Ministry of Foreign Affairs

Baseline Study Lake Turkana
Final Report

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BASELINE STUDY LAKE TURKANA
FINAL REPORT

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ACRONYMS AND ABBREVIATIONS

ATTZ	Aquatic-Terrestrial Transition Zone
BMU	Beach Management Unit
DCA	Danish Church Aid
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IOM	International Organisation of Migration
KeFS	Kenya Fisheries Service
KMFRI	Kenya Marine and Fisheries Research Institute
KWS	Kenya Wildlife Service
LTFMP	Lake Turkana Fisheries Management Plan
NEMA	National Environmental Management Authority
NGO	Non-Governmental Organization
RVO	Netherlands Enterprise Agency
SACCO	Savings and Credit Cooperative society
SAPCONE	Sustainable Approaches for Community Empowerment
StC	Save the Children
TFCS	Turkana Fisheries Co-operative Society
TUPADO	Turkana Pastoralists Development Organization.
UNESCO	United Nations Educational, Scientific and Cultural Organization
USADF	United States African Development Foundation
USAID	United States Agency for International Development
WFP	World Food Programme
WI	Wetlands International

EXECUTIVE SUMMARY

Lake Turkana is the world's largest endorheic desert lake, which means it only has inflows and no outlets, and it is located in a hot arid environment. The climate driven balance between uneven precipitation in the catchment area of the Ethiopian highlands, and the high rate of evaporation across the lake surface results in very high inter- and intra-annual variation of its water levels, with a maximum amplitude over the past century of 20 meters, and up to 8 meters during the past 50 years. Currently the lake has reached its highest level since 1978. The biology of the lake from primary production to fishes is adapted to these fluctuations and result in similar large fluctuations in productivity. Thus, in short, the large fluctuations of the fish stocks are strongly driven by the hydrological and physical characteristics of the lake system, and any attempt at calculating the potential (fish)production of the lake should take account of the changes and cycles in water levels. This is possible through developing an empirical fish production model. Likewise, due to these cycles in productivity, any investment in facilities to support trade in fish should take account of the boom-bust nature of the fishery and the seasonal unavailability of some commercially important species.

Given the size of the lake, the relative remoteness of its location, and the traditional livelihoods of migrating pastoralism of the riparian human communities, the lake has never been intensively exploited. From the initiation of a commercial fishery after WW2 to present, the catches and fishing effort have been relatively modest compared with the other great African lakes, and always fluctuated in concert with the unstable environment. Currently, judging from observations of the daily catch rates and relatively large sizes of the various species caught during the field visit in September 2023, and the ongoing experimental fishery, we tentatively conclude that the lake's stocks are still not heavily exploited, and that the current fishery most likely has a very limited impact on the variability in availability of stocks. One exception are the large riverine *Distichodus* and *Citharinus* species, which in any African lake fishery usually are the first stocks of species to become depleted after the commencement of a targeted fishery. After a total dominance in large 8-inch gillnets from around 1965, both these species became relatively rare in the fishery since 1975 (Kolding 1989).

The aim of the baseline study is to give insight into the potential opportunities and challenges for the sustainable development of the fisheries sector in the Lake Turkana Basin for commercial purpose as well as food security for the region. This is required as input for authorities of the Turkana and Marsabit county governments to provide a solid base for the sustainable management of Lake Turkana and surroundings, and background information for a pathway to the sustainable development of the fisheries sector, enhanced employment, improved food security and a more stable region. In addition, sufficient knowledge should be provided for the broader program, currently starting, to include further collection of data, the type of data needed for an integrated approach, and the local capacity needed for collecting data and for developing and monitoring a sustainable management plan of lake Turkana.

Our recommendations are based on a comprehensive analysis of the available primary and secondary literature, extensive conversations with a large number of stakeholders ranging from national to local government officials, researchers, fishers, traders, processors, and others before, during and after a field visit in Turkana and Marsabit counties, as well as initiating and analysing the collection of primary data of daily catches by gillnet fishers operating from seven sites along the lake. Recommendations are grouped in two categories: (1) fisheries organization and development and (2) research needs and management.

FISHERIES ORGANISATION AND DEVELOPMENT

Both historically and currently, a large focus of donors and NGOs in the region is devoted to technological solutions to improve fishing, processing, and trade of fresh and dried fish for the region, and in particular in developing a cold chain. However, these interventions have proven extremely fragile and are based on a very limited understanding of the biology of the lake's fish production and a lack of a social and economic analysis of the fish value chain operating under very different conditions along the lake in terms of logistics, enabling environment and (organizational) capacity of people involved in the industry. A thorough comparative economic cost-benefit analysis of the different nodes in the value chains of both forms of fish processing should be carried out, and investments in improving the dried, fried, or smoked fish trade should receive the same attention as continued attempts to develop a cold chain. Furthermore, high priority should be given to addressing competence and agency in organizational capacity, and education and training in financial management, trade, and marketing of the various groups of fishers, traders, and individuals around Turkana accounting for the aspirations of these different groups. Training of individuals or groups (individual entrepreneurs, women's groups, BMUs, cooperatives, etc.) in organizational management, business economics, marketing and trade is preferable and should be done prior to investments in technical solutions such as cold storage and freezing facilities and associated provision of fuel and transport facilities.

Thus, any development of cold storages or cold chains should go hand in hand with creating an enabling environment to diminish the current rapid deterioration of installations and high reliance on outside support to maintain cold chain facilities. Of primary importance is to strengthen the capacity of people in the industry to take care of maintenance of such facilities themselves. While technologically, simple solutions to provide cold chain facilities are available, several issues should be accounted for in a social and economic analysis. These are: (1) the very limited availability of fresh water for processing fresh fish as well as ice-making (both the old fish freezing plant in Kalokol and the new in Loiyangalani have never been operational due to a lack of freshwater). Simple domestic freezer boxes are preferred by many in the trade above larger cold storages due their flexibility and limited operational and maintenance costs; (2) the logistically difficult terrain and hence high costs to transport (fresh) fish; (3) building infrastructure on the lakeshore for landing, storing, processing, and handling fish for transport is heavily constrained by the large lake level fluctuations, and any infrastructure related to fish handling and storage therefore should be semi-permanent in nature and easily moveable.

There has been a 70-80 year long tradition of donor donations to support and develop the fishery and in discussions with fishing communities many fishers asked to be supplied with nets and boats. The numerous requests indicate that fishers are accustomed to continuous donor support or investments by traders in providing fishing implements, thus creating binding patron-client relationships. Donor support should be carefully evaluated to avoid continued dependency on such supplies and limit development of organizational self-sufficiency. Several important examples of successful organisations to create such self-sufficiency exist (e.g. a successful Savings and Credit Cooperative Society (SACCO) organized by a BMU in Kalokol). Any support in the form of providing fishing implements deemed necessary should be organized such that a local industry in boat, net and gear repair/making/maintenance can develop to avoid dependency on aid in fishing implements and foster self-sufficiency. Furthermore if nets are issued to fishers, avoid providing monofilament nylon nets, as these are not biodegradable and lead to ghost-fishing and "plastic" pollution in the lake.

Multifilament biodegradable nets are available and should be prioritized. And lastly, fiberglass boats deteriorate rapidly under direct sunlight and are not easily repaired under current economic conditions and lack of supply chains for repair and maintenance of fisheries assets. Locally made, wooden vessels (that cannot sink) should be preferred, to develop a boat building industry.

Fish is not part of the cultural diet in the region and during our discussions with fishers, fishers organisations, and traders fish as food was rarely mentioned. Fish is seen by most fishers as a trading commodity: a means to overcome mishap through droughts and ultimately to earn enough to buy livestock and return to the pastoral society they came from. Promotion to the people of Lake Turkana of the importance of 'fish as food' should be given high priority, as fish is an important source of proteins and valuable nutrients and vitamins, in particular for children. School feeding programs may have an important role in introducing fish as food as well as providing school going children with healthy food. The lake harbors unknown quantities of unexploited stocks of two small pelagic robbers (*Brycinus* spp.), which are highly productive small fish species (comparable to Omena from Lake Victoria) that potentially could form the basis of a large, dried fish industry if exploitation methods such as nightly light fishing with dipnets as used in other lakes (a.o. Lake Victoria, Tanganika, and Malawi) can be employed in Lake Turkana. In the 1970s, these stocks were estimated to be of considerable magnitude, but the current status needs revisions.

RESEARCH NEEDS AND MANAGEMENT

To provide insights in the highly variable nature (boom-bust character) of the fishery and trade, it is important to fully understand the changing dynamics of the lake ecosystem, fish and fishery production and the role of the variable discharges of water into the lake affected by upstream developments in Ethiopia and Kenya, as well as to advance knowledge of Lake Turkana's response to climate change impact on water supply to the lake. This requires: (1) continued long-term monitoring and analysing the interactive effects of ongoing activities in the region on the ecological functioning of Lake Turkana, and in particular the impact of changes in the river discharges to the lake as a result of hydro power development and water extraction in the upstream areas. This would require; (2) regular monitoring of environmental conditions, including annual lake water levels, river discharges, land cover, water quality nutrient levels and salinity, and (3) linking physical, environmental, and seasonal and annual hydrological variations to variations in the lake's ecology, and in particular fish and fishery production through observational models for short-term prediction.

To link the fishery to lake level fluctuations there is a need to develop a robust catch and effort data recording system, Regular Catch Assessment Surveys (CAS) are expensive and logistically very difficult to carry out and may not be the focus of the current program. It should be discussed with the governments of Turkana and Marsabit as well as on a national level how some form of catch (CPUE) monitoring can be organized on a regular basis. We contend that the Involvement of Beach Management Units should be considered. For that extensive training of fishers and BMU officials is required. Expensive and logistically challenging Catch Assessment Surveys can be replaced by experimental fishery data collection involving fishers (see next), that we successfully have implemented in a trial during the baseline study. If these surveys are expanded with a better statistical design covering all fisheries, they will provide the high quality data needed to assess the fishery. The experimental data collection involving fishers should be carried out at least during the inception phase of the project to provide basic information on species and size distribution of the daily catches of fishers on both sides of the lake and over the gradient from North to South to capture the differences in output of the fishery. This report provides recommendations on how the current trial can be expanded with full involvement of the KMFRI research team in Kalokol. Expansion of the program should focus on improving its statistical design to cover all fisheries over the lake to replace or cover for the lack of regular Catch Assessment Surveys.

However, to account for the total fishing pressure and pattern on the lake, it is important to carry out at least one frame-survey – a lake-wide census of the fishers and their fishing related assets as boats and fishing gear - either during the inception phase of the project or at least during the early stages of the full project as there is great uncertainty about the current fishing effort on the lake. By carefully adding additional questions to the census questionnaire valuable social and economic information can be obtained in addition to the direct needs for fisheries catch assessments.

The productivity of Lake Turkana's fisheries fluctuates due to lake level variations impacting nutrient input and phytoplankton growth. Leveraging existing satellite remote sensing algorithms for chlorophyll estimation by Tebbs *et al.* (2020), we propose to establish linkages between hydrology, water quality, and fish production. Such an empirical model can have predictive capabilities on the production potential of the lake that will facilitate short-term prognoses on the potential yields, which would be important information for the trade business. By integrating hydroacoustic surveys, satellite data, and advanced remote sensing techniques, it aims to inform sustainable development strategies for the lake's resources, ensuring the ecological soundness and economic viability of the planned interventions. To that end at least two lake-wide hydroacoustic surveys for abundance estimations covering the main seasons in the hydrological cycle should be carried out during the inception phase to obtain an estimate of the fish biomass in the lake, including the unexploited pelagic stocks of small endemic species, stratified by (1) a gradient from North to South; (2) the size distribution of the fish stocks in the lake; (3) with a particular focus on the two small unexploited stocks of offshore pelagic endemic robbers (*Brycinus* spp.) for their fishery potential. During the acoustic surveys limnological data should be collected to enable ground truthing of satellite imagery. KMFRI should discuss the set-up of the acoustic surveys with the researchers involved in the modelling exercise to obtain limnological data of high quality. During the inception phase of the main project an initial start-up budget is needed to further develop the model requirements, and guide KMFRI in collecting necessary data for ground truthing. Synergies should be sought between earlier lake monitoring efforts through satellite remote sensing by different research groups and organisations as for example the UNESCO Water Quality Portal and King's College (UK) African lakes algorithms. Furthermore, the Turkana advisory group of ACARE recently was granted funds to implement a water quality monitoring system in Lake Turkana. This system will focus on parameters such as temperature, chlorophyll a, dissolved oxygen (DO), and turbidity ACARE should be involved in seeking complementarity with the current Dutch funded project run by WFP and UNESCO. Lastly, full funding of staff time, research assistants, travel expenses, equipment, consumables, and capacity building activities with KMFRI staff should take place in the second phase of the project after analysis of initial data from the inception phase.

Based on initial findings of the ongoing experimental fishery, it appears that 98% of the number of fish caught, comprising nearly 75% (3 quarters) of the total catch by weight, are predominantly small sized species. These are caught in small mesh sizes (< 5"), which are technically illegal according to current mesh-size regulations. The legal catch basically only consists of large specimen of Nile perch (Iji), comprising 72% of total weight from legal nets; the catch from illegal nets is mainly *Alestes baremoze* (Juse, 52%), *Labeo hori* (Chubule, 22.2%) and Tilapia spp. (Kokine, 14.5%). These three species comprise 68% of the total catch in weight of the experimental fishery, compared to 20% of Nile perch, and currently form the mainstay of the fishery and fish trade. Enforcing mesh-size regulations would lead to an economic collapse of the fishery and is utterly unnecessary from a biological point of view. A thorough review of the rationale of current fisheries management measures should be carried out and made specific for the Turkana situation. Setting such measures should be grounded in a thorough review of the main goals of the fishery in cooperation with the main stakeholders and should be based in the experience of the main users of the fishery, fishers, and in recognition of the multispecies and size and multi-gear nature of the fishery.

1. INTRODUCTION

In her letter of 8th May 2023, the Netherlands Enterprise Agency (RVO) of the Dutch Ministry of Economic Affairs, The Hague, requested the Aquaculture and Fisheries Group of Wageningen University to submit a proposal for a short-term Baseline study of Lake Turkana, Kenya.

The **aim of the study** was to provide the Netherlands Embassy in Nairobi and County Governors of Turkana and Marsabit with a preliminary insight into the potential opportunities and challenges for the sustainable development of the fisheries sector in the Lake Turkana Basin for commercial purpose as well as food security for the region. The insights are required as input for local authorities of the Turkana and Marsabit county government to be provided with up-to-date data that can contribute to a more solid base for the sustainable management of Lake Turkana and surroundings, and background information for a pathway to the sustainable development of the fisheries sector, enhanced employment, improved food security and a more stable region. For RVO and the Netherlands Embassy in Nairobi it is paramount that there is sufficient knowledge for a broader program to be developed by the Embassy regarding including further collection of data, the type of data needed for an integrated approach, and the local capacity needed for collecting data and building and monitoring the sustainable management of lake Turkana.

With the letter of 8th May were included the Terms of Reference (ToR) detailing the background, objectives and expected results and outputs of the short-term study, as well as requirements of the methodology to be used and reporting requirements. The ToR was interpreted and worked out in an inception report detailing the activities to fulfill the requirements, including a workplan and a detailed proposed methodology on data collection including research questions, foreseen activities, and foreseen results. The inception report made clear that there is no overlap with other activities and that the current activity builds upon earlier research done.

