Lake Turkana: World's Largest Permanent Desert Lake (Kenya)

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Abstract

Located in the "cradle of mankind" of the East African Rift Valley, Lake Turkana is distinguished as both the world's largest permanent desert lake and alkaline water body. With a surface area of about 7,560 km^2, Lake Turkana is a highly pulsed, variable system as a result of its closed-basin nature, arid surroundings, and its strong dependence on River Omo for the majority of its inflow, which originates as rainfall over the Ethiopian highlands. In this article we describe the lake's unique ecosystem and associated vicissitudes, diverse habitats and incredible biodiversity, and ecosystem services. Although parts of the lake and lower Omo Delta have been zoned as an international biosphere reserve, Lake Turkana and the region are facing immense threat from anthropogenic activities. A combination of external factors (hydropower dams, irrigation schemes, climate anomalies) and internal drivers (demography, economic growth) will strongly impact the Lake Turkana basin over the next decade. In turn, this will have significant negative consequences on resource productivity and the wellbeing of local communities.

Keywords

Desert Lake · Alkaline · Omo Delta Wetland · Blue-green algae · Transboundary Wetland · Hydropower Dams · Irrigation Schemes · Dependent Communities

Introduction

Lake Turkana is a unique ecosystem, distinguished as the world's largest permanent desert lake and the largest alkaline water body. Of the East African Rift Valley Lakes, Lake Turkana is the most remote (Johnson and Malala 2009) and the last of the world's great lakes to be studied (Hopson 1982). Lake Turkana occupies an arid region in East Africa, largely within northwestern Kenya, but extending into southwestern Ethiopia (Fig. 1). The lake's catchment basin covers an area of approximately 130,860 km^2. With a surface area of about 7,560 km^2, the lake is 260 km long with an average width of 30 km, a mean depth of 31 m, and a maximum depth of 114 m (ibid.). It is fed by three major rivers: the Omo, Turkwel, and Kerio. In addition, numerous small seasonal streams discharge into the lake. The Omo River, which flows continuously and is fed by precipitation from the Ethiopian Highlands, accounts for more than 90% of the lake's freshwater influx and acts as the lake's "umbilical cord" (Kolding 1992; Avery 2010). The Turkwel and Kerio Rivers provide intermittent freshwater inputs (Ricketts and Johnson 1996). Thanks to the Turkwel dam, the river's discharge is today regulated and is perennial, but sometimes all of the water is lost through the riverbed before reaching the lake (Avery 2012a). The Turkana area has been called the "cradle of mankind" due to

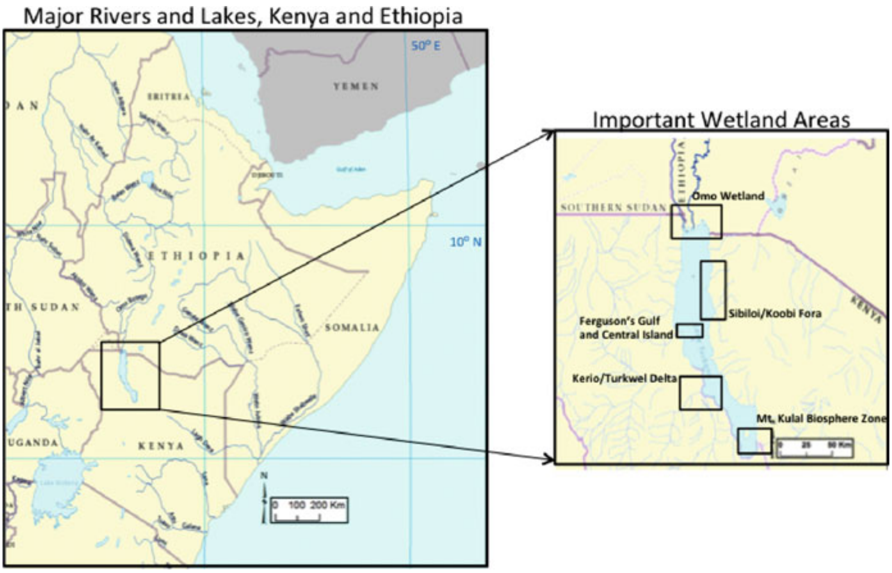

Fig. 1 Map of Kenya and Ethiopia water systems showing Lake Turkana and key areas mentioned in the text. Spatial data on lake and river centerlines were developed by Natural Earth (http://www.naturalearthdata.com/downloads/50m-physical-vectors/50m-rivers-lake-centerlines/) and base map was provided by the Environmental Systems Research Institute®

the preponderance of early hominid fossils that have been found in the region (e.g., Joordens 2011). Due to its national and global archaeological importance, Sibiloi National Park was created in 1973. In 1978, UNESCO listed Mount Kulal as a biosphere zone. In 1983 and 1985, the Central and South Island National Parks were formed, and together with Sibiloi, these were designated a UNESCO World Heritage Site in 1997. The lake is widely known as the "Jade Sea," because of its remarkable, almost incandescent color caused by the blue-green phytoplankton present on its surface.

