 Geographical location

The Aswan High Dam Reservoir is the second-largest artificial lake in Africa (Plate 1). Construction of the High Dam at Aswan began in 1959 and was finally completed in 1970. Aswan is a settlement on the first cataract of the Nile River in Egypt. Two dams straddle the river at this point: the newer Aswan High Dam and the older Aswan Low Dam (Plate 2). The Aswan High Dam was built nearly 9 km south (i.e. upstream) of the old dam. The High Dam is a rock-fill dam made of granite and sand, with a vertical cut-off wall consisting of impermeable clay. It is 3 600 m long, 980 m wide at the base, 40 m wide at the crest and 111 m tall. It contains 43 million m^3 of material. At maximum flow, 11 000 m^3 of water can pass through the dam every second.

The reservoir behind the High Dam is about 500 km long and 35 km wide at its widest point, near the Tropic of Cancer. It covers a surface area of 5 237 km^2 at 182 m water level and has a storage capacity of some 150–165 km^3 of water (Latif, 1979; El-Gohary, 1989). The reservoir is partitioned into Lake Nasser in Egypt (about 300 km long) and Lake Nubia (196 km long) to the south in the Sudan. It is confined between latitudes 23°58'N at the High Dam and 20°27'N at the Dal Cataract in the Sudan and between longitudes 30°07'E and 33°15'E. The reservoir is usually divided into three regions: (i) the riverine southern part; (ii) the lacustrine northern part; and (iii) a region in between that has riverine conditions during the flood season and lacustrine characteristics in the remainder of the year (Latif, 1977).

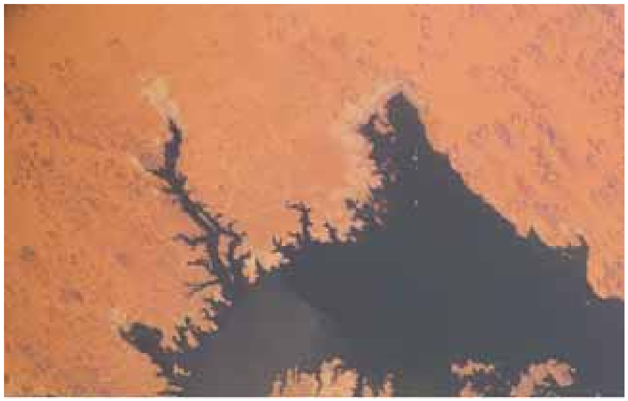
The presence of numerous dendritic inlets, or side extensions of the reservoir, known as *khors*, is an important feature of Lake Nasser. These are also important fishing areas (Plate 1). There are 85 *khors*, 48 of which are located on the eastern side of the reservoir. *Khors* that have perimeters of more than 100 km at a water level of 180 m are: Khor Kalabsha, Wadi El-Allaqi, Kurkur, Korosko, Khor El-Birba (El-Ramla), Rahma, Dihmit, Shaturma, Wadi Abyad, Mariya, Masmas, Tushka and Khor Or (Latif, 1974a). The existence of the *khors* greatly increases the length of the shore, which is estimated at 8 700 km. The Tushka Canal links the reservoir to the Tushka Depression (Plates 2 and 3). Floodwaters entered the depression in 1998 for the first time and filled it in 2000, greatly expanding the original reservoir by 25–30 percent and adding new fishing grounds.

3.2.2 Sedimentation

Lake Nasser is now steadily filling with about 100 million tonnes of sediment each year that formerly reached the Nile Delta flowing into the Mediterranean Sea. The current locus of deposition is far upstream of the High Dam and does not immediately threaten the operation of the power station. However, the reservoir will be filled within less than a millennium to the point that it may no longer be useful for storing irrigation water. Estimates suggest that almost half of the current value of irrigation water storage of Lake Nasser will have been lost within about 600 years. The sediment quantities are so huge that removal is not feasible with current technology. The largest sediment-dredging operations to maintain harbours, such as New York City harbour, are one or two orders of magnitude smaller than would be required to remove the annual influx of sediment into Lake Nasser. At present, there appears to be no plausible solution to this problem.

PLATE 1

Numerous dendritic inlets known as khors greatly enhance the perimeter of the reservoir and are an important feature of Lake Nasser



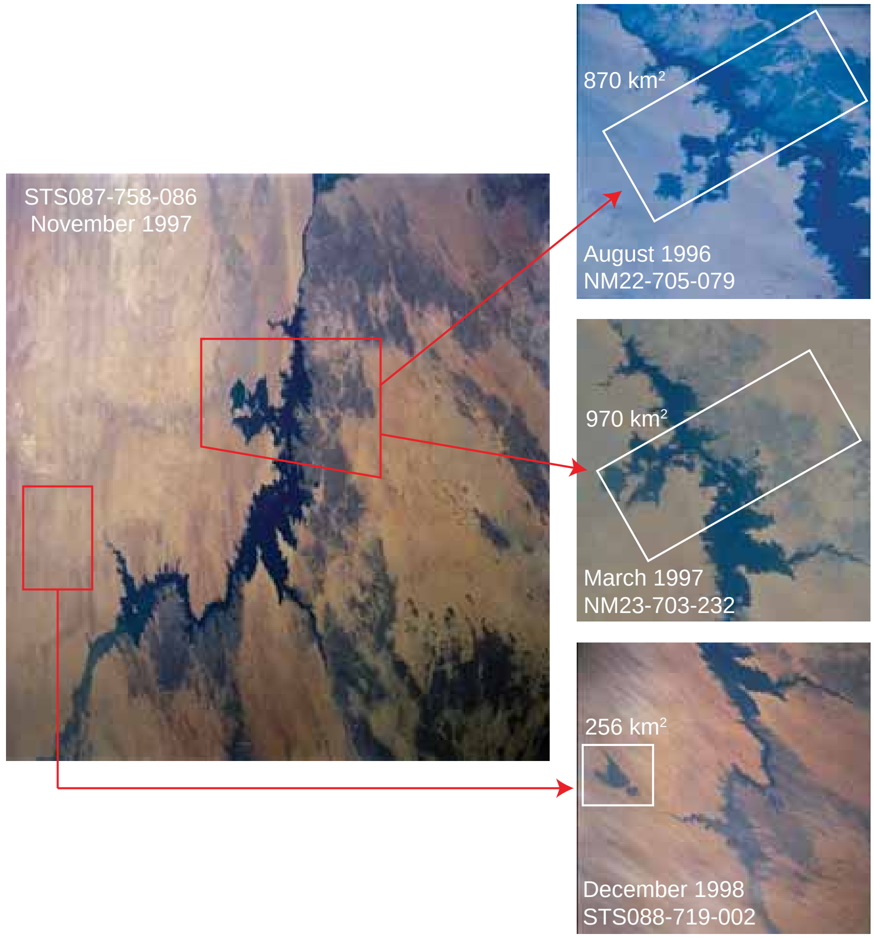
Notes: Top: dry season, note the presence of a floodplain, Botton: flood season.
Source: Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center.

PLATE 2

The photograph shows the two dams on the Nile at Aswan: Aswan High Dam, a rock-fill dam completed in 1970, and Aswan Low Dam constructed in 1902

Source: Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center, image modified from ESC_large_ ISS022_ISS022-E-92674.

PLATE 3
Lake Nasser and New Valley development in the Tushka Depression. Photo STS087-758-086 is an oblique view of most of Lake Nasser in November 1997. Water from Lake Nasser eventually may spill over into the lowlands to the west of the reservoir. Photos NM22-705-079 and NM23-703-232 compare water levels in the same section of central Lake Nasser in August 1996 and March 1997



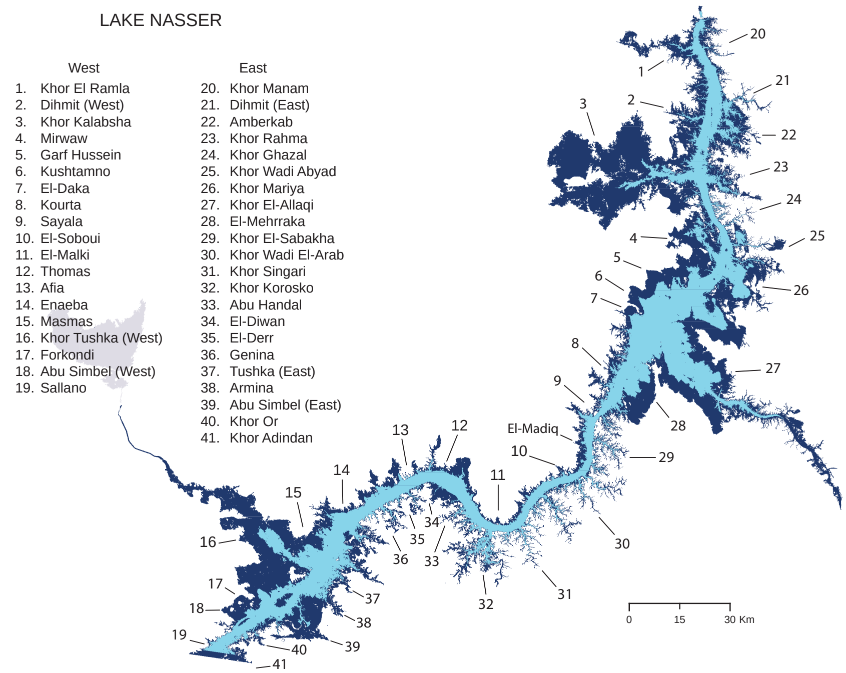
Source: Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center.

3.2.3 Physical features of the reservoir

Lake Nasser has a gross capacity of 169 km^3 of water. It reached its operating level of 175 m above mean sea level in 1975, storing 121.3 km^3 of water, of which 31.6 km^3 is dead storage. The depth of the reservoir varies from 112 m at Aswan High Dam to 45 m at Arkeen in the south, the deepest part is the ancient river bed. The mean depth of this central part gradually increases from 10 m at the southern end to 70 m in the north. Water flows at 100–150 cm/s at the southern, Nubian end of the reservoir, gradually reducing its speed within a few kilometres to 10–20 cm/s and, upon reaching Lake Nasser, 0–3 cm/s. After the rise in reservoir level around 1997, the New Valley Project was implemented, tapping Lake Nasser from the west and transporting water into a formerly barren wadi known as the Tushka Depression (not visible before June 1998). (Figure 21 shows reservoir area at minimum and maximum water levels).

FIGURE 21

Extent of Lake Nasser at minimum and maximum flood levels, main fishing areas and khors



Notes: The light blue colour shows the extent of the reservoir in March 1988, the lowest water level on record was reached that year in July at 150.6 m above sea level. Dark blue represents the area flooded in November 1998 when the highest water level of 181.3 m (above sea level) was reached.
Source: Created based on images provided by the Unites States Geological Survey (www.usgs.gov/).

3.2.4 Bottom substrate

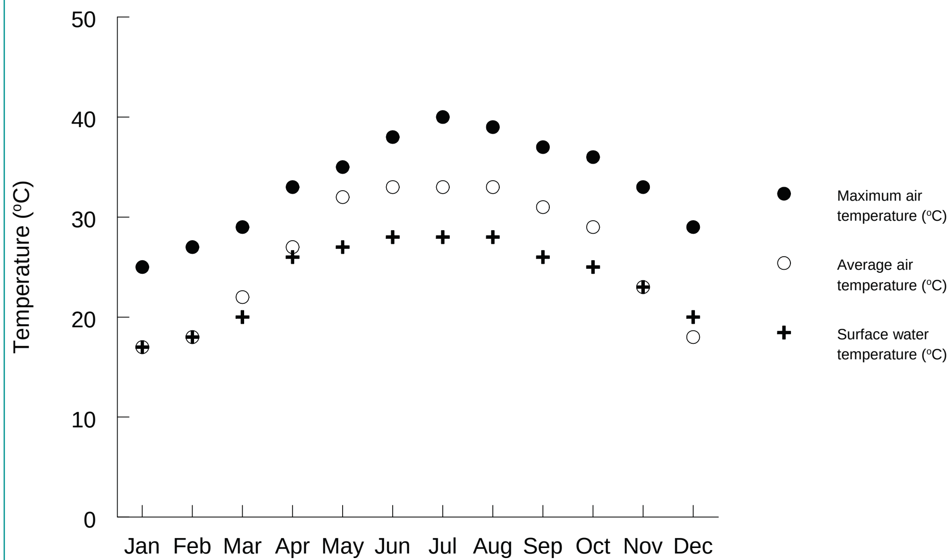
The bottom sediments of Lake Nasser are mainly silty clay and clayey silt, while the eastern and western sides are sandier. The highest percentage of mud was recorded in the main channel in the south near Tushka, Abu Simbel and Adindan (Fishar, 1995). Entz and Latif (1974) related the darkest-coloured sediments to relatively old deposits and the anoxic conditions during the summer stagnant period, which lasts longest near the High Dam and shortens in duration towards the south. The light colour, on the other hand, was attributed to freshly sedimented silt with little organic matter. Heavier and coarser parts of the suspended material are deposited in Lake Nubia, especially at its entrance, while the finer fractions settle in the Egyptian part of the reservoir (Higazy, Elewa and El-Rahman, 1986).

3.2.5 Meteorology and evaporation

The climate of the reservoir region is classified as subtropical, hot, very dry desert. From mid-October to April, evenings can be cold and night-time temperatures may drop to 8 °C. Day-time temperatures from April to June are similar to a warm summer in Europe. From June to September, the weather is dry and hot, with midday temperatures of 30–35 °C. The hottest months are August and September, when the temperature can surpass 40 °C. On the reservoir, the temperature is always a few degrees lower owing to the cooling effect of the large body of water (Figure 22) (El-Bakry, 1993; Abd Ellah, 1995, 2004a). Prevailing winds are northerly all year, strongest in autumn and winter. Recorded wind speeds vary between 2.7–4.7 m/s. The average wind speed in the southern part is 2 percent slower than in the north (El-Bakry, 1993).

The high humidity in the southern part of the reservoir is attributed to its exposure to northerly winds having passed over the water surface. Humidity over the reservoir increases to 50 percent during the cold season in December and decreases to 27 percent in July during the warm season (El-Bakry, 1993; Abd Ellah, 1995). Considerable amounts of water are lost to evaporation, which averages about 7.3 mm/day (2.7 m/year), removing 9.115 km^3 of water per year, or 12 percent of the reservoir volume (Abd Ellah, 1995). The average rate of evaporation in the northern part of the reservoir is higher than in the south (Omer and El-Bakry, 1970; El-Shahawy, 1975; El-Bakry and Metwally, 1982; El-Bakry, 1993; Abd Ellah, 1995).

FIGURE 22
Maximum and average air temperature over Lake Nasser and average surface water temperature



3.2.6 Water temperature and thermal stratification

In summer, the surface water temperature of Lake Nasser increases, often reaching 28–31 °C. During this period, differences in temperature between surface and bottom water can reach 18 °C (Latif, 1977). Thermal stratification is maximal, with the temperature difference between surface and near bottom water (T_s–T_b) ranging between 8.7 °C and 17.6 °C (average 11.9 °C). In autumn and winter, stratification breaks down as the air temperature drops and warmer floodwaters arrive from the highlands of Ethiopia (Elewa, 1987; El-Shahawy, 1975, Abd Ellah, 2004a). T_s–T_b ranges between 0.38–2.94 °C, with an average of 1.7 °C. In autumn, T_s–T_b values vary between 3.3 °C and 10.2 °C (average 7.3 °C) (Belal, 1992). Surface water temperature in the southern section of the reservoir is higher than in the northern section (El-Bakry, 1993). Seasonal averages ranged from 14.1 °C in February to 21.1 °C in August (Saad and Goma, 1994; Abd Ellah, 2004a).