This report presents the main conclusions and recommendations based on:

1. a literature survey reported in P.A.M. van Zwieten, K. Obiero, J. Kolding, J. Malala, M. Obiero, and E. Wanderi, **Baseline study Turkana: Inception Report, August/September 2023**, 31 p.
2. an inception workshop held on 10 August 2023 with representatives from the county governments of Turkana and Marsabit, State Department for the Blue Economy and Fisheries, World Food Program (WFP), Lake Turkana Water Body BMU network, National Environmental Authority (NEMA), Kenya Wildlife Service (KWS), Turkana Pastoralists Development Organisation (TUPADO), Water Resources Authority (WRA), Wetlands International, Embassy of the Kingdom of the Netherlands in Kenya and the Dutch Ministry of Foreign Affairs. P. van Zwieten, K, Obiero, J. Kolding. **Baseline Study Lake Turkana – Inception phase**. Power Point Presentation. August 2023.
3. a field trip in September 2023 to Lake Turkana by the research team executing the baseline study (Figure 1) consisting of Paul van Zwieten (team leader, Wageningen University), Jeppe Kolding (University of Bergen), Kevin Obiero (project coordinator, KMFRI Kenya), Maurice Obiero (KMFRI- Kalokol) and John Malala (KMFRI-Kalokol) reported in: P.A.M. van Zwieten, J. Kolding, K. Obiero, J. Malala and M. Obiero, **Baseline study Turkana: Field Report, December 2023**, 94 pp
4. a fisheries trial data collection program, preliminary results of which have been presented in:
   a. P.A.M. van Zwieten, J. Kolding, K. Obiero, M. Obiero, and J. Malala. **Baseline Study Lake Turkana: Preliminary review of the catch data obtained through logbooks of fishers**

from Lake Turkana. Status of trial fishery in Lake Turkana as per 29/11/2023, November 2023, 8 pages.

b. J. Kolding, P.A.M. van Zwieten, K. Obiero, M. Obiero and J. Malala. **Summary of the catch data obtained through logbooks of fishers from Lake Turkana. Status of trial fishery in Lake Turkana as per January 2024**. January 2024, 15 pages

5. discussions with representatives of Ministry of Economic Affairs/RVO, Embassy of the Netherlands Kenya, WFP, UNESCO, UNESCO-IHE, and the Permanent Secretary of the State Department for the Blue Economy including a debriefing of the field trip at the Embassy of the Kingdom of the Netherlands in Kenya on 28 September 2023. P. van Zwieten, K. Obiero, J. Kolding, **Baseline Study Lake Turkana, Kenya**. Power Point Presentation.
6. discussions with researchers from UNESCO IHE, Kings College London and ACARE on long-term monitoring needs
7. final online presentation to and discussion with stakeholders 11 March 2024 – **3 power point presentations**

In the following we present (1) a situational analysis that partly overlaps and expands upon the Inception report and the Field report mentioned and includes a summary of the analysis reports (4 a and b) of the experimental data collection of the Turkana fishery, (2) a monitoring survey and research agenda, including division of roles and gaps in capacity and knowledge and (3) two sets of recommendations focusing respectively on fisheries development issues and fisheries research and management issues.

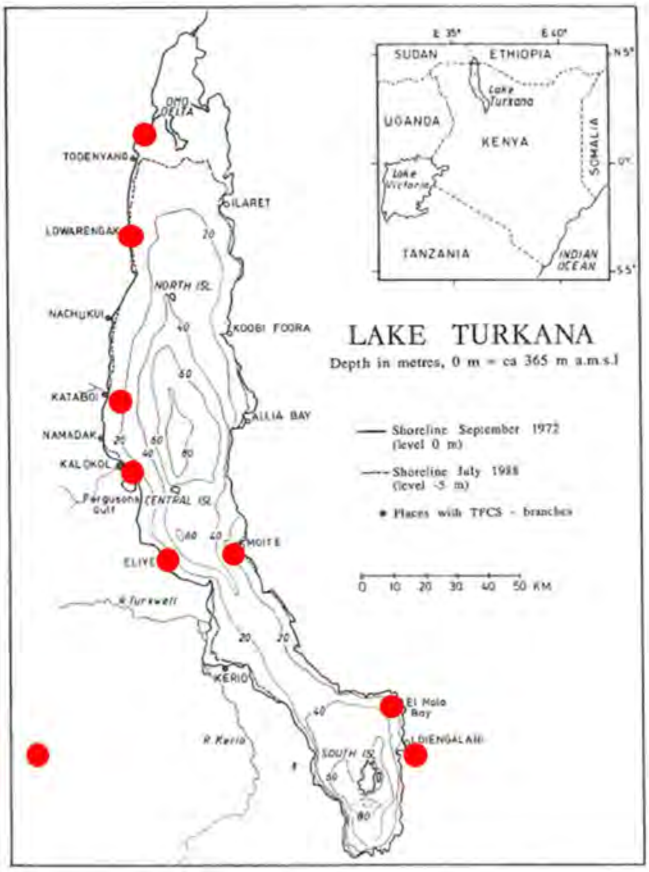

FIGURE 1 SITES VISITED DURING THE FIELD TRIP FROM 10-23 SEPTEMBER 2023 INCLUDE LODWAR, KALOKOL (INCL. FERGUSSON GULF) , KATABOI, LOWARENGAK, TODENYANG, EDGE OF THE OMO RIVER DELTA, ELIYE SPRINGS (TURKANA COUNTY), AND MOITE, LOIYANGALANI AND EL MOLO BAY (MARSABIT COUNTY).

2. SITUATIONAL ANALYSIS

2.1. PHYSICAL, HYDROLOGICAL, ECOLOGICAL SYSTEM

Lake Turkana, located in northwestern Kenya and south-western Ethiopia, is Africa's fourth largest lake and the world's largest permanent desert lake. The lake lies in a closed basin and its limnology, ecology, and fisheries are driven by seasonal and long-term climatic precipitation cycles. The lake has two interconnected basins, each reaching over 70 m deep (Figure 2). The northern basin includes the Omo delta and northern and central sectors. The Turkwel sector in the middle is the narrowest part of the lake with depths not exceeding 30 m and is the link to the southern sector. The deepest point of the lake is over 100 m deep and is within the southern sector.

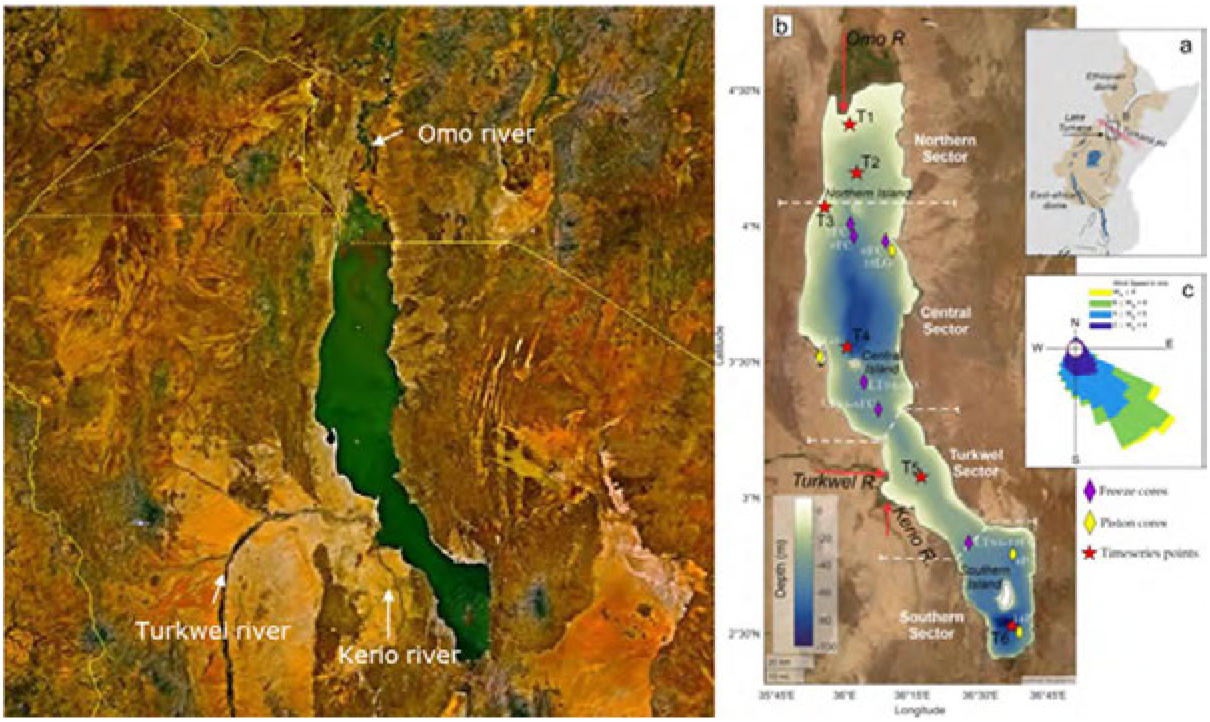

FIGURE 2 LAKE TURKANA: MAJOR INFLOWING RIVERS (LEFT), DEPTH PROFILE AND MAJOR WIND DIRECTIONS (MIDDLE) (IMAGES WIKIMEDIA COMMONS (ZĂINESCU ET AL., 2023).

The lake is subject to substantial and unpredictable annual fluctuations in Lake level. These fluctuations are almost fully dependent on a balance between rainfall in the highlands of Ethiopia and Kenya and subsequent discharge of water, sediments, and associated nutrients into the lake and annual evaporation rates. The main source of freshwater is the Omo River, which, between 1993 and 2014, provided on average around 84% of the lake's water input into the north of the lake. This discharge drives the productivity in the lake, especially in its northern reaches. The Kerio and Turkwel rivers are Kenya's two major influents to the lake, each discharging through individual deltas in proximity to the western shore and providing around 6% of the water inflow. Both rivers are perennial in their highland upper reaches but become ephemeral in the lower semi-arid plains approaching the lake. Around 10% of the water input into the lake is from precipitation and surface runoff (Avery and Tebbs, 2018). These two latter sources are particularly important for the productivity of the southern part of the lake (Figure 2).

Lake Turkana is a desert lake and around 94% of the water inflow is lost through evaporation. Evaporation rates are between 2.3 and 3.2 m/yr. In the late-1800s, the lake level was 20m higher than its lowest observed levels in the mid-1940s. The lake levels have risen since but have fluctuated over a range of 8m. In 2020 the lake level rose significantly to a level about as high as the intermediate peak in 1979/80 (Figure 3).

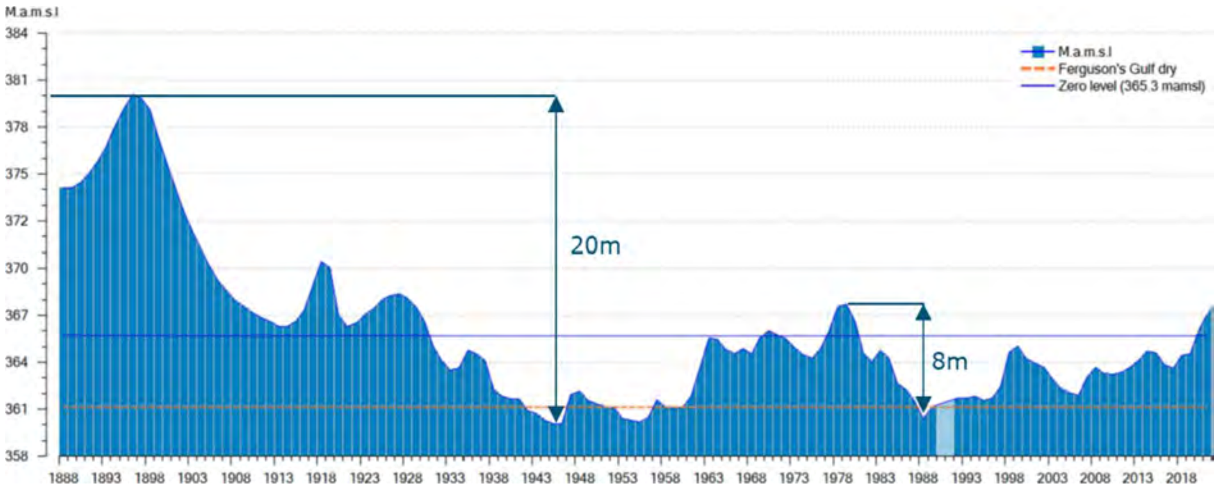

FIGURE 3 MEAN ANNUAL LAKE LEVELS OF LAKE TURKANA FROM 1888 TO 2022 BASED ON HISTORIC RECORDS AND INTERMITTENT GAUGE READINGS UP TO 1988 (KOLDING 1989) AND SATELLITE ALTIMETRY FROM 1992. INDICATED ARE THE LARGEST DIFFERENCE IN WATER LEVEL (20M) AS WELL RECENT WATER LEVEL CHANGES (8M). THE BLUE LINE IS THE "ZERO DATUM" AT 365,4 METER ABOVE SEA LEVEL (M.A.S.L.) .THE ORANGE LINE INDICATES THE WATER LEVEL AT WHICH FERGUSSON'S GULF FALLS DRY (362.3 M.A.S.L. (OBIERO ET AL., 2022)

In addition to the annual fluctuations, seasonal fluctuations of between 0.5-1m per year were previously present with a peak in December/January followed by receding waters to a low around May/June. This annual cycle likely was important for a range of fish species that make use of the seasonal flooding and receding of the lake shores and floodplain as nursery and breeding areas, the so called aquatic terrestrial transition zone (ATTZ). The seasonal cycle has significantly diminished after 2016 when the Gibe III dam in the Omo River was put into operation and this decrease may have a (considerable) impact on the annual productivity drivers of the lake through discharge of sediments and nutrients, inundation of the shorelines and floodplains, as well as seasonal water exchange in bays (Figure 4 and 5).

Historically, Ferguson's Gulf has periodically been the lake's most productive fishing zone, with an important tilapia fishery. However, this gulf dries up when the lake elevation falls to 362.3 meter above sea level (m.a.s.l.). The Fergusson gulf dried up in 1988 after a 10-year period of receding lake levels. The dry-fall coincided with the construction and failed investment in a large fish freezing factory in the early 1980-ies which never became operational as fish stocks declined as a result and no freshwater for processing of fish was available (Figure 3 and 6).

Raising and falling water levels have a direct impact on the extent of flooding of riparian (shoreline) areas, that in turn have an impact on the breeding and nursery grounds of a range of fish species. Periods of receding water levels thus have a large negative impact on both offshore (decreased nutrient inflows) and inshore fish populations and fisheries production. The Omo River Delta, the Turkwel and Kerio Delta's and bays, such as Alia Bay and Sandy bay likewise will be affected by water level fluctuations leading to boom and bust fish production cycles (Figure 7). Existing and intended dam building in the Omo River with the addition of planned irrigated agriculture development schemes in the lower Omo river basin to the north of the lake and associated extraction of water from the main flow are projected to have a (likely severe) impact on the water inflow of Lake Turkana and subsequently on the fisheries production. The current Gibe III dam already may have had an impact on the lake level when it's filling phase started in 2015 with a water inflow deficit resulting in around 2m lowered water levels than without the dam (Avery, 2010; Avery and Tebbs, 2018; Hodbod *et al.*, 2019).

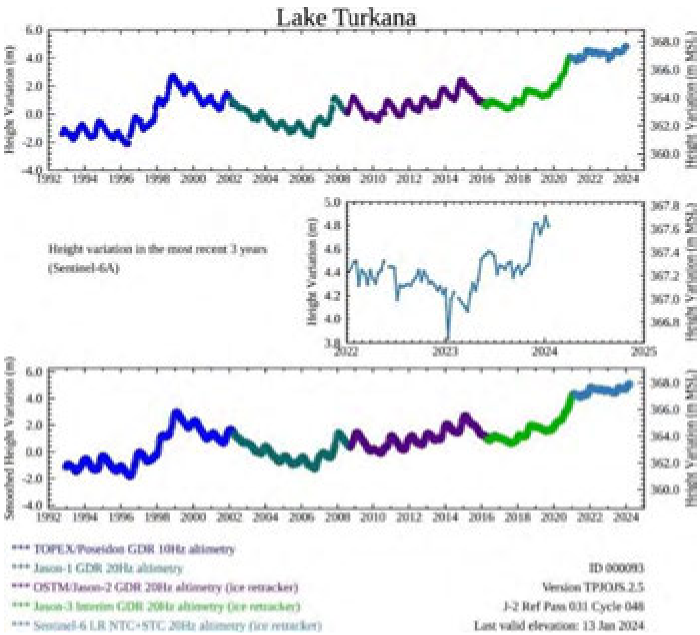

FIGURE 4 WATER LEVELS OF LAKE TURKANA OBSERVED THROUGH SATELLITE ALTIMETRY. TOP: ACTUAL OBSERVATIONS, BOTTOM: SMOOTHED TIME SERIES. MIDDLE: HEIGHT VARIATIONS OF THE MOST RECENT THREE YEARS. SINCE THE FILLING OF THE GIBE III DAM IN 2016 SEASONALITY IN WATER LEVEL FLUCTUATIONS HAVE DECREASED (SEE ALSO FIGURE 5). DATA FROM GREALM PROJECT HTTPS://BLUEICE.GSFC.NASA.GOV/GWM/LAKE/93