Hydrology

Despite its large size, Lake Turkana is a highly pulsed, variable system as a result of its closed-basin nature, arid surroundings, and its strong dependence on one river for the majority of its inflow. As a result, the lake is sometimes called an "amplifier lake", i.e., "amplifies" changes in climate (Street-Perrott and Roberts 1983). The water budget of the lake is balanced between river inflows, groundwater exchanges, and evaporation losses (Avery 2010). The surface area of the lake, which receives less than 200 mm year^{-1} of rainfall, is 5.7% of its drainage area (Avery 2012a). An estimated mean evaporation rate of 2.5 m year^{-1} (Kolding 1989) requires an inflow compensation of about 600 m^3 s^{-1} or 19 km^3 year^{-1} to maintain the lake's water balance. More recent water balance modeling suggested a similar but lower inflow of

550 $m^3 s^{-1}$ (Avery 2010). The Omo River's catchment area makes up 56.6% of the lake's drainage basin but the river contributes approximately 90% of the lake's inflow (Avery 2012b, 2013). As a result, the lake's water level fluctuations are almost entirely caused by variations in rainfall over the Ethiopian highlands. Rainfall in the lower Omo basin and over the lake is bimodal, as in the rest of Kenya, with peak rainfall in April and November. As one progresses north, the rainfall becomes unimodal, and in uppermost basin, the peak rains fall in July and August (Avery 2012a). This is the wettest part of the basin, and the lake peaks 1 month later (ibid.). At its present contemporary size, the lake has a relatively long residence time of about 12.5 years (Kolding 1992).

Data on historical and current water levels of Lake Turkana were provided by the Kenya Marine and Fisheries Research Institute (KMFRI) and obtained from TOPEX/Poseidon and other satellite records (Avery 2010, 2012a; Crétaux et al. 2011; USDA 2013). The highest lake level in recent history was recorded in the late 1800s, when levels were approximately 15 m above the zero datum of 365.4 m AMSL (Hopson 1982; Avery 2012a). Between the late 1800s and mid-1900s, the lake level dropped approximately 20 m (Avery 2012a; USDA 2013). The lake level rose 5–10 m in the 1970s and 1980s and then decreased again to current levels by 1990 (Photo 1). Over the past 25 years, the lake level has fluctuated between 360 and 365 m AMSL and has at times reached such low levels that the lake's most productive fisheries area, Ferguson's Gulf, has become dry (Avery 2012a). Ferguson's Gulf dries up when the lake level is 3.1 m lower than the Hopson zero datum, which happened most recently from 1993 to 1998, 2003 to 2008, and in 2010 and 2012 (Fig. 2). Within a given year, the lake level varies 1–1.5 m with the highest annual water levels generally occurring from September through December (USDA 2013; Fig. 3).

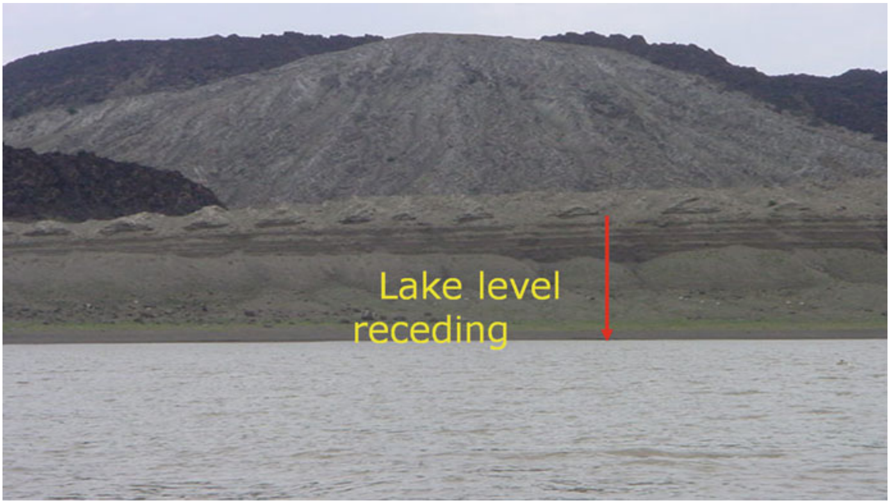

Photo 1 Historical lake level changes (Photo credit: W. Ojwang ©)

