EAST AFRICAN COMMUNITY
LAKE VICTORIA FISHERIES ORGANIZATION

A REPORT OF THE LAKE VICTORIA 2022 HYDRO-ACOUSTIC SURVEY

Hydro-acoustics Regional Working Group

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EXECUTIVE SUMMARY

In Lake Victoria, hydro-acoustic surveys have been conducted since 1999 to estimate the standing stock and distribution of major fish groups (Nile perch, *dagaa*, Haplochromines, other fish, and the freshwater prawn *Caridina nilotica*). This report presents the findings of the 25th survey, carried out between November 7th and December 7th, 2022. Data were collected and analyzed using standard operating procedures, and the results contribute to a time series analyzed using a consistent approach, enabling direct comparison of biomass estimates across various years. Unlike previous surveys that presented biomass estimates as standing stock (i.e., instantaneous biomass or biomass at any given point in time), the 2022 survey further processes the estimates to reflect the total biomass for the entire year (i.e., annual production), accounting for growth and recruitment. Subsequently, we compared this total annual biomass (production) with the total annual landings from Catch Assessment Surveys (CAS) reported for the same period, to determine the exploitation rate. These exploitation rates are then compared with benchmarks from literature to assess whether fishing is sustainable or unsustainable. The results from the 2022 survey indicate that::

- The standing stock (instantaneous biomass) was 2.23 million metric tons (t), which was 20% lower than that recorded during the 2021 survey.
- *Dagaa* constituted 47% of the standing stock, followed by *Caridina nilotica* (23%), the "Haplochromines" (15%), and Nile perch (15%).
- The mean standing stock of Nile perch was 333,341 t, which is equivalent to annual biomass (production) of 736,683 t. This biomass was 33.72% lower than that in 2021, and the reduction was highest in Tanzania and least in Kenya, while Uganda recorded a slight increase in biomass. Considering the average catch of 250,000 tons, the 2022 annual biomass translates to an exploitation rate of 34%, which may be higher than sustainable levels of 25-30%.
- In addition, the size structure of Nile perch was dominated by smaller sizes less than 50 cm, which could be attributed to concentrating fishing effort on big size, especially those above the upper slot size limit of 85 cm total length.
- The mean standing stock of *dagaa* was 1,060,589 t which, which is equivalent to annual biomass of 4,189, 327 t. This biomass was 14.3% (on average) higher than that from the 2021 survey, but the increase was observed only in Uganda, while Kenyan and Tanzanian portion of the lake recorded a decrease of up to 46.15% and 2.53%, respectively. Considering the average catch of 900,000 tons, the 2022 annual biomass translates to an exploitation rate of 21%, suggesting that the catch for *dagaa* can be doubled without negatively affecting the stock.
- The estimated standing stock of haplochromines and other unidentified fish was 331,709 t, which is equivalent to total annual biomass of 779516 t. This biomass was 44.8% lower than that estimated in 2021, with the largest decline observed in the Tanzanian portion of the Lake. Considering the average catch of 60,000 t, the exploitation rate is approximately 8%. Although this exploitation rate is substantially low, we advise not to increase it beyond 10% given that the species is an important prey for Nile perch, which supports a highly lucrative Nile perch fishery.
- The mean standing stock of *Caridina nilotica* was 509,183 t which translates into annual biomass of 5,840,329.01 t. This biomass was 35.42% lower than that recorded in 2021, and the decline was observed across all the three countries.

- Time series data demonstrated interannual variability in biomass for fish groups, but no major changes in trends were observed, suggesting that the fisheries are still resilient to the current exploitation rates.
- Thermal stratification patterns were evident in the lake-wide CTD sampling sites, particularly in the northwestern and north-eastern sectors. The DO profiles were much lower than the optimal for fish.
- Generally, the biomass for all fish groups positively correlates with dissolved oxygen and transparency, while it negatively correlates with temperature, chlorophyll a, and turbidity.

We recommend the following, based on the current study's findings and experiences:

i. Regularly assess and update information on allowable catch for each species to ensure sustainable exploitation. Allowable catch should take into account the annual biomass and exploitation rates, as well as spatial differences in stock abundance.
ii. Investigate spatial differences in exploitation rates and allocate fishing effort accordingly to prevent overfishing in specific areas, such as inshore and coastal regions. This may include establishing protected zones or adjusting fishing effort based on local stock assessments.
iii. Strengthen enforcement of size limits, particularly for Nile perch, to prevent the overexploitation of larger individuals and maintain a healthy size structure within the population. Additionally, ensure that appropriate gear restrictions are in place to reduce bycatch and the capture of undersized fish.
iv. Efforts should be made to monitor and regulate pollution levels in Lake Victoria, as high levels of conductivity and chlorophyll negatively impact fish abundance. Implementing stricter pollution controls and promoting sustainable waste management practices can help improve water quality and support healthier fish populations.
v. Protecting and restoring critical habitats, such as inshore and coastal areas, can enhance fish populations by providing suitable breeding and feeding grounds. This may include regulating shoreline development and implementing habitat restoration projects.
vi. Fisheries management should incorporate the observed relationships between fish abundance and environmental parameters, adjusting management strategies as necessary to accommodate changes in environmental conditions. This may include implementing seasonal closures, or modifying gear restrictions based on environmental factors.
vii. Pursue further research on the relationship between fish abundance and environmental variables, and conduct yearly hydro-acoustic investigations in conjunction with stock assessments.
viii. Engage local communities, fishermen, and other stakeholders in the conservation and management of Lake Victoria's fisheries is crucial. Raising awareness about the importance of environmental parameters on fish abundance can help garner support for management actions and encourage responsible fishing practices.

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DEFINITIONS OF TERMS

***Biomass*:** total mass of living organisms in a particular ecosystem or geographic area.

***Scientific echosounders*:** are specialized instruments that are used for scientific research purposes, such as studying marine biology, oceanography, and fisheries.

***Echogram*:** graphical representation of the acoustic signals received by an echosounder, which is a device that uses sound waves to detect and locate objects underwater

***Nautical area scattering coefficient (NASC)*:** The area backscattering coefficient (ABC) scaled down to one square nautical mile (unit is $m^2ni.mi^{-2}$).

Standing/instantaneous stock: The amount or quantity of organisms present at the time of observation within a unit area of lake or a unit volume of water

INTRODUCTION

Lake Victoria is the largest freshwater body in Africa, shared by Kenya (6%), Uganda (43%) and Tanzania (51%). Its fishery contributes significantly to the Gross Domestic Product (GDP) of three East African countries and to the income and food security of the riparian people in the Lake Victoria basin region. The fisheries of Lake Victoria provide employment to thousands of people and serve as a vital source of food for millions of individuals, both locally and globally. Moreover, the lake plays a critical role in providing numerous ecosystem services. However, it is important to acknowledge that fisheries are not an inexhaustible resource, and their sustainability depends on effective management practices. To ensure sustainable management, fishery managers must answer questions such as the abundance and distribution of a given stock, its size structure, and the accuracy of abundance estimates. To aid in addressing these questions, resource managers and scientists have developed various tools and methods.

The use of population dynamic applications and methods is an important element in estimating fish stocks in lake ecosystems. The abundance of the lake's population is evaluated using both fishery-dependent and fishery-independent surveys. Catch assessments to acquire landing records, effort estimations using frame surveys, and population characteristic evaluations using gill netting surveys are all examples of fishery-dependent surveys. Trawl, acoustic, video, and side-scan sonar study surveys are examples of fishery-independent surveys. These stock abundance estimates help fisheries managers make informed choices to guarantee sustainability and maximize economic gains from the fishery, while also implementing conservation and restoration measures.

Fisheries acoustics is a widely used method for estimating stock abundance in marine and freshwater systems. This technique employs underwater sound to detect, count, and assess the distribution of fish and other aquatic organisms while characterizing their habitat. The application of acoustics in fisheries management has grown over time, largely due to its capacity to gather data directly from populations and measure organism distribution across vast spatial scales.

Hydro-acoustics serves as a valuable tool in fisheries research, enabling rapid and effective surveys of expansive areas, particularly for highly mobile species that necessitate extensive spatial sampling. This method is cost-effective, non-destructive, and fast in data acquisition, making it particularly well-suited for studying aquatic environments. Unlike other survey techniques, hydro-acoustics is unaffected by factors such as water clarity, strong currents, or diving depth restrictions. In summary, hydro-acoustic methods play a vital role in understanding aquatic ecosystems' ecology and managing fisheries sustainably.

This report presents the findings from the 25th Lake Victoria regional hydroacoustic survey, conducted between November 7th and December 7th, 2022. The biomass estimates primarily concentrate on four major groups: *Lates niloticus* (Nile perch), *Rastrineobola argentea*

(*dagaa*), haplochromines, and *Caridina nilotica* (freshwater prawn). For commercially significant species like the Nile perch, the report highlights the distribution and biomass estimates for individual fish with a total length (TL) of 10 cm or more. Additionally, the size structure of Nile perch is presented to inform fishing strategies (slot size). A standardized methodology was employed to reanalyze all data gathered by the EK60 split beam echo sounders since 2007, allowing for direct comparisons of biomass estimates across different years. The hydroacoustic results are compared with catch composition, catch rates, and size structure obtained from bottom trawl hauls and pelagic trawl fishing gear. Furthermore, the analysis is supported by data on physical, biological, and chemical attributes, which are compared with fish distribution.

MATERIALS AND METHODS

1.1 Study area

The survey was conducted in Lake Victoria (surface area of 68,800 km^2). The lake area is partitioned by quadrant (SE, SW, NW, NE), depth (Deep, Coastal, Inshore), special areas (Speke, Emin Pasha, and Nyanza gulfs and Ssese islands), and country (Kenya, Tanzania, Uganda).

1.2 Organization of the cruise

This survey took place between November 7th and December 7th, 2022. A seven-day preparation period preceded the survey, during which echo-sounders and CTDs were calibrated. Additionally, other research materials and equipment, such as the pelagic trawl, were assembled and tested.

1.3 Calibration of echo-sounder

The first calibration was successfully conducted on 5th November 2022 at the beginning of the survey in Mwanza gulf, whilst the second was done on 3rd December 2022 off-Sizu Island. Tungsten carbide sphere of diameter 38.1 mm (TS= -40.6 dB) was used in the calibration for the 70 and 120 kHz transducers. The calibration protocol used for this survey is detailed in the SOPs for hydro-acoustic surveys on Lake Victoria (LVFO 2018). At each calibration site, we lowered the CTD to determine the local environmental conditions. The water temperature measured at the calibration site was used to predict sphere target strength using the formula provided at https://swfscdata.nmfs.noaa.gov/AST/SphereTS/. Using the same CTD information and analysis protocol in the SOPs, the temperature-dependent equivalent two-way beam angles was estimated and used to update transducer settings in the EK80 software, including sound speed and absorption values.

1.4 Cruise track

The cruise followed the radial design. On average one net haul and three CTD measurements were conducted on each day of the survey. Sampling was restricted to daylight hours.

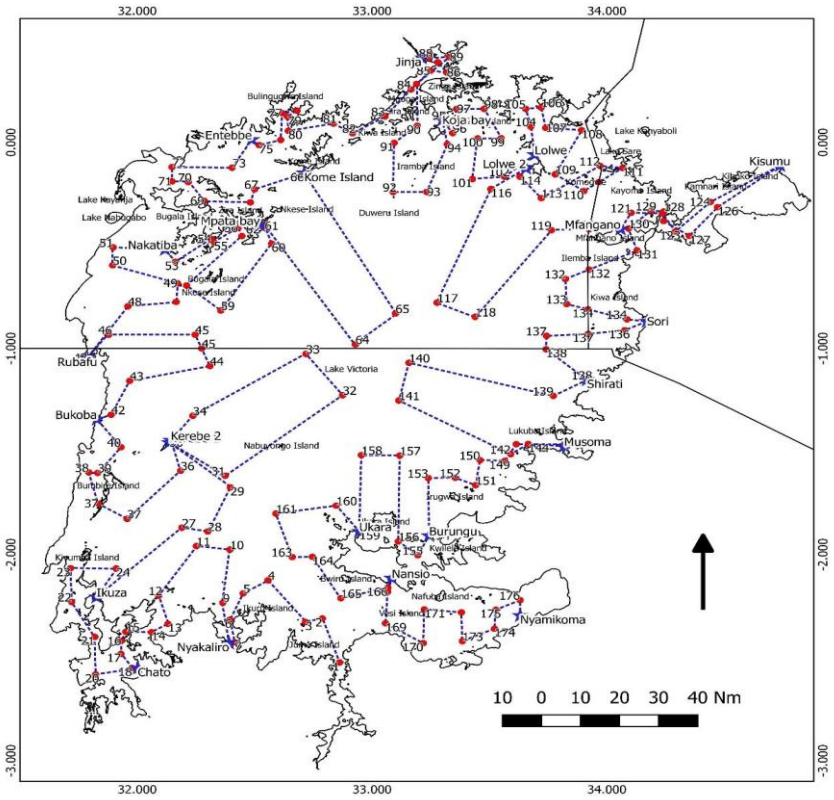

Figure 1. Survey cruise track of 7th November 2022 to 7th December 2022. Numbers denote transects and deadheads (see appendix IV)

The organization of sampling and data collection procedures were structured according to the type of activity taking place. The following activities were organized;

a) Transect: an acoustic survey track with the vessel proceeding in the same nominal direction at constant speed (normally about 9 knots). The following types of transects were designated:

- Deep Transect (Code TD) (>40 m deep strata);
- Coastal Transect (Code TC) (20 – 40 m deep);
- Inshore Transect (Code TI) (< 20 m deep);
- Deadhead (Code DH), the track between two independent transects;

b) Net haul: During this survey pelagic trawls and bottom trawls (NB) was used for fish sample collection. Detailed results of net haul sampling are provided as appendix to this report.

c) CTD: Involving deployment of a CTD probe and Secchi disc, and other environmental observations at geo-referenced sampling points.