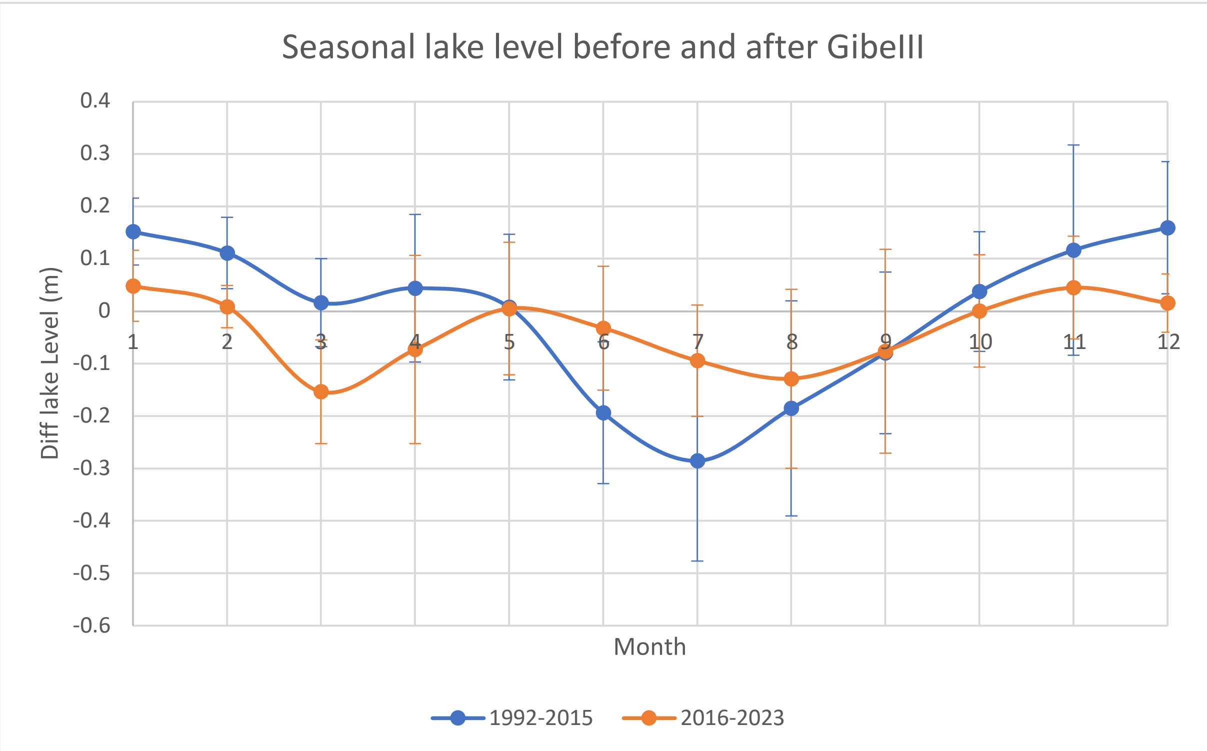

FIGURE 5. MEAN AND STANDARD DEVIATION IN MONTHLY (DIFFERENCED =DIFF) LAKE LEVELS IN METER (M) BEFORE AND AFTER THE START OF OPERATIONS OF THE GIBE III DAM IN THE OMO RIVER. DATA BASED ON SATELLITE ALTIMETRY FROM APRIL 1992 TO NOVEMBER 2023. MONTH 1= JANUARY THROUGH TO MONTH 12=DECEMBER

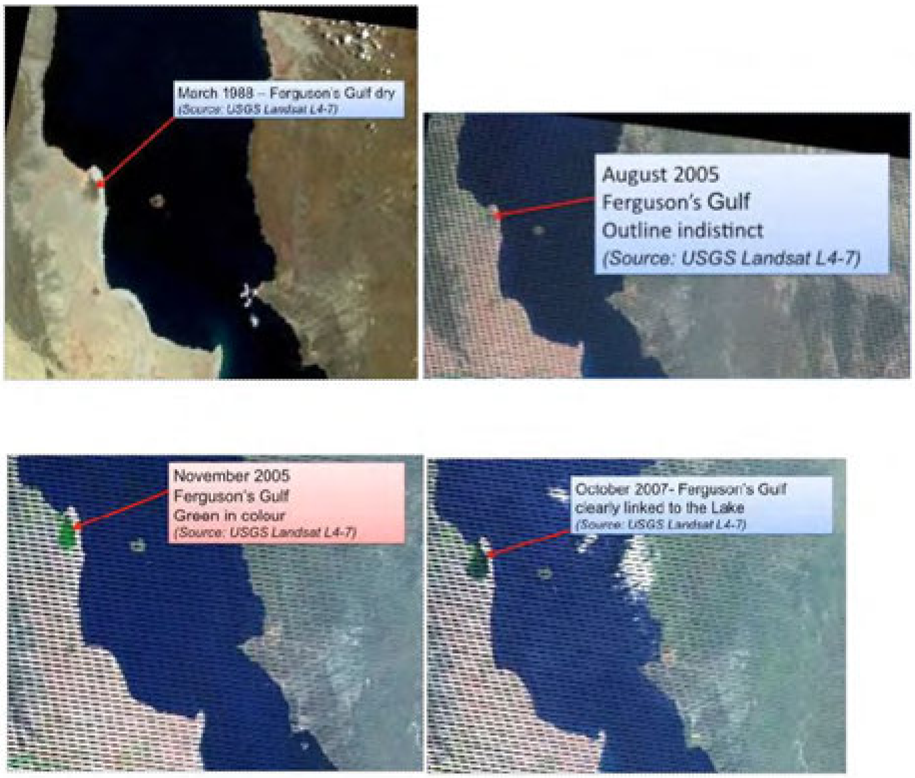

Figure 6 Landsat imagery of Ferguson's Gulf (Source: USGS website)

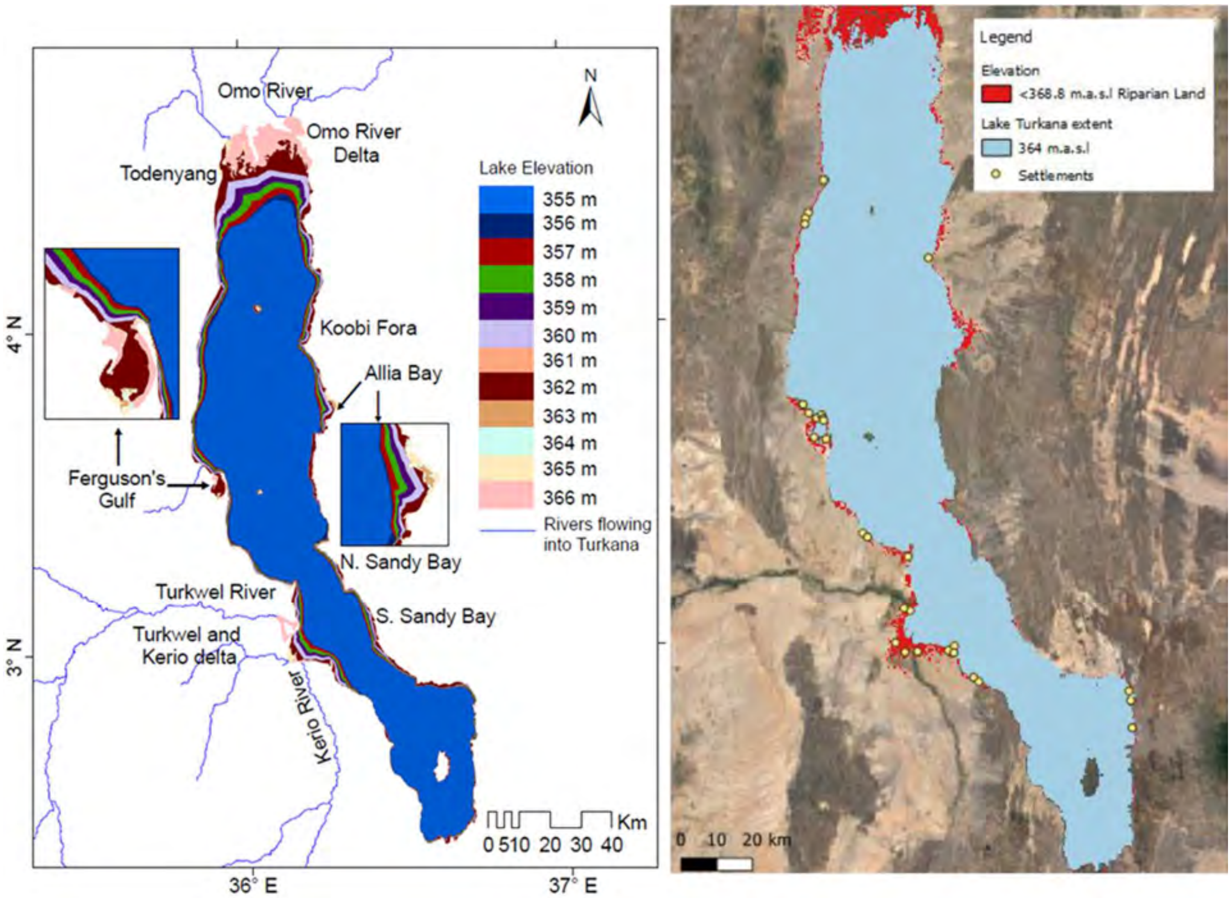

Figure 7. Impacts of changes (left) and increasing (right) water levels on the extent of flooding of riparian zones in lake Turkana (UNEP-DHE, 2021)

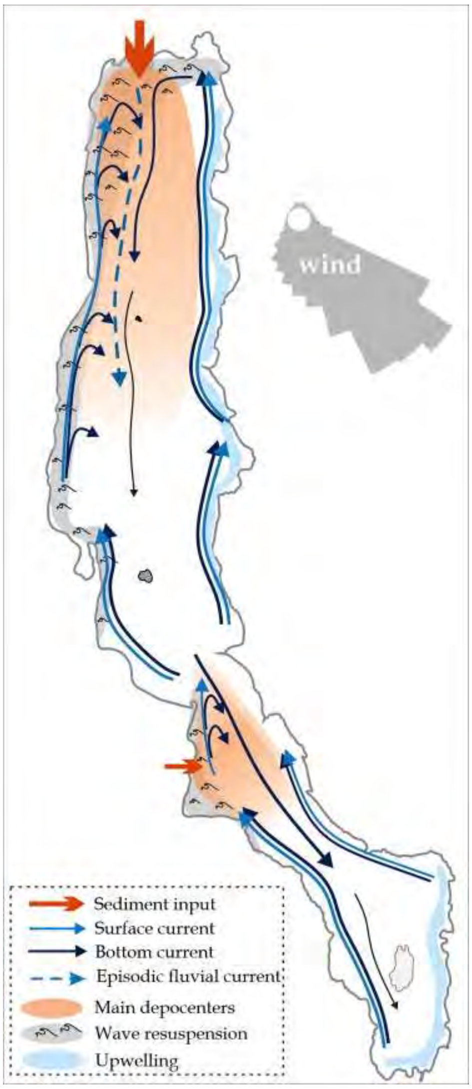

FIGURE 8 CONCEPTUAL MODEL OF HYDRO-SEDIMENTARY DYNAMICS IN LAKE TURKANA BASED ON NUMERICAL SIMULATIONS WITH DELFT3D (ZĂINESCU ET AL., 2023).

However, climate change projections for the next 20 years predict a marked increase in inflow to Lake Turkana, primarily from the Omo River, but also increased inflow from Kerio and Turkwel rivers (UNEP-DHI, 2021a; UNEP-DHI, 2021b), which may result in an overall increase in water level. The flooding of 2020, which was considered a rare event, is likely to become more regular in the future. The new evidence of continued rising lake water levels is partially based on climate change scenarios and a predicted change in rainfall patterns. The expected impact of the dam building and associated irrigation schemes may thus be counteracted by the predicted impact of climate change. These climate change projections, however, are associated with an unknown degree of uncertainty. As a result, there will be both a considerably increased risk of flooding with more settlements around the lake being inundated if no adaptation measures are implemented, while water extraction in the Omo basin for irrigation purposes or other water use will lead to increased deficits during dry spells (Figure 7). Nevertheless, as discussed, the changes in water inflow as a result of dam building has an additional impact on the seasonality of the lake water levels (Figure 4 and 5) with potentially an associated negative impact on the productivity and fish production as seasonality in water levels are important for the breeding cycles of several fish species (including Tilapia's) as well as flushing of enclosed bays such as the Fergusson's Gulf (Kolding, 1993).

Finally, an important aspect of the lakes' physical functioning are wind and associated sedimentation patterns. Wind speeds show a persistent high diurnal variability with values ranging from 2-15 m/sec (15 m/sec = 10 Beaufort). The high diurnal variability, with strong morning winds, is caused by the differing cooling speeds of the lake water surface and the land surface around Lake Turkana during the night. This wind pattern causes the lake to be fully mixed and no stratification takes place. Sediments and associated nutrient inputs are predominantly entering the lake through the Omo River, and to a lesser extent the Turkwel and Kerio rivers and surface runoff during rainfall. Currents caused by the predominant wind patterns transport and re-suspend sediments on the western side of the lake near both major inflows. Sediments are subsequently transported to the deeper areas of the lake. Along shore flow patterns in a northern direction cause most sedimentation and associated nutrient inputs to take place in the Northern part of the lake and around the Turkwel sector. Combined with the long distance from the Omo River, the middle and southern parts of the lake are therefore less productive. Upwelling takes place on the eastern shores of the lake. However, as the lake is usually fully mixed this does not seem to cause additional productivity in these areas (Figure 8).

2.2. PRODUCTIVITY, FISH SPECIES, BIOMASS, FISH CATCHES

2.2.1. PRODUCTIVITY AND LAKE LEVEL FLUCTUATIONS

Primary production is the basis of the Lake Turkana food-web including its dependent fish stocks. With a mean chlorophyll-a concentration for Lake Turkana of 37.6 ± 28.4 mg m^{-3}, Lake Turkana can be categorized as eutrophic[1]. Seasonal and long(er) term fluctuations in discharge of nutrient inputs impact primary production, indicated by chlorophyll densities. Chlorophyll densities largely follow the sedimentation patterns and are highest in the North around the Omo River delta with a secondary area of importance around the Turkwel and Kerio river delta (Figure 8). In addition, specific shallow coastal regions that show high seasonality in inundation and run-off patterns, such as the Omo River Deta, the Fergusson's Gulf and Alia bay, are highly productive as well. Chlorophyll-a production appears to be strongly correlated to the Omo River discharge and strong seasonal cycles in chlorophyll have been observed, related to natural fluctuations in the Omo River's discharge rate. Peaks of river discharge and chlorophyll-a both occur between August to October and lows in February-March. Tebbs *et al.* (2020) found that prior to dam completion on the Omo River, mean lake chlorophyll-a showed a strong relationship with both river inflows and lake levels, and estimated that for 2015–2016 during the filling of Gibe III reservoir annual mean Lake Turkana chlorophyll-a densities declined by 30%. Phytoplankton dynamics and associated fish productivity are thus anticipated to change as a result of changing seasonal discharge patterns of the Omo River. Likewise, dam building in the Turkwel and Kerio river systems may have affected and in the future may continue to affect the seasonal discharge patterns in the southern part of the lake, with similar impacts on the seasonal primary production of the lake.

The large inter-annual lake level changes lead to boom-bust production modes in the fishery, i.e. there will be years with very high or very low catch rates following the interannual variations in river discharge of the Omo River and to a much lesser extent the Turkwel and Kerio rivers (Figure 9). Likewise seasonal patterns are important for the annual reproductive patterns in fish species both

[1] However, most of the offshore phytoplankton consist of blue green algae (cyanobacteria), which are largely indigestible for most species, and therefore needs to be channelled through a bacterial decomposition before entering the food chain as feed for detritivores zooplankton, which means a loss of energy in the process and hence loss in biomass production of higher trophic levels (Kolding 1992).

due to cycles in primary production as well as the seasonal inundation of shoreline habitats leading to local increased productivity in the Aquatic-Terrestrial Transition Zone (ATTZ).

Lake level fluctuations and seasonal inundation patterns lead to a seasonally inundated ATTZ that ranged between 40 and 140 km^2 between 1993 – 2014 (Gownaris *et al.*, 2017). The AATZ is important as spawning and nursery areas (i.e. feeding and shelter habitats for juvenile fish, particularly important for the tilapia fishery). Thus, changes in long term and seasonal patterns in water discharge including its sediment and nutrient load affect the productivity of stocks of different species. Thus, seasonal oscillations play an important role in the lake's fish production, and with a complete loss of these oscillations, the lake's predicted fisheries yield is expected to decrease by over two thirds (Gownaris, 2015; Gownaris *et al.*, 2017; Gownaris *et al.*, 2018; Kolding and van Zwieten, 2012; Ojwang *et al.*, 2016).

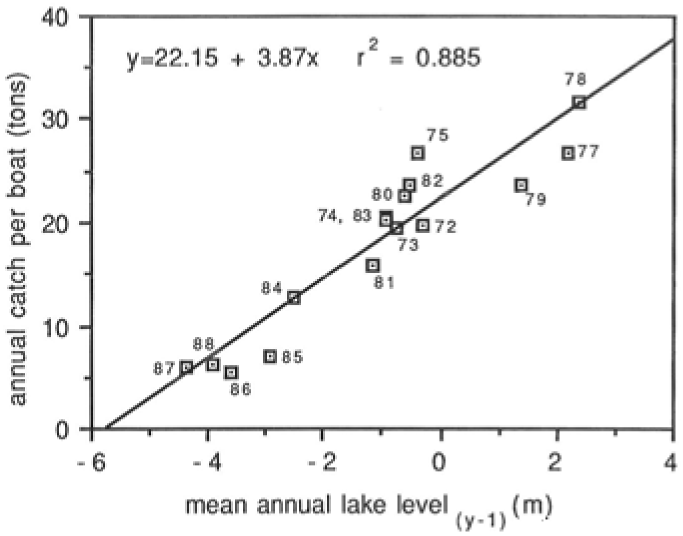

FIGURE 9 MEAN ANNUAL LAKE LEVELS IN THE PERIOD 1972 TO 1988 CORRELATED WITH MEAN ANNUAL CATCH PER BOAT IN THE FOLLOWING YEAR, SHOWING THE STRONG RELATIONSHIP BETWEEN LAKE LEVEL CHANGES AND FISHERY PRODUCTIVITY. THE REGRESSION SUGGESTS A 3-4 TON INCREASE IN PRODUCTION WITH EVERY 1M INCREASE IN WATER LEVEL. FROM KOLDING (1989, 1992).