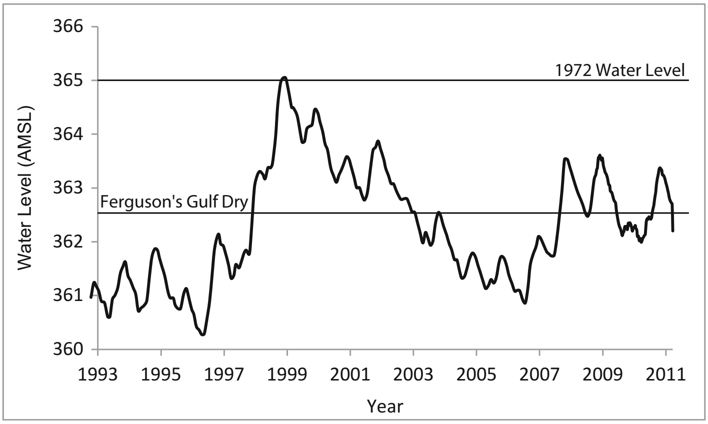

Fig. 2 Satellite altimetry data showing Lake Turkana water levels from 1993 to 2011, downloaded from http://www.LEGOS.pbs-mip.fr/soa/hydrologic/HYDROWEB (as described in Crétaux et al (2011)). The top horizontal line represents the 1972 water level and provides historical context. The bottom horizontal line represents the water levels at which Ferguson's Gulf, the lake's most productive area, dries up (Hopson 1982; Avery 2010)

Geochemistry (Water Quality and Nutrients)

Lake Turkana has average conductivity levels of 3,500 μScm^{-1}, making it a "high ion" or "Class II" lake (Talling and Talling 1965). Due to its closed-basin nature, the conductivity of the lake has been increasing by approximately 0.45 μScm^{-1} year^{-1} (Hopson 1982). Current salinity levels are approximately 2.5 practical salinity units (psu) (Odada et al. 2003), with the system moving toward the limit of 3 psu defining true saline lakes. Lake Turkana is also the world's largest alkaline lake, with a pH range of 8.6–9.5 (Cohen 1986). The annual surface temperature ranges between 27.2 °C and 29.4 °C and bottom temperatures vary only 1.0 °C from 25.4 °C to 26.4 °C. Turbidity levels are high in Lake Turkana and the euphotic zone extends to only 6 m in the open lake (Källqvist et al. 1988). The lake is known for its strong southeasterly winds, which create surface water currents to the northwest and deep reverse bottom water currents (Hopson 1982). Due to these currents and the lake's relatively shallow nature, the lake is well mixed and the water is generally well oxygenated at all depths (Källqvist et al. 1988), with oxygen levels of $\geq$5 mgl^{-1} observed at all stations in a recent study (Ojwang et al. 2007).

Lake Turkana is considered to be an "allotropic riverine lake" (Jul-Larsen et al. 2003), meaning that it has a high dependence on riverine nutrient inputs (Hopson 1982; Källqvist et al. 1988). In the past, very low to trace nitrogen levels were measured (<1 mgl^{-1}) with dissolved phosphorus levels of approximately 2 mgl^{-1} (Ferguson and Harbott 1982). Recent measurements indicate much higher total nitrogen levels of 6–520 mgl^{-1} and total phosphorus levels of 0.5–140 mgl^{-1} (Ojwang et al. 2007). Although nitrogen levels are higher than they were in the past,

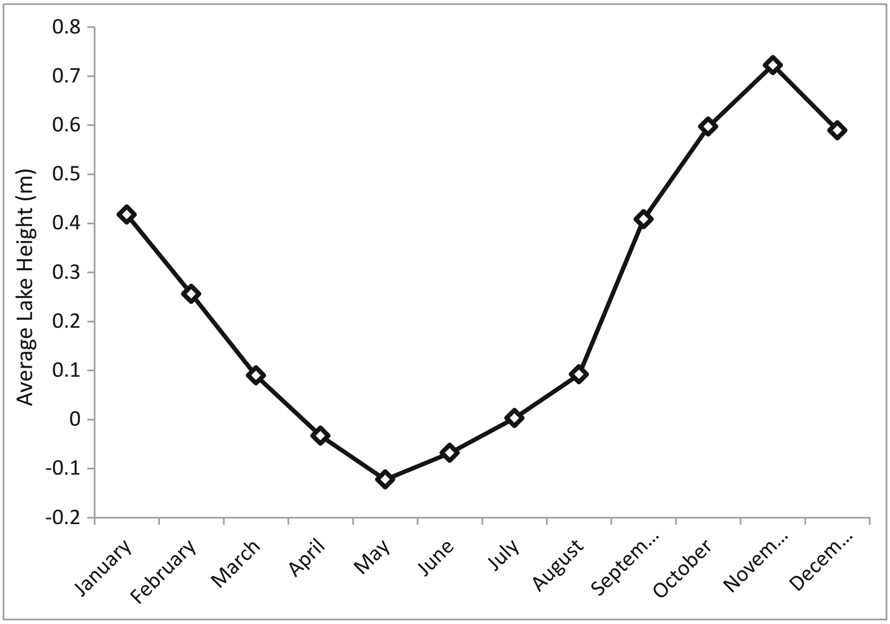

Fig. 3 Average monthly water levels (years 1993–2013) relative to a 9-year average as measured by satellite altimetry (USDA 2013, held in the public domain). Lake Turkana generally has intra-annual fluctuations of 1–1.5 m (Avery 2010)

the N:P ratio for the system is still lower than the Redfield ratio, indicating nitrogen limitation. Continued nutrient inputs from the Omo River are therefore essential to maintain the lake's productivity. The Omo River also controls the salinity and alters the turbidity of the ecosystem (Photo 2). Typical of tropical lake ecosystems, Lake Turkana exhibits relatively little seasonal variation in water temperature, and day length also varies little (Lowe-McConnell 1987). Instead, periods of high inflow from the Omo River and the resultant changes in the lake's limnological parameters act as signals for the lake's fishes to move into shallow areas or inflowing rivers to breed (Hopson 1982). The volume of the river's inflow, which controls the lake's water levels, also influences the availability and distribution of different habitat types. Sediment plumes extend up to 100 km into the lake following flood influxes (Yuretich 1979).