Groups of activities at the same nominal location were given the designation ‘Stations’ to indicate that they might be analyzed together. Transects in close proximity and occurring in the same stratum were allocated the same station number. The implication is that later high-

resolution analyses could tie together transects and environmental data through stations. The detailed event log for the cruise is set out in Appendix II.

1.5 Acoustic data acquisition, processing and analysis

1.5.1 Data logging and storage

The echo-sounder operation parameters, particularly the data recording range (which was set to 120 m), were thoroughly reviewed and the recording was directory set at the start of each day. Data was logged in 1 GB files and then transferred to three different SSD disk drives.

1.5.2 Acoustic data preparation

Each day's raw acoustic data files were loaded into Echoview v. 12 Myriax, Hobart, Australia software using a standardized template to ensure consistency, specifically for selected exports and analysis telegrams and saved as EV files using the day's date as the file name. SIMRAD EK60 echosounders were utilized in acoustic measurements. The transducers, which are mounted on the protruding instrument keel, operate at the frequency of 70 kHz and 120 kHz. All the two transceivers were calibrated before the survey. Calibration settings were applied in an Echoview calibration file to update the calibration of all variables within each EV file. Unlike previous years, the daily mean temperatures were used to estimate the average sound speed and temperature-dependent equivalent two-way beam in the calibration file for the EV file for each day.

1.5.3 Setting analysis lines and definition of regions

Four analysis lines (checked bottom, test bottom, Dagaa and top lines) were set with specifications as detailed in the acoustic SOPs (LVFO 2018). Regions were defined by quadrant and strata, and according to the events given in the Event log. The occurrence of bottom echoes was checked between the "checked bottom" & "test bottom" lines and removed according to the standards detailed in the SOPs.

1.5.4 Estimation of EDSU

To ensure that all cells produced for analyses from the two frequencies in and between integration and single target analyses were similar, depth layers were set at 2 m intervals with a horizontal grid of 1 km (Elementary Distance Sampling Unit – EDSU). Data collected from regions designated as 'Transect' were used for analyses for the estimation of standing stock. For single target detections, analysis from each cell was exported by transect and by cell. To ensure that cells where no target was recorded are included in the calculation of average density, the option of "Output empty cells" was selected in Echoview – EV File properties Export window prior to data export.

The GPS positions of the start and end of each cell were used to determine the distance of the cell. Through the main part of each transect, these estimated distances correspond to the

intended distance of 1 km. However, some cells produce distances well below 1 km, but these were all included in the analysis, weighted by their length.

1.5.5 Single target analysis

Estimation of Nile perch densities were done using single target detections (split beam Method 2, with no TVG range correction; LVFO (2018)) in Echoview version 12. Data were exported by transect and by cells (constituting individual EDSUs). To produce results comparable to the previous surveys, only data from the 120 kHz transducer were used for standing stock estimation. Single targets were threshold at -50 dB, equivalent to a minimum detection length for Nile Perch of ca. 10 cm (LVFO 2018).

Data were exported within 2m depth strata in two parts from top line to dagaa line and from dagaa line to Checked-bottom-line and converted to mean numerical density and mean biomass densities using equations 1 and 2 respectively:

$$Density = \left(\frac{NTargets}{VBeam}\right) \quad (1)$$

Where NTargets and *VBeam* are the number of targets detected and the beam volume within the cell respectively.

$$Biomass = Density \times Mean\ weight \quad (2)$$

The mean size was estimated from the mean TS and length/weight relationship. This was multiplied by the numerical density to give the estimated standing stock within the beam volume of each respective cell. Area density was estimated from the volume density by multiplying by the sampling effort (proportion of layer sampled) and the EDSU Area density estimated by summing the Layer Area densities.

Whereas the Length/Weight relationships used in analysis was the same as that used for the previous surveys under Implementation of a fisheries management plan (IFMP) project, the TS/Size relationship was that determined by Kayanda et al. (2012) (equations 3 and 4) . They are:

$$TL=10((TS+84.14)/30.15) \quad (3)$$

and

$$Total\ weight = 0.0042 \times TL3.26 \quad (4)$$

1.5.6 Integration analysis

Estimation of the standing stock of dagaa, the benthic crustacean *Caridina nilotica,* and the other species (haplochromines and others) were done by using echo integration.

Dagaa

Integration was undertaken in the layer from top line to the 'dagaa line' in the 120 KHz SQ1 telegram echogram and exported by regions (transects) and by cells (EDSUs) and marked "Integration dagaa". The exported volume scatter (Sv) values were converted to Area Backscattering Coefficient (ABC) using equation 5:

$$ABC = 10^{(sv/10)} \quad \textbf{(5)}$$

The ABC values from dagaa were summed up for each EDSU.
The ABC values due to Nile perch in the dagaa layer were estimated from Sv values obtained by exporting the numerical density of Nile perch in the layer top line to dagaa line in the 120 KHz split beam method 2 echogram. The Nile perch Sv values were estimated from the single target detections included in the integration range (from top line to dagaa line) according to a model developed from the previous survey (equation 6) through observations of several slow speed transects.

$$Sv\ Nile\ perch = TS\ mean + 10\ log\ N\ Targets - 10\ log\ Beam\ Vol - 2.3 \quad (6)$$

Where TS = Target strength, N = No of Targets, Beam vol = Beam volume and 2.3 is an observed difference between corrected and uncorrected values for single targets detected during Slow Speed transects (February 2006, acoustic survey report).
The ABC for Nile perch were estimated from Sv values determined above from the following equation 7:-

$$BC\ Nile\ perch = 10^{((Sv\ Nile\ perch)/10)} \quad (7)$$

The ABC values due to *dagaa* alone denoted ABC_{dagaa} were obtained by subtracting ABC due to Nile perch in the dagaa range ($ABC_{Nileperchdagaarange}$) from the total ABC in the dagaa range (ABC dagaarange) according to equation 8:

$$ABCdagaa = ABC_{dagaarange} - ABC_{Nileperchdagaarange} \quad (8)$$

The ABC values for *dagaa* alone were converted into numerical densities and consequently into biomass using the TS/length relationship (equation 9) determined by Getabu et al., 2003. TS = 20 log TL – 72.2, and TS per kilogram of -29.4dB. (9)

Caridina nilotica

Caridina that were noted to occupy the bottom layers of the water column were estimated by the difference in the volume scattering coefficient (Sv) between 70 and 120 kHz SQ1 telegram echograms. Integration was done between dagaa line and checked bottom in the 70 and 120 kHz echograms and exported by region and by cell. The exported Sv values of 120 kHz transducer were subtracted from the 70 kHz by EDSU and layer and whenever the Sv differences were between -5 and -10 dB, the Sv values from 120 kHz in those layers were accepted as Sv values due to *Caridina*. The protocol and logical equations used to estimate *Caridina* density are the same as those in the Feb 2008 acoustic survey report.
The selected Sv values due to *Caridina* were converted to density using TS per kg of -38.77 dB (TS for Krill – acoustically similar to *Caridina*) according to equation 10:

$$Caridina\ \text{density} = 1000^{((Sv - TS)/10)} \quad \mathbf{(10)}$$

Haplochromines and others

In the case of haplochromines and other unidentified species, after taking out cells attributed to *Caridina,* the Sv values from the remaining cells were converted into ABC and summed up for each EDSU. Nile perch equivalents from the integration range (dagaa line to checked bottom) were estimated from single targets and converted to ABC due to Nile perch in a

similar way to those in the dagaa range demonstrated above. Consequently, estimation of the standing stock of haplochromines and others was made by, subtracting the area backscattering ABC of Nile perch (ABC Nile-perch-other-taxa-range) from the total layer values (Integration other taxa - ABC other-taxa-range) according to equation 11:

$$ABC_{Other\text{-}taxa} = ABC_{other\text{-}taxa\text{-}range} - ABC_{Nile\text{-}perch\text{-}other\text{-}taxa\text{-}range} \quad (11)$$

The ABC values for haplochromines and other taxa were then converted to Sv and finally to numerical density using the TS per kg of -25.17 dB according to equation 12:-

$$\text{Haplochromines and other taxa density} = 1000 * 10^{((Sv - TS)/10)} \quad (12)$$

1.5.7 Estimation of Standing Stock

The mean transect density for each taxon for each EDSU was calculated as the mean of all EDSUs within the respective transect. The mean density of all EDSUs, within a stratum and their 95% Confidence interval (CI) calculated in through bootstrapping in the R statistical package, version 4.2.2 (R Development Core Team, 2022). Under the bootstrapping method, resampling is done n times, where n is the number of ESDUs in the zone in question, and the mean and confidence limits are determined from 5000 times repeat. Unlike in the previous surveys, ESDU values are weighted by ESDU length to enable all ESDUs to be used, and to prevent ESDUs of 0.9 km length being given equal weight in the bootstrap as 1 km ESDUs (LVFO, 2018). The biomass of each taxon for each stratum was determined by multiplication of the mean densities and stratum area. The stratum areas are given in Table 1.

Table 1. Area of Lake Surface (km^2) within each stratum

Quadrant	Deep	Coastal	Inshore	Special localities
South East	6,166	5,786	2,003	2,909 (Speke Gulf)
South West	6,251	6,601	3,181	2,022 (Emin Pasha)
North West	6,226	4,865	3,115	2,494 (Sesse Islands)
North East	4,724	3,786	5,729	1,335 (Nyanza Gulf)
TOTAL	23,367	21,038	14,028	8,760

Estimation of Standing Stock by country and by stratum

Stock of the three major taxa (Nile perch, *dagaa*, Haplochromine and others) were estimated by country and by strata. Any transect that crosses territorial boundaries was divided into two and marked “a” and “b”. In respect to estimating biomass by strata and country, each part of the divided transect was analyzed in the stratum of the country where it occurred. In addition, the boundary way of 17 points between Kenya and Uganda were plotted in NE quadrant and the areas occupied by the coastal and inshore strata in Kenya and Uganda were re-calculated from the map grid squares (Table 2). The rest of the strata were analyzed by country and by quadrant.

Table 2. Strata areas (Sq. Km) by quadrant and by country

Quadrant	Deep	Coastal	Inshore	Gulfs/Inlets
SE	6166 (TZ)	5786 (Tz)	2003 (TZ)	2,909 (SG)
SW	6251 (TZ)	6601 (TZ)	3181 (TZ)	2,022 (EP)
NW	6226 (Ug)	4865 (Ug)	3115 (Ug)	2,494 (SI)
NE	4,724 (Ug)	2,704 (Ug)	3,966 (Ug)	1,335 (NG)
		1,082 (Ke)	1,763 (Ke)	
TOTAL	23,367	21,038	14,028	8760

Tz = Tanzania, Ug = Uganda and Ke = Kenya

1.5.8 Estimation of annual biomass

Estimates of standing stock (instantaneous biomass) were converted into annual biomass by multiplying standing stock (B) by the production per unit of biomass (P/B=productivity=turnover rate). Under steady state conditions, P/B is approximately equal to the instantaneous rate of total annual mortality (Z) (Allen 1971). Estimates of P/B for Nile perch, dagaa, and haplochromines were derived from an Ecopath model of Lake Victoria (Natugonza et al., 2026). For Nile perch, we considered P/B of 2.21/year, which is the average turnover rate between juvenile and adult Nile perch. For haplochromines, we considered P/B of 2.35/year, which the average turnover rate between benthivorous, zooplanktivorous, and 'others' haplochromines groups. For Dagaa, we considered P/B of 3.93/year, while for Caridina, we considered P/B of 11.47/year.

1.6 Biological and environmental data acquisition

1.6.1 Biological Data

Bottom net hauls and pelagic trawls were used to collect biological samples and estimate catch rates from surveyed areas. Majority of the net hauls were done in coastal and inshore waters. In total, 25 bottom trawls and 4 pelagic trawls were completed using the RV Lake Victoria Explorer stern trawler with propulsion power of 215 hp and length of 17 m, trawl head rope of 24.4 m and vertical opening of 3.5 m, and cod-end fitted with inner netting of 4 mm stretch mesh size to ensure retention of small fish and *C. niloticus*. The duration of each haul was generally 30 minutes and the towing speed was 2.9-3.2 knots. Start and end times, water depths and warp length were recorded.

Like other previous surveys, fish caches were all sorted into taxa at species level, except for the haplochromines, and individual weight and length recorded together with biometric data (LVFO. 2005; 2007); where possible, every fish in the catch was individually measured. For large catches, Nile perch above 30 cm TL were individually recorded and smaller fish were sub sampled. The catch was mixed thoroughly and a subsample was taken for recording lengths and weights. The results were raised by the proportion by weight of the total catch (after the large fish were removed) against the sub sample taken from it. Specimens of Nile perch and other large species such as, the Nile tilapia were dissected for sex/maturity and

dietary analysis. Then, for fish stomach analyses the Point method was used to determine the contribution of each prey item to the diet according to the SOPs (LVFO 2007).

1.7 Environmental data

Location of the sampling points (CTD stations) for measurements of water physical and chemical attributes followed the provisions in the Standard Operating Procedures (SOPs) for Lake Victoria Hydro Acoustics Surveys (LVFO, 2018). The fifty-three (53) points were purposively and subjectively selected by stratified sampling strategy to ensure even distribution and representation of all the strata, quadrants, special regions, and countries, while logically coinciding with the trawl sampling points. Hence, the sites occurred systematically and intermittently between acoustics cruise transects covering the entire lake and followed closely, the CTD stations for the previous surveys, with minor logistical deviations occasioned following local prevailing conditions like the weather and time of day. Figure 2 shows the spatial positions of the CTD stations. More detailed descriptions of the CTD stations are presented in Annex II.