2.2.2. FISH SPECIES, STOCKS AND FISHERIES

Being the world's largest endorheic[2] dessert lake, Lake Turkana is a unique ecosystem and is home to at least 79 fish species of which 12 are endemic, the world's largest remaining population of Nile crocodile, and hundreds of resident and migratory bird species. There are 12 commercially exploited species, which can be grouped into the following categories:

a. The inshore tilapia fishery in the littoral zone (shallow areas, bays) dominated by tilapia spp. (Kokine) (mainly *Oreochromis niloticus*[3]). It is rarely caught in the open lake. Kokine is, at times, especially abundant in the shallow lagoons, such as the Ferguson's Gulf, which fill during high floods in river Omo, but dry up periodically. They are caught by set gillnets, and beach seines, and recently also a shallow purse seine type fishery has been introduced in Ferguson's Gulf. This is a

[2] It has no with no evident outlet.

[3] There are three species of tilapia in the lake (*Oreochromis niloticus, Sarotherodon galilaeus* and *Coptodon zillii*) , but Nile tilapia (*O. niloticus*) is by far the dominant one.

typical boom-bust fishery associated with large inter-annual fluctuations: booms following shortly after lake level rises, and busts after stagnation of floods and receding waters (Kolding, 1993). Catch rates are also dependent on the seasonal fluctuations of the lake: Kokine disperse into shallow water for breeding during lake level rise and is mainly caught during the period of receding seasonal floods from January to June with low catches from September-December. During our field visit we regularly heard about current low catches in the fishery which, according to informants from El Molo, were normal for the time of the year and has also been described by several of the early commercial fishers in Ferguson's Gulf (Kolding, 1993).

b. The inshore and offshore demersal fishery on *Labeobarbus horie* (Chubule), *Bagrus bayad* (Loruk), *Bagrus docmac* (Liis), *Clarias gariepinus* (Kopito), *Distichodus nefasch* (Gwolo), and *Citharinus citharus*[4] (Gage). These are pre-dominantly caught by 4–5-inch meshed set gillnets. All these species are to varying extent dependent on the seasonal fluctuations for breeding and nursery areas and the changes in productivity caused by the annual fluctuations.

c. The pelagic fishery, now dominated by *Alestes baremoze* (Juse, Lelete) the squeaker *Synodontis* sp. (Tiir) and to a lesser extent, tigerfish *Hydrocynus* sp. (Lokel), caught in 2-3 inched meshed gillnets. Juse and Lokel are to some extent also dependent on the river delta for breeding and as nurseries. Nile perch (*Lates* spp[5], Iji) is targeted by a longline fishery and gillnets with large mesh sizes (8-10 inches): it is an open water spawner, but also makes use of nurseries close to the shore that are likely important drivers of the size of the annual recruitment to the adult stock of the species. *Brycinus minutus* and *Brycinus ferox* are two small endemic pelagic offshore species that are currently unexploited but may have a large potential as they are abundant, have a very high productivity (short lifespan), but likely to be dependent on the fluctuations in primary productivity (see later under research needs, Chapter 4.1.3).

In many African lakes, fish catches are more strongly related to hydrological variables than to fishing effort (Jul-Larsen *et al.*, 2003a; Jul-Larsen *et al.*, 2003b; Kolding and van Zwieten, 2012). Lake Turkana is no exception. There is little anecdotal support that fish stock abundance is driven by fishing effort in the system, despite an increase in most effort variables (numbers of fishers, boats, and gears). Catch data indicate that the lake's production fluctuates greatly over time: lake Turkana's fisheries catch since the 1990-ies showed cyclical fluctuations, with peaks of 9,000-10,000 metric tons occurring approximately every 5 years (Figure 10) (Gownaris *et al.*, 2017). Catch estimates were positively correlated with the lake level with 88.5% of the variation in catch explained by lake level (Kolding, 1989) (Figure 9). Any investment decision into the development of the fishery around the lake must take account of these fluctuations and the associated boom-bust situations.

Total catch and effort estimates after around 1990 (Figure 10) are highly uncertain, while the species resolution of the catch in the available data is low. The current (2021) KMFRI estimate is 14,667 ton caught by 7,000 fishers (Malala *et al.*, 2022). This would mean that on average fishers catch 2.1 ton per fisher per year, which is within the range for African small scale fisheries in general (2-3 ton per fisher per year is normal, (Halls *et al.*, 2006; Kolding and van Zwieten, 2012)).

[4] *Citharinus citaris* initially dominated the gill net fishery for 10 years from around 1965 but disappeared almost completely after 1975.

[5] There are two species in the lake: *Lates niloticus* (Nile perch), which is found in most of Northern Africa, as well as introduced to Lake Victoria, and *Lates longispinis* (dwarf perch), a smaller species which is endemic to lake Turkana

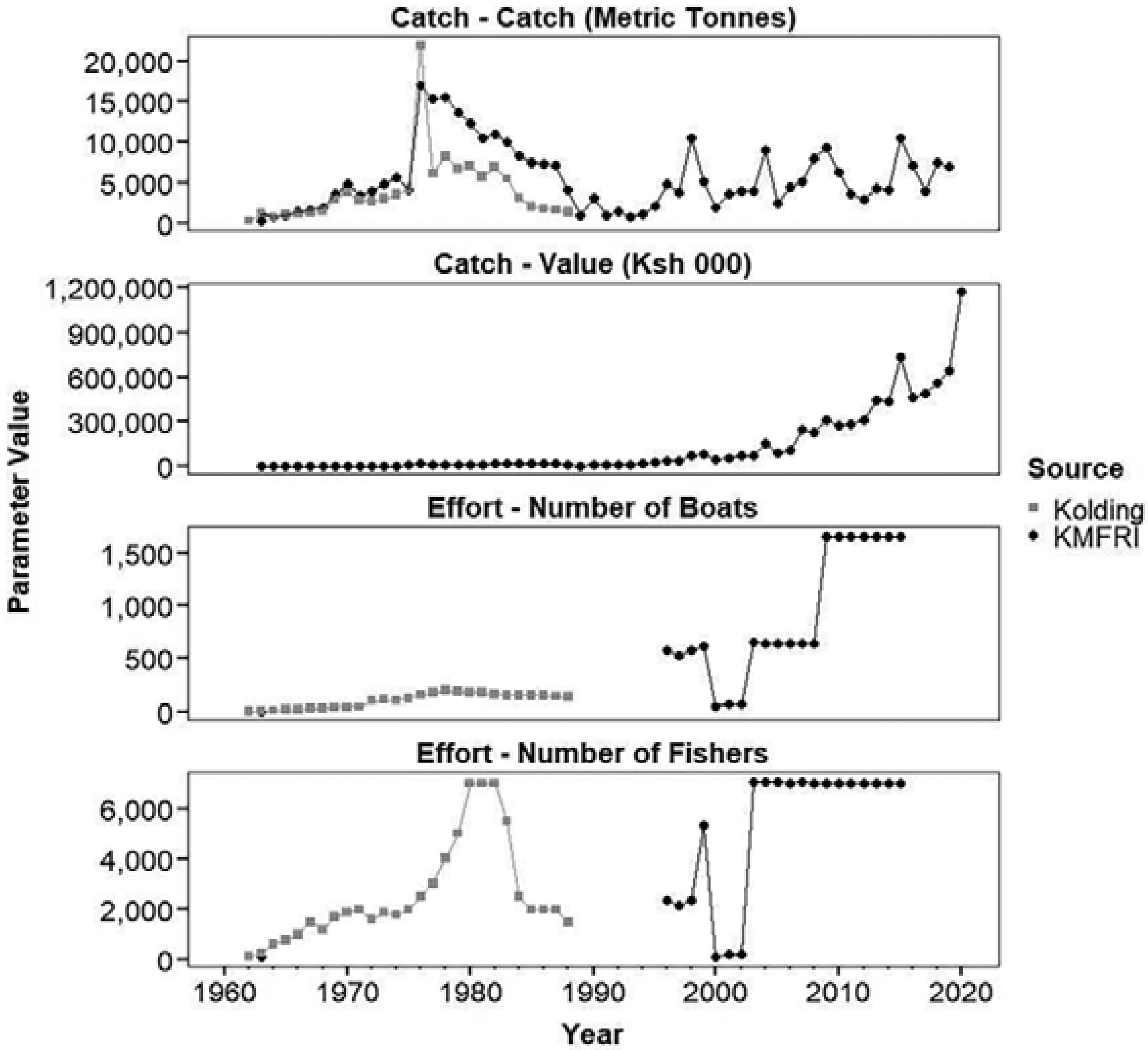

FIGURE 10 TRENDS IN LAKE TURKANA'S FISHERIES SHOWING CATCH (TONNES AND VALUE) AND EFFORT IN TERMS OF THE ESTIMATED NUMBER OF BOATS AND FISHERS FROM 1960 TO 2020. DATA SOURCES: KMFRI (2008); KOLDING (1989). DATA AFTER 1990 ARE ASSOCIATED WITH A HIGH DEGREE OF UNCERTAINTY DUE TO INSUFFICIENT MONITORING. FIGURE TAKEN FROM (OBIERO ET AL., 2022)

However, in the ongoing trial experimental fishery (see next section for more detail), organized as part of the current baseline study, a group of gillnets fishers collecting daily catch data produced around 16.4 ± 5.5 kg/day of fish (all species). Assuming these fishers, distributed all along the lake, and their daily catches are representative of the Lake Turkana fishery, a back of the envelope calculation indicate that with the current assumption of 7,000 fishers fishing 300 days per year, this average catch per day would amount to a total catch of Lake Turkana of 34,000 ± 11,550 ton per year. While the fishers involved in the experimental fishery may not be fully representative of all fishers in Lake Turkana, as the experimental fishery excluded a range of fishing modes (longlines, beach seines and the small scale doum palm raft fishery) and the data were collected over 3 months only (October to December 2024), the results strongly suggest that current total catch estimate may be significantly underestimated.

TABLE 5 Various estimates of maximum sustainable yield (MSY) for Lake Turkana

Reference	MSY estimate (tons/year)
Rhodes, 1966	50,000–160,000
Coche & Balarin, 1982	20,000–30,000
Hopson, 1982	37,000
Hopson, 1982[a]	560,000
Källqvist et al., 1988	15,000–30,000
Källqvist et al., 1988[b]	22,000
KMFRI, 2008	88,404

[a]Considerably higher than the first Hopson (1982) estimate due to the inclusion of small pelagic fishes, which may not be sustainable to exploit due to their high climate sensitivity (Kolding, 1995).

[b]The two estimates by Källqvist et al. (1988) differ in methodology, with the second based on the relationship between primary production and fish production described by Melack (1976).

FIGURE 11 VARIOUS ESTIMATES OF MAXIMUM SUSTAINABLE YIELD: TABLE COPIED FROM GOWNARIS ET AL. (2017): CITED PAPERS ARE TO BE FOUND THERE.

The overall biomass of fish as well as the potential production for Lake Turkana is unknown. MSY estimates have been attempted in the past and range from 15,000 - 160,000 tons per year (Figure 11). Potential production based on average African lake productivity per unit area gives an additional estimate of 57,000 ton per year (Lymer *et al.*, 2016). However all these predictions are ‘‘at worst very mistaken and at best very conditional” (Bayley 1977, cited in (Kolding, 1992)) and this statement is still true. Boom-bust production and associated fisheries catches, as were observed in the past, are still highly likely given the physical characteristics of the lake (water level, nutrient and productivity fluctuations) and fish species targeted (e.g. the tilapia fisheries of the highly productive Fergusson’s Gulf, when it exists), and any attempt at calculating potential production by necessity would have to take account of the strong relationship of lake productivity and seasonal- and inter-annual water-level changes and fluctuations. This could be done by linking a water level/discharge-primary productivity model based on satellite imagery of chlorophyll-a concentrations and lake levels (Avery and Tebbs, 2018; Tebbs *et al.*, 2020) with concurrent estimates of fish biomass and production, e.g. through a series of lake-wide acoustic surveys over several years. With such an empirical model, short-term forecasts may be possible based on changes in water-levels only.

Thus, in short, the large fluctuations of the fish stocks are strongly driven by the hydrological and physical characteristics of the lake system, and any attempt at calculating the potential (fish)production of the lake must take account of the changes and cycles in water levels. Currently, judging from observations of the relatively large sizes of the various species caught during the field visit in September 2023, and the ongoing experimental fishery, we tentatively conclude that the lake’s stocks are still not heavily exploited with the present level of fishing, and that the current fishery most likely has a very limited impact on the variability in availability of stocks. One exception are the *Distichodus* and *Citharinus* species, which are always highly vulnerable to fishing pressure in any African lake fishery and usually are the first species to become depleted (though not extinct!) after the commencement of a targeted fishery. After a total dominance in large 8-inch gillnets from around 1965, both these species became relatively rare in the fishery since 1975 (Kolding 1989).

2.2.3. Results of the experimental trial fishery

Involving local fishermen in the data collection process has several benefits. These benefits include increased participation and ownership, improved data quality and resolution, an exact picture of the fishing pattern, cost effectiveness and improved relationships between researchers, managers and local communities (Ticheler *et al.*, 1998). Therefore, to gain insights into the current fishery, 14 fishers from 7 different landing sites on Lake Turkana were trained to collect species and size data of their catch during a two days' workshop at Kalokol, Turkana on 13 and 14 September 2023. They were asked to measure their daily catch for three days per week in the period from October up to and including December 2023. Data were noted in logbooks. Digital photos were made of the pages of these logbooks and sent to the KMFRI station in Kalokol via WhatsApp. These data were digitised in MSExcel and subsequently validated by counterchecking the original logbooks and transferred to PASGEAR (Kolding and Skålevik, 2010), a customized data base package primarily intended for storing and analysing experimental or artisanal fishery data.

The data so far only show the actual catch by numbers, sizes and estimated weights of species caught and are not yet standardised by the precise sampling effort (the number and size of nets and other gear used), to obtain a relative catch (so-called Catch per Unit Effort, CPUE). This means that so far CPUE is only calculated as **total catch per day** per team. No direct comparison can yet be made between sites as the number of nets used may differ or with earlier data collection efforts (Gownaris *et al.*, 2017; Kolding, 1989), but will be included later. Further cleaning and standardising the data is still needed, but a preliminary overview and summary of the data collected and digitised as per January 2024, at the end the initial trial data collection period, has been provided separately (Reports 4a and b: see Chapter 1: Introduction).

The main insights from the study so far are:

1. Daily average catches of the 14 fishers were around 16.4 $\pm$ 5.5 kg/day of fish (all species), which is quite normal for small-scale gillnet fisheries.
2. Eighteen species were caught in total but catches were dominated by 5 species Juse (*Alestes baremoze*, 39%), Iji (*Nile perch*, 19%), Chubule (*Labeo horie*, 17%) and Kokine (*Tilapia* sp. 12%).
3. Species composition by gear and mesh sizes, the so called specific "gear signature", highlights the specific size-species combination caught by specific gears. In this case we could observe the gear signature for different mesh sizes in gillnets (Figure 12). For instance, it is clear that *Alestes baremoze* (Juse) can only be caught in 2-, 2.5-, and 3-inch nets. Tilapia sp (Kokine) is caught mainly in 3-to-4-inch nets and *Barbus bynni* (Momwara), *Distichodus niloticus* (Gwolo), and *Nile perch* (Iji) in larger mesh sizes ($\geq$5-inch nets).
4. This leads to an important observation on the catch rates and species composition in the illegal versus the legal mesh sizes (Figure 14, Table 2). It appears that 98% of the number of fish caught are predominantly small sized species, comprising nearly 75% (3 quarters) of the total catch by weight, that is legal and illegal combined. The legal catch basically only consists of large specimen of Nile perch (Iji), comprising 72% of total weight from legal nets; the catch from illegal nets is mainly *Alestes baremoze* (Juse, 52%), *Labeo hori* (Chubule, 22.2%) and Tilapia spp. (Kokine, 14.5%). These three species comprised 68% of the total catch in weight of the experimental fishery, compared to 20% taken by Nile perch.