Diversity of Wetland Ecosystems

The most notable wetland ecosystem in Lake Turkana is the Omo Delta. Other notable wetland ecosystems within the lake include Ferguson's Gulf, Central Island National Park, and the mouths of the Kerio and Turkwel rivers (Fig. 1). In addition, the lake margins host many smaller but important wetlands, in some cases physically separate from the lake.

Photo 2 Turbid waters of River Omo flowing through delta into Lake Turkana (Photo credit: W. Ojwang ©)

Omo Delta Wetland

The Omo Delta is located at the northern tip of Lake Turkana. The delta has a complex pattern of waterways, which experience strong spatial and temporal fluctuations (Olago and Odada 2007). During the early 1970s, the Omo Delta was entirely contained within the boundary of Ethiopia. The delta increased by 500 km^2 between mid-1980s and late 1990s (Haack and Messina 1997). By the mid-2000s, the front edge of the delta had moved approximately 12 km to the south and had crossed over the Ethiopian border into Kenya, and the area of wetland vegetation had increased nearly 300%, from 117 to 334 km^2. The basis for the delta expansion is likely to be reduced lake levels and increases in sediment inflow (Avery 2010). Increases in sediment inflow are a consequence of anthropogenic influences on the river's watershed that have led to deforestation, including overgrazing (Photo 3) and clearing of land for agriculture (Haack and Messina 1997; Ayalew 2009; Avery 2010). There is a unique mode of succession taking place within the lake, with wetland vegetation largely replacing the previously water-covered region, but when the lake rises again, as it has done in 2015, these vegetated areas become inundated. While a consequent increase in faunal biodiversity in the delta area has been noted, the expansion of the delta has also attracted human population, possibly fueling the recent increase in human-wildlife conflicts (Olago and Odada 2007). The expansion of the delta southward has also increased conflicts between Ethiopian and Kenyan tribes, as Ethiopian tribes have migrated south into Kenya in order to continue fishing in the lake.

The Omo Delta and fringing riverine wetlands are characterized by dense macrophyte vegetation, dominated by *Potamogeton* spp., and the emergent grasses

Photo 3 Herds of cattle within the Omo Delta (Photo credit: W. Ojwang ©)

Paspalidium geminatum and *Sporobolus spicatus*, which occur in shallow areas. Several submerged plants, including *Ceratophyllum demersum* and *Hydrocotyle* sp., and floating plants, including *Lemna gibba*, *Nymphaea* spp., and *Ottelia ovalifolia*, have been recorded in the area (Hughes and Hughes 1992). Besides the ubiquitous acacia tree *Acacia tortilis* that dominates the landscape, there is the gingerbread palm tree *Hyphaene thebaica*, whose oval fruit is edible, and the doum palm *Hyphaene coriacea*, used for making local raft boats. The presence and imminent impact of the noxious invasive weed water hyacinth *Eichhornia crassipes* is of great concern to many conservationists, though it presumably may not survive in the semi saline lake.

Although the Omo Delta and the fringing riverine wetlands may well be considered as part of the broader Lake Turkana, they are home to some unique species that are rarely and/or hardly found in the lake proper. These include several species of mormyrids (freshwater elephant fish), *Mormyrus longirostris*, *Marcusenius victoriae*, *Marcusenius macrolepidotus*, *Mormyrus anguilloides*, *Mormyrus kannume*, *Marcusenius stanleyanus*, *Hyperopisus bebe*, and unidentified *Mormyrus* sp.; Arapaimidae (*Heterotis niloticus*), the African arowana; Gymnarchidae (*Gymnarchus niloticus*), the African knife fish (an electric fish); and Polyteridae (*Polypterus senegalus*) (Photo 4). Together with the riverine fish species, the Delta hosts representatives of more than 15 different fish families (Ojwang et al. 2011).

Other species found within the Delta include Nile crocodiles *Crocodylus niloticus* (average of eight individuals/km^{-1} along the river channel – Photo 5), several rare and endemic species of invertebrates, reptiles and amphibians, and over 128 avian species (Ojwang et al. 2011).

Photo 4 *Polypterus senegalus* inhabits the Omo Delta (Photo credit: W. Ojwang ©)

Photo 5 Nile crocodile *Crocodylus niloticus* inhabiting the mouth of R. Omo (Photo credit: W. Ojwang ©)

Kerio/Turkwel Deltas

These two smaller deltas differ greatly from each other and are associated with the seasonal Kerio and Turkwel Rivers (Fig. 1). The Kerio River runs parallel to the primary direction of the wind in the region, so its mouth is situated on a low-energy shore. It is also protected from the direct north–south wave action that arises when winds change direction and has consequently developed a dense mass of riverine-associated macrophytes. The Turkwel River, on the other hand, drains directly into the part of the bay facing the strong SE winds for which the lake is known. As a result, rooted macrophytes have failed to take hold along the banks, and there is little permanent vegetation except for the invasive thorny shrubs of *Prosopis juliflora*.