Measurement of water environmental attributes followed published standard methods for aquatic environmental studies (APHA, 2005). A depth-profiling system; a submersible was used to log the vertical profile data of the water physical and chemical parameters. Calibration of the probe was performed ahead of the survey by running analytical tests on sample waters for pH, DO and turbidity and comparing with sensor logged values. Corrective calibration was then done accordingly. Calibration for temperature measurements was done by comparing with readings of different thermometric instruments of same samples of water and mean deviation of temperature values noted for onward correction of field measured data. Periodically the instrument was serviced by clearing off clogging debris from the conduits and pump orifices to prevent instrument malfunction.

Water transparency was determined as Secchi depth using a standard Secchi disc and measured following standard procedures.

Locations of CTD stations (GPS Coordinates) were logged on to a smart phone application-based GPS system, Maps. MAPS.ME and collated with those displayed on the RV Explorer on board GPS and the echo-sounder system.

The habitat characteristics and weather conditions at the CTD stations were noted in detailed descriptive statement and referred to for data analysis and interpretation.

All data was compiled in comprehensive electronic datasheets, the main summaries, and statistical computing done using the R programming language (R Core Team, 2022) while GIS mapping and spatial visualization was done on QGIS. The GIS base maps were obtained from Hamilton (2016).

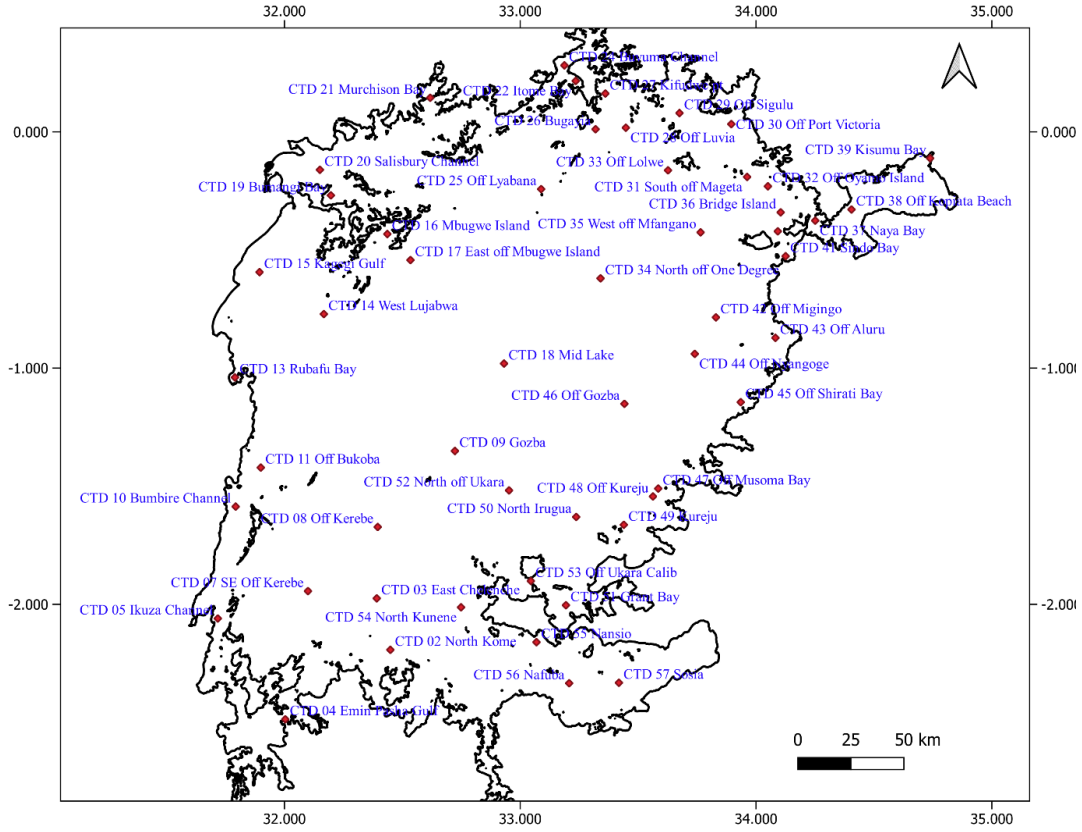

Figure 2. Map of Lake Victoria showing the CTD stations, November-December 2022

RESULTS AND DISCUSSION

1.8 Nile perch

1.8.1 Standing stock of Nile perch

Table 3 displays the estimated standing stock of Nile perch that were more than 10 cm TL. The instantaneous lake-wide mean biomass was 333,341 t, suggesting that the annual biomass for 2022 was 736,683 t. The estimated biomass of the Nile perch in 2022 was 33.72% lower than that recorded in 2021. At country level, biomass was lower by 47.3% and 19.04% in Tanzania and Kenya, respectively, but higher by 4.56% in Uganda. Overall, Tanzanian side of the lake had 48.57% of the Nile perch biomass, while Uganda and Kenya had 47.33% and 4.10%, respectively. Unlike previous surveys, Nile perch densities appeared to be near uniform throughout the lake (Figure 3).

1.8.2 Temporal trends of Nile perch biomass

Historical data collected since 2007 reveals no consistent visual trend in biomass, except for the interannual fluctuations (CV = 18.1) in some years. The estimates of the annual fish biomass range from 674,867 in 2007 to 1,103,399 in 2021, with the lowest annual biomass occurring in 2007 and the highest annual biomass in 2021.

On the other hand, the estimates of instantaneous biomass provide a snapshot of the fish biomass at a specific time, and may fluctuate more than the annual biomass estimates (Figures 4 and 5). There also appears to be a general increasing trend in instantaneous biomass from 2007 to 2021, except for a decline in 2008. However, the estimates for the most recent year, 2022, suggest a decline in instantaneous biomass.

Overall, while there may be fluctuations in fish biomass estimates from year to year, the trend in the annual biomass estimates suggests an increase in fish biomass over time. However, the decline in the most recent year's instantaneous biomass estimate could indicate a need for further monitoring and management of the fish population.

Table 3. Estimates of density and biomass for Nile perch >10 cm TL in Lake Victoria, categorized by country and stratum during the November-December 2022 survey.

Region	**Area**	**2022**								
		Densities (t/km^2)			**Standing stock (tonnes)**			**Annual Biomass (tonnes)**		
		Tanzania								
		Mean	Low	Upper	Mean	Low	Upper	Mean	Low	Upper
TzSECoastal	5786	6.19	5.32	7.14	35790.91	30768.30	41340.35	79097.90	67997.95	91362.17
TzSEDeep	6166	6.31	5.78	6.87	38908.57	35647.15	42339.44	85987.95	78780.20	93570.17
TzSEInshore	2003	5.62	4.44	7.03	11259.60	8902.27	14086.28	24883.71	19674.03	31130.68
TzSESpekeGulf	2909	2.55	2.24	2.89	7412.07	6528.71	8412.50	16380.67	14428.45	18591.63
TzSWCoastal	6601	4.37	3.94	4.84	28846.21	25987.00	31955.21	63750.12	57431.27	70621.01
TzSWDeep	6251	3.68	3.26	4.12	23025.93	20383.12	25774.22	50887.30	45046.69	56961.02
TzSWEminPasha	2022	1.60	1.08	2.22	3235.18	2174.40	4488.17	7149.74	4805.42	9918.86
TzSWInshore	3181	4.23	3.69	4.81	13439.78	11729.53	15293.88	29701.91	25922.27	33799.48
Subtotal					**161,918.24**	**142,120.49**	**183,690.05**	**357,839.31**	**314,086.28**	**405,955.01**
		Uganda								
UgNECoastal	2704	8.54	7.67	9.42	23100.87	20743.73	25475.77	51052.92	45843.65	56301.46
UgNEDeep	4724	8.05	7.21	8.91	38035.16	34079.31	42100.63	84057.69	75315.28	93042.39
UgNEInshore	3966	7.68	6.48	9.00	30467.04	25696.67	35682.03	67332.16	56789.64	78857.29
UgNWCoastal	4865	3.52	2.86	4.27	17146.76	13933.84	20777.44	37894.33	30793.78	45918.13
UgNWDeep	6226	2.81	2.39	3.26	17480.60	14900.27	20307.62	38632.12	32929.60	44879.84
UgNWInshore	3966	5.87	5.27	6.51	18292.49	16415.11	20280.46	40426.41	36277.40	44819.81
UgNWSesse	2494	5.31	4.44	6.31	13248.94	11085.55	15729.77	29280.15	24499.07	34762.79
Subtotal					**157,771.85**	**136,854.49**	**180,353.71**	**348,675.78**	**302,448.42**	**398,581.71**
		Kenya								
KeNECoastal	1082	9.14	8.01	10.28	9889.08	8670.56	11121.74	21854.87	19161.94	24579.04
KeNEInshore	1763	1.67	0.72	2.82	2935.71	1269.54	4966.10	6487.92	2805.67	10975.07
KeNENyanzaGulf	1335	0.62	0.43	0.83	825.82	573.82	1108.41	1825.06	1268.14	2449.59
Subtotal					**13,650.61**	**10,513.91**	**17,196.25**	**30,167.85**	**23,235.75**	**38,003.71**
Total					**333,340.70**	**289,488.89**	**381,240.01**	**736,682.95**	**639,770.45**	**842,540.42**

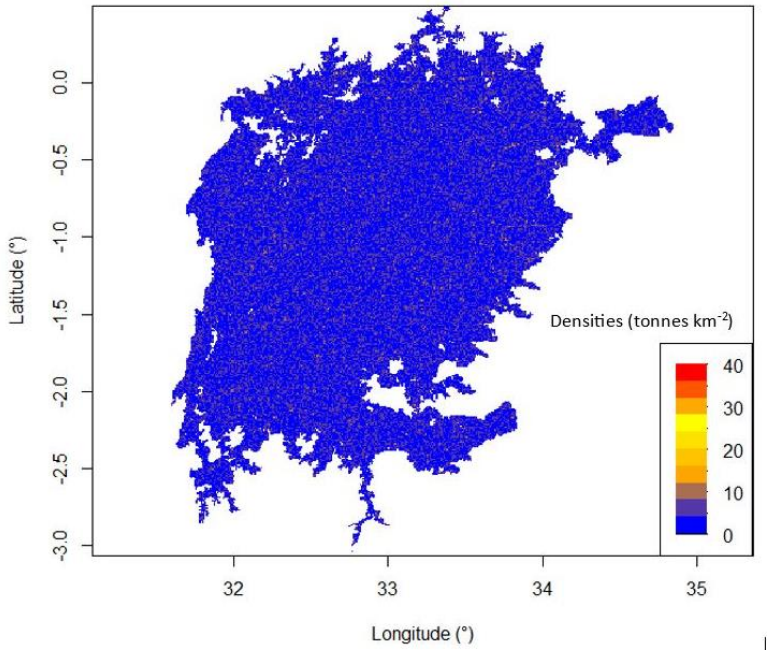

Figure 3. Spatial distribution of Nile perch in Lake Victoria during the 2022 November-December hydro-acoustic survey. (The heat map is derived from kriging interpolation of fish densities observed in individual EDSUs on the cruise track).

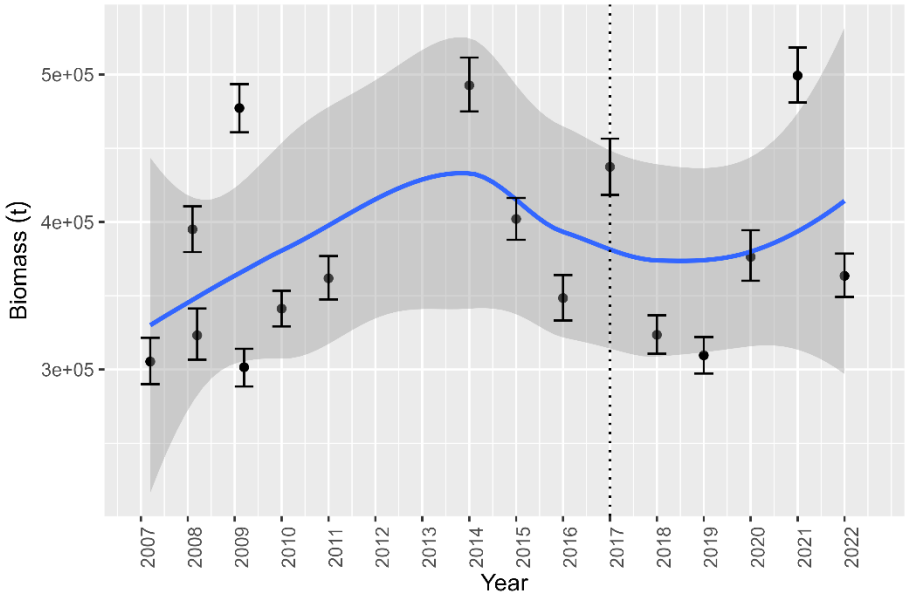

Figure 4. Changes in Nile perch biomass in Lake Victoria over time, spanning from 2007 to 2022.