3.2.7 Transparency

The transparency of the Lake Nasser is affected by three important factors: (i) inflowing turbid water of the Nile River; (ii) development of phytoplankton; and (iii) vertical water movement caused by wind. The inflowing water of the Nile River is very turbid, especially during the flood period, and its rich load of suspended inorganic and organic matter is brownish-grey. On the arrival of the flood into the reservoir, the Secchi disc depth diminishes within a few hours from 70–140 cm to 20–30 cm or even to 5–10 cm. The border zone between turbid floodwater and old reservoir water is sometimes very sharp.

As the flood progresses, continuous sedimentation takes place within the reservoir, accompanied by gradually reduced turbidity. Ultimately, the visible borderline between floodwater and old reservoir water disappears. In areas where sedimentation is already completed, there is permanent high Secchi disc depth in deeper waters of about 300–600 cm. In these areas, the transparency of the epilimnion is controlled mainly by phytoplankton. From December to February, Secchi disc depth ranges between 200 and 400 cm. As soon as algal development starts, usually in March or April, the Secchi disc depth reduces to 80–130 cm, or even as low as 50–70 cm in dense algal blooms.

3.3 HYDROLOGICAL FEATURES

3.3.1 Water balance in the basin

The Aswan natural inflow is an estimated figure for the inflow that would arrive at Aswan were no water to be extracted in the Sudan. According to the 1959 treaty between the Sudan and Egypt, the average Aswan natural flow is 84 km^3/year, of which 18.5 km^3 is allocated to the Sudan and 55.5 km^3 to Egypt. Some 10 km^3 is assumed to be lost to evaporation. Water released from Lake Nasser is Egypt's annual share of the Nile River discharge as agreed by international conventions. Additional volume may be released for safety reasons, if the water level in the reservoir becomes very high (Latif, 1984a).

The White Nile River, flowing from Lake Victoria to its confluence with the Blue Nile River at Khartoum, is 3 700 km long (Figures 23 and 24). It supplies some 15 percent of the total volume entering Lake Nasser. Lake Victoria is the first natural lake in the Nile system. Rainfall on the lake is almost balanced by surface evaporation, and the outflow of 23 billion m^3 from the lake is mostly from the rivers in its catchment area. Leaving Lake Victoria, the river is also known as the Victoria Nile River. It flows for approximately 500 km, through Lake Kyoga, until it reaches Lake Albert. From Lake Albert, the river is known as the Albert Nile River. It then flows into South Sudan, where it becomes known as the Bahr al Jabal. Throughout this stretch, the White Nile River is a wide, placid stream, often with a narrow fringe of swamps and it loses considerable amounts of water through evaporation and seepage. At the confluence at Lake No with the Bahr el Ghazal, 720 km long, the river becomes known as the Bahr al Abyad, or the White Nile River proper, from the clay suspended in its waters. After 970 km, it joins the Blue Nile River at Khartoum.

The White Nile River provides a regular supply of water to the Nile River throughout the year (Figure 25). More than 80 percent of the inflow comes from the White Nile River during April and May, when the mainstream is at its lowest level. The White Nile River obtains its water equally from the rainfall on the East African Plateau in the previous summer and drainage from southwestern Ethiopia through the Sobat River (consisting of the tributaries the Baro and Pibor Rivers), which enters the mainstream below As-Sudd. The annual flood of the Sobat River is responsible for variations in the level of the White Nile River. Rains swell its upper course at the beginning of April, inundating the 320 km of plains through which the river passes and delay the arrival of the rainwater at its lower reaches until November–December. Relatively small amounts of silt carried by the flood from the Sobat River reach the White Nile River.

Meanwhile, the Blue Nile River, or Bahr al Azraq, springs from Lake Tana in the Ethiopian highlands and flows 1 400–1 600 km to Khartoum, where it joins the White Nile River to form the Nile River (Figure 24). The Blue Nile River plays the major role in the floods of Egypt. In the Sudan, it meets two tributaries – the Ar-Rahad and the Ad-Dindar – both of which also originate in Ethiopia. The flood of the Blue Nile River causes the first floodwaters to reach the central part of the Sudan in May, reaching the maximum in August, after which the level falls again. The rise in water level at Khartoum averages more than 6 m. When the Blue Nile River is in flood, it holds back the water of the White Nile River, turning it into an extensive lake.

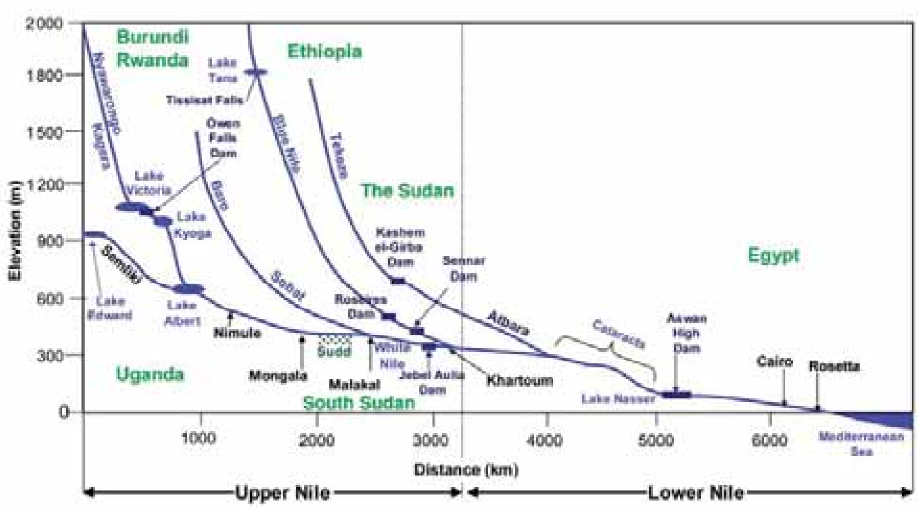
FIGURE 23

The Nile Basin, showing rivers, lakes and dams

Source: Courtesy Mr Pierre Dubeau.

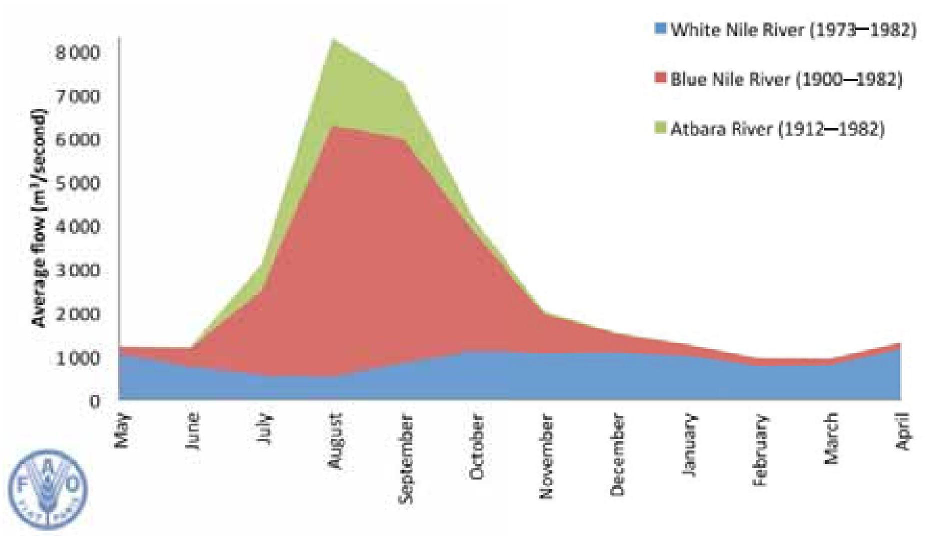
FIGURE 24

Elevation cross-section of the Nile Basin



Source: Adapted from the Nile River Awareness Kit, courtesy Hatfield Consultants Ltd.

FIGURE 25
Average discharge of the main tributaries of the Nile entering Lake Nasser



Source: Drawn based on data available at www.grdc.sr.unh.edu/

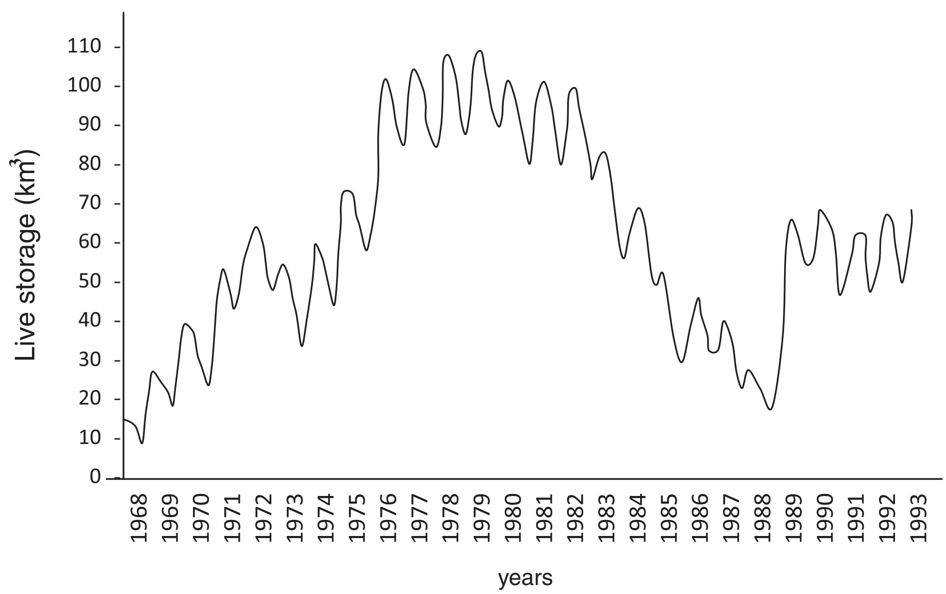
The Atbara River joins the Nile River 300 km below Khartoum and is the last major tributary of the Nile River. It originates in Ethiopia north of Lake Tana and is 800 km long. The Atbara River draws its floodwater from rain on the northern part of the Ethiopian Plateau, but it shrinks to a series of pools in the dry season. The Nile River then reaches Lake Nasser, 270 km from the border between the Sudan and Egypt.

The peak of the flood does not enter Lake Nasser until late July or August, when the average daily inflow from the Nile River rises to 7.7 km^3. Of this, 64 percent is from the Blue Nile River, 21 percent from the Atbara and Sobat Rivers and 15 percent from the White Nile River (Figure 26). The White Nile River provides a steady stream all year, hence its crucial importance. In early May, the inflow into Lake Nasser drops to a minimum and the total discharge of 0.5 km^3/day comes mainly from the White Nile River. On average, about 85 percent of the water in Lake Nasser comes from the Ethiopian Plateau. The rest is contributed by the East African Plateau and its system of lakes.

Most water balance studies of the Nile River have analysed flows at Aswan. However, flow records over the past two decades have demonstrated the importance of the different rainfall regimes over the catchments of the Blue Nile and White Nile Rivers. Flows in the White Nile River between 1962 and 1985 have increased by 32 percent, or 8 km^3, above the 1912–1961 mean. This occurred as flows in the Blue Nile River decreased by 9 km^3 in the period 1965–1986, or 16 percent below their 1912–1964 mean. Although it could be inferred that the two rainfall regimes are negatively correlated, past records show that the relationship between annual inflow to Lake Victoria and recorded flows in the Blue Nile River at Khartoum is random (MacDonald and Partners, 1988). A main feature of the Nile flow series, apart from the high flow period at the end of the last century, is the steep fall in discharge since the mid-1960s. This fall is more pronounced and persistent than any previous low-flow period. An analysis of the long-term records of water levels measured with the Roda Island "Nilometer" indicates that during the past two centuries the variability of the annual flood far exceeded that of other periods since records began in AD 622.

The Lake Nasser and Nubia reservoir is so huge that it permits storage of several years of average flow of the Nile (Figure 26), completely eliminating the natural cycle of annual flooding in Egypt. To a large extent, Egypt has been unscathed by droughts owing to large overyear storage in Lake Nasser. However, other factors have contributed to reducing the impact of drought. One of these is the exceptionally high water level in Lake Victoria, which has helped maintain higher flows in the White Nile River. The higher levels result from very heavy rainfall in Kenya and Uganda between 1961 and 1963 and above average rainfall since. The higher flows of the White Nile River have helped to compensate for lower discharges from the Blue Nile River, which have been more adversely affected by the Sahelian drought.

FIGURE 26
Developments in live storage of Lake Nasser



Source: Evans, 1996.

3.3.2 Water levels: seasonal variability of the water mass

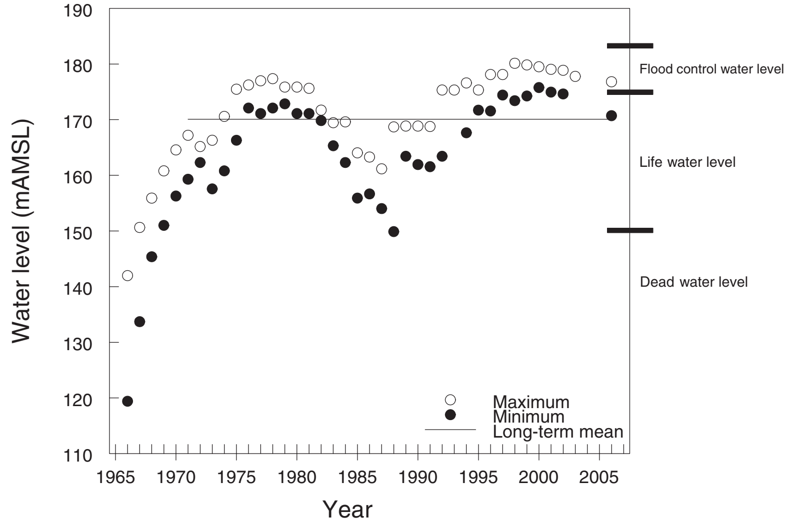
Water levels are distinguished in three categories (Figure 27):

- Dead water level, less than 150 m above mean sea level, is the minimum required for operating the hydroelectric power station of the High Dam.
- Live water level ranges between 150–175 m above mean sea level.
- The flood control water level is 175–183 m.

During the first 11 years after the damming of the river, the water level increased continuously, ranging from a minimum 105.44 m to 126.80 m, with extreme values in 1964. During the period 1975–1981, the maximum water level generally ranged between 165.6 and 175.7 m (Appendix 1, Table A1.1). From 1982 to 1987, the water level fell, reaching 158.5 m in 1987. After that, the water level rose again and reached 170.8 m in 1992 (Abd Ellah, 1995). Water levels are generally high in autumn and winter and lowest in summer.