Ferguson's Gulf

Ferguson's Gulf is the most important tilapia habitat in Lake Turkana, especially for the indigenous tilapia species *Oreochromis niloticus*. The Gulf generally experiences annual water level fluctuations of 0.5–1.5 m, but has also dried up completely three times in the last 25 years (Fig. 2). The Gulf, which is approximately midway down the lake's western shoreline east of Kalokol market, is protected from the open lake's wave action and direct mixing by the Longech/Namukuse spit. The relatively calm waters of the Gulf support a different phytoplankton community from the rest of the lake, with primary production rates up to three orders of magnitude higher than in the open lake (Källqvist et al. 1988). Intensive fishing activities conducted using small-mesh beach seine, set gillnets, and purse seines are rampant in the area. The fishery is characterized by boom and bust cycles that are largely dependent on the Omo River's floods. The invasive shrub, *P. juliflora*, heavily covers the shores of the Gulf. Its thick interlocking thorny canopy blocks access to previously important fishing grounds and certain landing beaches.

Sibiloi/Koobi Fora Protected Area

Sibiloi National Park was designated a protected area under Kenyan law in 1973. The shoreline within the Park is approximately 90 km long and is characterized by several spits, muddy shorelines, some rocky shorelines, inlets, seasonal river mouths, and some lush growths of submerged and rooted macrophytes (e.g., *Potamogeton pectinatus*). Sibiloi Bay and Allia Bay are shallow regions near the Park's headquarters that boast the largest submerged beds of rooted aquatic macrophytes of Lake Turkana proper. Another important wetland habitat in Sibiloi National Park is Koobi Fora, which lies directly east of North Island, midway between the southern and northern ends of Sibiloi National Park. The wetland areas of Sibiloi National Park, which are devoid of fishing activities other than some sports fishing and cases of poaching, support the highest fish biomass in Lake Turkana. Furthermore, experimental fishing within Sibiloi National Park produced individuals larger than those caught with the same fishing gear in highly fished areas, such as those surrounding Ferguson's Gulf (Ojwang et al. 2007).

Other Protected Areas of the Lake

In 1978, UNESCO listed Mt Kulal and the southern lake area, including South Island, in its Biosphere Reserves Directory. In 1983, South Island was created as a national park in its own right, followed in 1985 by Central Island. At the south end of the lake, there are a crater lake and some small lakes that are hydraulically connected to the main lake. At Loiyangalani, on the southeastern shore, an oasis of potable springs and doum palms is the focal point for the largest human settlement on the eastern shores of the lake. Another oasis not far north is the water source for El Molo village on the lake. Similar spring-fed oases on the western lake shores at Eliye and Lobolo provide valuable sources of potable water to the local population. These springs are crucially important, as the main lake water itself is too high in fluoride for safe consumption (Avery 2010, 2012a, 2014).

Central Island is especially interesting as it includes three distinct lakes within the main lake, each with different salinities and each providing a distinct habitat for birds in particular, including lesser flamingos (Avery 2012b).

Lake Turkana Biodiversity

Phytoplankton diversity is relatively low in Lake Turkana. The phytoplankton community is dominated by the blue-green algae *Microcystis aeruginosa* and the green alga *Botryococcus braunii.* The total annual photosynthetic plankton primary production was estimated at ca. 2 kg O_2/m^2/year (Källqvist et al. 1988). The zooplankton community includes copepods, cladocerans, and protozoans, whose total production has been estimated at 216,000–540,000 tonnes dry weight per year (Hopson 1982). There are records of 50 species of benthic organisms, dominated by ostracods and insects, within the lake and Omo Delta (Cohen 1986).

Lake Turkana is home to at least 60 fish species (Froese and Pauly 2013), 12 of which are endemic. For the most part, the species found in Lake Turkana can be found elsewhere in Nilo-Sudan lake and river systems. The number of fish species in the lake is low when compared to other African lake and river ecosystems, except for Lake Albert, which has a similar fish composition and diversity. Many of the more diverse lake systems, which host hundreds of species dominated by cichlids, are older and deeper than Lake Turkana (Lowe-McConnell 1987). Endemic species of fish include small zooplanktivores (*Brycinus minutus*, *Brycinus ferox*) that form a unique mid-water scattering layer in the lake, a smaller and more pelagic species of *Lates* (*L. longispinus*) and cichlids (*Haplochromis turkanae*, *Hemichromis exsul*). Unlike in Lake Victoria and some other African Lakes, the Nile tilapia *Oreochromis niloticus* and Nile perch *Lates niloticus* are native to Lake Turkana and in fact are the highest valued species in the lake's commercial fishery.