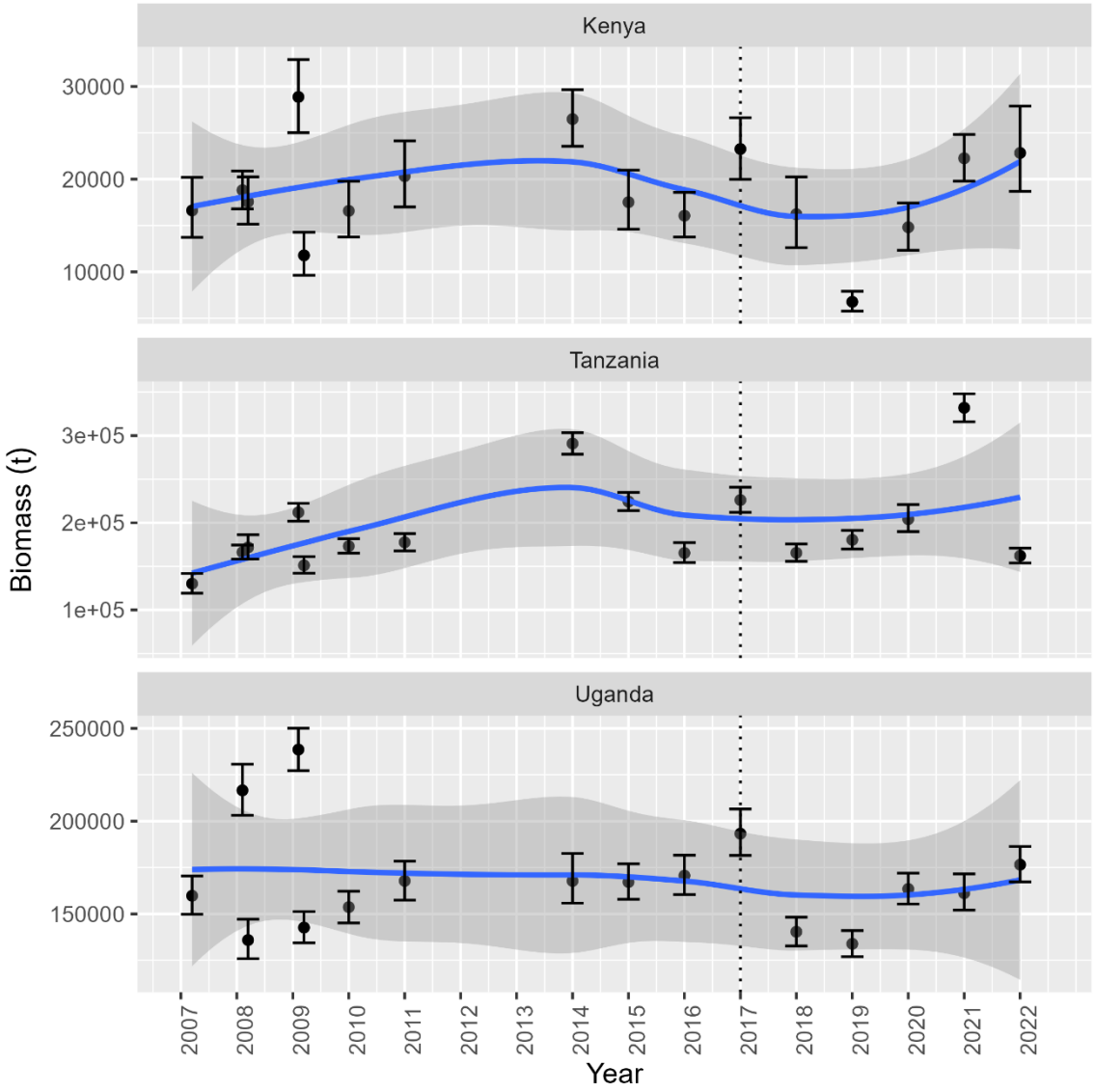

Figure 5. Temporal patterns of Nile perch biomass in the three countries bordering Lake Victoria from 2007 to 2022.

1.8.3 Size structure of Nile perch

The size distribution of Nile perch was primarily composed of classes under 50cm TL, accounting for 99.9% (Figures 6 & 7). Generally, the modal length for Nile perch was observed about 20 cm with no notable spatial variation at the country level (Figure 7). Furthermore, Nile perch larger than 50 cm (the minimum cutoff length of the suggested slot size) contributed only 6.6% to the species' biomass (Figure 8).

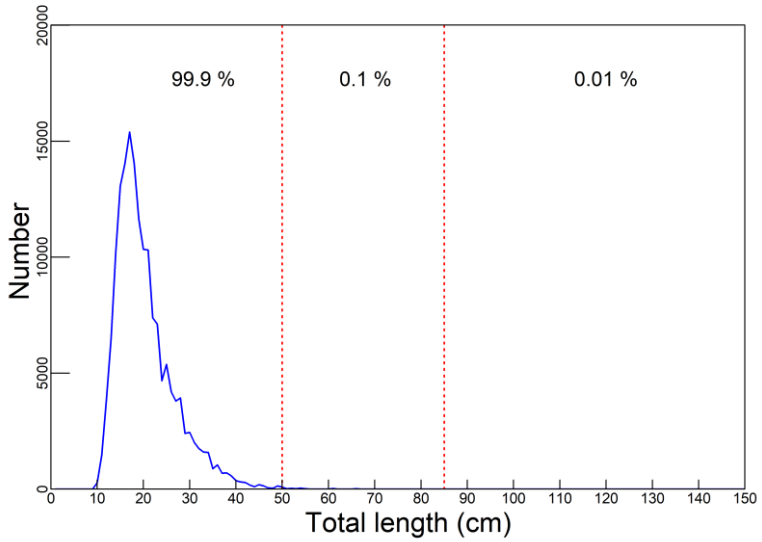

Figure 6. Biomass distribution of Nile perch in different size classes determined from acoustic single target detections during the November-December 2022 survey.

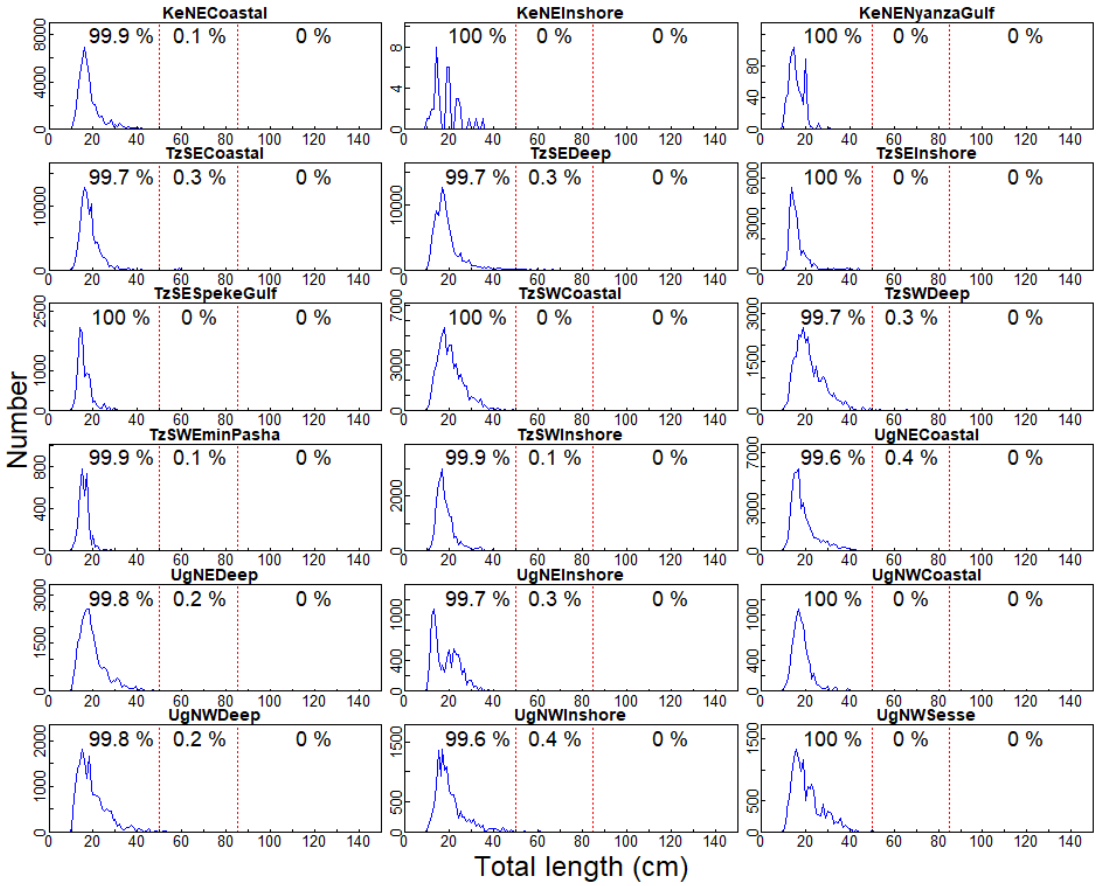

Figure 7. Length frequency distribution of Nile perch determined from acoustic single target detections in the various strata in Lake Victoria during the November-December 2022

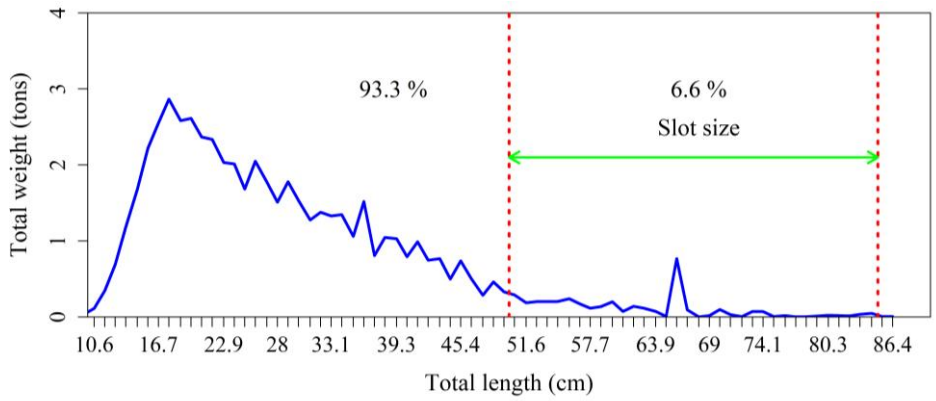

Figure 8. Contribution of individual size classes of Nile perch to the total biomass in Lake Victoria during the 2022 hydroacoustic survey.

1.9 Dagaa

1.9.1 Standing stock of *dagaa*

The estimated densities and biomass of *dagaa* in various lake regions are indicated in Table 4. The estimated average standing stock for the whole lake was 1,060,589 t, suggesting that the annual biomass for 2022 was 4,189,327 t. The standing stock represented 47.46% of the total fish biomass in the lake. In comparison to 2021, this biomass was 46.1% and 2.5% lower in the Kenyan and Tanzanian portions of the lake, respectively, but 64.38% higher in the Ugandan portion of the lake. The South-East coastal and inshore regions of Tanzania had the highest densities (>20 t km^2) followed by Uganda's North-East inshore regions with 26.51 t km^{-2} and Kenya's North-East coastal region with 21.57 t km^2. Comparatively, Emin Pasha Gulf and North-East Inshore region (in Kenya) had the lowest densities of 3.5 and 6.3 t km^2, respectively. The spatial distribution of *dagaa* was found to be more concentrated in the open waters of the lake, with a lower density in the coastal and inshore regions (Figure 9). This pattern suggests that the species may prefer the deeper, open water habitats, possibly due to factors such as availability of food sources or favorable environmental conditions

1.9.2 Temporal trends of *Dagaa* biomass

In general, the biomass of Lake Victoria experiences interannual fluctuations across its entirety. The biomass of *dagaa* remained relatively stable between 2007 and 2015, but has been on a consistent upward trend since 2016 (Figures 10 and 11). The increase in biomass may be attributed to the high turnover rates of the species or various environmental factors influencing their population.