FIGURE 27

Annual maximum and minimum water level in Lake Nasser, and the dead, live and flood-control water levels



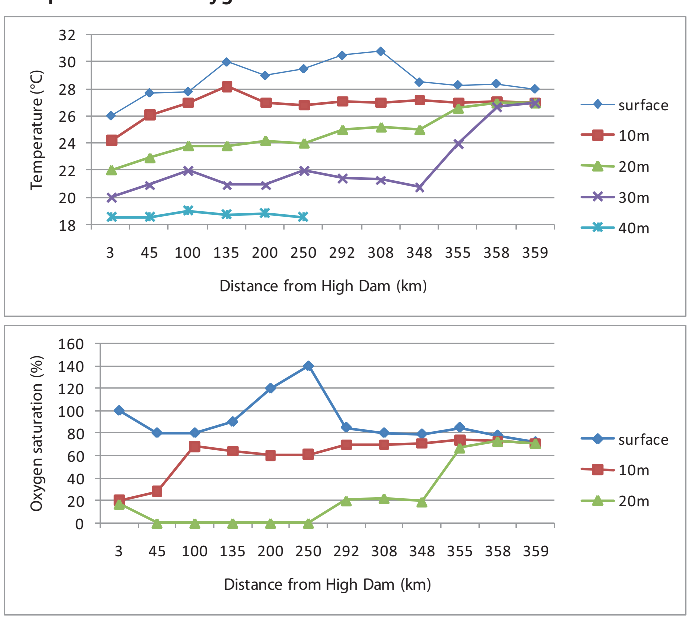
3.4 LIMNOLOGICAL CHARACTERISTICS AND PRIMARY PRODUCTION

3.4.1 Oxygen

The water column is completely oxygenated during winter and spring when dissolved oxygen concentrations are about 18–19 mg O_2/litre, or 110–160 percent of saturation (Ali, 1992), caused by a high rate of photosynthesis and a lack of stratification (Entz, 1970). Oxygen concentration is higher in the main channel than in the *khors* (El-Darwish, 1977). During thermal stratification in the summer, the oxygen concentration of the reservoir's upper layer ranges from 6.0 to 11.2 mg O_2/litre with a maximum difference between the surface and bottom water of 4–7 mg O_2/litre. The depth of the oxygenated epilimnion becomes greater southwards. The southern part,

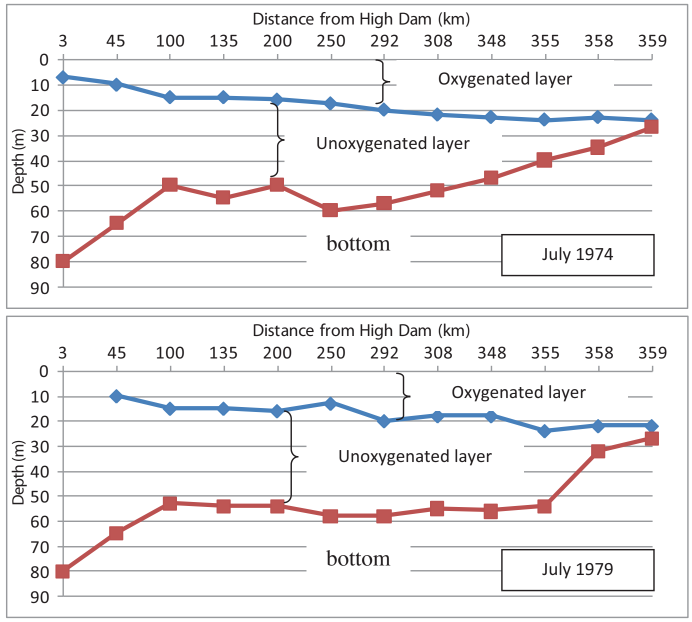
FIGURE 28

Water temperature and oxygen saturation of Lake Nasser and Lake Nubia in 1974



Source: Elewa, 1980.

FIGURE 29
Depth of oxygenated and unoxygenated layers along the main channel of the Aswan High Dam Reservoir



Source: Elewa, 1980.

only 20 m deep, is completely oxygenated from the surface to the bottom (Figures 28 and 29) (Elewa, 1980; Latif, 1984a; Nour El-Din, 1985). The breakdown of thermal and oxygen stratification starts in the south with the incoming floodwater and extends to the northern region with the cooling of the water.

3.4.2 Chemical oxygen demand

Chemical oxygen demand (COD) only fluctuates slightly by season and locality. Moreover, the reservoir water is characterized by low demand values because of a lack of organic matter. In the main channel of Lake Nasser, values fluctuate from 0.4–4.91 mg/litre and in the main *khors* from 0.1–7.8 mg/litre (Anon., 1996).

3.4.3 Specific conductivity

In general, conductivity in Lake Nasser does not reach high levels because of the continuous circulation of water (Abd Ellah, Belal and Maiyza, 2000, Abd Ellah, 2004b). To a certain extent, variations in conductivity in Lake Nasser follow the movement of masses of floodwater. The highest conductivity values have been recorded in summer, before the flood period, and the lowest at the end of the flood season, because of the low conductivity of water from the Blue Nile River (Entz, 1974; El-Shahawy, 1975; Elewa, 1980; Fishar, 1995). Measurements of electrical conductivity range between 158–300 µS/cm, with higher values near the bottom during floods and the summer (Nour El-Din, 1985; Abd Ellah, 2004b).

3.4.4 Acidity (pH) values

The pH of Lake Nasser water tends to be slightly alkaline (Table 12). The reservoir water is more alkaline in winter than in summer and autumn. The pH values increase from the southern to the northern part of the reservoir (Elewa and Latif, 1988; Mohamed, 2000; Abd Ellah, 2004b) and increase from the surface to the bottom (Elewa, 1976). The pH of the reservoir water lies within the optimal range for most freshwater fish species (Latif, 1981).

TABLE 12
Ranges of pH values along the main channel of Lake Nasser, 1987–1992

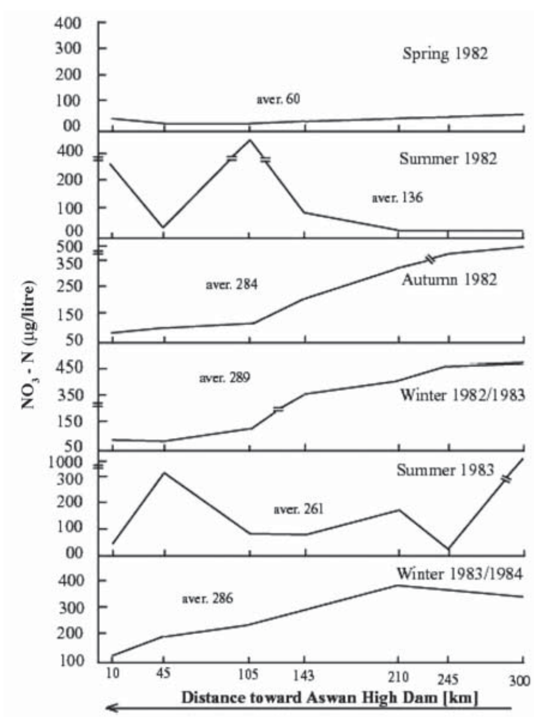
Year	1987	1988	1989	1990	1991	1992
pH range	6.8–8.9	7.4–9.2	7.1–9.1	7.2–8.9	7.57–8.9	7.1–8.9

Sources: Abdel-Rahman and Goma, 1995a, 1995b, 1995c.

3.4.5 Nitrogen

Data on carbon and nutrient cycles in the reservoir are quite inconsistent and cover only short temporal and spatial scales. Nutrient concentrations are reported to be higher in the southern part of the reservoir. Ahmed *et al*. (1989) found a general decrease in nitrate-nitrogen (NO_3-N) concentration towards the dam when studying Lake Nasser between 1982 and 1994 (Figure 30). Exceptions to this trend were recorded during the summers of 1982/83, when high values of up to 400 µg NO_3^-/ litre were measured 100 km south of the dam. On the south–north transect, the average concentrations were 61, 136, 284 and 289 µg NO_3^-/ litre in spring, summer, autumn and winter of 1982, respectively, while 261 and 286 µg NO_3^- / litre were recorded during the summer and winter of 1983, respectively. The vertical distribution at a sampling site 10 km in front of the dam showed low N concentrations in early spring and late summer. The lowest values of 2 µg N/litre and 8 µg N/litre were observed in September 1982 in the surface layers (Ahmed *et al*., 1989). The reduction in N concentrations in the trophogenic zone down to 8 m in August and September 1982 was attributed to relatively high rates of phytoplankton growth (Ahmed *et al*., 1989; Mohammed, Ahmed and El-Otify, 1989).

FIGURE 30
Seasonal local variations in nitrate-nitrogen concentration in Lake Nasser from spring 1982 to winter 1983/84



Source: Modified from Ahmed *et al.* 1989.

Mohamed, Ahmed and El-Otify (1989) found a close correlation between nitrate concentration and chlorophyll, and they suggested that low N concentrations limited primary production for at least some algal genera or species. A drop in N concentrations to 20 µg N/litre, limiting the growth of algal species, was also reported in the Blue Nile River during the maximum growth period of the diatom *Melosira* (Rzoska and Talling, 1966). Measurements made in February 1970 in Lake Nasser close to the Aswan High Dam showed irregular variations in nitrate concentrations from the surface to the bottom, ranging from a minimum of 280 µg N/litre at 20 m in depth to a maximum of 950 µg N/litre at 10 m (Saad, 1980). Small amounts of nitrite were detected in Lake Nasser, with the vertical distribution fluctuating between a minimum of 20 µg N/litre at 50 m depth and a maximum of 42 µg NO_2^-/ litre at 30 m (Saad, 1980). Average concentrations over the entire water column were 670 µg N/litre for nitrate and 30 µg N/litre for nitrite.

The quality of data available only allows for the calculation of tentative scenarios of N uptake and release. If it is assumed that the decrease from 500 to about 60 µg N/litre observed during the winters of 1982/83 and 1983/84 in the south–north transect of Lake Nasser from 245 km to 10 km was due to N uptake, mainly by phytoplankton and macrophytes, then annual biological N consumption in Lake Nasser would be about 71 000 tonnes N/year. With a molar ratio of 106 C: 16 N, the equivalent annual primary production rate required to fix 71 000 tonnes N/year is 67 g C/m^2. This rate is found to be much lower than a minimum of 270 g C/m^2 that characterizes eutrophic systems. Also, if the higher concentrations along the flow path of about 440 µg N/litre in the summer of 1982 and 220 µg N/litre a year later were due to the mineralization of the organic matter, an average mineralization flux of 50 000 tonnes N/year, or 70 percent of total N consumption, should be observed. In summary, the observed N dynamics indicate rather low primary production.

3.4.6 Phosphorus

In general, phosphate (P) concentrations are described as being variable in space and time, with higher concentrations of 120–160 µg P/litre reported in the southern part of the reservoir (Lake Nubia in the Sudan) and lower (30–160 µg P/litre) in the northern part of Lake Nasser (Rashid, 1995). The values are highest in August and November and lowest in February and increase with depth. In February 1970, measurements in Lake Nasser at a site close to the Aswan High Dam showed PO_4 values fluctuating between a minimum of 10 µg P/litre at 50 m depth and a maximum of 90 µg P/litre at 10 m (Saad, 1980). Total P profiles also showed considerable irregular variations between 60 µg P/litre and 175 µg P/litre. In general, the values of reactive phosphate found in most Lake Nasser water samples were much lower than those of non-reactive phosphate, illustrating the mineral origin of total P. The high concentration of reactive phosphate was therefore attributed to the decomposition of organic matter and the release of absorbed phosphate. The average concentration of the reactive phosphate of 35 µg P/litre was about 2.5 times lower than total P (Kinawy, 1974).

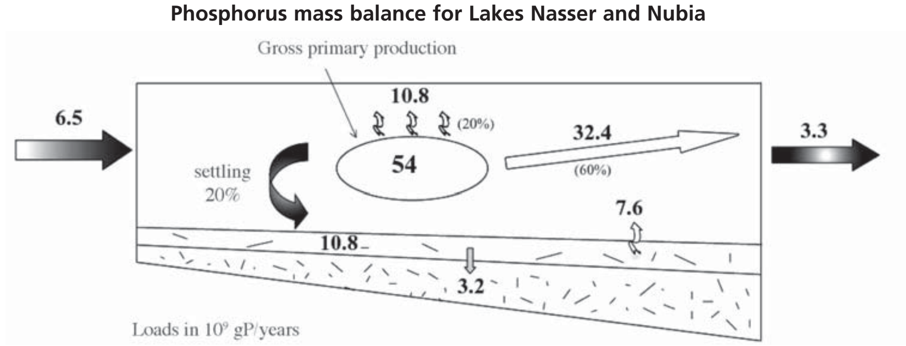
3.4.7 Dissolved phosphorus balance

The literature offers no data on nutrient inflow into the reservoir. The P concentration can be roughly estimated from a mass balance calculation. Considering that, for an annual estimation, the reservoir is a conservative system where inputs must be balanced by net sedimentation and the output for a annual primary production rate of 370 g C/m^2 or an equivalent P flux of almost 9 g P/m^2, P uptake would be 54×10^9 g P/year. If it is assumed that 20 percent of the P uptake or 10.8×10^9 g P/year is deposited in the reservoir sediment, and half is retained and the other half is released back into the water column, then net sedimentary P retention is 5.4×10^9 g P/year.

Prior to the construction of the Aswan High Dam, the Nile River flood delivered to the Mediterranean coast about 7.2–11.2×10^3 tonnes/year of biologically available P (3.2×10^3 tonnes in dissolved form and 4–8×10^3 tonnes as sediment) and 6.7×10^3 tonnes of inorganic N (Nixon, 2003). Low discharges after dam construction, resulting from high nutrient retention in an extremely productive reservoir behind the dam, were estimated to be 0.03×10^3 tonnes P/year and 0.2×10^3 tonnes N/year. Therefore, up to 3.2×10^3 tonnes P/year can be considered to represent the net P retention in the sediment of the reservoir. This value is comparable with retention of 5.4×10^9 g P/year estimated above.

The outflow P concentration can be calculated from the average value reported for the small lake downstream from the Aswan High Dam of 39 µg P/litre. If the annual water discharge at the Aswan High Dam is 84 km^3/year, the output load would be 3.3×10^9 g P/year. However, the output load can be actually much higher. The mass balance can be approximated with the equation: $P_{input} - P_{net\ retention} - P_{output} = 0$. If all parameters are considered in the equation, the balance indicates an input load of 6.5×10^9 g P/year. For an inflow of 84 km^3/year, the incoming P concentration would be ~77 µg P/litre (Figure 31).

FIGURE 31
Phosphorus mass balance for Lakes Nasser and Nubia



Source: Teodoru, Wüest and Wehrli, 2006.

3.4.8 Organic matter and silicate

The upper 40 m of the water column are characterized by a general concentration of silicon dioxide (SiO_2) of 11.5 mg per litre, increasing to 13 mg SiO_2/litre at 50 m and decreasing to a minimum of 10.2 mg SiO_2/litre at 60 m. The values at 70 and 80 m were 12.3 and 11.5 mg SiO_2/litre, respectively. The vertical distribution of silicate was thought to be influenced by the physicochemical conditions of the reservoir rather than by diatom consumption (Saad, 1980). Dissolved organic matter content in Lake Nasser was found to increase from a minimum of 1.56 mg/litre at the surface to a maximum of 10.6 mg/litre at 30 m depth, attributed mainly to the decomposition of the phytoplankton in the water column. In general, a constant concentration of about 8 mg/litre is measured below 40 m. It should be noted, however, that the irregular trend in the vertical distribution of nutrients in February was due to the absence of clear thermal stratification as a result of cooling-induced mixing of reservoir water during winter.

3.4.9 Phytoplankton abundance, chlorophyll *a*

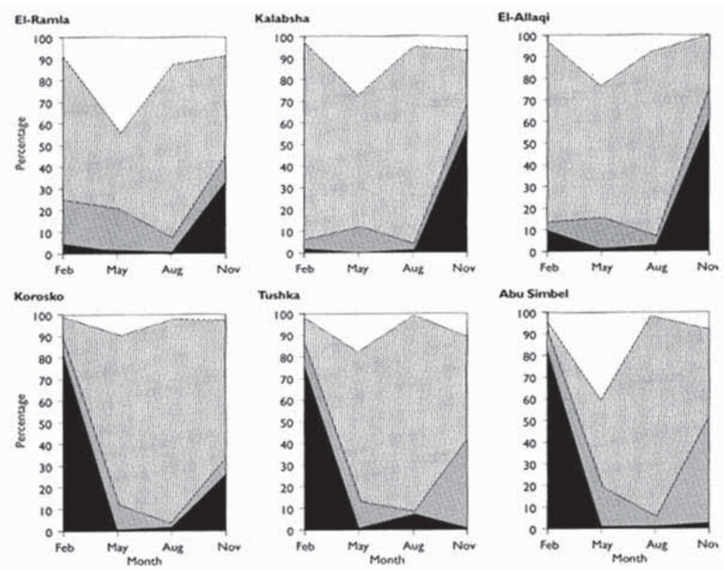
The phytoplankton community is composed of cyanophytes (blue-green algae, 12 spp.), diatoms (14 spp.), chlorophytes (green algae, 24 spp.) and dinoflagellates (3 spp.) (Habib, 2000). Blue-green algae dominated the community as a percentage of the total number of algae in samples during spring and summer. Diatoms dominated the community only once in winter. Noticeable peaks of green algae have been recorded in spring and summer at various places in the reservoir. There were very few dinoflagellates except for some peaks in late winter and spring. Various studies on the spatial distribution of phytoplankton found that cyanophytes generally dominate in the northern part of the reservoir, ranging from 22–96 percent in different surveys, with peaks in autumn and lows in winter, while in the southern part of the reservoir there are periods when diatoms dominate (Latif, 1984b; Gaber, 1982; Abdel-Monem, 1995; Habib, 2000). Chlorophytes are concentrated in the northern parts of the reservoir, but generally constitute less than 21 percent of the community total composition, with a minimum of 2 percent (Figure 32).