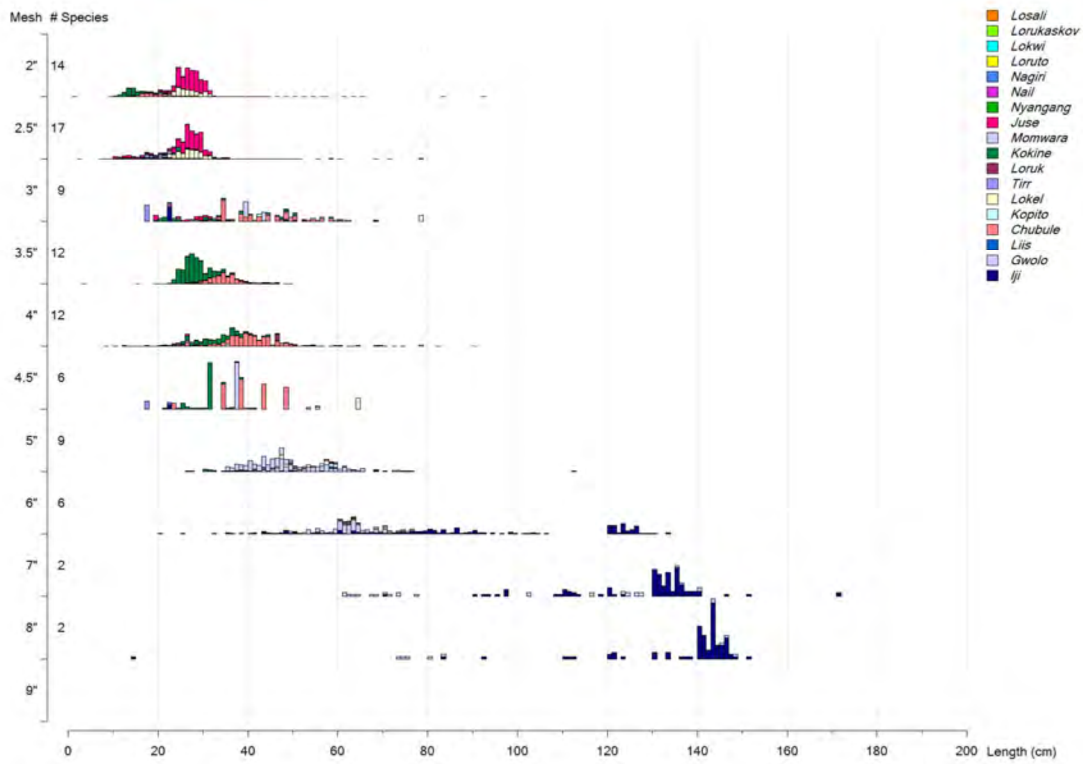

FIGURE 12 *CATCH COMPOSITION AND RELATIVE SIZE DISTRIBUTION (PERCENTAGES) BY MESH SIZES, THE SO-CALLED 'GEAR SIGNATURE', SHOWING THE CHARACTERISTIC CHANGE IN BOTH SPECIES AND SIZE-FREQUENCY COMPOSITION WITH INCREASING MESH SIZES*

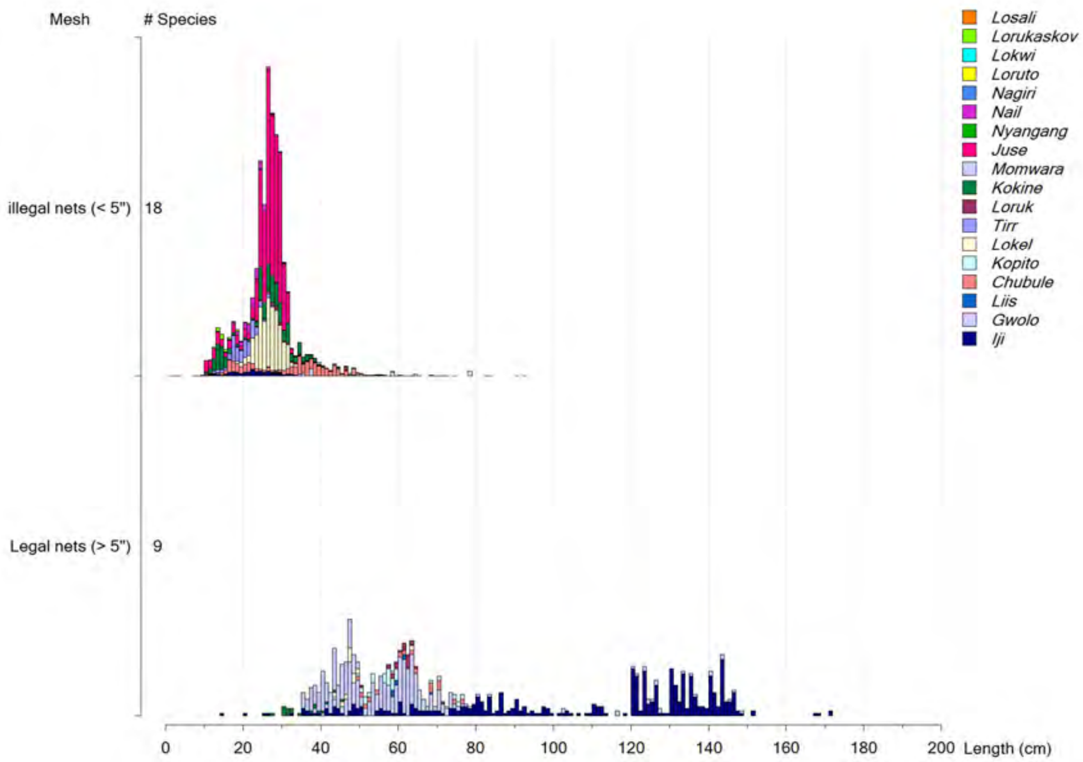

FIGURE 13 *CATCH COMPOSITION AND RELATIVE SIZE DISTRIBUTION (PERCENTAGE* **NUMBERS***) BY MESH SIZES, SPLIT INTO ILLEGAL AND LEGAL SIZES, RESPECTIVELY. IT IS CLEAR THAT THE SPECIES COMPOSITION* **BETWEEN LEGAL AND ILLEGAL GEARS IS** *SIGNIFICANTLY DIFFERENT***.** *ONLY USING LEGAL MESH SIZES WOULD PREVENT THE CAPTURE OF SMALLER SIZED SPECIES.*

Table 1 Catch composition in the illegal versus the legal mesh sizes. 98% of the number of fish caught are predominantly small sized species, comprising nearly 3 quarters of the total catch by weight. The legal catch is basically only targeting large Nile perch (Iji), comprising 72% of total legally caught weight; the catch from illegal nets is mainly Juse (52%), Chubule (22.2%) and Kokine (14.5%) of the "illegal" catch.

	Illegal nets (< 5")			Legal nets (> 5")			Total		
Species	No	Weight (kg)	% Weight	No	Weight (kg)	% Weight	No	Weight (kg)	% Weight
Juse	61,670	15,495	52	48	117	1.2	61,718	15,612	39.2
Iji	773	228	0.8	472	7,260	72.2	1,245	7,488	18.8
Chubule	4,816	6,613	22.2	30	140	1.4	4,846	6,753	17
Kokine	19,927	4,314	14.5	595	191	1.9	20,522	4,506	11.3
Lokel	8,559	1,907	6.4	20	22	0.2	8,579	1,929	4.8
Gwolo	230	153	0.5	330	1,511	15	560	1,665	4.2
Kopito	157	351	1.2	168	412	4.1	325	764	1.9
Momwara	150	84	0.3	253	314	3.1	403	398	1
Tirr	2,088	360	1.2				2,088	360	0.9
Loruk	295	108	0.4	30	52	0.5	325	160	0.4
Nail	1,011	111	0.4				1,011	111	0.3
Liis	36	42	0.1	8	30	0.3	44	72	0.2
Nyangang	31	8	0				31	8	0
Lorukaskov	171	6	0				171	6	0
Loruto	4	0	0				4	0	0
Lokwi	6	0	0				6	0	0
Nagiri	1	0	0				1	0	0
Losali	1	0	0				1	0	0
Total	99,926	29,782	100	1,954	10,050	100	101,880	39,832	100
Percent	98.1	74.8		1.9	25.2				

It is evident from the current experimental fishery that fisheries regulations on Lake Turkana, where the smallest legal mesh size is 5" (127 mm) stretched mesh, are consistently violated, and that the numbers of smaller meshed nets are far more numerous than larger. It is highly likely that this can be extended to the whole fishery, indicating that most of the present catches from the fishery are technically illegal. It would have severe consequences for the catch composition, total catch, trade, and the food security in the area, if the legal mesh size regulations were to be enforced. Thus, there is an urgent need to discuss and revise these regulations, as they have no ecological justifications, and only create unnecessary conflicts between fishers and managers (Kolding and van Zwieten, 2011).

Overall, the experimental fishery, using local fishers as sampling agents, has been a remarkable success. The different teams of fishers generally have returned incredibly good data, albeit with quite varying sampling frequencies. Thus, obtaining relatively cheap high resolution catch data from fishers from Lake Turkana is highly promising. The current experimental survey should be extended to at least one year of data collection covering all seasons to enable a full analysis of the fishery. Preferably more years would be necessary to enable comparisons between years and relations of catch and catch composition with water levels. It is therefore strongly recommended that the present sampling design should be extended - preferably covering more sites, fishers, and fishing methods - over a longer period. Next to providing detailed biological and ecological information, further work should be conducted on the possibility to replace expensive and logistically difficult standard Catch Assessment Surveys. An unbiased stratified sample of a selection of fishers using different fishing methods spread over all lake environments through logbook data collection comparable to the experimental survey could well be a way of obtaining the detailed data needed to estimate total catches, with a much higher resolution than is possible through CAS.

Involving local fishers, using their own gears and methods without interference, has proven to be a unique and cost-effective way to obtain high quality data from the fishery that can form the basis of fishery assessments that are unprecedented for a small-scale fishery of this size and in a remote location with enormous logistical challenges of accessing many of the most important sites in the vast and remote Turkana Basin, as well as to facilitate year-round research. Moreover, returning the result to the communities that participate in the survey through reports based on their own data will enable them to assess the results of their own efforts as well as to compare their catches to those of others. Based on these data, fishers can make their own assessments and will be empowered in co-management discussions. For instance, by linking the catch data of individual fishers to daily revenues from fish (by fish prices) and daily costs a simple bookkeeping of profits and losses can be made. Furthermore, understanding (changes in) their own catches will assist fishers to engage more equitably in co-management of the fishery (Ticheler *et al.*, 1998). We expect that this will lead to better understanding and communication between fishers and managers on the management of the fishery.

2.3. FISHERS - NUMBERS, OPERATIONS, PROCESSING

Lake Turkana has the highest biological productivity in the Northern end where the Omo River enters the lake. Productivity subsequently decreases towards the southern end. The main fisheries therefore take place in the Northern part of the lake. Most fishing activities are concentrated in a few places such as Kalokol, Eliye, Kerio, Kataboi, Nachukui, Lowarengak and Todenyang on the western side, and Ilaret, Koobi Fora, Alia Bay, Moite, Elmolo Bay and Loiyangalani on the eastern side. There are currently estimated to be around 7000 fishers and around 1600 fishing vessels including doum-palm rafts (i.e. around 4.3 fisher per vessel!).

Three main fishing methods are employed on the lake: beach-seining (main target: tilapia), set gillnets (focusing on pelagic and inshore species, as well as the inshore tilapia) and longlines (main target: Nile perch). Currently a form of purse seining, or ring netting using modified gillnets is being introduced in Ferguson' Gulf.

1. Beach-seining is operated from the shore and mainly in the shallow productive areas like the Fergusson Gulf.
2. The set-gillnet fishery is operated either from rafts made of doum-palm logs using nets that are set overnight on day trips, or from larger (mostly wooden) vessels with or without outboard-engine powered propulsion. The latter generally carry around 4-5 fishers each with a set of nets that are set-overnight and hauled on board the next day. In the northern part of the lake, fishers tend to stay up to five days and nights on the lake processing each day's catch on board (gutting, salting, drying). This mode of operation is rare for African freshwater fisheries where fishers tend to carry out day trips only. We contend that the current mode of operation of Turkana fishers is a sign that daily catches are relatively low: apparently it is not worthwhile the effort to land fish immediately after catch, and while space for processing on board is limited, it appears to be sufficient to process the day's catch of 4-5 fishers that are operating from a boat. Fishers pre-dominantly use gillnets (2-6 inch), beach-seines and (baited) longlines.

FIGURE 14. TILAPIA SEINING AT LONGESH SPIT AT THE ENTRANCE TO FERGUSON'S GULF (BACKGROUND). ON THE RIGHT ARE THE RAFTS MADE OF DOUM PALM TRUNKS CARRYING GILLNETS. PHOTO BY PETER KELLER 2010

3. Longline fisheries targeting (large) Nile perch and demersal catfish species (*Claria lazera, Bagrus docmac* and *Bagrus bayad*) may operate differently: large specimen of Nile perch are brought to the shore fresh and immediately processed – an incentive for this may be the highly valuable fish maw (swim-bladder) that is taken from the fish and the difficulty in sundrying large specimen. Fish maw, a relatively new product, is directed at a highly valuable Chinese market.

Fishing vessels used in the gillnet and longline fisheries (and to set a beach seine) are doum palm log-rafts or 5-7.5m wooden vessels, propelled by paddles, sail or outboard engine. (Wooden) vessels last up to 3 years before major repairs are needed.

Most fish species caught are (salted[6] and) dried directly on the ground near homesteads and therefore often are contaminated with dust and sand. Near-shore littoral zone tilapia is traded fresh or dried. Fresh tilapia is generally processed further by deep frying. In rare cases fish are dried on raised racks or are hung on lines. Fish processed in this way may be of higher quality, but in discussions with processors it appeared that the price per specimen of rack or line dried fish did not differ from fish dried on the ground, though spoilage rates may be lower using racks. This means that there is limited incentive for processors to invest in methods that lead to a better-quality dried product. Other reasons why racks are not a preferred method of drying are (1) the low quality of racks that have been provided in the past; (2) communal use of racks is not preferred due to fear of stealing - most processors prefer to dry fish close to the homestead.

[6] Salting depends on the fat content of the species. Lean species, such as tilapia are just dried, while other, such as Alestes are normally also salted before drying.

Since the beginning of the commercial fishery, 70-80 years ago, there has been a long-continued tradition of donor donations to support and develop the fishery. Therefore, in discussions with fishing communities along the lake, many fishers asked to be supplied with nets and boats. Net losses are high in Lake Turkana due to the heavy winds and wave action during the night and early morning. Nets, boats and sometimes outboard engines and daily supplies (food, fuel, salt) are generally supplied through donor projects or fish traders (mongers, middlemen) (see later). The numerous requests indicate that fishers are accustomed to continuous donor support or loans in kind (nets, boats, engines) or investments by traders in providing fishing implements, thus creating binding patron-client relationships. Donor support should be carefully evaluated to avoid continued dependency on such supplies and limit development of organizational self-sufficiency. This was, for instance, a goal of a successful Savings and Credit Cooperative Society (SACCO) organized by a BMU in Kalokol. We advise that any support in the form of providing fishing implements (boats, nets) should be organized such that a local service industry in boat and net and gear repair/making can develop[7]. For example, many fishers we spoke to have a clear preference for wooden boats rather than the fiber-glass boats that were often given without consultation through donor support. Wooden vessels, due to their weight, give higher stability in rough waters, and do not sink if they capsize. Boat-builders are present in various places along the lake who utilize wood obtained from Western Kenya. Supplied with the necessary materials they are very capable of building boats to specification in a very short time.

An issue mentioned by several stakeholders is the frequent loss of nets during fishing operations, mainly because of the frequent strong winds and regular violent storms at night over the lake. The ubiquitous losses of monofilament nets made from a variety of nylon is worrying as these nets are not biodegradable: apart from the issue of "ghost fishing"[8], lost nets are an important source of plastics pollution of the lake. When issuing nets to fishers, this should be accounted for: multifilament biodegradable nets are available and should be prioritized.

2.4. FISH TRADE - OPERATIONS, INFRASTRUCTURE, DISTANCES, WATER

Fish trade is carried out mostly from the western side of the lake due to logistical challenges. To the north, trade is routed within Turkana County through Loarengak in the northwest and through Ari town, a border trading center in Marsabit County specialising in chilled fresh fish to Ethiopia. Nearly all fish harvested in the delta region and parts north of Todenyang is marketed in Ethiopia. Some of this fish is consumed locally in this part of Ethiopia, or marketed through an Ethiopian fish marketing Parastatal (SNV and Mwikya, 2005). This cross-border trade is poorly documented as access is often restricted for security reasons.