Table 4. Density and biomass estimate of *dagaa* in Lake Victoria by country and stratum during the November-December 2022 survey

Region	Area	2022								
		Densities (t/km^2)			Standing stock (tonnes)			Annual Biomass (tonnes)		
		Tanzania								
		Mean	Low	Upper	Mean	Low	Upper	Mean	Low	Upper
TzSECoastal	5786	28.966	25.157	33.21	167602.7	145555.9	192167.6	662030.76	574945.83	759062.04
TzSEDeep	6166	15.4236	13.535	17.418	95100.79	83454.4	107397.1	375648.12	329644.87	424218.60
TzSEInshore	2003	21.479	17.381	25.975	43024.37	34814.96	52028.86	169946.25	137519.10	205514.01
TzSESpekeGulf	2909	13.220	11.329	15.229	38459.17	32956.57	44300.73	151913.72	130178.46	174987.90
TzSWCoastal	6601	14.7210	13.318	16.234	97178.41	87914.05	107158	383854.71	347260.48	423274.18
TzSWDeep	6251	5.3550	4.226	6.637	33476.72	26418.96	41490.4	132233.05	104354.87	163887.10
TzSWEminPasha	2022	3.5244	2.0383	5.366	7126.346	4121.58	10849.92	28149.07	16280.24	42857.20
TzSWInshore	3181	19.2491	16.008	22.809	61231.42	50920.85	72557.14	241864.09	201137.35	286600.70
Subtotal					**543,200**	**466,157**	**627,950**	**2145639.76**	**1841321.21**	**2480401.73**
		Uganda								
UgNECoastal	2704	25.829	22.826	28.96	69842.49	61722.1	78308.41	275877.82	243802.29	309318.20
UgNEDeep	4724	23.582	19.466	28.061	111399.6	91959.3	132559.6	440028.39	363239.22	523610.34
UgNEInshore	3966	26.510	21.916	31.443	105138.8	86920.31	124702.5	415298.39	343335.22	492574.84
UgNWCoastal	4865	9.323	7.504	11.346	45356.39	36504.88	55197.6	179157.75	144194.27	218030.52
UgNWDeep	6226	14.990	12.480	17.761	93387.23	77702.58	110578.6	368879.54	306925.21	436785.54
UgNWInshore	3966	9.564	8.125	11.125	29794.04	25308.58	34654	117686.44	99968.89	136883.32
UgNWSesse	2494	7.187	5.683	8.896	17923.79	14174.49	22186.28	70798.99	55989.25	87635.79
Subtotal					**472,842**	**394,292**	**558,187**	**1867727.32**	**1557454.34**	**2204838.54**
		Kenya								
KeNECoastal	1082	21.576	17.843	25.398	23345.43	19306.93	27480.47	92214.46	76262.38	108547.84
KeNEInshore	1763	6.301	4.341	8.403	11109.22	7653.298	14814.66	43881.41	30230.53	58517.90
KeNENyanzaGulf	1335	7.559	6.0126	9.263	10091.78	8026.772	12365.5	39862.51	31705.75	48843.74
Subtotal					**44,546**	**34,987**	**54,661**	**175958.38**	**138198.66**	**215909.48**
Total					**1,060,589**	**895,437**	**1,240,797**	**4189325.46**	**3536974.20**	**4901149.75**

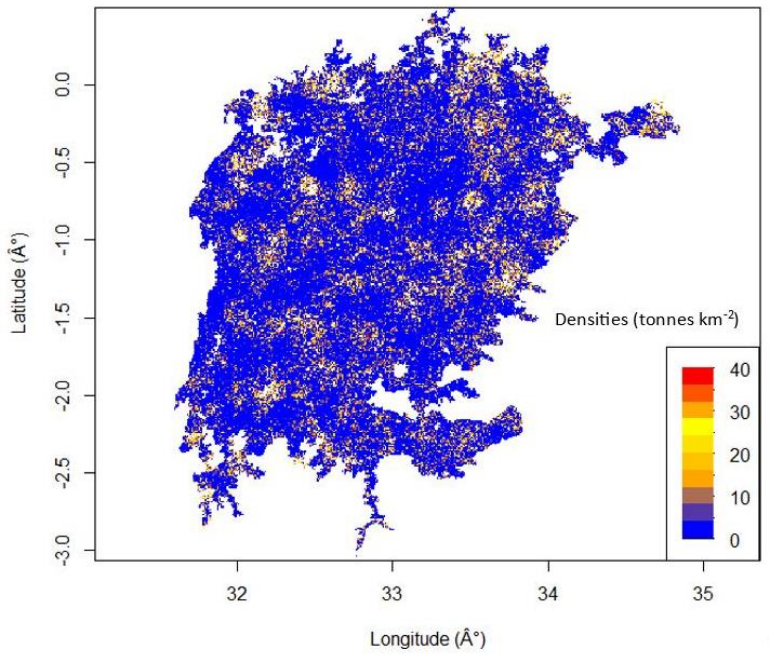

Figure 9. Spatial distribution of d*agaa* in Lake Victoria during the 2022 November-December hydro-acoustic survey.

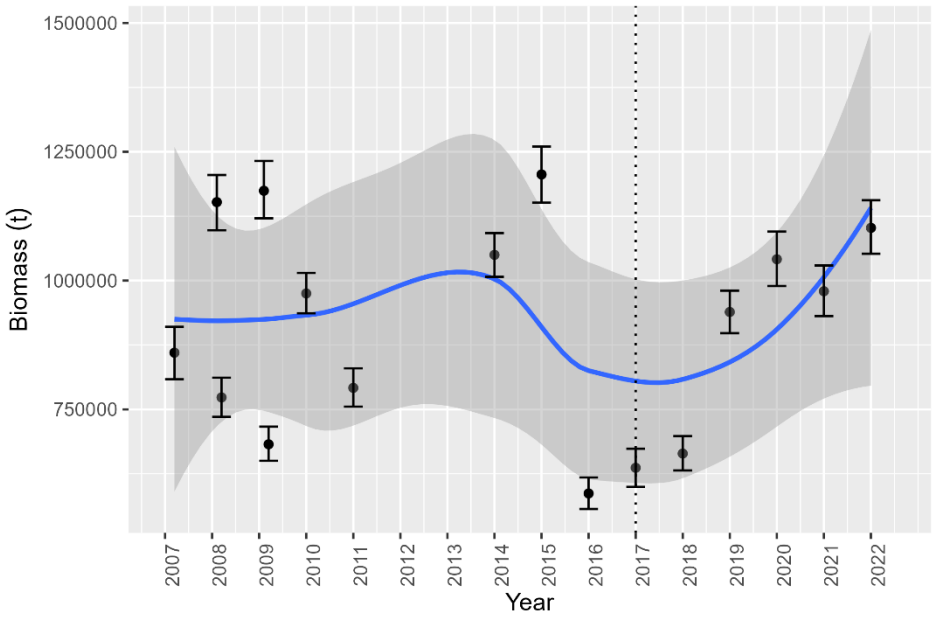

Figure 10. Time-series of *dagaa* biomass variations in Lake Victoria between 2007 and 2022.

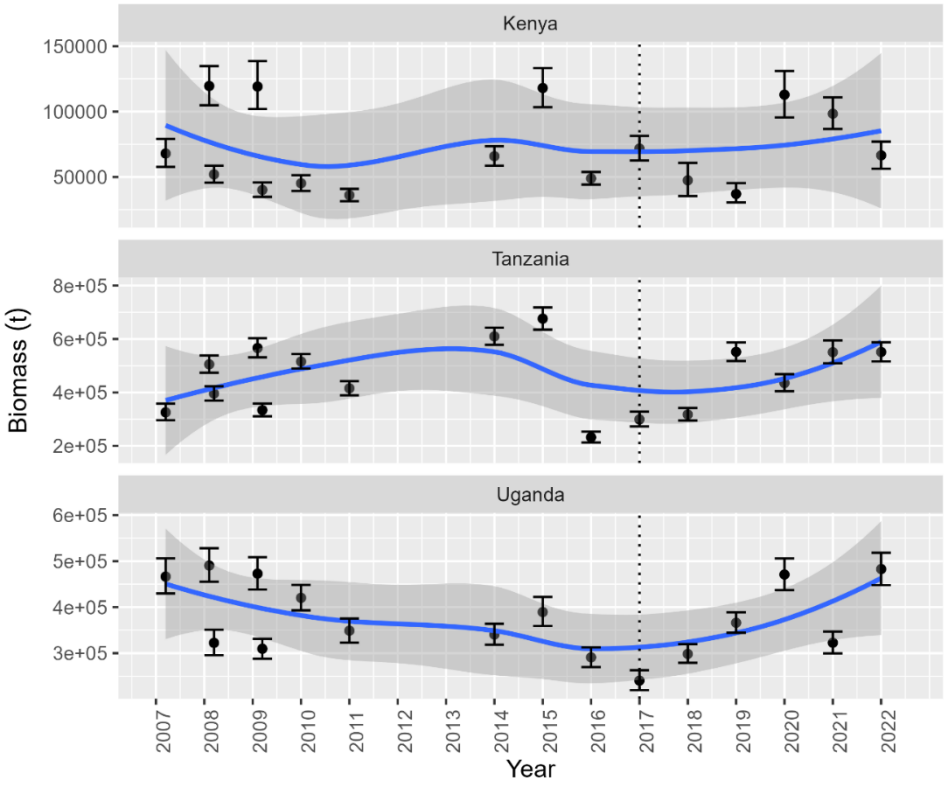

Figure 11. Temporal trends of *dagaa* biomass trends in three countries sharing Lake Victoria from 2007 to 2022.

1.10 Haplochromines and others

1.10.1 Standing stock of Haplochromines and others

Table 5 shows the estimated densities and biomass of haplochromines and other species in different regions of the lake. The estimated average standing stock for the whole lake was 331,709 t, suggesting that the annual biomass for 2022 was 779,516.2 t. In comparison to 2021, this biomass was 53.68%, 33.43%, and 31.05% lower in Tanzania, Kenya, and Uganda, respectively. Spatially, the North-East Coastal region of Kenya and the North-East inshore region of Uganda exhibited the highest levels of haplochromines concentrations, while the South-West deep and Emin Pasha in Tanzania recorded the lowest densities.

Table 5. Estimated standing stock and biomass of Haplochromine cichlids and other unidentified fish species in Lake Victoria by country and by strata during the November-December 2022 surveys.

Region	**Area**	**2022**								
		Densities (t/km2)			**Standing stock (tonnes)**			**Annual biomass (tonnes)**		
		Tanzania								
		Mean	Low	Upper	Mean	Low	Upper	Mean	Low	Upper
TzSECoastal	5786	6.276	5.489	7.176	36310.99	31761.45	41517.99	85330.82	74639.411	97567.27
TzSEDeep	6166	5.656	4.607	6.928	34877.38	28407.14	42720.02	81961.85	66756.784	100392.1
TzSEInshore	2003	5.515	4.384	6.853	11047.39	8781.418	13724.79	25961.37	20636.332	32253.25
TzSESpekeGulf	2909	4.744	4.368	5.132	13801.45	12711.83	14927.67	32433.4	29872.803	35080.03
TzSWCoastal	6601	4.264	3.863	4.703	28150.98	25497.24	31043.83	66154.79	59918.525	72953.01
TzSWDeep	6251	2.584	2.301	2.881	16154.26	14381.33	18006.99	37962.51	33796.132	42316.44
TzSWEminPasha	2022	3.183	2.687	3.778	6437.15	5434.895	7638.601	15127.3	12772.0	17950.71
TzSWInshore	3181	6.336	5.504	7.269	20154.06	17507.6	23124.47	47362.05	41142.85	54342.5
Subtotal					**166,934**	**144,483**	**192,704**	**392,294**	**339,535**	**452,855**
		Uganda								
UgNECoastal	2704	5.476	5.006	5.979	14807.84	13536.34	16168.44	34798.43	31810.4095	37995.84
UgNEDeep	4724	3.385	2.994	3.843	15989.97	14142.48	18155.21	37576.42	33234.8259	42664.75
UgNEInshore	3966	7.366	6.262	8.564	29212.36	24836.82	33965.8	68649.04	58366.52612	79819.63
UgNWCoastal	4865	2.847	2.408	3.323	13849.42	11714.88	16168.65	32546.14	27529.97088	37996.33
UgNWDeep	6226	4.061	3.527	4.617	25284.81	21961	28748.15	59419.31	51608.33847	67558.16
UgNWInshore	3966	5.826	5.208	6.462	18148.07	16223.77	20127.96	42647.96	38125.85032	47300.71
UgNWSesse	2494	6.970	5.827	8.237	17382.74	14534.36	20543.96	40849.43	34155.73453	48278.3
Subtotal					**134,675**	**116,950**	**153,878**	**316,487**	**274,832**	**361,614**
		Kenya								
KeNECoastal	1082	10.042	8.868	11.336	10865.58	9595.319	12265.94	25534.1	22548.99892	28824.95
KeNEInshore	1763	7.042	4.161	11.353	12415.38	7335.06	20014.69	29176.14	17237.39114	47034.52
KeNENyanzaGulf	1335	5.108	4.411	5.815	6818.955	5888.598	7762.705	16024.54	13838.20508	18242.36
Subtotal					**30,100**	**22,819**	**40,043**	70734.79	53624.59515	94101.83
Total					**331,709**	**284,252**	**386,626**	**779,516**	**667,991**	**908,571**

1.10.2 Temporal trends and distribution of Haplochromines and others biomass

The biomass of haplochromines was highest in the open and coastal water similar to dagaa at a lake-wide basis (Figure 12). Haplochromines and others exhibited a slight, albeit insignificant, increase in biomass across the entire lake over time (Figure 13 and 14). In 2007, the biomass of this group was 416,561 t which increased to 532,628 t in 2014. However, biomass began to decline in 2017, hitting its lowest point of 374,133 tonnes in 2019, before gradually recovering in subsequent years. Notably, the 2022 biomass indicated a decrease in biomass of 331,709 t, which was 44.8% lower than the previous year. The Haplochromines and Others group plays a critical ecological role as the primary food source for Nile perch, which, in turn, drives the development of other fish species (Nyamweya et al., 2016). Despite their ecological importance, fishermen are increasingly targeting Haplochromines, as evidenced by their rising contribution to fish landings (LVFO, 2022). To ensure the sustainable development of economically significant Nile perch, fishing for Haplochromines should be prohibited, as recommended by Nyamweya et al. (2017), who demonstrated that such an approach would yield optimal ecological and socioeconomic benefits.