Phytoplankton recorded in Lake Nasser in the period 1981–1993 included 135 species belonging to five classes: 54 spp. of chlorophytes, 34 spp. of cyanophytes, 33 spp. of bacilariophytes, 13 spp. of dinophytes and one species of euglenophytes. Comparison with the results obtained by Abdel-Monem (1995) and those of previous investigators leads to the conclusion that, of the 135 recorded species, 51 were new invaders and 52 species have completely disappeared since the reservoir was created. In addition, a further 32 species were recorded by various investigators during the same period.

The amount of chlorophyll *a* in water is an index of phytoplankton productivity and has been used to estimate primary productivity. The southern region of Lake Nasser has higher mean annual values of chlorophyll *a* than the northern region. Fead (1980) recorded the highest values of chlorophyll *a* at Abu Simbel directly preceding the annual flood.

Seasonal changes in chlorophyll *a* are observed, with chlorophyll concentrations homogeneous over the depth of the reservoir during the winter from November to February, coinciding with low water temperatures (Figure 33).

FIGURE 32
Seasonal variation in the major phytoplankton groups at various sites in Lake Nasser

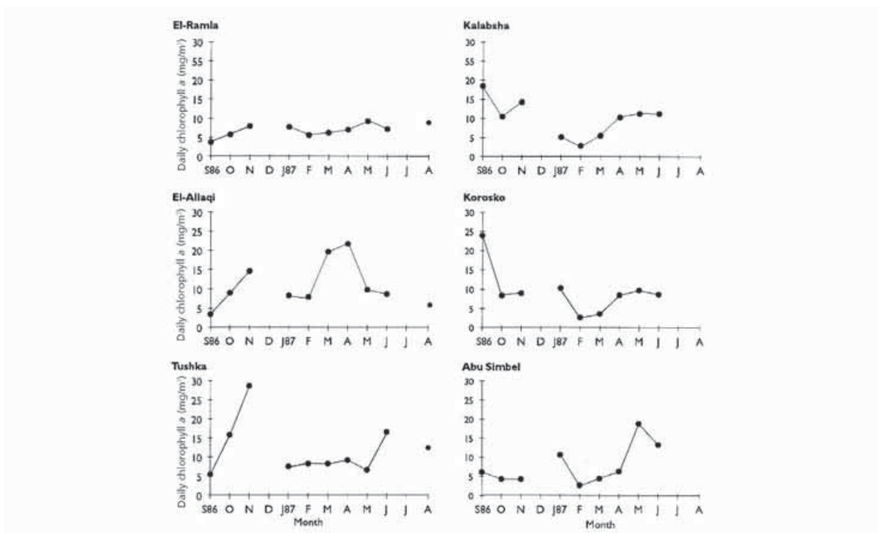


Seasonal variation (%) in the major phytoplankton groups over the year 1991 at various sites in Lake Nasser (Habib 2000). Diatoms ■, chlophytes ▒, cyanophytes ▢, dinoflagellates ▢

Source: Habib, 2000.

Chlorophyll *a* concentrations are stratified from April through September, coinciding with a clear thermocline observed from March to October. Thus, the highest production was obtained at 2 m depth and gradually decreased with depth. Low values of chlorophyll *a* were recorded in deep layers up to 30 m as light faded. Observed maximum concentrations of chlorophyll *a* were 24 mg/m^3 at the surface in January 1984 at Korsoko and 27.2 mg/m^3 at 10 m in January 1993 (Latif, 1974a; Fead, 1980; Habib and Aruga, 1988; Mohamed, 1993a). The distribution of chlorophyll *a* at 13 stations inside and outside Khor El-Ramla of the High Dam Lake in Egypt, monitored from 1982 to 1985, generally followed the same mixing patterns as the main reservoir, but maximum concentrations were much higher at 57.6 mg/m^3 at 2 m in November 1984 and an extreme value of 106.8 mg/m^3 at 4 m in April 1984 at one station (Habib, Ioriya and Aruga, 1987). Chlorophyll *a* concentrations and Secchi disc depth are inversely correlated (Figure 34); transparency in Lake Nasser is determined by inputs of allochthonous silts of riverine origin and autochthonous suspended matter. Chlorophyll *a* concentrations in the main channel have not changed over time.

FIGURE 33
Seasonal variation in mean chlorophyll *a* concentration in the euphotic zone at various sites in Lake Nasser



Source: Habib and Aruga, 1988.

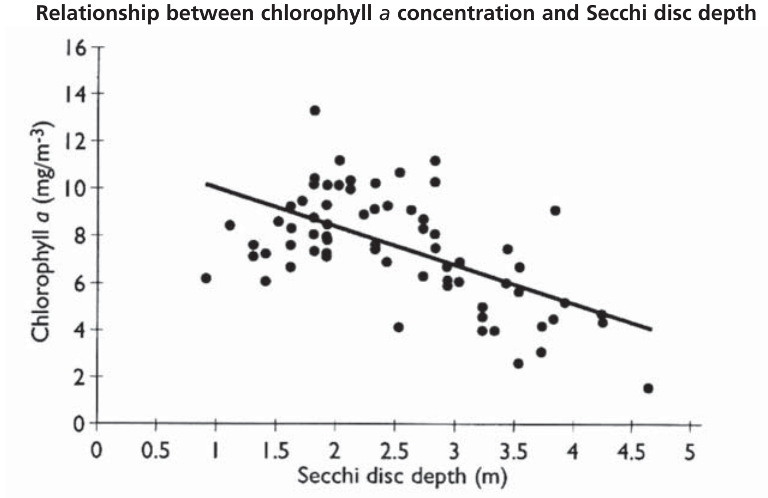
In sluggish areas of Lake Nasser, cyanophytes can cause floating crusts and sumps, where plants die quickly and disintegrate in the intense sunlight. This causes depletion of oxygen below the concentration required by fish and other aquatic animals. Mohamed (1993b) recorded the occurrence of algal blooms in Lake Nasser eight times during six years from 1987 to 1992 and pointed out that they occurred only in very limited areas of the southern part of the reservoir. Cyanophytes dominated in all samples of blooms, with *Microcystis aeruginosa* as the dominant species.

Previously, *M. aeruginosa* water blooms occurred annually for several months before the flood period, but now may occur intermittently all year round (Mohamed and Loriya, 1998). Recently, algal blooms have been recorded in the central part of the reservoir. Occasionally, they have occurred at Korosko in the northern area.

3.4.10 Primary production

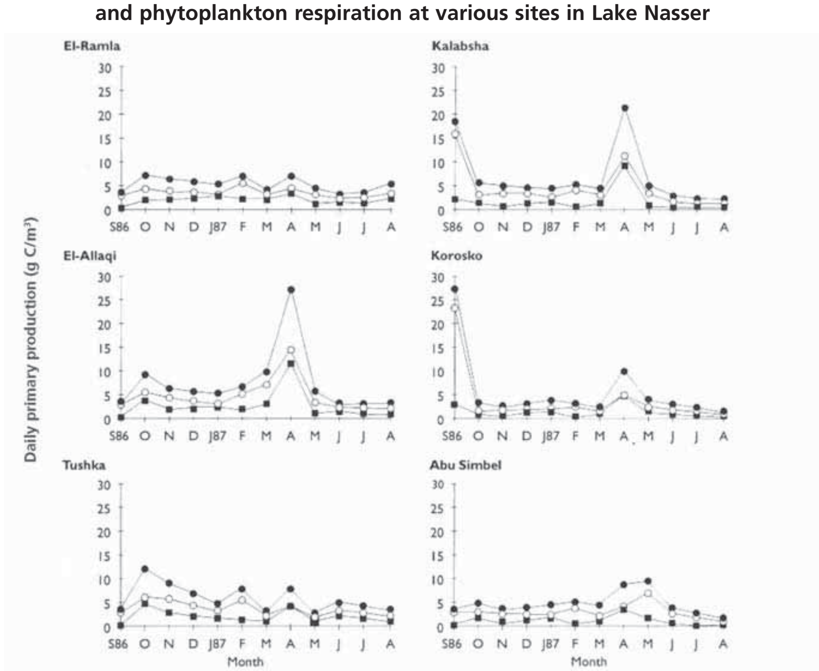
Primary productivity can be calculated using information on phytoplankton photosynthesis and respiration and the diurnal and seasonal changes in light conditions (Aruga and Monsi, 1963) (Figure 35). Large geomorphological and hydrodynamic differences in the extent of thermal stratification and the depth of the photic zone were considered the main reasons for different ecosystem characteristics between the main channel of Lake Nasser and the *khors* (Abu-Zeid, 1987). Primary production was estimated at various stations over the years in Lake Nasser (Figure 36). Although it is not always clear from the literature whether the measurements were made at the same stations and depths and using the same methodology, the ranges show the same order of magnitude over the years: the lowest hourly values recorded were 2.4 mg C/m^3 and the highest 247.5 mg C/m^3.

FIGURE 34
Relationship between chlorophyll *a* concentration and Secchi disc depth



Source: Mohamed, 2000.

FIGURE 35
Seasonal variation in gross primary production, net primary production and phytoplankton respiration at various sites in Lake Nasser

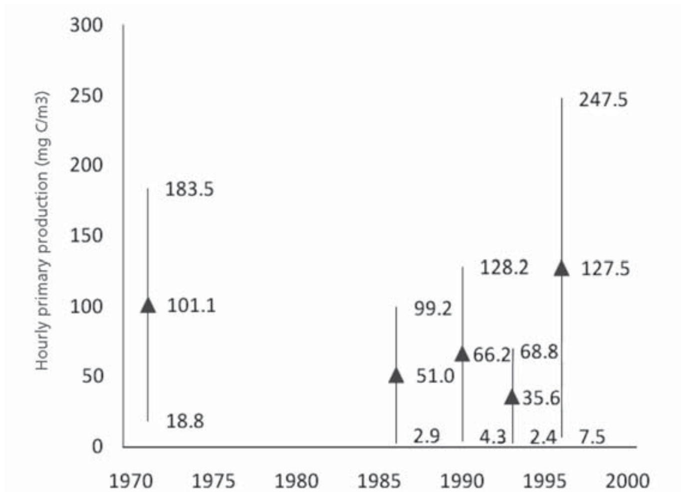


Note: Closed circles = gross primary production; open circles = net primary production; and squares = phytoplankton respiration.

In general, daily rates of biological production in the reservoir were estimated as high as 8–15 g C/m^2 from diurnal changes in open water measurements in some side bays (Abu-Zeid, 1987). Similarly high daily rates of gross primary production of 5.23–13.2 g C/m^2 were measured in March 1970, while higher rates of 10.7–16.4 g C/m^2 were recorded in 1979 when the biologically active zone of the reservoir extended down to about 4 m (Latif, 1984a). However, doubts may be raised regarding the validity of some of these measurements, as a daily average of 10 g C/m^2, or 3 650 g C/m^2 in a year, is extremely high, beyond the highest values measured in eutrophic lakes (Downing, Plante and Lalonde, 1990). The measurements may represent primary production in some of the *khors*.

Some assumptions need to be made to estimate a realistic rate of primary production for the entire reservoir. The primary production corresponding to an average P concentration of 50 µg P/litre typically varies between 150 and 250 g C/m² per year. It can be considered that the reservoir consists of 5 percent *khors* (300 km²) where production reaches high annual rates up to 3 600 g C/m², and the remaining 95 percent is the main channel (5 700 km²), with an average annual production of 200 g C/m². According to this scenario, a weighted average annual primary production of 370 g C/m² can be calculated. As this figure should be understood as highly uncertain, calculating annual primary production for Lake Nasser to vary between 200 and 400 g C/m² may be a better estimate.

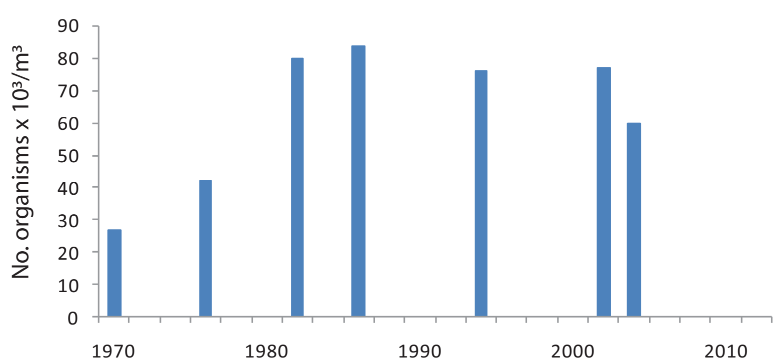
FIGURE 36
Ranges in primary productivity in Lake Nasser



Sources: Samaan, 1971; Abdel-Monem, 1995; Anon., 1996; SECSF, 1996; Habib, 2000.

Abdel-Monem (1995) contends that the gradual eutrophication of Lake Nasser may be a result of continuous sedimentation of organic matter that accumulates annually with floodwater rich in nutrients. This would be expressed as a gradual increase in primary productivity, but the data show no strong evidence to that effect (Figure 37). Abdel-Monem (1995) also suggested that primary productivity in the reservoir was characterized by its high value in the epilimnetic water (3 m) compared with hypolimnion water (15 m), except in summer when the situation was reversed. This is mainly owing to the faster sinking rate of phytoplankton cells as water becomes less dense at high summer temperatures.

FIGURE 37
Variations of zooplankton numbers recorded in Lake Nasser, 1970–2005



3.4.11 Zooplankton

In the period 1987–88, the zooplankton community was composed in order of abundance of: copepods (3 spp.), cladocerans (9 spp.) and rotifers (17 spp.). The relative proportion of copepods decreases towards the south from about 90 percent to 60 percent, replaced by cladocerans and to a lesser extent rotifers. The seasonal changes in zooplankton coincide with those of the phytoplankton (as chlorophyll *a*) in Lake Nasser (Habib, 1997) and are concurrent with transparency. Zooplankton of the main channel of Lake Nasser and its *khors* were studied in the early 1970s by many investigators. Samaan (1971) reported 15 species (9 Crustacea and 6 Rotifera); Rzoska (1976) recorded 13 species (mainly Crustacea); and Samaan and Gaber (1976) recorded 15 species (9 Crustacea and 6 Rotifera). Studies conducted since 1971 have shown that the standing stock of zooplankton increased during the first 10–15 years after damming and has since stabilized (Figure 37) (Samaan, 1971; Gaber, 1981; Zaghloul, 1985; Habib, 2000; El-Shabrawy and Dumont, 2003; Mageed and Heikal, 2005).