Most fishers are residents of the western side, and the major trading center is Kalokol for both local (within Kenya) and regional markets (Busia to DRC via Uganda; Kisumu to Tanzania and Zambia up to Lubumbashi (DR Congo)) as there is a tarmac access road to Lodwar. Furthermore, fish is traded from areas south of Kerio, e.g. Illeret and Loiyangalani towns to Busia and Kisumu in Kenya. Significant fisheries take place in the mid- and southern parts of the lake e.g. in areas adjacent to Eliye Springs

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[7] However, we acknowledge that such initiatives have been tried many times before during the development of the lake Turkana fishery, and very few have proved sustainable over time. Poorly organised foreign donor support, through a multitude of NGOs, appears to be still the norm in Lake Turkana.

[8] Nets keep on catching fish when they are lost and free floating in the water column

(Wadach-Lobolo and Lolibekai areas) and adjacent to Kerio Town (Kerio Bay, near river Turkwel delta (Alukat Beach and Merer). These are mainly tilapia fisheries, sometimes traded with refrigerated vehicles waiting for fish at Kerio. Fish from Loiyangalani is transported to Kisumu, Nairobi, and other towns via Mararal. Kitale is the main destination for fried Lake Turkana fish, which is either retailed in the town or sold to neighboring markets. Fish from the North-Eastern part of the lake is transported to Kisumu and Nairobi via Marsabit.

Several reports give anecdotal data on prices of fish by species product and along the value chain from fisher to retailer that will be examined at a later stage. Based on these, total values of the fishery have been calculated that are to be taken with a grain of salt given the high uncertainty over total catches as well as price structure over the value chain. In general various authors maintain that prices of fish from Turkana are relatively low due to the specific characteristics of the fish that seem to be relatively low in fat content compared to same species from other lakes (as Lake Victoria) (Larive-International and Lattice-Aqua, 2022; SNV and Mwikya, 2005). Other reasons may be the high transport costs reducing on the beach prices offered to fishers.

Distances from most landing sites to main markets or local hubs are considerable with hazardous connections through dirt roads or tracks that are all but impassable due to rocky terrain and sand dunes along the shore or during (rare) rainfall. Costs of transport are likewise increasing rapidly with the increasing distance of landing sites from the main hubs in Lodwar on the Turkana side and Loiyangalani on the Marsabit side at the southern end of the lake. The distances between these two main hubs and the main markets in Kitale, Busia and further into Uganda differ considerably, disadvantaging trade via Loiyangalani on the east side of the lake even further. Much dried fish produced at the eastern side is therefore transported across the lake to markets and traders operating from the western side of the lake before further trade to Busia and elsewhere.

The current project proposal of WFP emphasizes the potential of a fresh fish trade mainly focused on tilapia and Nile perch. Currently some trade in fresh fish within Kenya is taking place from middle and southern areas of the lake, as well as trade to Ethiopian markets in the north of the lake, but as far as we have observed this is a highly irregular and a highly vulnerable business. Any developments in fresh fish trade should take account of at least the following challenges:

1. The boom bust nature of the fishery – in particular tilapia – results in an unsteady supply of fish. Each year there will be months with very low supply, which can extend into longer periods during stagnant or receding water levels. Any investment in facilities to support trade in fish that does not take account of these natural fluctuations of the fishery and the seasonal unavailability of some important species, but require a steady supply of fish, will fail to become sustainable.
2. Placing infrastructure on the lakeshore for landing, storing, processing, and handling fish for transport is heavily constrained by the large lake level fluctuations. As the landscape around the lake is mostly flat, any permanent structure near the lake shore related to fish-trade (dried/fresh fish storage) will at some point be either submerged during raised water levels or find itself at large distances from the lakeshore during receding periods. For instance, the county government of Marsabit, in collaboration with the European Union, had established a fish factory with freezers in Loiyangalani, but the factory is currently flooded with water after the recent lake water level rise (Figure 15).

Figure 15 Structures related to the fishing industry in Loiyangalani (Marsabit county) flooded during the recent high water levels in Lake Turkana. The processing factory to the left is 3 years old but has never been put into operation due to lack of fresh water. Photos taken in November 2023 by Abdulkareem Abdi.

3. Producing ice for fish transport and trade with an irregular market supply of fish may require substantial amounts of fresh water which currently is in short supply all along the lake. The 3-year-old factory in Loiyangalani has never been operational as there is no freshwater available. Lack of freshwater was also one of the main reasons for the failed Norad fish factory built in Kalokol during the late 1970s (Kolding 1989), and it is disheartening to learn that the same mistakes are repeated without learning from recent history.
4. Long distances over difficult roads makes any transport of fresh fish from sites away from main hubs in Kalokol, Lodwar and Loiyangalani including El Molo Bay, expensive and volume constrained. For example: transport of a cooler box of fresh fish (around 20 kg) by motorbike from El molo to Loiyangalani currently costs KSh400,= while the same journey from Moite taking 3-4 hours travel costs KSh5000,=.
5. There is no enabling environment with regards to maintenance and repair of cold chain and ice production facilities, and supply of parts for even relatively simple cold storage installations. Consequently, there is a high reliance on outside support to maintain cold chain installations associated with limited agency of people to take care of maintenance themselves. Several examples can be given - of the six units of cold store containers along the south-eastern shore of the lake, recently installed by the EU, only two were reported functional during our visit. One in Moite has a broken fuse and is now operating solely as a cellphone charger; another in a village in El Molo region misses some parts that had been ordered a year ago. However, the storage is still not operational and the community had no idea what was going on. Another example is the building of a cold storage in Lodwar by the Natogo Self Help Group, that had sufficient solar power installed for a cold store, but insufficient number of batteries installed to store energy and run the facilities. In general processors interviewed prefer small cooling units (household freezers) that can be run and filled according to supply and are easy to operate and maintain.
6. Trade to areas within Kenya seems possible but require a good knowledge of markets and contacts with customers that seem lacking with people operating storage and trading facilities in many instances. A thorough economic value chain analysis is required before further investments in fresh fish are made and compared with investments in improvements in the dry-fish trade. Training of individuals or groups (women’s groups, BMUs. Cooperatives etc.) in marketing is highly recommended.

3. Fisheries organisation and development

3.1 FISHERIES ORGANISATION

Fisheries are organized in Beach Management Units (BMUs) and cooperatives and are managed at the county level. Furthermore, the Kenya Fisheries Service (KEFS) manages national fisheries programs that have not been devolved. Turkana county currently has 32 registered BMUs - 12 in Turkana North subcounty and 20 Turkana Central sub-county - and Marsabit County has 10 registered BMUs - 4 in North Horr subcounty and 6 in Loiyangalani subcounty.

The Turkana Fishermen's Cooperative Society (TFCS), with current membership at 225 persons, used to be the largest fisher's association on the Western side (more than 5000 members), with a monopoly of the fishing on the lake, which was lifted in 1997. It is now the owner of the old Norad built fish factory in Kalokol, which is largely defunct. The dry fish wing (North Wing) is operational and is used for storage bulk packaging fish by traders who target Busia (border with Uganda) or DR Congo external markets. Its sources of income are rental houses and stores, packaging fees, and the sale of dry fish brought by some members. The fresh fish (South Wing) is defunct and has never been operational, though there is a wish to revive it and acquire a refrigerated truck. However, the issue of sufficient freshwater supplies in Kalokol still has not been solved.

On the Eastern side, Loiyangalani Fisheries Cooperative has 205 registered members and serves as the primary middleman between fishers and external markets. On behalf of its members, the cooperative hires a lorry to transport dried fish, at least twice a month, to the Busia market. The Loiyangalani cooperative also offers some cold storage facilities owned by its members. Fishermen and traders are charged one shilling per fish, which is used for maintenance costs.

3.1.1 LOCAL KNOWLEDGE AND AGENCY

In essence, three main groups of local[9] fishers can be distinguished operating around the lake:

1. Fishers from the small El Molo tribe, who have been permanently fishing for generations, can be considered "true" fishers.
2. Fishers who are descendants from previously destitute pastoralists and who are now permanently involved in fisheries for a few generations.
3. Pastoralists who recently lost their livestock and have migrated to the lake shores to utilize the lakes' fishing opportunities as a last resort to survive.

These groups (may) have very different knowledge about the lake's functioning, productivity and production and have different outlooks and aspirations with regards to the fishery: while the first group of El Molo people have intimate local knowledge about the lake's functioning and the consequences of lake level variation on stocks (e.g. a clear view on seasonality of fish availability, knowledge on fish behavior, concern about apparent changes in seasonality of lake levels), such knowledge was rather limited or not present with the two other groups.

Fish is seen by most fishers as a trading commodity: a means to overcome mishap through droughts and ultimately to earn enough to buy livestock and return to the pastoral society they came from. Fish is not part of their cultural diet and during our discussions with fishers, fisher organisations, and traders, fish as a food commodity was rarely mentioned. Nevertheless, most fishers we talked to

[9] There has been an influx of experienced Luo fishers from the Lake Victoria region, though we do not know how large a proportion of the total number of fishers these are.

seem to have very limited knowledge about the functioning of markets and the role of middlemen and traders in trade. While middlemen act as intermediaries between distant markets and processing of fish, who often take risks in supplying fishers with goods and services and transporting fish, such roles were not perceived in discussions with fishers, who only saw the price differences between lakeshore and distant markets as totally unfair with only limited understanding of the costs of transport involved as well as the skills required to enter “distant” markets. Limited knowledge on building and maintaining trustworthy customer relationships seemed to be present, while price setting at different nodes in the value chain is not transparent for fishers. In some cases, traders may have formed a cartel in beach price setting, very often mentioned by fishers from various sites, which requires further investigation. However, in most instances variation in landing prices and a choice to sell fish at landing to several traders seem to indicate that negotiation is possible.

A common problem for many small-scale fisheries all over the world is very limited access to capital for investments in boats, gears, and engines, as fishers generally do not have tangible assets to serve as collateral. This role is generally taken over by middlemen. Complaints about possible organised middlemen (cartels), potentially unfair price forming sometimes expressed as complaints about the “free market economy”, difficulties in acquiring basic fishing implements, difficulties in accessing funds and loans to invest in the fishery, issues with the role of middle-men and the proliferation of BMUs and other professional organisations, point to a strongly felt wish by many to regulate markets for fish, and regain control over those markets. The concept of a free market (Uchumi uhuru) was seen as unfair and discriminating by many people, both fishers and traders, we met around the lake.

Pastoral societies are traditionally fiercely independent and self-reliant, currently resulting in a limited organizational capacity of groups like BMU’s that hampers self-organisation to overcome some of these problems. A few important exceptions that may serve as examples of what may be possible are present. These few examples of self-organization or business acumen show potential solutions to the issues:

1. A women’s group in Nagasan Village, El Molo Bay, led by an entrepreneurial individual – after a training provided by ministry of trade – found customers in Marsabit hotels and lodges for fried tilapia: a photo of the product is presented to potential customers through social media with a set price and auctioned to the first buyer. After payment, the fish is sent in a cooler box by bus from Loiyangalani to Marsabit. Transport is paid for by the customer (12-14 hrs. drive).
2. A local fish trader (called “Chap chap”) operating from Kalokol and Eliye Springs buys dried fish both from the Eastern and Western sides of the lake and uses a similar approach to the women’s group from El Molo: customers receive an image of the product, with a price. After payment has been received the trader sends the fish on transport. Transport costs are paid by the customer. This trader owned property in Kalokol that serves as collateral for investments in fishery: i.e. providing boats, engines, and nets on loan to fishers willing to trade with him.
3. A BMU in Kalokol has formed a SACCO: members of the BMU paid a fee into a revolving fund out of which members could be supported to receive loans for boats and nets; members supported each other financially when mishap occurred. New members were carefully vetted and balloted before allowed in (fixed rules were that drunkards, thieves, drug sellers, troublemakers, and politicians cannot join the SACCO).

In all three examples the interviewed emphasized the role of mutual trust, personal connections, and loyalty as the most important preconditions for their success.

3.2 FISHERIES DEVELOPMENT

3.2.1 DEVELOPMENT ORGANISATIONS

There is much interest in developing the fisheries and in particular the fresh fish chain of Lake Turkana from several programs, such as the World Food Program (support to BMUs cold chain facilities), IGAD-E€OFISH (Inter Governmental Authority on Development, a.o. https://ecofish-programme.org/workplan-4-demonstration-projects/igad/) transboundary work on fisheries in Turkana-Omo River area has shown interest in developing the fisheries and a cold chain. This is part of a program with the Turkana and Marsabit county governments on the further development of the region through an integrated approach in which water, energy, and food security as well as economic interests and potential conflict issues should be balanced (Elizabeth Kariuki *et al.*, 2022; Giuliani *et al.*, 2022; Kaijage and Nyagah, 2009; SNV and Mwikya, 2005; UNEP-DHI, 2021a).

Several NGO's are present around Lake Turkana, that are focusing on (incomplete list!) a.o.:

1. Pastoralist livelihoods: Turkana Pastoralists Development Organization (TUPADO). For many pastoralists fishing is (or was) a secondary livelihood. Though TUPADO's focus is on livestock their concerns extend to fisheries as well (https://tupado.org/about-us/)
2. Environmental justice: Friends of Lake Turkana (https://www.friendsoflaketurkana.org/index.php/en/)
3. Nature Conservation:
    a. Wetlands International (https://africa.wetlands.org/en/video/a-new-dawn-quest-to-restore-turkanas-rangelands/)
    b. IUCN (https://worldheritageoutlook.iucn.org/explore-sites/wdpaid/145586)
4. Peace and security: Water, Peace, and Security (WPS) initiative (https://www.planetarysecurityinitiative.org/index.php/news/climate-security-practice-dialogue-and-peacebuilding-lake-turkana)
5. Food security: Diocese of Lodwar (Oduor *et al.*, 2012)

3.2.2 TECHNOLOGICAL SOLUTIONS AND NEED FOR EDUCATION AND TRAINING.

Many NGOs and donors supporting fisheries projects around the lake appear to focus primarily on quick-fix technological solutions: providing fishing equipment, improved processing methods (fish drying racks, solar driers (!)), simplified cold storages up to large scale investments in fish processing factories). However, lack of technology is rarely, if ever the main issue. Much more emphasis should be given to addressing competence and agency in organizational capacity, and education and training in financial management, trade, and marketing. Perhaps a persistent problem in the Turkana fishery is the lack of serious engagement with the fishery, as many people, particularly the older generations and newly arrived destitute pastoralists, dream of returning to the pastoral way of life. Fishing has very low cultural status in Turkana society where wealth is based on livestock.

3.3.3 FISH FOR FOOD AND FISH FOR ECONOMIC VALUE

Fish and in particular small fish that is eaten whole, is an important source of proteins and valuable nutrients and vitamins, in particular for children (Bavinck *et al.*, 2023; Kolding *et al.*, 2019). As, in the region, fish is mainly seen as a trading commodity, much effort may have to be invested in promoting fish as food. Eating habits are largely culturally embedded, and the pastoral societies, from where most fishers originate, do not see fish as traditional food: eating fish has a negative connotation of being poor and destitute. School feeding programs may have an important role in promoting fish as food as well as providing school going children with healthy food.

3.3.4 Aquaculture: an area of no potential

Several propositions, and attempts, have been made to further the potential of aquaculture in the region. We propose to refrain from such efforts within the context of the proposed project to be executed by WFP since all previous attempts have failed:

1. Cage culture on the lake is virtually impossible due to (a) the presence of crocodiles; and (b) the strong early morning winds and regular violent storms on a lake that has limited sheltered bays. Both crocodiles and storms will damage any cages present.
2. The huge evaporation rates (1 cm/day on the lake) and limited availability of freshwater will make any land-based aquaculture a costly affair.
3. Feed for fish need a large amount of (fish) proteins to the extent that fish have higher protein requirements than humans[10]. The costs of feed are high in any African aquaculture venture (around 80% of running costs), rendering most aquaculture endeavors unprofitable. It cannot be expected that these costs will be lower in the remote Turkana region – on the contrary.

All previous attempts at starting aquaculture in the region have failed because of at least one of these three issues.

[10] tilapia needs at least 30% protein in their feed to grow satisfactorily, which is more than twice of what is available to the average African population in their daily food intake.

RECOMMENDATIONS FISHERIES ORGANISATION AND DEVELOPMENT

1. **Trade and marketing:** within the project a high priority should be given to addressing competence and agency in organizational capacity, and education and training in financial management, trade, and marketing of the various groups of fishers, traders, and individuals around Turkana accounting for the aspirations of these groups. Training of individuals or groups (individual entrepreneurs, women's groups, BMUs, cooperatives, etc.) in organizational management, business economics, marketing and trade is preferable and at least should be done prior to investments in technical solutions as cold storage and freezing facilities and associated provision of fuel and transport facilities.
   1.1. Trade to areas within Kenya seems possible but requires good knowledge of markets and contacts with customers that seem lacking in many instances. A thorough economic value chain analysis is required before further investments are made in the fresh and dried fish trade.
   1.2. Investments in improving the dried, fried, or smoked fish trade should have the same attention as attempts to develop a cold chain: a thorough economic comparative analysis of both forms of fish processing should be carried out.