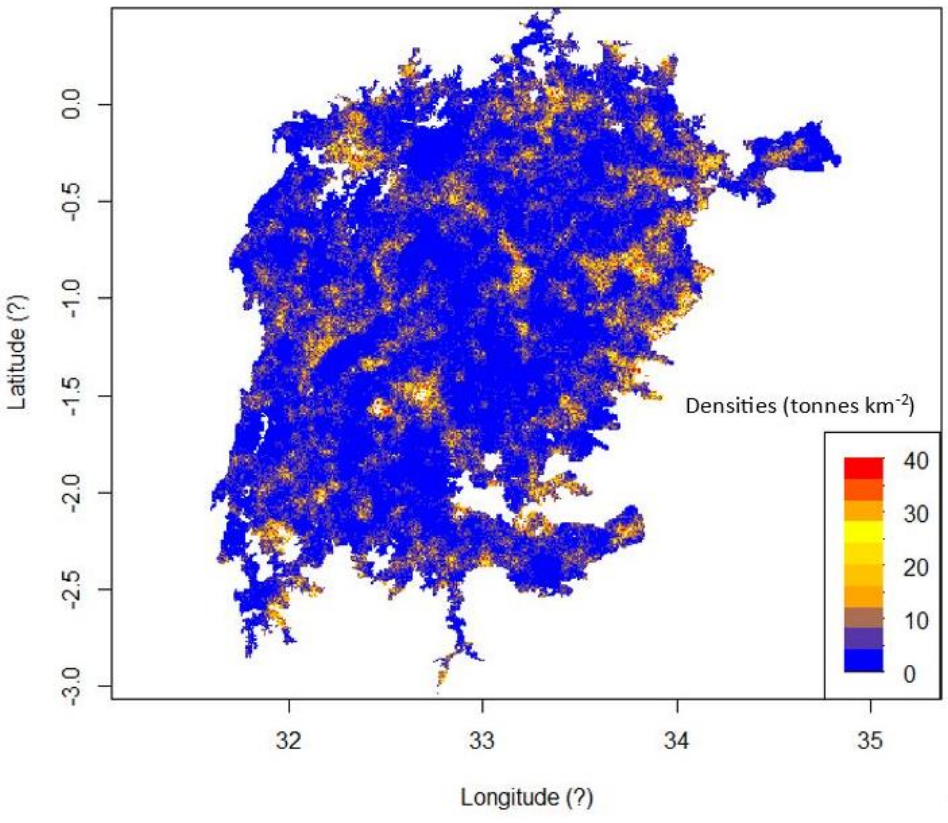

Figure 12. Spatial distribution of haplochromines and other fish in Lake Victoria during the 2022 November-December hydro-acoustic survey.

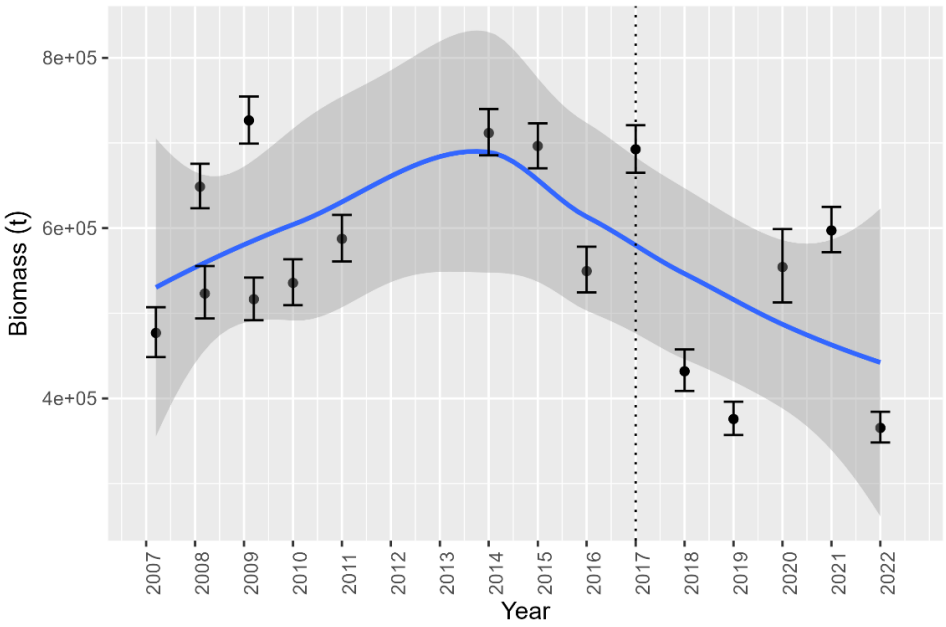

Figure 13. Temporal trends of Haplochromines and other fish biomass trends in Lake Victoria

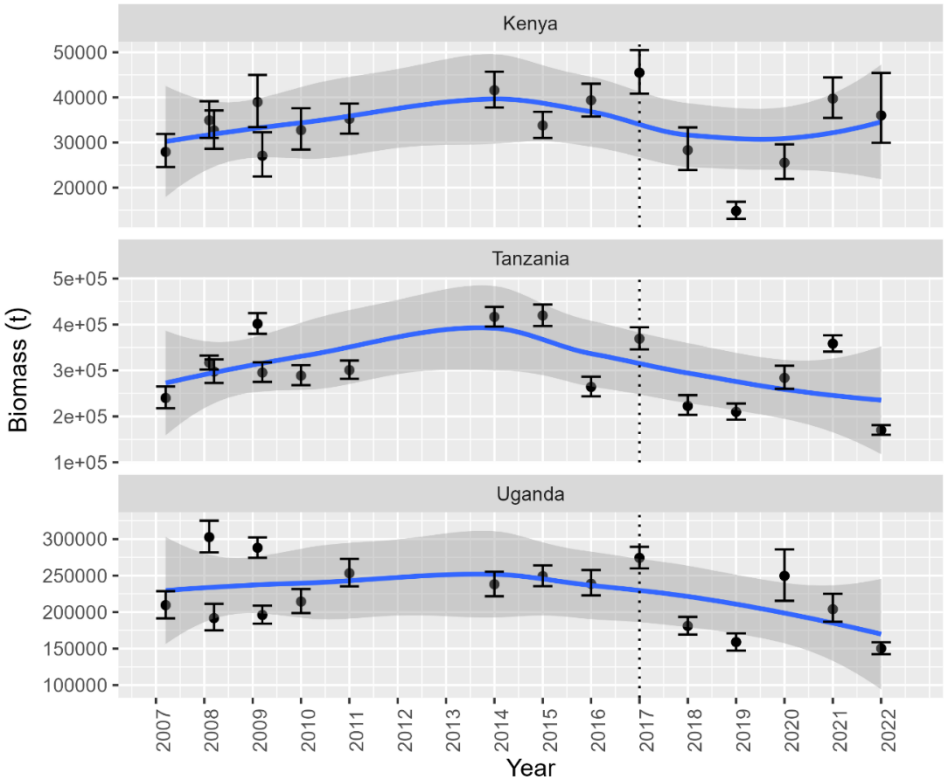

Figure 14. Temporal trends of Haplochromines and other fish biomass trends in three countries sharing Lake Victoria from 2007 to 2022

1.11 Caridina

1.11.1 Standing stock of *Caridina*

Table 6 presents a summary of the estimated densities and biomass of *Caridina* throughout various areas and depth strata of the lake. The data indicates that *Caridina* constituted about 22.78% of the lake's total biomass, with an average standing stock of 509,183 t, implying an annual biomass of 5,840,329 t for 2022. The standing stock in 2022 was 35.42% lower than the figure reported in 2021. This decrease in biomass was evident across all three countries surrounding the lake, with Tanzania, Uganda, and Kenya experiencing declines of 42.55%, 27.60%, and 20.00%, respectively. The highest densities were observed in the northeastern coastal regions of Uganda and Kenya. Nevertheless, *Caridina* densities were lower in all the Deep and most of the Coastal strata, and they generally did not exhibit a distinct spatial distribution pattern (Figure 15).

1.11.2 Temporal trends of *Caridina* biomass

From 2007 to 2014, the species' biomass experienced a consistent increase before stabilizing. The densities of *Caridina* in Tanzania and Uganda were similar, but markedly higher in Kenya. The minimum recorded biomass of 244,160 t occurred in 2010, while the maximum biomass of 922,424 t was registered in 2014 (Figures 16 and 17). As of 2022, the reported biomass stands at 509,183 t, which is 35.4% less than the 2021 figure of 788,426 t.

1.12 Relative proportion of biomass of fish groups

In the 2022 survey, the observed proportions of biomass for each species or group (*dagaa*, *Caridina*, Haplochromines, and Nile perch) reflect their relative abundance within the Lake Victoria ecosystem. The proportions suggest how much each group contributes to the total biomass in the lake. *Dagaa* accounted for the largest proportion (47%) of the biomass, indicating that they are the most abundant species within the lake during the survey. *Caridina* followed with 23% of the biomass, suggesting they are the second most abundant group. Haplochromines and Nile perch both made up 15% each, implying that they have comparable abundance within the lake. It is important to note that these proportions are a snapshot of the ecosystem at the time of the survey, and they may change over time due to various factors such as predation, environmental conditions, and human intervention.

Table 6. Density and biomass estimate of *Caridina nilotica* in Lake Victoria by country and stratum during the November-December 2022 survey.

Region	Area	2022								
		Densities (t/km2)			Standing stock (tonnes)			Anaul biomass (tonnes)		
		Tanzania								
		Mean	Low	Upper	Mean	Low	Upper	Mean	Low	Upper
TzSECoastal	5786	5.341	3.680	7.387	30903.32	21296.55	42742.85	354461	244271.4287	490260.5
TzSEDeep	6166	5.794	4.741	6.985	35730.91	29238.74	43070.37	409833.5	335368.3391	494017.2
TzSEInshore	2003	3.264	1.837	4.928	6539.069	3680.94	9871.18	75003.12	42220.38616	113222.4
TzSESpekeGulf	2909	1.572	0.767	2.553	4573.931	2232.566	7427.264	52462.98	25607.53754	85190.72
TzSWCoastal	6601	7.433	5.519	9.586	49065.89	36429.45	63280.31	562785.8	417845.7409	725825.1
TzSWDeep	6251	6.185	4.092	8.637	38660.97	25579.82	53996.01	443441.3	293400.5818	619334.3
TzSWEminPasha	2022	33.891	5.477	80.222	68526.5	11075.27	162209.9	785999	127033.2962	1860548
TzSWInshore	3181	6.255	2.663	12.076	19896.48	8472.509	38414.36	228212.6	97179.67487	440612.7
Subtotal					**253,897**	**138,006**	**421,012**	**2,912,199**	**1,582,927**	**4,829,011**
		Uganda								
UgNECoastal	2704	6.410	4.807	8.227	17332.98	12997	22247.81	198809.3	149075.5397	255182.4
UgNEDeep	4724	5.709	4.432	7.129	26970.18	20937.51	33681.68	309347.9	240153.232	386328.9
UgNEInshore	3966	16.621	10.104	24.453	65917.43	40075.47	96980.73	756072.9	459665.6694	1112369
UgNWCoastal	4865	3.342	1.494	6.235	16264.92	7268.512	30334.61	186558.6	83369.82906	347938
UgNWDeep	6226	4.236	3.187	5.461	26370.37	19847.14	33998.71	302468.2	227646.7161	389965.2
UgNWInshore	3966	12.745	8.823	17.485	39701.67	27484.5	54468.32	455378.1	315247.2646	624751.6
UgNWSesse	2494	6.364	4.187	8.91	15872.23	10443.76	22244.21	182054.5	119789.8841	255141.1
Subtotal					**208,430**	**139,054**	**293,956**	**2,390,690**	**1,594,948**	**3,371,676**
		Kenya								
KeNECoastal	1082	6.840994	4.549	10.285	7401.955	4922.526	11128.93	84900.42	56461.37156	127648.8
KeNEInshore	1763	0	0	0	0	0	0	0	0	0
KeNENyanzaGulf	1335	29.55351	15.448	45.906	39453.94	20623.26	61284.55	452536.7	236548.7399	702933.8
Subtotal					**46,856**	**25,546**	**72,413**	537437.1	293010.1114	830582.6
Total					**509,183**	**302,606**	**787,382**	**5,840,326**	**3,470,885**	**9,031,270**

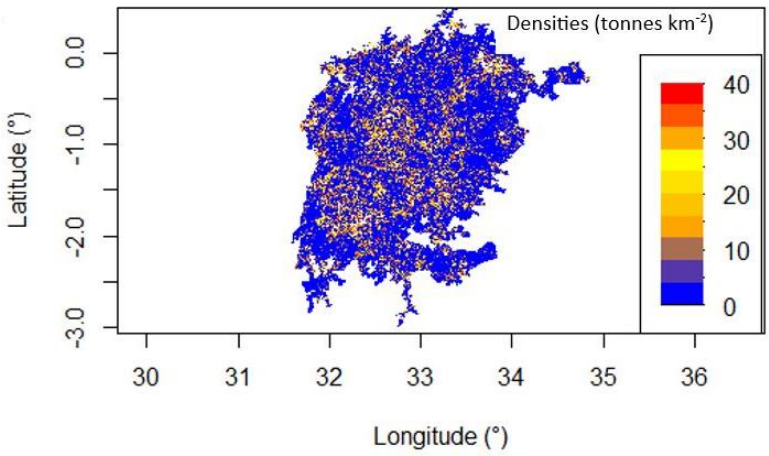

Figure 15. Spatial distribution of *Caridina nilotica* in Lake Victoria during the 2022 November-December hydro-acoustic survey.