3.4.12 Bottom fauna

Fifty-nine species of benthic invertebrates have been recorded from Lake Nasser by various investigators. These belong to five phyla: Cnidaria (Coelenterata) (one class, one sp.), Bryozoa (one class, one sp.), Arthropoda (two classes, 33 spp.), Annelida (two classes, 5 spp.) and Mollusca (two classes, 19 spp.), in addition to larvae, pupae, nymphs and adult insects. The major components of the benthic fauna in Lake Nasser were the oligochaetes, while those of Lake Nubia were mainly molluscs (Latif, 1979). Iskaros (1993) recorded in Khor Kalabsha 27 species in the three phyla (by relative abundance): Arthropoda (85.1 percent), Mollusca (11.1 percent) and Annelida (3.8 percent).

3.4.13 Macrophytes

Major changes have occurred in the aquatic macrophytes in Lake Nasser following the completion of the Aswan High Dam (Table 13). In the 1960s, 1970s and 1980s, 12 euhydrophyte species were recorded in Lake Nasser waters, of which seven appear to be new to the region (Springuel and Murphy, 1990). Changes in aquatic macrophytes were related to dynamic changes in Lake Nasser hydrology: (i) from lotic to lentic waters; and (ii) the continuously changing physicochemical and soil characteristics of the reservoir (Ali, 2000). Recent changes in submerged macrophyte communities in Lake Nasser appear to be related to physical factors (e.g. water-level fluctuations and human activities).

TABLE 13
Long-term changes in freshwater macrophyte species in Lake Nasser

Species	1962–1964	1966–1967	1978–1986	1988–1990	1993–1994
Alsima gramineum	+				
Damasonium alisma var. *copactum*	+				
Potamogeton perfoliatus	+				
P. crispus	+	+	+		
P. pectinatus	+	+	+		
Zannichellia palustris	+	+	+	+	
Vallisneria spiralis		+	+	+	
P. trichoides			+		
P. schweinfurthii[1]			+	+	+
Najas horrida[2]			+	+	+
N. marina subsp. *armata*			+	+	+
Nitella hyaline[3]					+
Myriophyllum spicatum					+
Ceratophyllum demersum					+

[1] This species was misidentified as *Potamogeton nodosus.*
[2] This species was misidentified as *Najas pectinatis* (Ali, 1987).
[3] This species was misidentified as *Chara* sp. in Springuel and Murphy (1990).
Sources: Boulos, 1967; El-Hadidi, 1968; El-Hadidi and Ghabbour, 1968; Abdalla and Sa'ad, 1972; Ghabbour, 1972; Ahti, Hamet-Ahti and Pettersson, 1973; Ali, 1987, 1992; Springuel and Murphy, 1990; and authors' records.

3.5 THE LAKE NASSER FISHERIES

3.5.1 Fish species composition

The known Lake Nasser fish community consists of 52 species in 15 families (Table 14).

TABLE 14
Main fish families (15) and species (52) in Lake Nasser

Family	Species
Cichlidae	*Tilapia zillii, Oreochromis aureus, Sarotherodon galilaeus, Oreochromis niloticus*
Latidae	*Lates niloticus*
Alestidae	*Alestes nurse, Alestes baremose, Alestes dentex, Hydrocynus forskalii, Hydrocynus lineatus, Hydrocynus brevis*
Cyprinidae	*Barbus bynni, Labeo niloticus, Labeo coubie, Labeo horie, Labeo forskalii, Chelaethiops bibie, Barilius niloticus, Barilius loati, Discognathus vinciguerrae, Barbus werneri, Barbus prince, Barbus neglectus Barbus anema*
Bagridae	*Bagrus bayad, Bagrus docmac,*
Claroteidae	*Chrysichthys auratus, Chryischthys ruepelli, Clarotes laticeps, Auchenoglanis biscutatus, Auchenoglanis occidentalis*
Clariidae	*Heterobranchus bidorsalis, Clarias gariepinus*
Schilbeidae	*Schilbe mystus, Schilbe uranoscopus*
Mochokidae	*Synodontis schall, Synodontis serratus, Synodontis batensoda, Synodontis membranaceous, Mochocus niloticus, Chiloglanis niloticus*
Mormyridae	*Mormyrops anguilloides, Mormyrus kannume, Mormyrus caschive, Petrocephalus bane, Hyperopisus bebe, Marcusenius isidori, Gnathonemnus cyprinoides*
Citharinidae	*Citharinus citharus, Citharinus latus,*
Distichodontidae	*Distichodus niloticus*
Tetraodontidae	*Tetraodon lineatus*
Protopteridae	*Protopterus aethiopicus*
Polypteridae	*Polypterus bichir*
Gymnarchidae	*Gymnarchus niloticus*
Malapteruridae	*Malapterurus electricus*

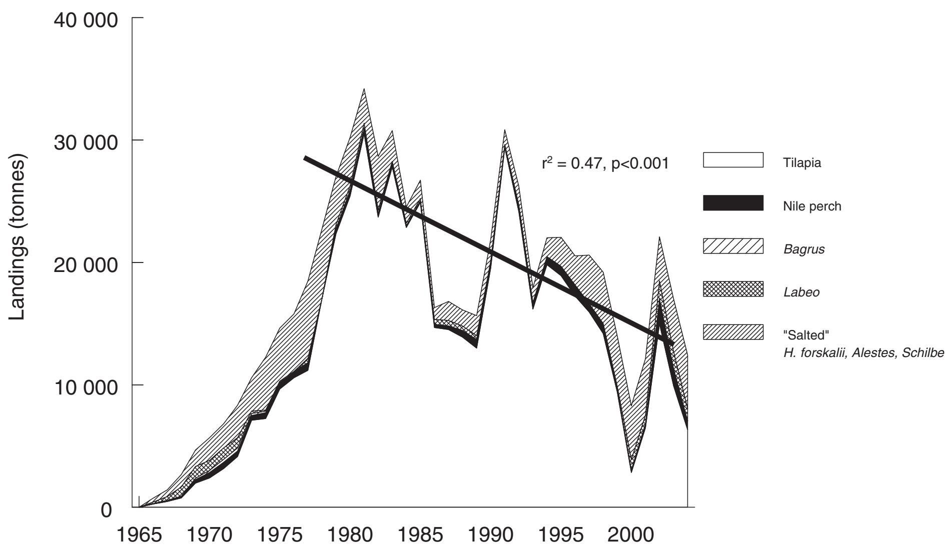
3.5.2 Developments in catch and fishing effort

The multispecies fishery of Lake Nasser is dominated by two tilapiine species: *Sarotherodon galilaeus* and *Oreochromis niloticus*. Since 2000, *Tilapia zillii* and *Oreochromis aureus* have appeared in the catch as well. The former contributes about 2 percent of the total catch. Following the two tilapiines in abundance, *Lates niloticus, Labeo* spp., *Bagrus* spp. and *Synodontis* spp. are marketed as fresh fish. *Hydrocynus forskahlii, Alestes* spp. and *Schilbe mystus* are salted (Latif, 1974a, 1974b and 1977). *Sarotherodon galilaeus*, *Lates niloticus*, *Hydrocynus forskahlii* and *Mormyrus* spp. are more dominant in the northern third of the reservoir than elsewhere in the reservoir. *Oreochromis niloticus* is, on the contrary, much more abundant in the middle third. *Alestes baremoze* and *A. dentex* are concentrated mainly in the southern third, where cyprinids are more abundant (Latif, 1979).

Catch is collected by about 200 carrier boats from various areas around the reservoir.[3] All of the collected fish, fresh and salted, are landed at three official landing sites – the fishing harbours of Aswan, Garf Hussein and Abu Simbel – where the fish are sorted. Catches levels are determined by total enumeration. With the gradual increase in the area of the reservoir since the early years of impoundment, fish landings from Lake Nasser increased from 751 tonnes in 1966 to a peak of 34 200 tonnes in 1981.

[3] The following analysis is based on official landings statistics, which are suspected to be significantly underestimated by about 50 percent. Fish smuggling started in about 1995 or 1996, leading to an underestimate of about 30 percent, reaching about 90 percent in 2000. After 14 June of 2001, when free marketing and pricing were applied for the first time, smuggling decreased to an estimated 25 percent. Around 2003, smuggling increased once again, associated with the division of the fishery resources of the reservoir between investment companies and fishery cooperative associations (O. Anwar, personal communication, 2009).

FIGURE 38
Officially recorded annual fish catch in Lake Nasser, 1966–2004



Source: LNDA, Aswan.

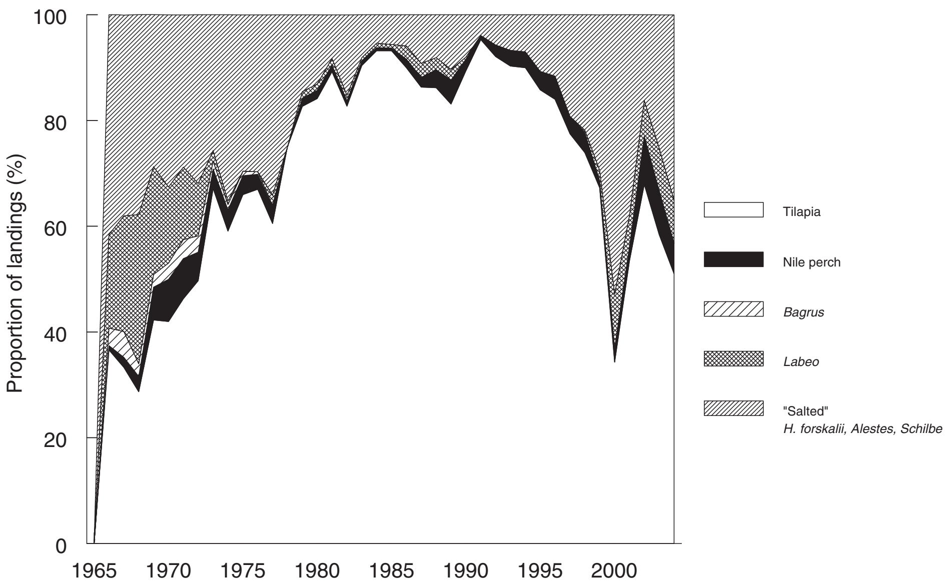
Since then, recorded landings have shown large fluctuations, but a decreasing trend of approximately 700 tonnes/year to 12 500 tonnes in 2005 (Figure 38). The decrease in recorded fish output from Lake Nasser is at least partly related to the imposition by the authorities of a fixed price for fresh fish, which spurred the development of a large black market for fresh fish. As a result, fish is smuggled outside the regular fish-marketing system and falls outside the official landing statistics. The sharp drop in the estimated fish landings in about 2000 is attributed mainly to this black market. Moreover, consumption by fishers, avoidance of taxation, poaching and discards owing to spoilage or catch below minimum legal size mean that a large proportion of the catch was not recorded as landings. Khalifa, Agaypi and Adam (2000) estimated that recorded harbour landings were about 50 percent of the total catch. There is, however, no exact information on changes in this proportion over time as a result of changed policies or market arrangements.

Catch

The reported annual fish catches from Lake Nasser from 1966 to 2004 are shown in Figure 38 (the complete dataset is provided in Table A1.2 and the composition by species in Table A1.3).

Fresh fish – tilapia (bolti) and Nile perch (samoos) – are recorded separately. Minor species, which have about the same value when marketed fresh, tend to be combined under others. Accordingly, the nominal catch statistics do not reflect the composition of the landings accurately (Khalifa, Agaypi and Adam, 2000). Tilapias have always formed the bulk of the catch, comprising as much as 81 percent of the catch in 2002, followed by Nile perch (11 percent) and salted fish (8 percent). The proportion of cyprinids and catfishes decreased rapidly in the first decade after impoundment but has increased in recent years. At the start of the fishery, 50 percent of the fish was sold salted. This proportion gradually decreased to 4 percent, but recently the proportion of salted fish rose again to about 50 percent (Figure 39) (Bishai, Abdel Malek and Khalil, 2000).

FIGURE 39
Proportion by main categories of officially recorded annual fish catch in Lake Nasser, 1966–2004



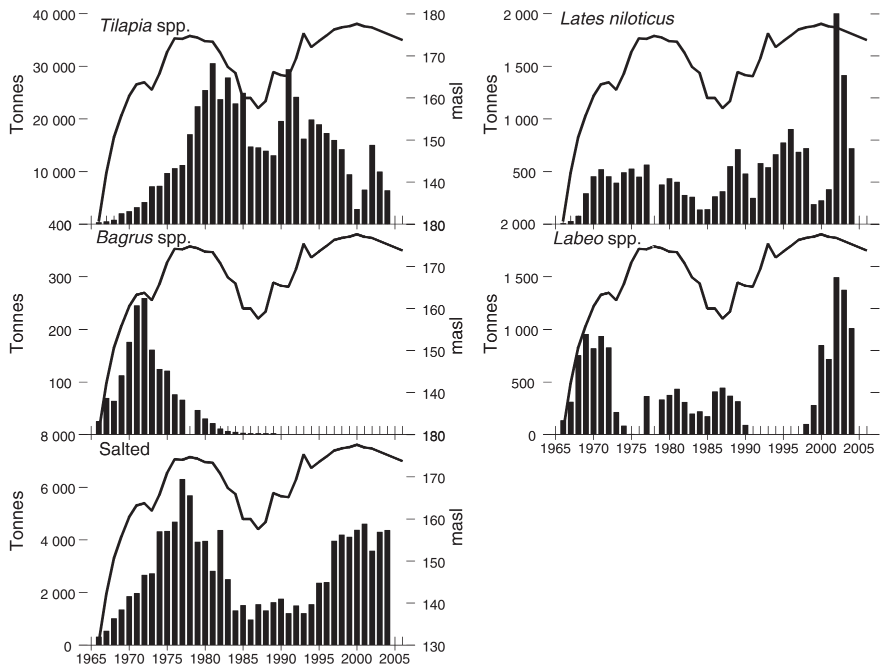
Source: LNDA, Aswan.

Development and trends in landings of different categories of species

An analysis of trends in landings is delicate if, as estimated, about 50 percent of the total landings are at present unrecorded. For the observed quantities, the trends are as follows. *Oreochromis niloticus* and *Sarotherodon galilaeus* landings increased from 278 tonnes in 1966 to a maximum of 30 529 tonnes in 1981. Subsequently, the tilapiine catch decreased to about 13 000 tonnes in 1989. This decrease was thought to be mainly due to the decline in the water level during the drought from 1984 to 1988, which shortened the shoreline, increased its slope and thereby shrank the fishing grounds. However, tilapiine landings increased again to 29 389 tonnes in 1991, but subsequently fell to only 8 281 tonnes in 2000 (Figure 40). This does not follow the expected trend of water levels and fish catches rising in tandem. Once again, part of this unexpected result could be attributed to the increased selling of tilapia on the black market.

Lates niloticus data show that the recorded catch increased from 6 tonnes in 1966 to 563 tonnes in 1977, after which the catch fluctuated greatly between approximately 200 and 900 tonnes. The large landings of 2001 to 2003 are associated with the free pricing policy from 14 June 2001 onwards. The *Bagrus* spp. catch increased from 25 tonnes in 1966 to 258 tonnes in 1972, after which the catch of this species decreased to zero from 1989 onwards. The catch of *Labeo* species increased rapidly from 133 tonnes in 1966 to a maximum of 933 tonnes in 1969. Then the catch dropped to low levels in 1975 and 1976, after which landings fluctuated between 4 and 444 tonnes. No records were obtained between 1992 and 1996. In 2000, a remarkable but unexplained surge in landings to 870 tonnes was recorded. The annual catch of salted fish, consisting mainly of *Hydrocynus forskalii*, increased gradually from 313 tonnes in 1966 to 6 297 tonnes in 1977, followed by a sharp decrease to 961 tonnes in 1986. From 1987 to 1994, the catch was about 1 500 tonnes annually. After 1995, the catch increased to between 3 500 and 4 500 tonnes annually.

FIGURE 40
Annual recorded catch by species category from Lake Nasser, 1966–2004



Note: Superimposed on graphs the mean annual water level in metres above sea level since 1965.
Source: LNDA, Aswan.