Lake Turkana supports over 350 native and migratory bird species, making it an "Important Birdlife Area" (UNESCO 2014). The lake and Omo River, in particular, also host the world's largest remaining population of Nile crocodile (*Crocodylus niloticus*) and contain protected breeding grounds for this species as well as for hippopotamus and several venomous snake species (UNESCO 2014). Mammals sighted in the park areas and their environs include Grevy's *Equus grevyi* and Burchell's zebra *Equus quagga burchellii*, Grant's gazelle *Nanger granti*, beisa oryx *Oryx beisa*, topi *Damaliscus korrigum*, greater kudu *Tragelaphus strepsiceros*, hippopotamus *Hippopotamus amphibious*, lion (*Panthera leo*; IUCN Red List status – vulnerable), cheetah (*Acinonyx jubatus*; IUCN Red List status – vulnerable), leopard *Panthera pardus*, striped hyena *Hyaena hyaena*, wild dog (*Lycaon pictus*; IUCN Red List status – endangered), and silver-backed jackal *Canis mesomelas*. There are also four species of endemic reptiles in the region, including three species of frogs (*Bufo chappuisi*, *B. turkanae*, and *Phrynobatrachus zavattari*) and the endemic Turkana mud turtle (*Pelusios broadleyi*; IUCN Red List status – vulnerable).

Ecosystem Services

Lake Turkana's broader basin, the lake, and its fringing floodplain wetlands provide a host of hydrologic, ecological, economic, and socioeconomic services. These services include water provision for domestic and livestock use, energy (hydroelectric power) and agricultural uses, habitat for fisheries, forage for livestock, fuel, building materials (Photo 6), natural food products, climate moderating effects, as well as significant opportunities for ecotourism and preservation of cultural values. Important sites for tourism include Sibiloi National Park and the geologically active Central Island, which hosts the magnificent Crocodile, Flamingo, and Tilapia lakes, also South Island National Park. The lake, the Omo and Turkwel rivers, and associated springs are permanent water sources utilized by thousands of people, hence forming important lifelines in the region for millennia, perhaps dating back to the dawn of humankind.

Fishing has taken place on Lake Turkana for at least 10,000 years, with catches used primarily for local consumption until the emergence of the commercial fishery

Photo 6 Macrophytes used to thatch huts within the Omo Delta (Photo credit: W. Ojwang ©)

in the 1940s (Owen et al. 1982) – see Fig. 4. Although Lake Turkana may have the potential to increase food security in a region where reliance on food aid is ubiquitous, the sustainability of the fishery has not been extensively studied. Pastoralism has been the preferred livelihood of people surrounding the lake (Photo 7) for the last few thousand years, but fishing provides an important alternative and a "safety net" livelihood (Photo 8) in the region (Kaijage and Nyagah 2010). Currently, one of the largest obstacles faced by the Lake Turkana fishery is postharvest losses, which can be as high as 50% (Ojwang et al. 2007).

Riparian Communities

Lake Turkana is abutted by Turkana County on its western side and Marsabit County on its eastern side, with some of the lake's southernmost regions within Samburu County. The Turkana tribe dominates Turkana County, but minor tribes that have migrated to the lake from other regions are also present. Marsabit County has a more diverse group of tribes, including the Dassanech, the Gabra, the Rendille, the Samburu, the El Molo, and the Turkana (Kaijage and Nyagah 2010). Nearly 100,000 members of at least eight distinct indigenous ethnic groups are heavily reliant on flood-recessional farming along the Omo River (Richter et al. 2010), while about 250,000 people of various ethnicities are dependent on fishing within the lake basin.

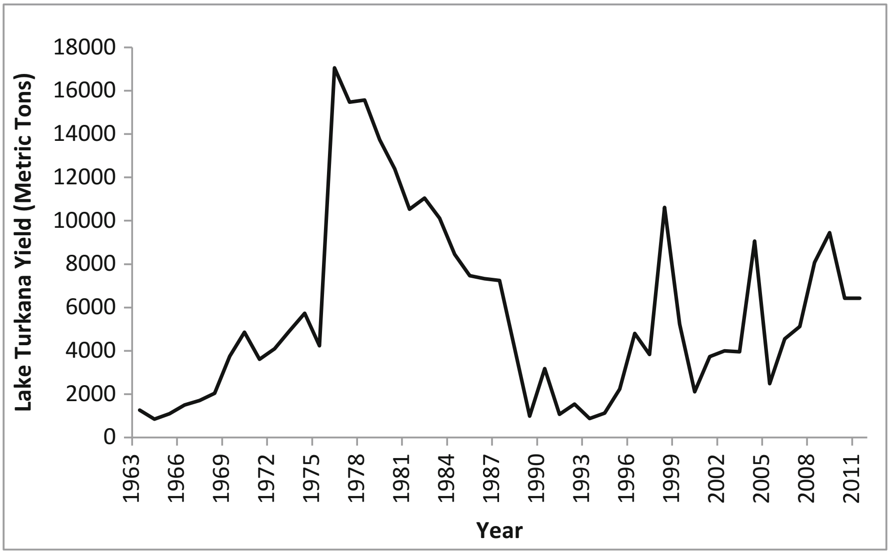

Fig. 4 Fisheries yield for Lake Turkana in metric tons 1963–2011. Fisheries data collected and provided by Kenya's Ministry of Agriculture, Livestock and Fisheries