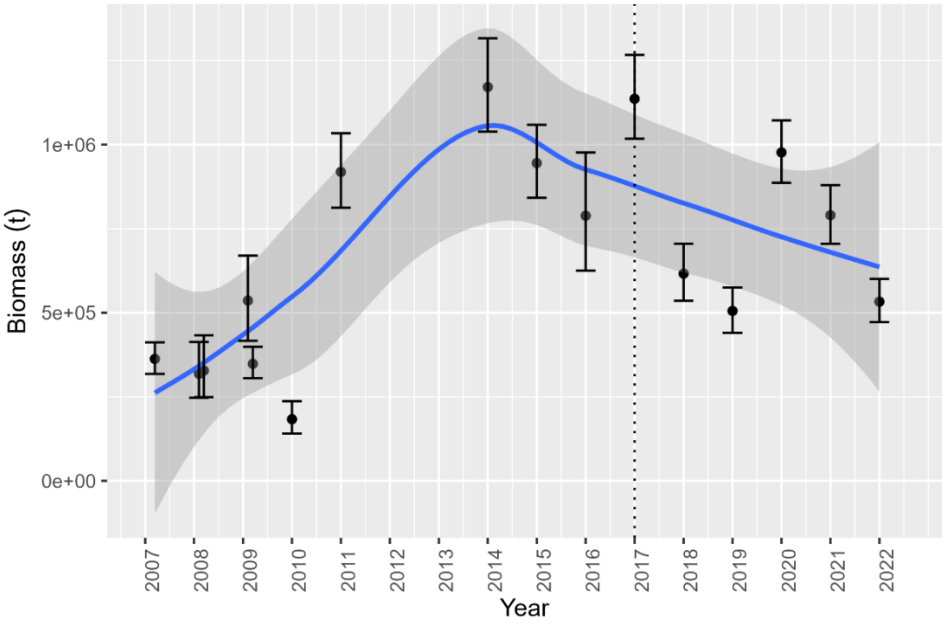

Figure 16. Temporal trends of *Caridina* biomass trends in Lake Victoria from 2007 to 2022

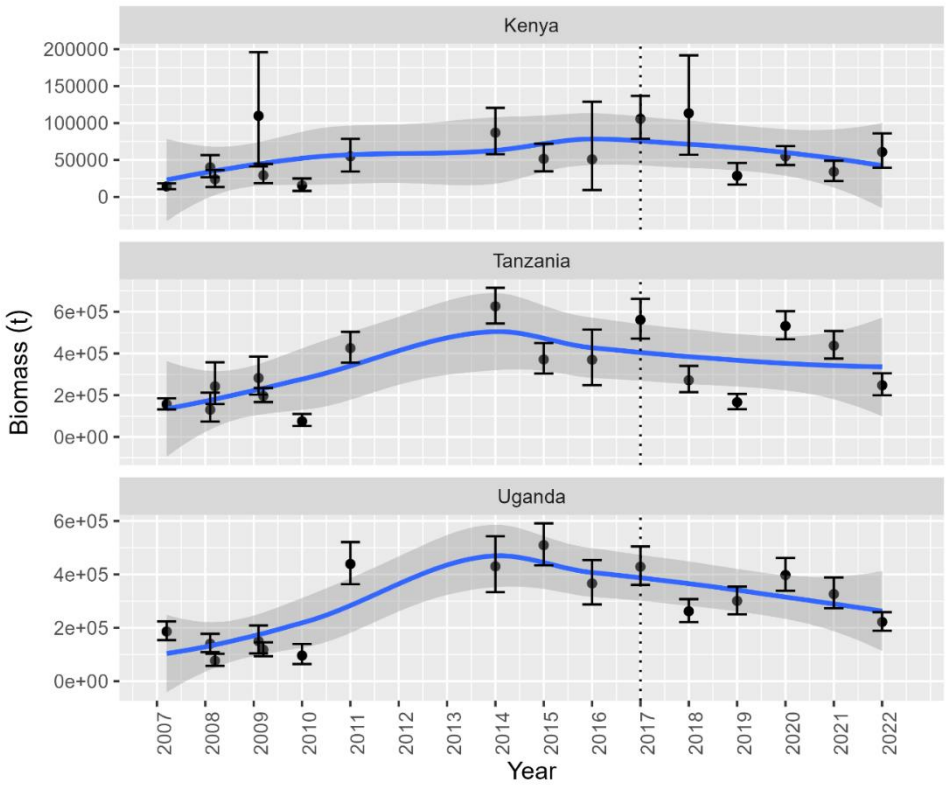

Figure 17. Temporal trends of *Caridina* biomass trends in three countries sharing Lake Victoria from 2007 to 2022

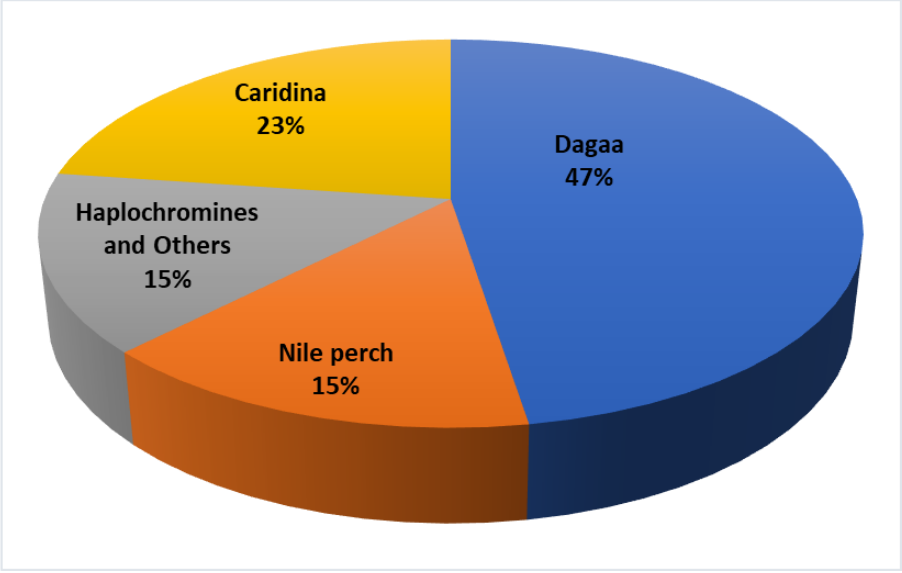

Figure 18. Proportion of biomass of fish groups estimated during the 2022.

1.13 Catch per Unit Effort (CPUE) from bottom trawl hauls

Table A1.2 presents the changes in catch per unit effort (CPUE) from 2015 to 2022, measured in kg/haul (Kg ± SE) for Nile perch, Haplochromines, dagaa, and other species. The data reveals

fluctuations in CPUE for each species over time, suggesting potential shifts in their abundance within the ecosystem.

For Nile perch, the CPUE varied throughout the observed period, peaking in September 2019 (116.36 ± 29.69 kg/haul) and reaching its lowest point in September 2016 (42.16 ± 6.72 kg/haul). In November 2022, the CPUE for Nile perch stood at 51.08 ± 23.62 kg/haul. Haplochromines' CPUE also exhibited fluctuations, with the highest value recorded in November 2015 (17.29 ± 5.25 kg/haul) and the lowest in September 2019 (2.43 ± 0.83 kg/haul). In November 2022, the CPUE for Haplochromines was 18.40 ± 9.99 kg/haul. The CPUE for dagaa demonstrated significant variations as well, with the highest value observed in September 2016 (4.77 ± 1.66 kg/haul) and the lowest in October 2020 (0.23 ± 0.11 kg/haul). In November 2022, the CPUE for dagaa was 4.54 ± 2.14 kg/haul. Other species' CPUE showed less pronounced fluctuations, with the highest value in September 2017 (7.58 ± 2.07 kg/haul) and the lowest in September 2016 (1.95 ± 0.62 kg/haul). In November 2022, the CPUE for other species was 4.92 ± 2.52 kg/haul.

These results show that the CPUE of each species has experienced variations over the years, which may be attributed to factors such as changes in population size, environmental conditions, fishing pressure, and predation.

1.14 Relationship between the relative abundance of key fish species, Caridina, and environmental factors

Figure 19 illustrates the relationship between the overall relative abundance of major fish species from acoustics and environmental parameters, while the same figure also displays the relationship between relative abundance and environmental parameters by region. Generally, the relative biomass for all fish groups positively correlates with dissolved oxygen and transparency, while it negatively correlates with temperature, chlorophyll a, and turbidity, which is expected. Spatially, relative biomass is differentiated by inshore and coastal areas, except for *Caridina*.

The correlation matrix in Figure 19 reveals that Nile perch exhibit a significant positive relationship with depth and dissolved oxygen (DO), while showing a significant negative relationship with conductivity, chlorophyll, and turbidity. Nile perch prefer deeper waters because these areas tend to have cooler temperatures and, consequently, higher levels of dissolved oxygen due to the well-established inverse relationship between temperature and dissolved oxygen levels. Furthermore, the abundance of Nile perch is affected by high levels of conductivity and chlorophyll, indicative of pollution, which can result in lower dissolved oxygen levels that are unsuitable for the species. High turbidity levels are also unfavorable for Nile perch, as they are active predators relying on visual cues to locate prey. Therefore, areas with high turbidity levels may hinder the Nile perch's ability to find prey, ultimately leading to a decrease in their abundance. Consequently, the positive correlation between Nile perch abundance and depth can be attributed to the favorable conditions found in deeper waters, while the negative relationships between Nile perch abundance and conductivity, chlorophyll, and turbidity reflect the adverse impact of environmental pollution on the species. Similar factors also influence the abundance of *dagaa*. The correlation matrix analysis

indicates a significant positive relationship between *dagaa* and dissolved oxygen and a significant negative relationship with temperature, conductivity, chlorophyll, and turbidity.

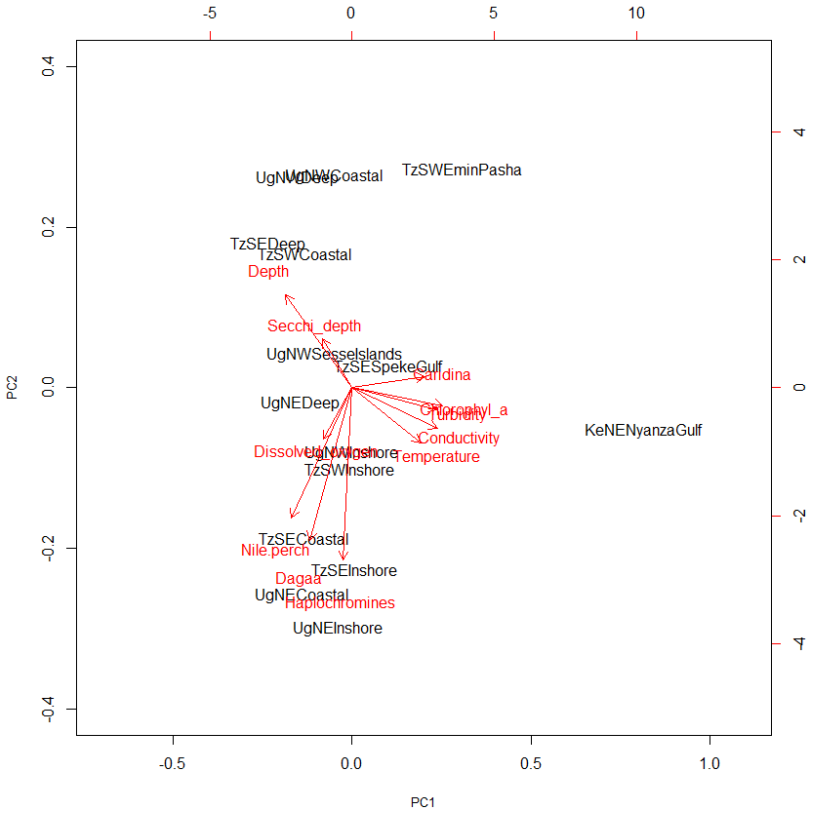

Figure 19. Principal component analysis (PCA) biplot of relative biomass and environmental parameters in the different regions. Abbreviations stand for: Ug (Uganda), Ke (Kenya), Tz (Tanzania), NE (North East), NW (North West), SW (South West) and SE (South East).

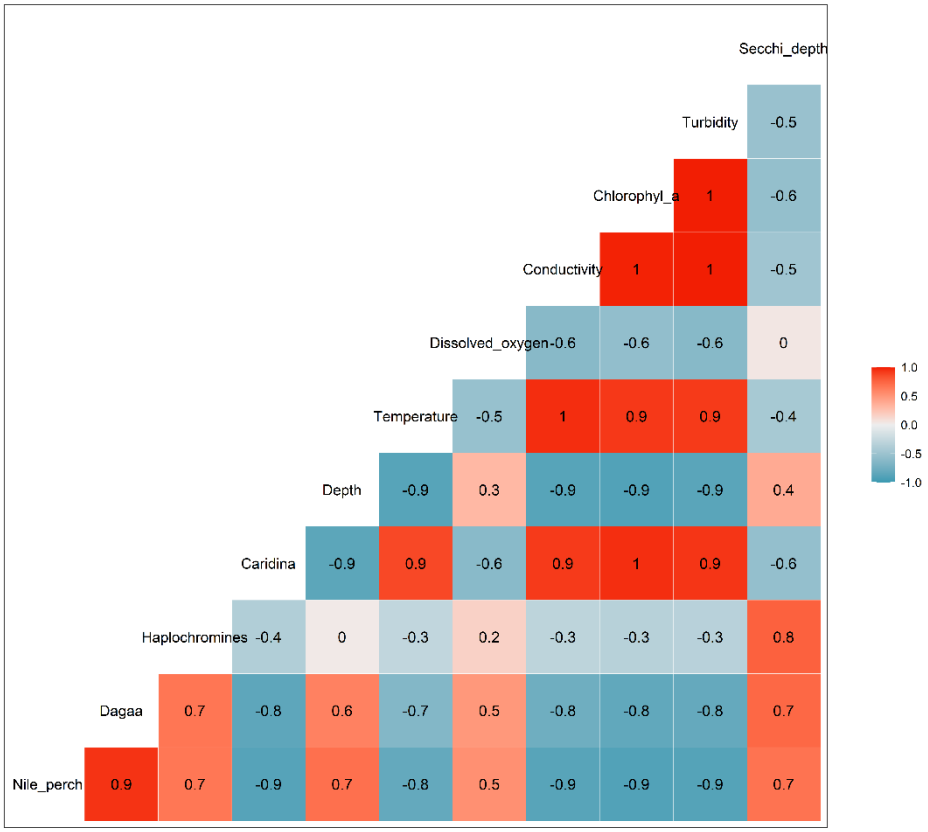

Figure 20. Relationship between relative biomass from acoustics and environmental parameters

CONCLUSIONS

The objective of this survey was to employ acoustic techniques to evaluate the standing stock of major commercial fish species (Nile perch, *dagaa*, haplochromines, and *Caridina*) in Lake Victoria. Results indicate that the stocks are generally stable, with interannual variability in biomass. However, exploitation could be unsustainable for Nile perch, particularly at specific spatial scales. For instance, considering the average annual catch of 250,000 t, the 2022 annual biomass suggests an exploitation rate of 30-35% for Nile perch, potentially exceeding the sustainable levels of 25-30%. Moreover, the current exploitation rate may be even higher in inshore and coastal areas. The size structure of Nile perch is dominated by individuals smaller than 50 cm, possibly due to focusing fishing efforts on larger sizes, particularly those above the upper slot size limit of 85 cm TL. In the case of *dagaa*, the 2022 annual biomass implies an exploitation rate of 21%, given the total landings of 900,000 t in 2021. This indicates that *dagaa* catch could be doubled without adversely impacting the stock, although spatial differences in exploitation rates may require further exploration. For haplochromines, the 2022 annual biomass suggests an exploitation rate of around 8%, based on the total catch of 60,000 tons in 2021. While this rate is relatively low, we recommend not increasing it beyond 10% due to the species' importance as prey for Nile perch, which supports a highly profitable fishery. Regarding the lake's limnological conditions, thermal stratification patterns were observed in the lake-wide CTD sampling sites, particularly in the northwestern and northeastern

sectors. Dissolved oxygen (DO) profiles were considerably lower than optimal for fish, which could explain the reduced biomass recorded in 2022 compared to 2021.