Fishing effort

According to the LNDA, at Aswan in 2002, 4 103 fishers operated 2 703 registered fishing boats on Lake Nasser.[4] Although, the number of boats has increased in the past decade, the number of fishers reached its maximum in 1975, decreased rapidly to about 3 000 in 1981 and subsequently increased slowly. The number of fishers per boat decreased from about three in 1980 to a little more than one since 2000 (Figure 41), which is surprising considering the labour needed to operate the vessels typically in use on Lake Nasser. It suggests that either the number of inactive boats is not recorded or the definition of fishers and assistants has changed over time. The boats are made of wood or steel and some are motorized.

Five fishing methods are commonly used in Lake Nasser fisheries: trammel net, bottom gillnet, floating gillnet, beach seine net and longline (Entz and Latif, 1974; Khalifa, Agaypi and Adam, 2000). In the northern part of the reservoir, fishing is mostly carried out using trammel nets, while in the southern part fishing with top-set gillnets predominates.

(1) Top-set gillnets (*sakarota*). The stretched mesh size varies from 3 to 7 cm. The net length varies from 20 to 50 m and floating depth from 1.5 to 2 m below the surface. A number of nets, typically 20–40, are strung together to form one long net. The net is used for fishing raya (*Alestes* spp.) and kalb el samak (*Hydrocynus* spp.). This type of fishing is done every night and the catch is gutted and salted.

[4] Other data used are 2 662 boats and 3 906 fishers, according to a survey in 2002 (O. Anwar, personal communication).

(2) Midwater or bottom-set gillnets (*kobok*). The stretched mesh size of this type of net ranges from 10 to 20 cm. Nets are 10–20 m in length but can be as short as 4 m. Up to 20 nets are joined together and the nets may operate at a depth of up to 10 m. They are usually set in *khors* but sometimes in open waters. The fish caught by these nets are usually *Lates niloticus* (samoos), *Oreochromis niloticus* and *Sarotherodon galilaeus* (bolti), *Labeo* spp. (lebeis), *Bagrus* spp. (bayad), *Barbus bynni* (benny) and *Clarias* spp. (karmout). Most of these fish are sold fresh. The nets are raised every night or every second night.

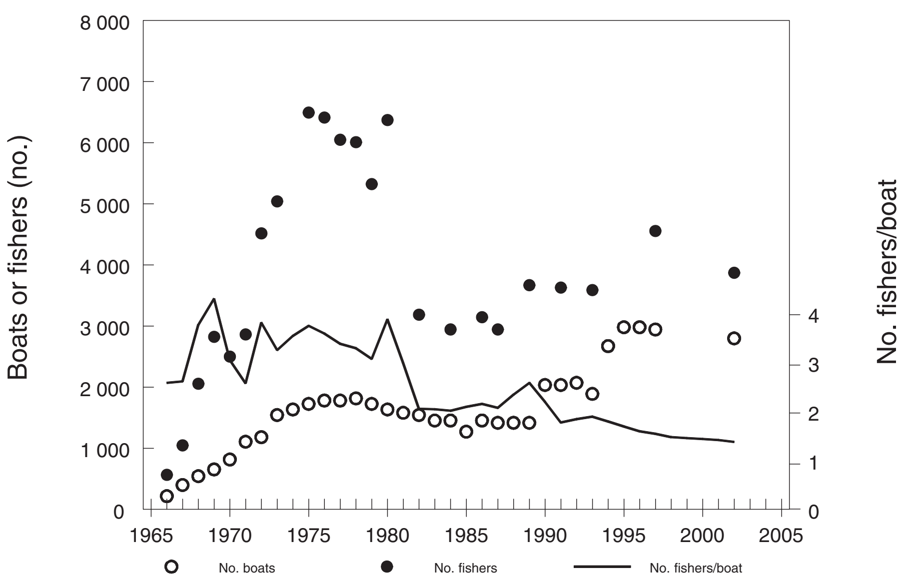
(3) Trammel nets (*duk*). The net length ranges from 10 to 20 m and the operating depth is about 1.5 m in shallow areas and about 3 m in deeper areas. The two outer panels of the net have a stretched mesh size of 20–40 cm with an inner panel of stretched mesh size 8–12 cm. The trammel net is piled up at the rear of the boat and easily handled by a single fisher, while another crew member rows the boat. The net is cast and set off against the rocky faces of the shoreline a few metres away from the shore. The boat then moves in between the shore and the net. One of the fishers hits the surface of the water using a pole (so-called beat fishing) and drums on the deck with his feet, driving fish into the net. Landings consist mainly of bolti (tilapiine species), samoos (*Lates niloticus*), bayad (*Bagrus bayad*) and karmout (*Clarias* spp.). This type of fishing starts after dark and continues until just before dawn. It is confined to shallow water with a depth ranging from 1 to 2.5 m. The trammel net fishery is the main supplier of fresh fish.

(4) Beach seines (*gorrafa*). This net is used for daytime fishing and lands mainly tilapiine species (bolti).

(5) Longlines. Longline fishing is little practised, but is more common in the southern than in the northern part of the reservoir. It is used in deep waters to catch samoos and bayad with bolti and lebeis (*Labeo* spp.) fry and fingerlings as bait.

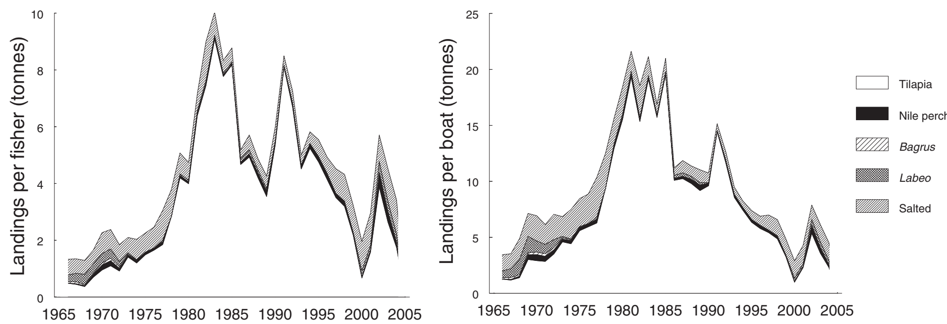
No information is available on changes in numbers of gear, gear use, mesh sizes or effort allocation.

FIGURE 41
Annual variation in number of boats and fishers in Lake Nasser and numbers of fishers per boat



Source: Fishery Management Center, LNDA, Aswan.

FIGURE 42
Developments in officially recorded annual landings per boat and per fisher in Lake Nasser



Reported catch rates decreased between 1979 and 2004 from about 20 tonnes per boat to 5 tonnes (a decrease of 0.75 tonnes/year) and from about 8 to 4 tonnes per fisher (a decrease of 0.2 tonnes/year) (Figure 42). The annual catch rate of 4 tonnes/fisher is close to the annual average catch of 3 tonnes that is observed across African freshwater fisheries (Kolding *et al*., 2008; Jul-Larsen *et al*., 2003). Examination of Lake Nasser fish production and output efficiency has shown that fish production in 2001–04 indicates an annual average yield of about 15.3 kg per feddan (1 feddan = 4 200 m^2), or 36.4 kg/ha. This is 29–43 percent of the potential annual yield of 84–125 kg/ha, given an annual primary production of 200–400 g C/m^2 (see above). This is an extremely low level of catch compared with lakes and reservoirs elsewhere in the world (see discussion in Chapter 5). It is also low compared with theoretical values calculated from primary production. According to Downing, Plante and Lalonde (1990), the relationship $\log_{10}$ (FP) = 0.6 + 0.575$\log_{10}$ (PP), where FP is fish production and PP is primary production, indicates that primary production levels in the reservoir would translate to an annual fish production of 84–125 kg/ha. On the other hand, if one assumes that the reported landings represent only 50 percent of the total landings, the production of 73 kg/ha is comparable with low-productivity reservoirs in China (79 kg/ha), Thailand (74 kg/ha) and Indonesia (64 kg/ha). The mean annual production from a range of 19 African lakes and reservoirs is 316 kg/ha (Kolding and van Zwieten, 2006).

Effect of water level, reservoir area and shoreline length on fish production

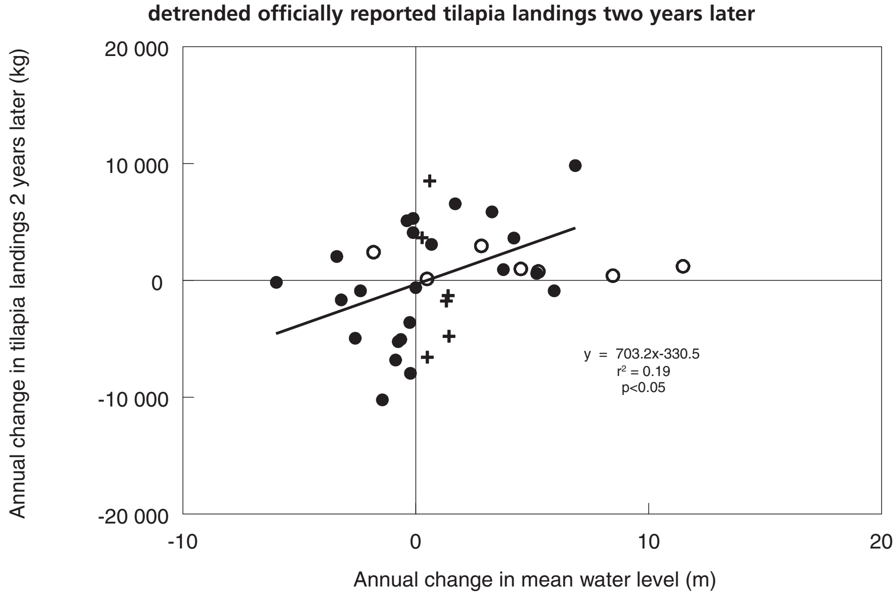
Total tilapia landings increased to 10 582 tonnes from 1966 to 1976, concomitant with the filling of the reservoir and the increase in the number of fishing boats. In the next five years to 1981, landings increased to 30 529 tonnes, the mean water level was kept at about 174 m and fishing effort was constant at 1 600 fishing boats. Thus, the water level was relatively high and considered suitable for tilapia reproduction. The high production could also result from the general fact that reservoirs have high production rates shortly after inundation (Kolding and van Zwieten, 2006). The catch decreased by about 60 percent to 13 000 tonnes from 1982 to 1989 and this period included an extended drought that saw mean water levels fall from 171 m to 160 m. Landings of tilapia increased again to about 29 000 tonnes with rising water levels in 1991. Since then, the water level has remained more or less stable at about 174 m, but in 2004 reported tilapia landings fell to 6 300 tonnes, suggesting underreporting.

Based on these observations, and as the tilapiines *O. niloticus* and *S. galilaeus* (contributing about 85 percent of the catch) inhabit shallow inshore areas that are profoundly affected by reservoir levels, a relationship can be expected between the total annual fish production and reservoir water level, particularly considering the large interannual fluctuations of 19 m between 1971 and 1996 and seasonal fluctuations of approximately 8 m. Water level, reservoir surface area and/or shoreline length can be used as proxies for the level of inundation of essential fish habitat and reservoir productivity. For this review, only mean water levels are available. As the effect of water-level changes operates simultaneously with changes in fishing effort, it is important to attempt to separate the two through, for example, multivariate statistical methods. To do so, catch rates by species (or total average annual catch rates) would need to be independently estimated from landings of individual fishers. However, this information is not available. Therefore, the following analysis uses the annual change in total landings and the annual change in average catch per fisher and per boat of tilapiines, and relates these – with appropriate time lags to account for the response time of recruitment into the fishery – to annual changes in mean water level. Alternatively, annual absolute fluctuations in water level (i.e. maximum minus previous minimum water level) could be used.

Trends in both water levels and total annual catch (kilograms) or catch rates (kilograms per fisher or per boat) can form spurious correlations if there are long-term trends in both variables. Therefore, trends are removed from the time series by differencing, so increases or decreases around the trends (anomalies) in both the water level and the catch time series can be related. A significant relation that explained about 19 percent of the variation in anomalies was found between changes in water level and changes in total catch of tilapias with a lag of two years, meaning that the amplitude of annual change in water level appears to affect significantly the catch of tilapia two years later, as has also been described for Lake Kariba by Karenge and Kolding (1995). No significant relationships were found between annual change in water level and annual changes in catch rate, expressed either as kilograms per boat or as kilograms per fisher, at lags of between one and four years. An important caveat needs to be reiterated in relation to this analysis: the illegal unreported catches are assumed to be constant at about 50 percent, but more likely developed gradually from around the time that prices started to become fixed on the reservoir (see the section below on socio-economic issues and footnote 3). Despite the bias, the expected relation between change in water level and change in tilapia catches is seen (Figure 43), but the extremely low proportion of explained variation ($r^2 = 0.19$) points to the high uncertainty of the observation.

FIGURE 43

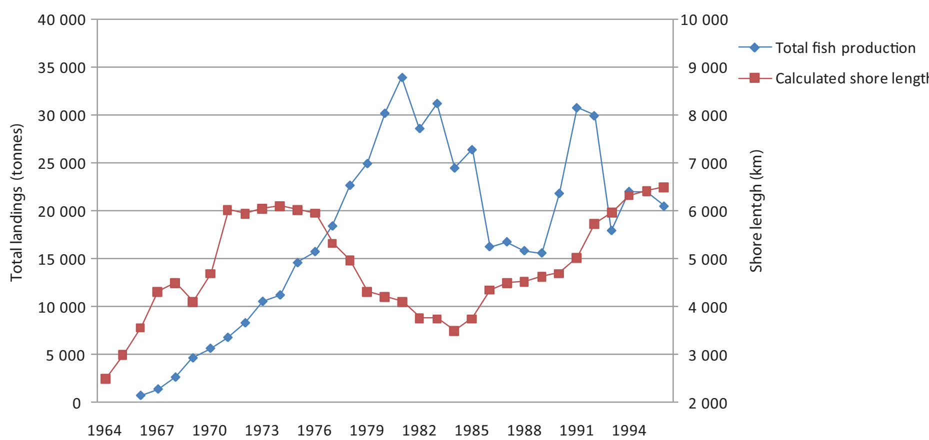
Relationship between detrended mean water level and detrended officially reported tilapia landings two years later



Note: The regression shows a significant positive relation between the annual change in mean water level and the annual change in landings of tilapia two years later (filled circles). Data on tilapia landings during the filling phase of the reservoir, 1965–1975 (open circles), and during a period of particularly poor reporting of landings, 1995–2001 (crosses), were excluded from the analysis.

Littoral areas provide tilapia with suitable breeding and nursery grounds. The length of the shoreline and its slope are important factors for the development of periphyton and littoral fauna, the main food of tilapia species. Accordingly, it is expected that the total fish catch, particularly of tilapiines, should increase greatly with a longer shoreline. The mean length of the shoreline of Lake Nasser between 1966 and 1996 is calculated using the mean water level in different years. As a result of the continuous increase in the mean water level between 1991 and 1999, the shoreline length of Lake Nasser extended from 2 539 km in 1966 to 6 438 km in 1978 and from 4 702 km in 1991 to 7 482 km in 1999. Yamaguchi *et al.* (1996) found that total fish production in Lake Nasser is positively affected by a longer shoreline or negatively affected by a shorter shoreline with a lag of three years. Their analysis by visual inspection (Figure 44) is not convincing, as there is no increase in shoreline length to account for the pronounced second peak in fish production.

FIGURE 44
Relationship between total fish production and calculated mean length of shoreline of Lake Nasser



Source: Yamaguchi *et al.*, 1996.