2. **Food security:** promotion to the people of Lake Turkana of the importance of 'fish as food' should be given high priority, as fish is an important source of proteins and valuable nutrients and vitamins, in particular for children. School feeding programs may have an important role in promoting fish as food as well as providing school going children with healthy food.

3. **Cold chain:** Any development of cold storages or cold chains should go hand in hand with creating an enabling environment to diminish the current rapid deterioration of installations and high reliance on outside support to maintain cold chain facilities. Of primary importance is to strengthen the capacity of people to take care of maintenance of such facilities themselves. Several issues should be accounted for:
   3.1. Both non-functional fish-freezing factories built in Kalokol and in Loiyangalani have never operated primarily because of the lack of access to freshwater. Any cold chain development that is dependent on freshwater for processing of fish or ice should account for the limited availability of fresh water.
   3.2. Producing ice for fish transport and trade with an irregular market supply of fish may require substantial amounts of freshwater storage which currently is in short supply all along the lake.
   3.3. Simple freezer boxes are preferred by many in the trade above larger cold storages due their flexibility and limited operational and maintenance costs.
   3.4. Any investment in facilities to support trade in fish should take account of the boom-bust nature of the fishery and the seasonal unavailability of some important species.
   3.5. Placing infrastructure on the lakeshore for landing, storing, processing, and handling fish for transport is heavily constrained by the large lake level fluctuations. Infrastructure related to fish handling and storage therefore should be semi-permanent in nature and easily transportable.

4. **Fisheries development**: Strong links with NGO's that have their 'feet on the ground' and where their goals align with the WFP program should be fostered to avoid duplication of efforts and provide grounding of the WFP program into relevant communities and local organisations.
    4.1. Any support in the form of providing fishing implements (boats, nets, cold chains, etc.) should be organized such that a local industry in boat, net and gear repair/making/maintenance can develop to avoid dependency on aid in fishing implements and foster self-sufficiency.
    4.2. If nets are issued to fishers, avoid monofilament nylon nets, as these are not biodegradable and lead to ghost-fishing and "plastic" pollution in the lake. Multifilament biodegradable nets are available and should be prioritized.
    4.3. Avoid the issuing of fiberglass boats as fiberglass gets brittle and easily cracks under direct sunlight and is not easily repaired under current economic conditions and lack of supply chains for repair and maintenance of fisheries assets. Locally made, wooden vessels (that cannot sink) should be preferred, to develop a boat building industry.

5. **Aquaculture:** No effort should be undertaken to develop any form of aquaculture in the Lake Turkana region within the context of the proposed project to be executed by the WFP since all previous attempts have consistently failed and a thorough analysis of such failures should be made first. Given the main aims of the proposed project this is outside its current mission.

4. FISHERIES RESEARCH AND MANAGEMENT

4.1 RESEARCH AND MONITORING NEEDS

A recent review by Obiero *et al.* (2022) based on the available literature and on expert discussions and surveys showed that there is a marked lack of interdisciplinary and applied research on Lake Turkana. Much of the work published on the system (63.3%) focuses on previous geological periods rather than the current state of the ecosystem. Basic fisheries data from monitoring and research are either lacking or outdated (See e.g. figure 10). The fishery is mainly carried out along the shores, and information on the pelagic system of the lake is scant both due to limited fisheries in this part of the system as well as lack of acoustic monitoring surveys, the last of which was carried out in 2009 (Muška *et al.*, 2012) The study advised four critical steps that need to be taken to improve research, surveillance and management in this system: local capacity building, consistent monitoring and data sharing, sustainable financing, and strengthened collaborative networks. We share this advice but will focus specifically on current research and monitoring needs to enable an assessment of the current fishery.

4.1.1. Catch Assessment Surveys and Frame Surveys

Primary information to assess a fishery are data on catch (output of a fishery) and fishing effort (input). Fisheries catch and effort data are normally obtained through a Catch and Effort Data Recording System (CEDRS) that usually consists of two elements: (1) a Catch Assessment Survey (CAS) to obtain an estimate of the average catch per unit of effort (CPUE) by species or species category through stratified random sampling of all the different fishing methods used in the fishery; and (2) a frame survey which is a census of the all fishers and their assets (boats, gears). This census gives the fishing effort (f) over the same strata as the CAS. Total catch (C) is then obtained by multiplying CPUE with total effort, again by strata, after which these estimates by stratum are summed. CAS should be carried out regularly (monthly, seasonal, or other regular data collection – but see below). Frame surveys to obtain total effort generally are carried out every 1 to 5 years. The (statistical) techniques to organize a CEDRS are well described in a vast literature (Bazigos, 1983; Caddy and Bazigos, 1985; FAO, 1999; Halls et al., 2005; Sparre, 2000; Stamatopoulos, 2002; Stamatopoulos, 2004) However, CAS and frame surveys are expensive and logistically difficult to carry out in the remote areas of Lake Turkana when solely reliant on governmental staff At the current level of fishing effort in Lake Turkana, a CEDRS operation (CAS + Frame survey) would suffice every 2 or 3 years. Involving Beach Management Units in daily catch data collection would be a possible solution that has been attempted elsewhere in Kenya, but require thorough training of fishers or BMU officials. It is highly dependent on the willingness of fishers to join in such an effort and the benefits they would see in or receive from such an effort. Frame surveys are census surveys that need to be carried out by the Kenya Fisheries Service and/or KMFRI staff and are expensive as well, although when well-designed give a vast amount of information about the fishery.

4.1.2. Experimental fisheries data collection

A trial of experimental fisheries data collection by local fishers as described in the previous chapters turned out to be a very good way of obtaining high-quality, high-resolution data. The data obtained can be used for a range of purposes that at least complement CAS surveys and may even in part supplant them. The experimental surveys, when carried out over longer time frames (several years) enable comparative assessments of relative biomass through standardized catch rates giving information on the (changes) in relative stock sizes over space and time. They give information on size and species distributions that can help in assessing the stocks as well as the fishing patterns in the fishery, e.g. through gear signatures (Figure 13: the specific size and species selection of a particular fishery or gear). And finally, they enable assessments of a fishing pattern in accordance with and ecosystem approach to fisheries (EAF), so-called balanced harvesting, that is, an examination of the distribution of the catch over the size distribution of species in the lake. When well designed, data collection with fishers could partly replace Catch Assessment Surveys as an estimate of the CPUE by fishery type (longlines, gillnets, beach seines etc.) can be obtained. A well designed, statistically rigorous, and expensive, Catch Assessment Survey is currently unattainable in Turkana and a good, much improved, estimate of the total catch can be obtained through data collection with fishers in combination with a Frame Survey.

The current trial has been very successful, performed with the assistance of local fishers (see separate report), and should be expanded with additional sites, and extended over a whole year to learn about the annual variability in availability of stocks and the modes of operation of fishers. Returning analyzed data and results from individual operations back to fishers will assist them in learning about the costs and revenues of fishing and efficiencies in effort allocation. It will further assist in better communication between fishers and managers about management needs and pave the way for equitable co-management.

4.1.3. MODELLING LAKE PRODUCTIVITY: ACOUSTIC SURVEYS AND LIMNOLOGY

The productivity of Lake Turkana's fisheries fluctuates due to hydrological variations impacting nutrient input and phytoplankton growth. Understanding fish production dynamics is vital for determining sustainable yield estimates, which will vary with lake levels. Leveraging existing satellite remote sensing algorithms for chlorophyll estimation by Tebbs *et al.* (2020) our proposal aims to establish linkages between hydrology, water quality, and fish production. Such an empirical model can have predictive capabilities on production potential that will facilitate short-term prognoses on the potential yields. By integrating hydroacoustic surveys, satellite data, and advanced remote sensing techniques, it aims to inform sustainable development strategies for the lake's resources, ensuring the ecological soundness and economic viability of the planned interventions.

To establish such a model two sets of data series are required: (1) acoustic surveys to establish stock sizes and distribution, and (2) limnological data and in particular chlorophyll-a densities to ground-truth remote sensing data. Both these data sets can be obtained during acoustic surveys.

ACOUSTIC SURVEYS AND LIMNOLOGY

Seasonal and annual catch rates from the experimental fishery (or CAS), in combination with lake-wide hydroacoustic surveys for abundance estimations, are essential elements in the suggested development of an empirical model for predicting potential yield estimates based on remote sensing of lake levels and primary productivity. In addition the ratio between estimated annual catches (C) and standing biomass estimates (B) from hydro-acoustic surveys will give a direct estimate of the fishing pressure (Exploitation rate E = C/B). Hydro-acoustic surveys are rapidly becoming part of the standard monitoring of fish stock in African lakes (Natugonza *et al.*, 2022; Nyamweya *et al.*, 2023) and should also become standard in Lake Turkana.

To start with, during the inception phase, two acoustic surveys (in the two main seasons) are recommended to obtain information on the status of stocks and initial limnological data. The acoustic surveys will in themselves provide valuable information on the current status of fish stocks in the lake. In addition to the stocks of larger species currently harvested (in particular Iji (Nile perch) and

Juse (*Alestes baremoze*), the surveys should focus on examining the potential of the stocks of unexploited small pelagic offshore fish species (*Brycinus minutus* and *B. ferox*, highly productive small fish species, comparable to Omena from Lake Victoria) that could form the basis of a large, dried fish industry if exploitation methods through light fishing with dipnets during night as used in other lakes (a.o. Lake Victoria, Tanganika and Malawi) can be employed in Lake Turkana.

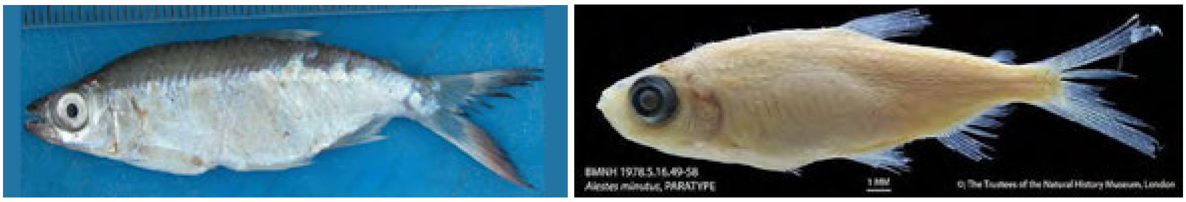

FIGURE 16 ***BRYCINUS FEROX (MAX LENGTH 8 CM) OR LARGE TOOTHED TURKANA ROBBER (LEFT); BRYCINUS MINUTUS (MAX LENGTH 3.3 CM) OR DWARF LAKE TURKANA ROBBER***

Evaluation of the results of these two initial acoustic surveys in the inception phase can form the basis of a long-term program of acoustic surveys that should take place over several years (at least four) to enable the development of the predictive forecast model linking lake levels with primary productivity (information that can be obtained by satellite data) to fish production.

EMPIRICAL FISH PRODUCTION MODEL

To establish an empirical fish production model the following steps organized in work packages are recommended:

1. Conduct ground truthing during hydroacoustic surveys.. During the hydroacoustic surveys spectral data and water samples (chlorophyll, turbidity, phytoplankton species composition etc.) are collected to refine and validate remote sensing algorithms. Investigate spectral signatures in satellite imagery to distinguish cyanobacteria, essential due to their impact on fish diet digestibility.
2. Use satellite data (Sentinels-2 and 3, Landsat, radar altimetry) to obtain lake level and water quality timeseries. Determine sediment plume extents from Omo and Turkwel/Kerio rivers, major nutrient sources.
3. Link fish abundance and species data from hydroacoustic surveys to satellite information. Develop a predictive model estimating fish production and sustainable yield based on remotely-sensed water quality and lake level data.

The key outputs of the modelling exercise are:

- Timeseries and maps of lake levels, water quality and fish production.
- Statistical models for estimating fish production and sustainable yield from environmental variables (in particular lake levels).
- Software tools for lake productivity and sustainable yield forecasts using latest satellite data.
- Capacity building of KMFRI staff in using the remote sensing analysis products

4.2 FISHERIES MANAGEMENT: MANAGEMENT REGULATIONS

A few comments need to be made on the current management regulations that were frequently invoked in the interviews with fishers and other stakeholder during the field work, and that are seen by many as a necessity to combat a (potential) source of overfishing on the lake. Some of the respondents vehemently oppose the catching of “undersized fish” and the use of “illegal” mesh sizes[11]. Others invoke the existence of and make claims about "breeding areas" that should be demarcated as protected areas. While managers call for the devolution of management to stakeholder institutions such as BMU's, they also wish to co-opt these fishing organizations in the surveillance and enforcement of the measures as well as territorial management.

The current fisheries management regulations are guided by the Fisheries Management and Development Act of 2016 (national in scope and applies to all lakes in Kenya) and BMU Regulations 2007 (which also applies to all BMUs nationally). The mesh size regulations which are applicable in Lake Turkana are found in the Fisheries Act Cap 378 (repealed) which placed the minimum mesh size for Lake Turkana at 5 inches for all fish species. Since the Fisheries Act Cap 378 was repealed by the Fisheries Management and Development Act in 2016, no mesh size regulations specific to Lake Turkana are mentioned in the new Act. Given the initial findings of the baseline study (chapter 2.2.3 and Figure 13 and Table 2) there is a need to revise the mesh size regulations by national and devolved governments specific to specific fisheries guided by research findings. To understand this need requires a short explanation on the theoretical background of mesh size regulations and spatial management compared to observations on African freshwater fisheries in general and Lake Turkana specifically.

There are, simply put, only two biological questions in fisheries management: 1) how much to catch (so-called fishing pressure), and 2) how (when and where) to catch it (so-called fishing pattern). In governance, the regulation of the fishing pattern is used deliberately to selectively protect or target certain species or sizes[12], either through gear regulations or through protecting life stages of fish in areas where no fishing is allowed or through time closures. These regulations do not require continuous data and are therefore also the cheapest tool in the "management toolbox" and the easiest to monitor and enforce, even by largely untrained fisheries officers. While total allowable catch (TAC) determinations are dynamic, data intensive, and expensive to monitor and limiting fishing effort (numbers of fishers, boats, or gear) is administratively and socially complex (both types of measures regulate fishing pressure), gear restrictions, or mesh size regulations (so-called technical measures) are static, much cheaper, and simpler to implement and control. Therefore, in most freshwater fisheries, size limits and gear and mesh size restrictions are the preferred and often only available option for managers, besides area closures and fishing seasons. No examples for regulated fisheries exist anywhere where there is not some kind of selectivity regulation in the form of gear restrictions or minimum landing sizes (Misund *et al.*, 2002) and mesh size as well as time and area-based regulations are ubiquitous in African fisheries.

In practice, African fisheries have always targeted a large range of species and sizes, small fish species as well as juveniles of larger fish, and Lake Turkana is no exception. The result of mesh-size regulations in place is that most of the current fishing is technically illegal: for instance, we now have data[13] (Figure 13; Table 2) that show that an important resource in the fishery, *Alestes baremoze* (Juse), can only be caught with 2-3 inch nets, which are illegal under the current regulations.

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[11] See for example this video from September 2023 https://www.youtube.com/watch?v=XBO8vBDYBcM

[12] Size is related to life-stages: with fish different life-stages (egg, fry, juvenile, adult) require different habitats

[13] See separate report on the trial experimental fishery (4b).

The tilapia fishery around Ferguson's Gulf is the oldest commercial fishery in Lake Turkana, dating back to shortly after WW2 (Kolding, 1993) and has been notorious ever after for its unpredictable boom and bust history. This was recognised already in 1954 when the British colonial administration (DC) in Lodwar wrote (cited in Kolding 1989):

> "*One problem which will be hard to solve is that the continuity of supply on which the trade insists and fickle – Rudolf*[14]*, so far refuses to cooperate.*"

The dynamics of this fishery, like the overall fishery in general, is strongly determined by the changing hydrology and lake level fluctuations. During low seasons or unproductive years (like the total drying up of the Gulf, Figure 6) the fishermen will leave the fishery and migrate to other areas, such as northwards close to the Omo delta. When favourable conditions are re-established, the fishery will respond by a rapid boom (see Figure 14 for the 2009 boom in Ferguson's Gulf), but which is usually short lasting for a few years only. In practice this means that the fishery is largely unmanageable from the point of view of achieving stable catches and any of the current attempts of controlling the fishing pattern to maintain or improve total catches is largely futile. The only sensible thing to do is to follow the boom and bust periods by a flexible, diversified, and dynamic fishery, and realizing that there will be periods where the general income will be low and the fishery unprofitable.

FIGURE 17 THE 2009 FERGUSON'S GULF TILAPIA BOOM. FISH ARE DRIED IN FRONT OF THE TFCS FACTORY IN KALOKOL. EVERY AVAILABLE SPACE IS USED FOR DRYING FISH. PHOTO BY PETER HELLER (FILMKRAFT FILMPRODUKTION).