Photo 7 Riparian settlements (typical of pastoralists) in the northern part of Lake Turkana (Photo credit: W. Ojwang ©)

Photo 8 Turkana lady amidst piles of dried fish (Photo credit: W. Ojwang ©)

Conservation Status and Management

Lake Turkana is a shared transboundary resource by Kenya and Ethiopia. The region is rich in natural resources and hosts unique endemic species. Even though parts of the lake and lower Omo Delta have been zoned as an international biosphere reserve, the protected areas are facing immense threat from anthropogenic activities. In spite of the apparent threats, there is no management plan in place to guide resource use in the region. Recent efforts toward the development of wildlife management and fisheries management plans by Kenya Wildlife Services (KWS), National Museums of Kenya (NMK), and the State Department of Fisheries, Kenya, are initiatives worth fast tracking. Otherwise the prevailing scenario of uncoordinated Lake Turkana resources management will ultimately compromise ecosystem services with drastic negative implications for development, poverty alleviation, and adaptation toward anticipated long-term environmental changes.

The natural resources and human populations within the Omo Delta, which is an "oasis" in the region, could benefit tremendously if it was considered for designation as a Ramsar Site. Other management efforts to consider include the establishment of a Lake Turkana-Omo Delta Transboundary Resource Management Committee, with members drawn from focal point ministries in Kenya and Ethiopia. Conservation and utilization of the World Heritage archaeological sites are needed to recognize and safeguard the region's cultural heritage and to create development opportunities.

Threats and Future Challenges

Human activities in the Lake Turkana basin have accelerated the rate of ecological change and increased threats to the existing natural resources. Major threats in the region include current and planned construction of dams on the Omo River; agricultural expansion and intensification through irrigation projects along the Omo River; environmental stressors including climate change, recent oil discovery, and ongoing exploration activities; associated resource use conflicts (Photo 9); and construction of Africa's largest wind power plant. The number and variety of threats facing the Turkana Basin all attest to a rapidly changing environment, which generates great concern for the future persistence and long-term viability of the important ecosystem services that have been provided over generations. Thus, a combination of external factors (hydropower dams, irrigation schemes, climate anomalies) and internal drivers (demography, economic growth) will strongly impact the Lake Turkana basin over the next decade. In turn, this will have significant negative consequences on resource productivity and the well-being of local communities.

Two dams (Gibe I and Gibe II) have been constructed along the Omo River, a third dam is under construction (Gibe III), and there are plans to build two additional

Photo 9 Insecurity and resource use conflicts (Photo credit: W. Ojwang ©)

dams in the future (Gibe IV and V) (See Fig. 5). Gibe III will be 240 m high and produce 6,400 GWh/year of energy (Asnake et al. 2009). The filling of its reservoir, which will store 11,750 m^3 of water, will lead to a reduction of 2 m in Lake Turkana's water levels (Avery 2010, 2012a; Velpuri and Senay 2012). Gibe IV's reservoir would require a similar volume of water to fill (Avery 2012a).

A minimum environmental flow and an artificial 10-day flood have been proposed for Gibe III, but it is unknown whether a flood of this duration and size will be sufficient to sustain the ecological functioning of the lake (Avery 2012a). Although a reduction in flooding is touted as a benefit by some (e.g., Asnake et al. 2009), the resultant dampening of Lake Turkana's water level fluctuations is of great ecological concern, given the importance of intra-annual fluctuations in controlling fish productivity in African lakes (e.g., Kolding and van Zweiten 2012). The amplitude of the controlled lake level fluctuations, assuming the environmental floods proposed by Asnake et al. (2009) are implemented, will be 400 mm less than the amplitude of the lake's natural fluctuations.

Associated with the Gibe dams are thousands of hectares of sugar cane and cotton plantations and their irrigation infrastructure. Currently 150,000 ha are being developed along the Omo River as part of the Kuraz Sugar Project (see Fig. 5), whose planting began in February 2013 (Ethiopian Sugar Corporation 2014). The Ethiopian government plans to increase sugar production within Ethiopia from 300,000 t in 2009/2010 to 2.25 million tons by mid-2015 (Ethiopian Sugar Corporation 2014). Additional land concessions have been awarded, mainly for cotton production. A total of 445,000 ha commercial agricultural development is planned, of which 135,285 ha has been excised from two national parks (Omo and Mago) and one wildlife reserve (Tama) (Avery 2012a, 2013, 2014).