3.5.3 Fishery biology

Since the 1970s, Lake Nasser fishery research has focused largely on general studies of fish biology. Stock assessments have rarely been conducted and results are considered too unreliable for management decisions. Many of the studies carried out on Lake Nasser have had limited impact on fishery policy and development. In fact, complementary to short-term studies, long-term monitoring programmes should be carried out on Lake Nasser. They should include, among other things, a good system of recording catch and effort in order to obtain time series of spatially defined catch rates and fishing effort, which would support short- and long-term decisions on fishery management and evaluation of the measures taken.

Food and feeding habits

In the early stages of the fishery, the fish landed were predominantly high-trophic-level piscivores and benthivores, but later changed to low-trophic-level planktivores (Tables 15 and 16) (Mekkawy, 1998; Bishai, Abdel Malek and Khalil, 2000). A fishery based on herbivorous fish is more productive than one based mainly on predators. It is not clear from this analysis whether the changes are caused by greater abundance of cichlid species or by a change in targeted species and/or consumers' preferences.

TABLE 15
Average catch of fish with different feeding habits in three successive periods

Years	Feeding habit		
	Periphyton-plankton feeders[1]	Carnivorous, zooplankton and insect feeders[2]	Omnivorous[3]
	(% by weight)		
1966–1972	39.92	42.04	18.04
1973–1978	66.27	32.96	0.77
1979–1996	88.27	10.76	0.97

[1] *Sarotherodon galilaeus* and *Oreochromis niloticus*.
[2] *Hydrocynus forskahlii*, *Lates niloticus*, *Bagrus bajad*, *B. docmak*, *Heterobranchus* spp., *Alestes dentex* and *A. baremoze*.
[3] *Labeo* spp., *Barbus* spp., synodontids, schilbeids and mormyrids.
Source: Bishai, Abdel Malek and Khalil, 2000.

TABLE 16
Food categories of major fish species in Lake Nasser

	Phytoplanktivores			Zooplanktivores	Benthivores					Piscivores
	Peri-phyton	Diatoms	Filamentous Algae	Zoo plankton	Molluscs	Nematodes/ annelids	Insect larvae	Shrimp	Crab	Fish
Lates niloticus							x	x	x	x
Bagrus docmac						x	x	x		x
Hydrocynus forskahlii							x	x		x
Synodontis spp.					x	x	x			
Schilbe mystus					x		x	x		x
Mormyridae						x	x			
Labeo spp.					x	x	x			
Alestes nurse, A. baremoze				x						
Oreochromis niloticus, Sarotherodon galilaeus	x									
Chrysichthys auratus, Chrysichthys rueppelli		x	x			x	x	x		

Sources: Latif and Khallaf, 1996; Entz and Latif, 1974; Tharwat *et al.*, 1994; Latif, 1979.

Spawning period and closed season

Fishing in Lake Nasser is prohibited from 15 April to 15 May, probably based on an analysis of maturity stages of the main species in the catch, *O. niloticus* and *S. galilaeus* (Figure 45 broken lines). Although both species reproduce year round, their main spawning period is during the first half of the year. Based on these observations, Mekkawy (1998) even suggested that a closed fishing period should be extended to six months, from January to June. However, this suggestion is impractical and without support from any observation or analysis showing that there is a recruitment problem with the two species. No evaluation has been carried out on how effectively the current closed period of one month protects the reproductive capacity of the two species.

Life history parameters and stock assessment results

Fish stock assessment provides advice on the optimal levels at which fish species should be exploited. The limiting reference point, maximum sustainable yield (MSY), is often given as the level of effort that should not be exceeded in a healthy fishery. Another indicator that is often used is the exploitation rate (E) ($E = F/Z$ where F = the fishing mortality rate and Z = total mortality rate), $E \leq 0.5$ is often considered the exploitation level needed for the maintenance of a healthy fishery. Estimates of MSY and E were made by Khalifa, Agaypi and Adam (2000) for *Oreochromis niloticus* and *Sarotherodon galilaeus*. They concluded that the stocks of both were overexploited, as E was about 0.8 for the two species (Table 17). The long-term effects of reducing fishing mortality by 10 percent would increase the catch of *O. niloticus* by about 65 percent and that of *S. galilaeus* by 7 percent.

TABLE 17

Life history parameters of five economically important fish species of Lake Nasser

Species	Reference	L_∞ (cm)	K	t_o (years)	Z	M	F	T_c/L_c (years/cm)	L_c (cm)	E = F/Z	Phi prime	Reference	Phi prime	Resilience	Population doubling time (years)	Vulnerability to extinction
L. niloticus	1	180	0.069	0.79	0.35	0.17	0.18	0.74	18	0.5	3.35	3	3.76	Medium	5.4	Very high (67.8)
T. zilli	1	26.49	0.325	2.346	1.37	0.79	0.58	1.47	17.6	0.4	2.36	3	2.74	Medium	1.6	Low, moderate (30.61)
A. dentex	1	40.022	0.322	1.205	0.8	0.7	0.1	1.35	20.3	0.1	2.71	3	2.68	Medium	2.68	Moderate(36.63)
O. niloticus	1	50.39	0.16	2.569	0.73	0.42	0.31	0.9	21.45	0.4	2.61	3	3.06	Medium	1.6	Moderate (35.42)
O. niloticus	2	54.73	0.27	-0.745	1.21	0.24	0.97	na	19	0.8	2.91					
S. galilaeus	1	42.75	0.12	4.17	0.83	0.36	0.47	0.8	19	0.6	2.34	3	2.66	Medium	1.6	Low, moderate (30.24)
S. galilaeus	2	37.8	0.294	-1.187	1.97	0.34	1.63	na	17	0.8	2.62					

Note: References: 1: Adam, 2004; 2: Khalifa, Agaypi, Adam 2000; 3: www.Fishbase.org

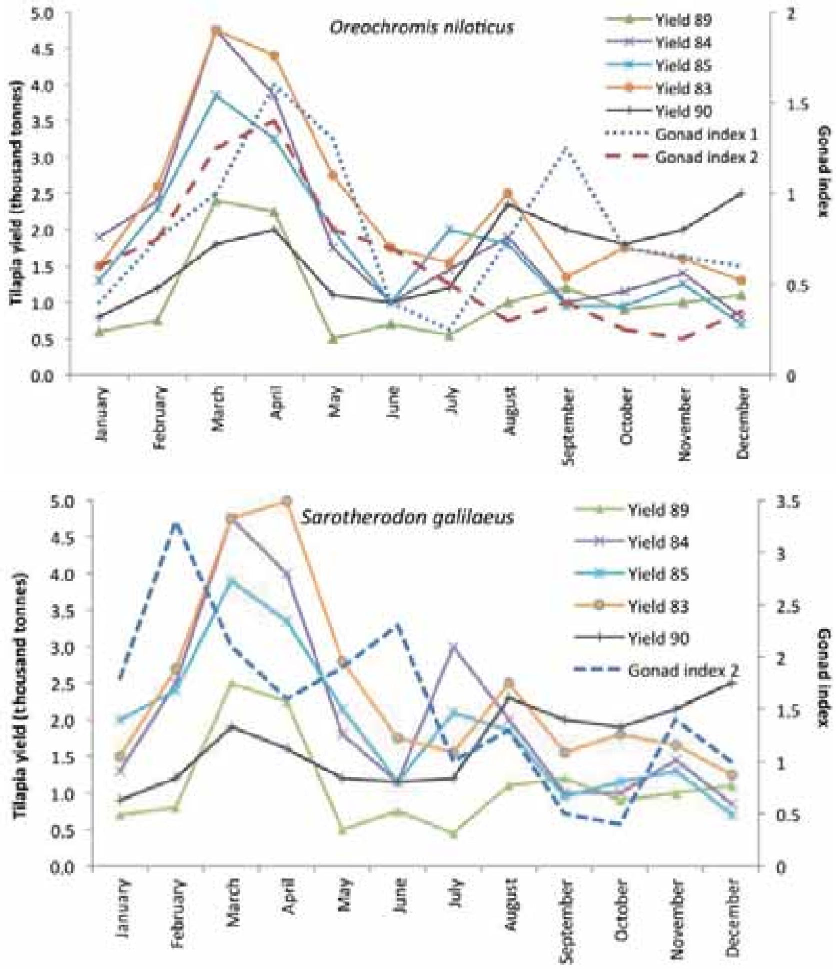
L_∞ = asymptotic body length; K = von Bertalanffy's growth coefficient; t0 = age at which length is theoretically zero; E = exploitation rate; Z = total mortality = F (fishing mortality) + M (natural mortality); Tc = age at first capture; Lc = length at first capture; Vulnerability to extinction is a figure between 1 and 100 as defined by Cheung, Pitcher, and Pauly, 2005; na = not available.

TABLE 18
Estimates of maximum sustainable yield (MSY) and F_{MSY} of various species of Lake Nasser[1]

Author	Adam (2004)	Pitcher (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy (1998)	Mekkawy 1998
Model used	Thompson and Bell		Schaeffer		Schaeffer	Hyperbolic	Schaeffer	Schaeffer		Graham?	Schaeffer	Generalized stock production model			Thompson and Bell
												Asymptotic	Gompertz	Logistic	
Years of data used	?	?	?	?	1988–1994	?	1973–1992	1981–1989		?	?	1966–1992	1966–1992	1966–1992	?
	MSY	MSY	MSY	F_{MSY}	MSY	MSY	MSY	MSY	F_{MSY}	MSY	MSY	MSY	MSY	MSY	MSY
Lates niloticus	2 217.2		1 490	1 061											
Alestes dentex	4 384.6														
O. niloticus	21 589.3		32 342	9 037							26 863	25 337	15 614	15 348	30 128
S. galilaeus	24 209.7		23 593	9 037							27 244	32 970	16 542	13 658	17 692
Hydrocynus spp.			3 364	2 636											
Labeo sp.			641	641											
Bagrus sp.			109	991											
Clarias sp.			107	1 009											
Total tilapiine								53 755			54 107	58 307	32 156	29 006	47 820
Others								3 738							
Total	52 400.8	80 000	61 646		59 742	55 617	61 645	57 493	1 313	57 869		62 360			
Highest catch recorded	34 206	34 206	34 206		34 206	34 206	34 206	34 206		34 206	30 529	30 529	30 529	30 529	30 529
Total catch (year of publication)	12 435	19 203	19 203		19 203	19 203	19 203	19 203		19 203	14 195	14 195	14 195	14 195	14 195
Total catch x 2	24 870	38 406	38 406		38 406	38 406	38 406	38 406		38 406	28 390	28 390	28 390	28 390	28 390
% MSY	47	48	62		64	69	62	67		66	52	49	88	98	59
Highest effort recorded				2 982					2 982						
Total effort (year of publication)				2 945					2 945						
% F_{MSY}				33					224						

[1] The proportion of catch over MSY is calculated using the total landings estimate in the year of publication of the MSY estimate multiplied by two to take into account unrecorded catches.

FIGURE 45
Relationship between female gonad index of *Oreochromis niloticus* (top) and *Sarotherodon galilaeus* (bottom) and monthly tilapia yield of Lake Nasser in different years



Notes: Gonad index 1 based on Latif and Rashid (1972), gonad index 2 based on Abdel-Azim (1974), Ahmad (1994) and Adam (1994).
Source: Redrawn from Mekkawy (1998).

However, not all assessments of the state of various species in the reservoir confirm this conclusion. In all these cases, exploitation rates were at or below 0.6 for any species examined (Table 17). With the assumption that only 50 percent of the landings were recorded, catches also appeared to be consistently at between 40 and 60 percent of MSY, with the exception of two analyses that indicated catches were at 88 percent or 98 percent of MSY (Tables 17 and 18). These analyses seem to have been carried out with the classic steady-state formulations of the biomass-dynamic and yield-per-recruit models. It is known that biomass-dynamic models for MSY largely follow observed catches with continuously increasing effort series, while yield-per-recruit models do not give an actual estimate of MSY. It is recommended that time series formulations of the biomass-dynamic models be used, which take into account annual changes in relative biomass. Moreover, none of the analyses took into account the impacts of fluctuating reservoir levels or long-term changes in productivity resulting from continuing sediment loading and associated potential changes in carrying capacity.

3.6 STOCKING AND INTRODUCTIONS

Tilapiine species do not migrate far from their original habitat. Hence, the fingerlings of *Oreochromis niloticus* released into *khors* grow to marketable size after 1.5 years within these areas. Although stocking *khors* is considered an effective method to increase fish stocks, no evaluations have been made to assess how effectively this method increases yields (see Béné *et al*., 2009). *Oreochromis niloticus* seed production is carried out by the Fishery Management Center in Aswan (Abdel-Shaheed and Shenouda, 1993).

The possibility of increasing fish production in the reservoir by introducing new commercial fish species was examined in relation to the insufficiently utilized open-water, pelagic area. Introductions of the freshwater herring (*Limnothrissa miodon*) from Lake Tanganyika, silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*) and *Labeo* spp. were suggested in 1983, as these were thought to be suitable for the open-water area in the reservoir. However, it was feared that freshwater herring fry might inhabit the coastal zone and compete with *O. niloticus* for zooplankton and space, although there was no evidence of this in the literature. Only silver carp was further investigated for introduction. Silver carp was originally transported from Hungary in 1982 to the Fuwwa Hatchery in the Nile Delta. Artificial propagation for acclimatization and mass production of fingerlings was carried out at the Fishery Management Center in Aswan. However, no stocking of the reservoir was done, although silver carp was reared in net cages without artificial feeding (Abdel Shaheed and Shenouda, 1993).

Experiments on the induced spawning and rearing of fry of *Labeo* spp., *Barbus bynni* and Nile perch (*Lates niloticus*) were also carried out by the Fishery Management Center in Aswan to give priority to local species for artificial propagation. Restocking *Barbus bynni* by artificial propagation and release of the reared fingerlings into the reservoir and *khors* was thought to be essential to increase fish resources. Studies on the timing of artificial propagation and techniques for mass producing fingerlings have been undertaken (Abdel-Shaheed, Shenouda and Ahmed, 1993). Attempts to induce artificial spawning in *Labeo niloticus* and *Labeo coubie* were undertaken but were unsuccessful (Abdel-Shaheed, 1996; Shenouda and Naguib, 1993). Further studies on artificial spawning are needed for the three species. Introductions of grey mullet (*Mugil cephalus*) were attempted in 1982 and 1986 in Lake Nasser's Khor El-Ramla. The growth performance was high, but the experiment was not completed. A third trial in 1988 included *Liza ramada*. Some fish escaped the trial ponds and were caught by commercial fishers, but no viable populations seem to have become established.

3.7 SOCIO-ECONOMIC ASPECTS OF LAKE NASSER FISHERIES

The Lake Nasser fisheries include all sectors of fish output, such as management, production, processing, marketing and manufacturing. The production system includes several thousand fish producers and a few thousand fishing boats with gear. Similarly, the marketing system includes hundreds of fish marketing intermediaries or agencies that own cold stores, trucks and processing plants. Coordinators and managers include governmental institutions and cooperative associations.

3.7.1 Fishing exploitation rights in the reservoir zones

Lake Nasser is divided into five zones with exploitation rights granted to specific companies and cooperatives (Table 19). Since 2002, the LNDA has redivided the fishery resources of the reservoir among five cooperative associations, as the "group of fish cooperatives sector", and six investment companies, as the "group of fishing investors" (the Egyptian Fish Marketing Company, HU Group Company, Misr-Kuwait Company, Misr-Aswan Company for Fishing and Fish Processing, Investor Association and Small Manufacturing and Grand Lake Company). The fish cooperative sector was given fishing rights to exploit lakeshore fish in an area occupying about 60 percent of the total reservoir surface, while the investment companies received fishing rights to exploit the rest of the reservoir, of which 34 percent is deep water fisheries and the remaining 6 percent enclosures (Béné, Bandi and Durville, 2008).

The cooperatives allocate to members their offshore fisheries and production on a timed basis to manage the exploitation rights as an economic unit (one of the terms of cooperative membership is to own fishing boats and gears).