Another set of measures that is being discussed, are setting up so called areas that protect "breeding fish", and shallow gulfs and bays are especially mentioned as well as areas around national parks. There is very little scientific rationale in these proposals. Fish species are either breeding in the open lake, in the Omo River, or indeed in shallow gulfs and bays and vegetated shorelines. Protecting fish breeding in the open lake has no rationale: most open water fish species breed year-round in no specific area.

[14] Lake Rudolf was the old colonial name of Lake Turkana.

Some species perform breeding migrations into the Omo River, but, as far as we know, there are no regulations in place that could lead to temporal measures in protecting upstream migrations, and there are no known spawning aggregations of other species. Lastly, shallow areas will change according to the rise and fall in lake levels, leading to problems of demarcation, leaving the question of the rationale behind measures closing such shallow areas. Sometimes, nursery areas are protected – that is areas where fish fry and small juveniles may have to be protected when there is a danger that specific fishing methods will destroy specific habitats for young fish -, but we have not heard that this is taking place in Turkana[15]. While there could be an economic rationale for protecting certain life-stages of specific fish species through time or area-based methods, so far, no such rationale has been presented for the Lake Turkana fisheries. The proposed measures all seem to be based on a general fear of overfishing, which has never been demonstrated in Lake Turkana. The recurrent boom and bust periods are driven by hydrology and have little to do with the current fishing pressure or fishing pattern.

In short, management dispositions, including taking measures to protect certain life-stages of fish should be based on empirical observations and facts, and discussed and implemented in close co-operation with the people who will be affected most by such measures. It is a paradox that all development initiatives on the fishery in lake Turkana aim at improving the potential and maximizing the output, while at the same time suggesting or supporting restrictive measures on the fishing pressure and the fishing pattern that will work in the opposite direction. There is a need to update the mesh size regulations and spatial management by national and devolved governments, in this case Turkana and Marsabit guided by research findings.

4.3. FISHERIES RESEARCH AND MANAGEMENT: ORGANISATION AND ACTIVITIES

The Kenya Marine Fisheries Research Institute (KMFRI) has a station in Kalokol (Figure 18). The office was established in 1983 with the research mandate of generating scientific data and information for freshwater fisheries, aquaculture, environmental and ecological studies, including limnological studies for sustainable development of the BE. The Institute focusses on limnological studies and fisheries, socio-economic and aquaculture research. However, limited work is carried out due to a lack of laboratory space, laboratory and field equipment, transportation facilities (vehicles, boats) and well-trained research and technical staff. So far, the station has four research scientists (3 senior), three technical staff, two Maritime staff and ten corporate support staff.

KMFRI will also work closely with Kenya Fisheries Service, National Museums of Kenya, Kenya Wildlife Service and Wildlife Research and Training Institute as well as local non-governmental organizations e.g., Turkana Basin Institute to develop a comprehensive lakeside basin management plan.

Fisheries monitoring through catch assessment surveys (CAS) and frame surveys (FS) are the responsibility of the Kenya Fisheries Service with stations in Loiyangalani (Marsabit) and Kalokol (Turkana) often in cooperation with KMFRI. These surveys are carried out rarely due to funding issues (The last CAS survey covered only one month in 2018 in a small, limited, area on the North-western side of the lake), and are of limited value. KMFRI conducted small CAS studies in 2018, 2022 and now in 2023.

[15] Naturally, protected nursery areas are now self-establishing along long stretches of the lake shores and in the shallow lagoons. The highly invasive introduced shrub, *Prosopis juliflora*, locally known as "Etirae" has established dense vegetation patches, which under rising lake levels are impenetrable to fishing operations. This plant was totally absent around 30 years ago but is now spreading rapidly and form a natural protected nursery area for several fish species, including tilapia.

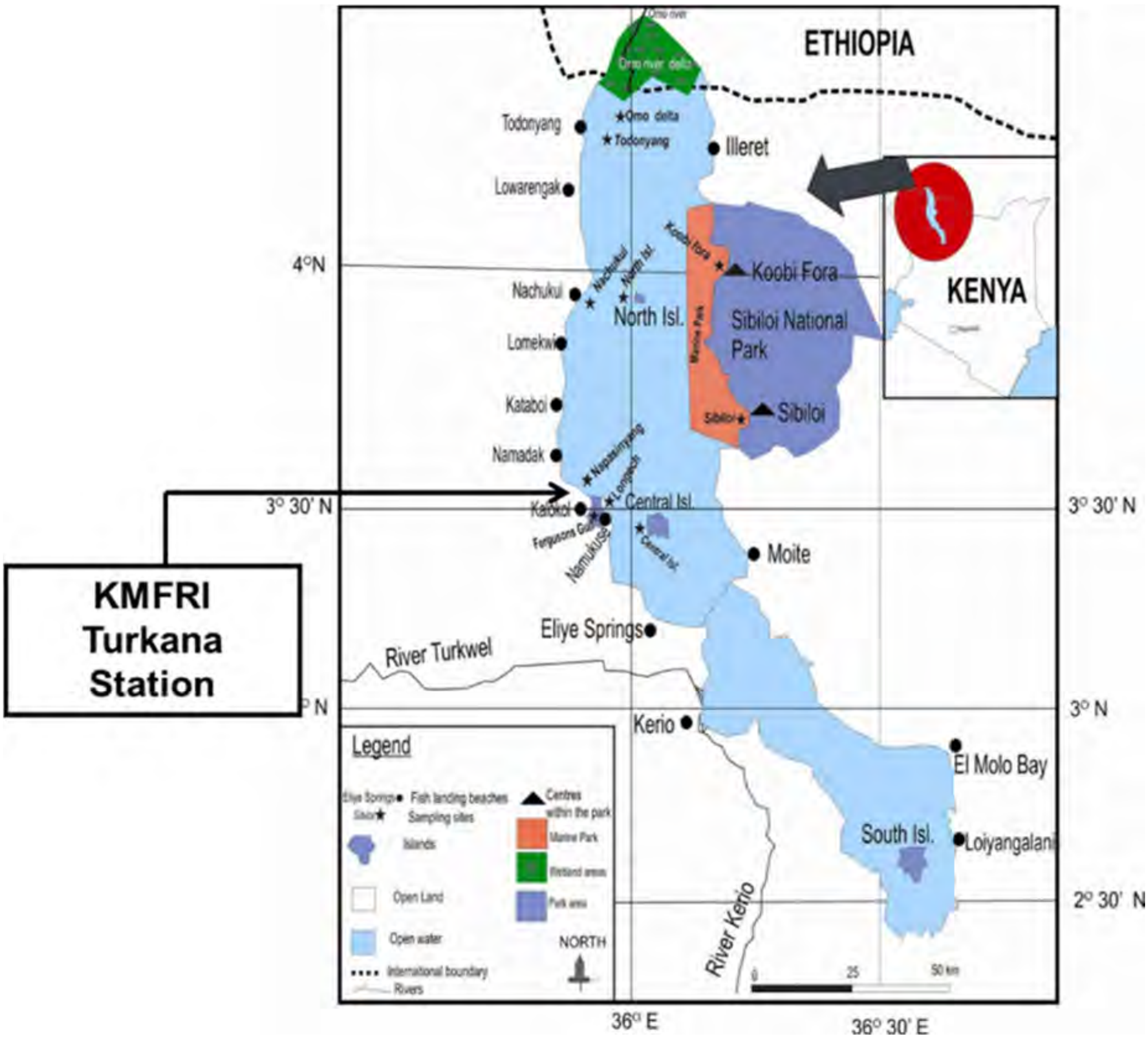

FIGURE 18. MAP OF LAKE TURKANA INDICATING MAIN LANDING SITES AND AREAS, THE NATIONAL PARK AS WELL AS THE LOCATION OF THE KMFRI TURKANA RESEARCH STATION IN KALOKOL. STATIONS OF THE FISHERIES SERVICE OF KENYA ARE LOCATED IN LOIYANGALANI AND KALOKOL..

RECOMMENDATIONS RESEARCH AND MANAGEMENT

1. **General:** It is important to fully understand the changing dynamics of the lake ecosystem, fish and fishery production and the role of the variable discharges of water into the lake affected by upstream developments in Ethiopia and Kenya, as well as to advance knowledge of Lake Turkana's response to climate change impact on water supply to the lake. This requires:
   1.1. Continue monitoring and analysing the interactive effects of ongoing activities in the region on the ecological functioning of Lake Turkana, and in particular the impact of changes in the river discharges to the lake as a result of hydro power development and water extraction in the upstream areas to the annual and seasonal fluctuations in the lake and their role in regulating lake productivity and fish production.
   1.2. Regular monitoring of environmental conditions, including annual lake water levels, river discharges, land cover, water quality nutrient levels and salinity.
   1.3. Linking physical, environmental, and seasonal and annual hydrological variation to variation in the lake's ecology, and in particular fish and fishery production through observational models for short-term prediction.

2. **Catch and Effort Data Recording:** A fisheries monitoring plan (CEDRS) should be developed including Frame surveys for total effort estimations.
   2.1. Catch Assessment Surveys are expensive and logistically very difficult to carry out and may not be the focus of the current program. It should be discussed with the governments of Turkana and Marsabit as well as on a national level how some form of catch (CPUE) monitoring can be organized on a regular basis. Involvement of Beach Management Units should be considered. For that extensive training of fishers and BMU officials is required.
   2.2. Catch Assessment Surveys can be replaced by experimental fishery data collection involving fishers (see next) if these surveys are expanded with a better statistical design covering all fisheries (gillnet, longline, beach seines, doum palm log-boats, wooden and fiber glass vessels etc.).
   2.3. It is important to carry out at least one frame-survey either during the inception phase of the project or at least during the early stages of the full project as there is great uncertainty about the fishing effort on the lake. A frame-survey will provide basic data on fishing effort in terms of numbers of fishers and their assets (fishing gears, vessels). By carefully adding additional questions to the census questionnaire valuable social and economic information can be obtained such as:
      I. Age, educational and occupational background, and ethnic affiliations of fishers
      II. Movement patterns in and out of the fishery
      III. Duration in the fishery
      IV. Assets

   etcetera, depending on the specific requirements of development programs.

3. **Experimental fishery data collection involving fishers**
   3.1. The experimental data collection involving fishers should be carried out at least during the inception phase of the project to provide basic information on species and size distribution of the daily catches of fishers on both sides of the lake and over the gradient from North to South to capture the differences in output of the fishery.
   3.2. The KMFRI research team should be supported and possibly augmented to continue providing training to new and participating fishers to standardize the data collection process and minimize errors, cross-check the collected data with other records to ensure consistency and accuracy and maintain regular communication with the participating fishermen to provide feedback to address any issues or discrepancies in data collected in a timely manner.
   3.3. A direct follow-up to the present assessment should be a visit by KMFRI to the various groups to discuss the results of the summary analysis provided (output 3b) and discuss the issues that have arisen. The research team of the baseline study should be assisted in continuing the training staff of KMFRI in the use of PASGEAR and the type of analyses that can be done as shown in the current report.
   3.4. Additional data on daily effort (numbers and sizes of gear used per trip) should be included and obtained from participating fishers as well as length-weight data enabling calculations of missing species specific length-weight relationships that will enable more accurate catch weight calculations important in lake productivity assessments.
   3.5. Expansion of the program should focus on improving its statistical design to cover all fisheries over the lake to replace or cover for the lack of a Catch Assessment Survey.

4. **Acoustic and limnological surveys:** At least two lake-wide hydroacoustic surveys for abundance estimations covering the main seasons in the hydrological cycle should be carried out during the inception phase to obtain an estimate of the fish biomass in the lake (1) over a gradient from North to South; (2) over the size distribution of the fish stocks in the lake; (3) with a particular focus on the two small unexploited stocks of offshore pelagic endemic robbers (*Brycinus* spp.).
   4.1. KMFRI is well equipped to carry out these surveys as they are regularly done in Lake Victoria.
   4.2. During the acoustic surveys limnological data should be collected to enable ground truthing of satellite imagery. KMFRI should discuss the set-up of the acoustic surveys with the researchers involved in the modelling exercise to obtain limnological data of high quality.
   4.3. The Turkana advisory group of ACARE recently was granted funds to implement a water quality monitoring system in Lake Turkana. This system will focus on parameters such as temperature, chlorophyll a, dissolved oxygen (DO), and turbidity ACARE should be involved in seeking complementarity with the current Dutch funded project run by WFP and UNESCO.

5. **Model development**: Develop a model correlating fish population data from hydroacoustic surveys with satellite-derived lake levels and water quality parameters to estimate fish production and maximum sustainable yield for Lake Turkana fisheries.
   5.1. During the inception phase an initial start-up budget is needed to further develop the model requirements, and guide KMFRI in collecting necessary data for ground truthing.
   5.2. Synergies between earlier lake monitoring efforts through satellite remote sensing by different research groups and organisations should be investigated as for example the UNESCO Water Quality Portal and King's College African lakes algorithms.
   5.3. Full funding of staff time, research assistants, travel expenses, equipment, consumables, and capacity building activities with KMFRI staff should take place in the second phase of the project after analysis of initial data from the inception phase.

6. **Review of fisheries management regulations**: a thorough review of the rationale of current fisheries management measures should be carried out and made specific for the Turkana situation. Setting such measures should be grounded in a thorough review of the main goals of the fishery in cooperation with the main stakeholders and should be based in the experience of the main users of the fishery, fishers, and in recognition of the multispecies and size and multi-gear nature of the fishery.

5. ACKNOWLEDGEMENTS

FIGURE 19. THE TEAM IN KALOKOL AT THE KMFRI STATION: FROM LEFT TO RIGHT JONATAN EKIRU (INTERN KMFRI), JEPPE KOLDING. DISMUS ESURON (DRIVER), JOHN MALALA, JEREMIAH MISIKO (COXSWAIN), MAURICE OBIERO, PAUL VAN ZWIETEN

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APPENDIX

NUMBER OF PEOPLE REACHED

See field report December 2023 (Introduction point 3) for details:

PSD 7b: Number of people reached				
Dutch		Kenya[16]		
			Direct	Indirect
Netherlands Embassy, Ministry of Foreign affairs, Ministry of Economic Affairs	8	National government officials	10	
Delft IHE	1	Government officials county and ward administrations Turkana and Marsabit	68	
		NGOs (national, local)	22	
		Fishers, traders, processors Turkana	116	

Next to these discussions were held with participants in ACARE-Turkana group; and scientists from King's College, UK and members of the the Omo-Turkana research network, Michigan State University, US

- PSD 7c: Number of identified opportunities for investment and/or follow-up PSD projects.

- PSD 3a: Number of strengthened organizations for a sustainable business climate. Distinguish between 1) Government 2) Semi-government and 3) Other;

[16] See Field report for extensive reporting on people reached

EMPIRICAL FISH PRODUCTION MODEL DEVELOPMENT

Deliverables/Activities for the full program

1 **Ground-truthing satellite water quality algorithms**

1.1 ***Field data collection***

1.1.1 Develop data collection protocols

1.1.2 Transport/install spectrometer [ASD for initial 9 months, So rad automated system for rest of project]

1.1.3 Train team members

1.1.4 Collect spectral and limnological data during hydroacoustic surveys

1.1.5 Lab analysis of water samples

1.2 ***Data processing [desk-based]***

Compile ground data into database

1.2.1 Refine and validate satellite water quality algorithms

1.2.2 Evaluate atmospheric correction methods

1.2.3 Investigate cyanobacteria spectral signatures

2 **Satellite data processing**

2.1 Download radar altimetry lake level data for Lake Turkana

2.2 Develop script to apply water quality algorithms to satellite imagery (Landsat, Sentinels-2 and 3) for Lake

2.3 Generate timeseries of lake level and water quality parameters from archival satellite data (1980s - present)

3 **Sustainable Yield Modelling**

3.1 Develop/update database of fish biomass, lake level and water quality data (after each hydroacoustic survey)

3.2 Use archival satellite data to develop model for predicting lake productivity (chl-a) from lake levels

3.3 Develop empirical model predicting spatial variability in fish biomass

3.4 Develop an empirical model for predicting spatial and temporal variability in fish biomass from satellite data.

4 **Co-design and capacity building**

4.1 ***Co-design of sustainable yield modelling tools with managers***

4.1.1 Stakeholder co-design workshop [run by KMFRI with support from KCL]

4.1.2 Quarterly online meetings with key stakeholders (KMFRI, county gov, fisheries managers)

4.1.3 Co-develop software tool/app for automated calculation of sustainable yield from latest satellite data, for

4.2 ***Capacity building***

4.2.1 Co-design training plan and training materials

4.2.2 Train KMFRI staff on ground truthing and satellite data processing

4.2.3 Dissemination workshop / deliver training on the developed sustainable yield calculation tool.

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