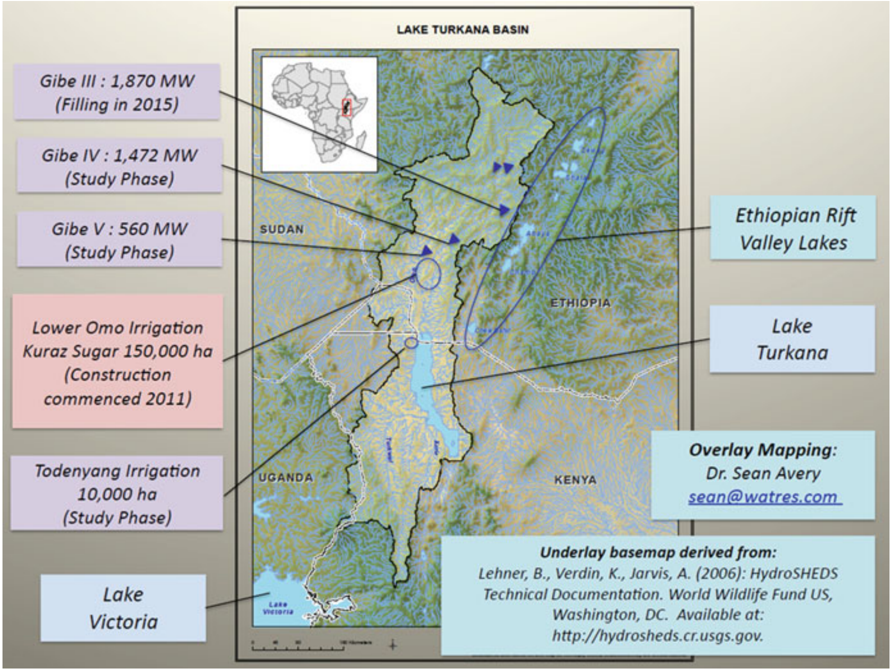

Fig. 5 Lake Turkana basin showing major development projects

The Kuraz sugar scheme will alone abstract at least 30% of the Omo River's flow (ibid.). With the development of other irrigation schemes, the abstraction can only increase, which means the inflow to the lake will diminish. If there is 33.5% reduction in the lake's Omo River inflow, the lake will drop 13 m, and its volume will reduce to 59% of its otherwise sustainable volume (ibid.). If there is 52% reduction in Omo inflow, the lake will fall 22 m, and over half the lake's volume will be lost (ibid.). A drop of as little as 10 m in lake level would reduce the lake's size from 7,560 to 5,900 km^2 and the lake's volume from 238 to 170 km^3 (Avery 2012a). Changes in the lake's water levels will also lead to changes in the shape of the lake's shorelines, which will be the most prominent in the wetland areas shown in Fig. 1 (Omo Delta, Ferguson's Gulf, Allia Bay of Sibiloi National Park, and at the Turkwel and Kerio Deltas; Avery 2010, 2012a, 2014; Velpuri and Senay 2012). Changes in the annual volume and patterns of water inflow from the Omo River will impact a variety of important parameters in Lake Turkana, including turbidity, salinity, productivity, and habitat availability. These changes will interact to influence the feeding, breeding, movement, and ultimately the population levels of fishes in the lake and therefore the lake's fishery. The Gibe Dams and irrigation schemes under construction will also have impacts beyond water inflow changes. For example, eutrophication caused by increased nutrient loads from fertilization of upstream crops or changes in turbidity due to deforestation along the Omo River will also alter the Lake Turkana ecosystem.

In addition to local development projects, the impacts of global climate change on the Lake Turkana ecosystems are projected to increase in severity. The ecosystem, which is already known for its historical environmental vicissitudes, will progressively experience even more extreme changes as a result of global climate change (e.g., Bishaw 2012). Greater efforts are therefore needed to forecast hydrodynamic and ecological responses to climate change in Lake Turkana. It is also important to understand and to strengthen local adaptation not only to improve local conditions but to avoid destabilization of the region occasioned by resource use conflicts.

In addition, the Lake Turkana region, which has historically been ignored by investors, has rapidly gained interest recently. This is attributed to the discovery of oil in the area and the ongoing exploration, which covers nearly the entire lake basin. The oil discovery is seen by many as the ultimate solution to the perennial resource use conflicts, poverty, and famine in the region. However with recent tumbling oil prices (in late 2014 and early 2015), the expected bonanza may be long delayed. Plus, if experiences from other part of Africa are anything to go by, then the usual “oil resource curse” may be unavoidable, i.e., a scenario where African countries with oil are ironically among the most economically troubled, undemocratic, and most conflict prone. Other socioeconomic activities that are usually associated with oil discovery and exploitation are also likely to have negative impacts on human well-being and biodiversity in the region.

The Lake Turkana region has also been earmarked for the development of one of the largest wind power farms in the region. The project when completed is expected to generate 310 MW. Other development activities in the area include the construction of the Lamu Port-South Sudan-Ethiopia Transport Corridor (LAPSSET), which will cut across the Lake Turkana area. These activities are not well planned and mitigated as per the requirements of Environmental Impact Assessments and will have enormous negative impacts on the resources of the region as well as potentially compromising the various ecosystem services that are currently enjoyed by the local communities and the region as a whole.

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