TABLE 19
Lake Nasser zones with exploitation rights granted to companies and cooperatives

Zone	Location	Shoreline (km)	Exploitation rights
1	High Dam to Dahmeet	187	Misr-Aswan Company for Fishing and Fish Processing
2	Dahmeet to Mirwaw	300	Aswan Sons Cooperative
3	Mirwaw to Ebreem	800	Cooperative Association of Aswan Fishers (known as the mother cooperative)
4	Ebreem to the Egyptian border	370	Nubian Cooperative Association for Fishing
5	Khor Or on the east side of the reservoir to the Egyptian border	66	El Takamol Cooperative for Fishing

3.7.2 Fish marketing

The Aswan harbour engages in three marketing activities: concentration, dispersion and equalization.

Concentration encompasses the daily collection of fish harvested by fishers spread along the shores of the reservoir, channelling them to Aswan, Garf Hussein and Abu Simbel harbours or to the fish wholesale market. Fish output from Lake Nasser is transported to markets through carrier boats with capacities ranging from 2 to 20 tonnes and refrigerated trucks. Preservation starts on the reservoir by cooling with crushed ice in insulated boxes of 10–30 kg capacity. The boxes are stored in refrigerating stores belonging to two companies: Misr-Aswan Company for Fishing and Fish Processing and the Egyptian Company for Fish Marketing. Large tilapia and Nile perch are filleted, while small ones are cooled and transported to markets in Egypt. One hundred and ninety-five fish carriers operated on Lake Nasser in 2007, of which 6 belonged to the Misr-Aswan Company for Fishing and Fish Processing (zone 1), 29 to Aswan Sons Cooperative (zone 2), 117 to the Mother Cooperative (zone 3), 41 to the Nubian Cooperative (zone 4), and 2 to the El Takamol Cooperative (zone 5).

Dispersion refers to taking fish from the wholesale market and distributing it through retailers to consumers. The Egyptian Fish Marketing Company and Misr-Aswan Company for Fishing and Fish Processing are the most important fish wholesale agencies for Aswan fish. They own processing plants, cold stores, trucks and even several retail shops in Cairo and Alexandria. In addition to providing marketing services, they produce tilapia and Nile perch fillets.

Balancing or equalizing refers to adjusting fish flows in response to changing fish supply and demand. The wholesale fish market at either Aswan, Garf Hussein or Abu Simbel harbours or Cairo's El-Obour fish market receive fluctuating supplies from Lake Nasser fish producers and release them as required to meet the changing needs and demands of fish consumers. In the period 1979–2009, this system was heavily influenced by government intervention, as ministerial decrees from the Ministry of Supply determined Lake Nasser fish prices both for producers and consumers, while all other Egyptian lakes remained without any government control and their fish was sold at free-market prices. Lake Nasser prices were always lower than free-market prices. They remained constant for periods of 1–4 years, and over the 23 years prices changed only 11 times (Appendix 1, Table A1.4).

3.7.3 Potential of Aswan fish marketing

Lake Nasser fisheries provide a living for about 7 000 fishers, 4 000 of whom fish illegally without a licence. However, the reservoir is situated in an isolated region of southern Egypt with very long distances to the nearest population centre at Aswan.

In addition, the extremely hot summers and the hazards to life and health from scorpions and snakes hinder effective marketing. The Aswan fish market may expand by developing alternative fish products such as whole fish, dressed fish, fish steaks, fish fillets, fried fish, grilled fish and different forms of salted and smoked fish. Introducing these alternatives could improve the economic sustainability of fishery resources and increase rural employment and income.

3.7.4 Fishing labour force on Lake Nasser

Lake Nasser fishers can be classified into two groups: owners of fishing boats and gear, and hired labour. Owners of fishing boats and gear are the membership of fishers' cooperative associations. They have the resource rights in all the fishing areas of the reservoir as a result of the cooperative terms of membership. Hired labour describes most of the community and includes the poorest fishers. Fishing is paid through monetary wages or more frequently with a percentage of the catch in a sharecropping system (Finegold *et al.*, 2011). Most hired labourers come from such governorates as Qena, Suhag, Fayum and Aswan and cities around other water bodies, such as Quaron, Brollos and Edko. They work and live away from their families at the fishing bases for six to seven months a year.

3.7.5 Fisheries regulations and development

The LNDA is responsible for managing and developing reservoir fisheries. Several procedures and regulations are applied to maximize fish production and utilize high reservoir productivity:

- A closed fishing season from 15 April–15 May, during the peak of Nile tilapia *Oreochromis niloticus* L. spawning, has been established to maintain the stocks.
- Restrictions on gear type and mesh size are set to prevent the capture of immature fish weighing less than 500 g.
- The LNDA determines the allowable marketing size.
- The LNDA rears and restocks native fish species, and it is currently experimenting with aquaculture techniques and fish farming, including the propagation of native species. The potential for introducing new species into the reservoir for net cage culture has been tested. Fish farming in *khors* and enclosures has been carried out to increase fish production, but the results are inconclusive. Fishmeal is produced from fish carcasses and fish waste and used in animal feeds. A fish feed factory has been constructed to provide feed to LNDA hatcheries.
- The LNDA has established infrastructure, notably ice plants at fish landing centres at Aswan, Garf Hussein and Abu Simbel for fish carrier boats. Carrier vessels have been designed and constructed to transport fish and to keep it fresh.

3.7.6 Impediments to developing Lake Nasser fisheries

Impediments to developing Lake Nasser fisheries exist regarding coordination and management, fish production and fish marketing.

Impediments in coordination and management

The LNDA has paid considerable attention to establishing the necessary fisheries infrastructure, including: three fishing harbours at Aswan, Abu Simbel and Garf Hussein; three fish hatcheries at Sahary, Garf Hussein and Abu Simbel; two ice factories and freezers at Aswan and Abu Simbel; an ice factory and a fish feed factory at Sahary; a fish research station at Abu Simbel; a floating dock for repairing fishing boats; a fish nursery and fish ponds; and a fisheries research vessel. The most important impediments to the functioning of the authority are as follows:

- Different government authorities are responsible for managing various aspects of the reservoir, creating issues of coherency in decision-making.
- The membership of the cooperative associations of Lake Nasser fishers, the main sector in the reservoir economy, is heterogeneous, including members with no experience in fish production.
- There are not enough fishing harbours around the reservoir to cover the huge length of its shoreline.

Impediments in fish production

The most significant barriers affecting fish production in the reservoir are:

- illegal fishing methods;
- the closed season from 15 April–15 May;
- low fixed prices.

Impediments in fish marketing

The most significant impediments in fresh fish marketing are:

- delays in receiving information on the value of fish, usually about two weeks;
- taxes per kilogram of about 18 percent of the fish value (Appendix 1, Table A1.5);
- the committee that administers the fish landed at Aswan harbour is composed of several members affiliated with different administrative offices, causing bureaucratic complexity;
- illegal catching and smuggling.

All these impediments are related to the fixed-price system.

The problem of fish smuggled from Lake Nasser outside the official fish-marketing system was particularly bad during the final years of the fish price-fixing policy and fishery conservation laws (Béné, Bandi and Durville, 2008). According to ministerial decree No. 621, issued in 1981 by the Ministry of Supply, fish producers at Lake Nasser were obliged to sell their fish at fixed prices. From 1979 to 2001, these prices were always lower than the free-market prices for similar fish produced from other lakes. After the liberalization of Lake Nasser fish prices, they jumped by 49 percent, from EGP260 per tonne in 2001 to about EGP387.5 per tonne in 2002, and have continued to rise. Faced with these "adjustments" and fearing some impacts on the consumers, the government reintroduced a fixed-price mechanism until 2009.

The fisheries of Lake Nasser can exceed their current value provided that an environmentally and socially sustainable system is developed. The productivity of Lake Nasser could be increased by reducing management and exploitation impediments and by increasing the value of existing production by improving processing and marketing. Moreover, the idea has yet to be explored that Lake Nasser has substantial potential for fishery enhancement using a range of techniques, such as cove culture. New warm-water aquaculture techniques such as producing bait fish in ponds, aquarium fish production and crayfish production could also be explored.

3.8 FUTURE DEVELOPMENT OF LAKE NASSER FISHERIES

3.8.1 Development aims

Important national economic development aims in Egypt are to:

- increase fish production for local and national consumption;
- increase the contribution of Lake Nasser fisheries to the gross national product;
- provide employment, particularly for young people;
- improve incomes and the standard of living of the local fishers and their families;

- achieve more rational and sustainable use of the natural resources of the reservoir.

Reservoir fisheries are thought to present a relatively low-risk investment, and investors are encouraged to initiate programmes to develop Lake Nasser fisheries. The development process is directed to four main elements: (i) increasing income through increased fish production; (ii) increasing employment; (iii) developing fishers' capacity, including the skills to use modern fishing gear and technologies; and (iv) modifying laws and regulations to remove obstacles facing fishery development projects on the reservoir. All these development priorities assume that Lake Nasser is underexploited. Whether this is the case can be verified by studying trends in the size of fish caught or mesh sizes used, according to the processes of the fishing-down theory (Welcomme, 1999; see also Chapter 4 on Lake Volta). The fact that the best correlations between catch and reservoir level are with flood conditions two years previously (Figure 45) leads to the conclusion that the reservoir is not very heavily fished, as many overexploited inland fisheries harvest fish less than one year old. In those cases, the best correlations are with the same hydrological year. Similarly, the actual fish production of the reservoir, assuming 50 percent underreporting, is still near or below the potential productivity based on estimates of primary production.

3.8.2 Promoting fisheries development

Any development promoting fisheries in the reservoir should take economic, social, environmental and managerial activities into account. These are mentioned below without elaboration or prioritization. It should be noted that many of these activities can conflict with one another or may not even be feasible (e.g. removing annual silt deposits on the reservoir bottom).

Economic activities include:

- liberalizing fish prices;
- stocking and restocking the *khors*;
- facilitating transport, especially from the southern parts of the reservoir to improve the use of Abu Simbel harbour;
- encouraging the private sector and cooperatives to invest in marketing Lake Nasser fish;
- carrying out economic research projects to improve the efficiency and impact of production elements.

Social activities include:

- empowerment of fishers through capacity building;
- providing health and other social services to fishers and their families;
- forming new urban communities by establishing beach farming around the reservoir;
- expanding the activities and improving the efficiency of fish cooperative societies;
- granting small fish-farming projects to young fishers;
- providing training to technical and research leaders in fields related to reservoir fisheries.

Environmental activities include:

- taking care of historical sites and temples located along the reservoir shore;
- encouraging ecotourism;
- raising waterfowl such as swans, ducks, etc.;
- treating sewage and other discharges from motor boats transporting fish and floating hotels;
- making use of Nile crocodiles in development programmes;
- encouraging water sports and recreational fisheries;
- controlling algal blooms;

- regularly removing silt deposits in the reservoir to use as alternative fertilizer in agriculture.

Managerial activities include:

- integrating managerial authorities to achieve the highest possible degree of coordination between the various entities involved in the management of the reservoir;
- strictly monitoring the reservoir basin, especially during the closed season for fishing;
- reconsidering the decree concerning the artificial division of the reservoir fisheries;
- reinforcing fishing laws and regulations and strictly prohibiting the use of fishing methods that violate these laws and regulations;
- addressing the causes of fish smuggling;
- declaring the reservoir a natural reserve, with rules similar to those applied to the Nile islands and El-Qanater El-Khairia Barrage.

3.8.3 Development initiatives

In recent years, the LNDA has undertaken several initiatives to support and enhance the development of reservoir fisheries, such as setting up three hatcheries with total annual capacity of 50 million fry. Other hatcheries are planned to raise capacity to about 150 million fry. Several breeding ponds have been constructed to aid in stocking the reservoir. However, no studies have investigated the need for stocking or the actual enhancement effect of the present stocking regime.

In addition, three fishing ports have been established in the northern, middle and southern reaches of the reservoir and other fish-landing centres are planned; a fish-feed production plant has been established; and roads and marketing facilities are being set up. Last, the authority conducts occasional skills training for fishers.

3.8.4 Identified information gaps and recommendations

While this desk review is comprehensive in its descriptions of various ecosystems, it is limited in its analysis of the current status of the stocks. Based on the modelling information summarized in Section 3.5.3 (Table 18) and other indicators (such as the relationship between catch and water level, and actual fishery productivity and potential productivity based on primary production), it would seem that the problems with regard to exploitation levels are relatively minor and that the reservoir is apparently only moderately exploited. However, as the information available does not allow determination of what data were used in the stock assessment models, this conclusion remains tentative.

It is also important to recognize that the modelling results cannot explain the observed decline in landings and catch rates other than by postulating underreporting. The only information available on the amount of underreported catch suggests that it is of the same magnitude as the reported catches over the whole period examined. If this is indeed the case, then the conclusion should be that catch and catch rates are declining, which is contrary to the conclusions of the models and to the other information available. There is also the possibility that the level of underreporting has changed with, for example, changed policies regarding price setting, and consequently that the accuracy of the landings estimates has also changed over time. It is most likely that underreporting and smuggling developed gradually over time, as smuggling requires a logistical network that needs careful planning. Hence, the major gap in information seems to be the lack of consensus on the actual status of the fishery: Is it indeed moderately exploited, as the models suggest? Or is it overexploited, as the landing data suggest? Is there room for expansion?

Furthermore, the relative impacts of different drivers and pressures on the state of the stocks are unclear. What is the role of fluctuating and changing climate as indicated by water levels and shore inundation? How do continued sedimentation, the expansion of the reservoir and changes in the relative contribution of flows from the major tributaries of the Nile affect productivity? The lack of such information implies that fishery-management regulations and development initiatives cannot be evaluated with regard to their effective impacts. Actual problems related to stock status and the impacts of fishing cannot be fully addressed, quantified goals cannot be set and measures cannot be precisely evaluated.

This review, together with earlier studies of Lake Nasser carried out in the 1980s and 1990s (such as those of El-Zarka [1985] and Craig [2000]), clearly indicate the need to focus future work on directed monitoring efforts and specific problem-oriented studies, as follows:

- Review the catch and effort data-collection system and revise if necessary, perhaps with a sampling system at landing sites instead of total enumeration at major ports.
- Review past assessments with regard to their information base.
- Review catch and effort in relation to environmental changes, starting with such simple drivers as seasonal and annual variation in water levels and associated parameters, such as reservoir area and area of inundation. Then review more complex relations regarding, e.g. sedimentation rates and the influence of flows of different tributaries on primary productivity changes, etc.
- Include monitoring aspects of the geographical distribution of the fish catch and the catch per unit effort (CPUE) for the different regions of the reservoir.
- Evaluate past acoustic surveys of the reservoir basin, especially of the open-water areas, to obtain biomass estimates and review the need, methodology and costs of possible new surveys against the value of information obtained. Establish indicators.
- Update the assessment of the reservoir's stocks of the dominant fish species to determine the current potential of reservoir fisheries and the sustainable exploitation of its resources in relation to fishing effort, including the efficiency of the various fishing gears and methods, as well as natural drivers.
- Evaluate past estimates of life history parameters (growth, feeding habits and reproduction) of important fish species in the reservoir and carry out research to obtain such parameters for species other than tilapia to use in model assessments and as indicators for monitoring.
- Describe species interactions and feeding relationships for the most important and dominant fish species to carry out ecosystem modelling assessments.
- Assess the need for modelling water movement and dynamics in the reservoir basin under different meteorological and water-level conditions to obtain insights into impacts on fish stocks.
- Assess the possible role of land-based aquaculture in increasing the production of fish of high economic value.
- Develop indicators of ecosystem drivers, stock state and fishing pressure, including biological, social, economic and policy indicators and reference levels.
- Quantitatively evaluate the adequacy of the resource-management measures currently applied in the reservoir, including fishing laws and regulations, and consider the need for their critical review and updating.

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