RECOMMENDATIONS

Based on the results of this hydro-acoustic survey and synthesis of relevant information, we make the following recommendations:

ix. Regularly assess and update information on allowable catch for each species to ensure sustainable exploitation. Allowable catch should take into account the annual biomass and exploitation rates, as well as spatial differences in stock abundance.

x. Investigate spatial differences in exploitation rates and allocate fishing effort accordingly to prevent overfishing in specific areas, such as inshore and coastal regions. This may include establishing protected zones or adjusting fishing effort based on local stock assessments.

xi. Strengthen enforcement of size limits, particularly for Nile perch, to prevent the overexploitation of larger individuals and maintain a healthy size structure within the population. Additionally, ensure that appropriate gear restrictions are in place to reduce bycatch and the capture of undersized fish.

xii. Efforts should be made to monitor and regulate pollution levels in Lake Victoria, as high levels of conductivity and chlorophyll negatively impact fish abundance. Implementing stricter pollution controls and promoting sustainable waste management practices can help improve water quality and support healthier fish populations.

xiii. Protecting and restoring critical habitats, such as inshore and coastal areas, can enhance fish populations by providing suitable breeding and feeding grounds. This may include regulating shoreline development and implementing habitat restoration projects.

xiv. Fisheries management should incorporate the observed relationships between fish abundance and environmental parameters, adjusting management strategies as necessary to accommodate changes in environmental conditions. This may include implementing seasonal closures, or modifying gear restrictions based on environmental factors.

xv. Pursue further research on the relationship between fish abundance and environmental variables, and conduct yearly hydro-acoustic investigations in conjunction with stock assessments.

xvi. Engage local communities, fishermen, and other stakeholders in the conservation and management of Lake Victoria's fisheries is crucial. Raising awareness about the importance of environmental parameters on fish abundance can help garner support for management actions and encourage responsible fishing practices.

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Appendix I: Echo-sounder calibration output

1st calibration (5th November 2022)		
Field	70 kHz	120kHz
FileFormatVersion	1.05	1.05
Copyright	Copyright(c) Kongsberg Maritime AS	Copyright(c) Kongsberg Maritime AS
TimeOfFileCreation	2022-11-05T16:42:45.5279716+03:00	2022-11-05T17:07:54.1740826+03:00
Transducer Name	ES70-7C	ES120-7C
Transducer SerialNumber	1	2
TransducerDepth	2	2
ChannelName	ES70-7C Serial No: 1	ES120-7C Serial No: 2
Type	TransceiverTypeGPT	TransceiverTypeGPT
SoftwareVersion	50112	50112
Impedance	1000	1000
Application Name	EK80	EK80
SoftwareVersion	1.12.2.0	1.12.2.0
Frequency	70000	120000
Gain	27	25.25
BeamWidthAlongship	6.73	6.77
BeamWidthAthwartship	6.82	6.85
AngleOffsetAlongship	0	0.07
AngleOffsetAthwartship	-0.03	0.09
SaCorrection	0	-0.62
EquivalentBeamAngle	-20.7	-20.7
Impedance	75	75
Phase	0	0
BeamType	BeamTypeSplit	BeamTypeSplit
FrequencyStart	70000	120000
FrequencyEnd	70000	120000
PulseLength	0.000512	0.000256
PulseForm	CW	CW

Slope	0	0
TransmitPower	750	200
SampleInterval	0.000128	0.000064
MainOperation	Normal	Normal
TsDeviation	2	2
RangeStart	8.05	6.86
Range	2.45	1
MinTSValue	-50	-50
MinEchoLength	0.8	0.8
MaxEchoLength	1.8	1.8
MaxPhaseDeviation	20	20
MaxSweepPhaseDeviation	25	25
MaxGainCompensation	3	3
MinSpacing	0	0
WBTDistanceBeforeTracePeak	0.15	0.15
WBTDistanceAfterTracePeak	0.7	0.7
SoundVelocity	1499.84	1499.84
AbsorptionCoefficient	0.000909	0.002671
Temperature	26.2	26.2
Salinity	0	0
Acidity	8.2	8.2
TargetReference Name	Tungsten (WC-Co) 38.1mm	Tungsten (WC-Co) 38.1mm

2nd calibration at off Sizu island		
Field	70 kHz	120 kHZ
FileFormatVersion	1.05	1.05
Copyright	Copyright(c) Kongsberg Maritime AS	Copyright(c) Kongsberg Maritime AS
TimeOfFileCreation	2022-12-03T15:13:33.9377675+03:00	2022-12-03T15:55:42.6748879+03:00
Transducer Name	ES70-7C	ES120-7C

Transducer Serial Number	1	2
Transducer Depth	2	2
Transceiver Channel Name	ES70-7C Serial No: 1	ES120-7C Serial No: 2
Transceiver Type	TransceiverTypeGPT	TransceiverTypeGPT
Transceiver Serial Number	0	0
Transceiver Software Version	50112	50112
Transceiver Impedance	1000	1000
Application Name	EK80	EK80
Application Software Version	1.12.2.0	1.12.2.0
Frequency	70000	120000
Gain	26.04	25.34
Beam Width Alongship	6.74	6.81
Beam Width Athwartship	6.74	6.81
Angle Offset Alongship	-0.04	-0.04
Angle Offset Athwartship	0.03	-0.03
Sa Correction	-0.01	0.06
Equivalent Beam Angle	-20.7	-20.7
Impedance	75	75
Phase	0	0
Beam Type	BeamTypeSplit	BeamTypeSplit
Frequency Start	70000	120000
Frequency End	70000	120000
Pulse Length	0.000256	0.000256
Pulse Form	CW	CW
Slope	0	0
Transmit Power	225	200
Sample Interval	0.000064	0.000064
Main Operation	Normal	Normal
TS Deviation	2	2
Range Start	2.12	0.2

Range	13	18.15
Min TS Value	-50	-50
Min Echo Length	0.8	0.8
Max Echo Length	1.8	1.8
Max Phase Deviation	20	20
Max Sweep Phase Deviation	25	25
Max Gain Compensation	3	3
Min Spacing	0	0
WBT Distance Before Trace Peak	0.15	0.15
WBT Distance After Trace Peak	0.7	0.7
Sound Velocity	1501.12	1501.12
Absorption Coefficient	0.000892	0.002623
Temperature	26.7	26.7
Salinity	0	0
Acidity	8.2	8.2
Target Reference Name	Tungsten (WC-Co) 38.1mm	Tungsten (WC-Co) 38.1mm

Appendix II: Event log for the 2022 hydroacoustic survey on Lake Victoria

Date	Event No.	Activities	Transect ID	Station	Quadrant	Strata	Country	Time start (GMT)	Time end (GMT)	Remarks
07/11/2022	1	TI	1		SW	I	Tz	0725	0840	Left Mwanza
	2	CTD		1	SW	I	Tz	0840	0849	
	3	DH	2		SW	I	Tz	0849	0920	
	4	TI	3		SW	I	Tz	0920	11;10	
	5	DH	4		SW	D	Tz	11;10	1201	
	6	CTD		2	SW	D	Tz	1201	1213	
	7	TC	5		SW	C	Tz	1213	1310	
	8	TI	6		SW	I	Tz	1310	1356	
	9	DH	7		SW	C	Tz	1356	1407	End of Day Nyakaliro
08/11/2022	10	TI	8		SW	I	Tz	0322	0448	Left Nyakaliro
	11	TC	9		SW	C	Tz	0448	0635	
	12	CTD		3	SW	C	Tz	0635	0644	
	13	DH	10		SW	C	Tz	0644	0752	
	14	NP		1	SW	C		0752	0830	
	15	TC	11		SW	C	Tz	0835	1034	
	16	TI	12		SW	C	Tz	1034	1133	
	17	DH	13		SW	I	Tz	1133	1207	
	18	TI	14		SW	I	Tz	1207	1253	
	19	DH	15		SW	I	Tz	1253	1314	
	20	DH	16		SW	EP	Tz	1314	1340	
	21	CTD		4	SW	EP	Tz	1340	1351	
	22	TI	17		SW	EP	Tz	1355	1526	End of Day Chato
09/11/2022	23	DH	18		SW	EP	Tz	0353	0405	Left Chato
	24	NB		1	SW	EP	Tz	0422	0451	
	25	CTD		5	SW	EP	Tz	0502	0509	
	26	TI	19		SW	EP	Tz	0510	0626	
	27	TI	20		SW	EP	Tz	0626	0752	
	28	TI	21		SW	EP	Tz	0752	0837	
	29	NB		2	SW	EP	Tz	0846	1050	
	30	CTD		6	SW	EP	Tz	1113	1121	
	31	NB		3	SW	EP	Tz	1127	1230	
	32	DH	22		SW	EP	Tz	1242	1254	End of Day Mazinga
10/11/2022	33	DH	23		SW	C	Tz	0310	0332	Left Mazinga
	34	DH	24		SW	C	TZ	0332	0504	
	35	TC	25		SW	C	Tz	0504	0734	
	36	DH	26		SW	C	Tz	0734	0818	
	36	NB		4	SW	C	Tz			Unable to fish because of bad weather
	38	TC	27		SW	C	Tz	0818	0927	
	39	CTD		7	SW	C	Tz	0927	0938	
	40	TC	28		SW	C	Tz	0939	1219	End of day at Kerebe
11/11/2022	41	TC	29		SW	C	Tz	0126	0251	Left Kerebe
	42	TD	30		SW	D	Tz	0251	0654	
	43	CTD		8	SW	D	Tz	0654	0710	
	44	DH	31		SW	D	Tz	0711	0854	
	45	TD	32		SW	D	Tz	0854	1426	
	46	TC	33		SW	C	Tz	1426	1722	End of day Bumbire
12/11/2022	47	DH	34		SW	I	Tz	0410	0423	

										Left Bumbire
	48	CTD		9	SW	I	Tz	0423	0434	
	49	NB		5	SW	I	Tz	0433	0650	
	50	NB		6	SW	I	Tz	0712	0931	
	50	TI	35		SW	I	Tz	0931	1051	End of day Bukoba
13/11/2021	Rest day at Bukoba									
14/11/2021	51	DH	36		SW	I	Tz	0355	0434	Left Bukoba
	52	TI	37		SW	I	Tz	0434	0551	
	53	TC	38		SW	C	Tz	0551	0823	
	54	CTD		10	SW	C	Tz	0826	0835	Hard bottom, no grab sample
	55	NP		2	SW	C	Tz	0838	0930	
	56	DH	39a		SW	C	Tz	0945	1026	
	57	DH	39b		NW	C	Ug	1026	1057	
	58	TC	40		NW	C	Ug	1057	1333	
	59	TI	41		NW	I	Ug	1333	1433	
	60	CTD		11	SW	I	Tz	1434	1440	
	61	NB		7	SW	I	Tz	1456	1514	The haul did not last for 30 min, the net encountered an obstacle at the bottom End at Rubafu
15/11/2022	62	TI	42a		SW	I	Tz	0316	0346	Left Rubafu
	63	TI	42b		NW	I	Ug	0346	0531	
	64	TC	43		NW	NW	C	0531	0700	
	65	CTD		12	NW	C	Ug	0700	0708	
	66	NB		8	NW	C	Ug	0718	0752	
	67	DH	44		NW	C	Ug	0801	0831	
	68	TI	45		NW	I	Ug	0831	1033	
	69	CTD		13	NW	I	Ug	1033	1041	
	70	NB		9	NW	I	Ug	1048	1118	
	71	DH	46		NW	I	Ug	1129	1156	
	72	TI	47		NW	I	Ug	1156	1333	End of Day Nakatiba landing site
16/11/2022	73	DH	48		NW	I	Ug	0316	0353	Left Nakatiba
	74	TI	49		NW	I	Ug	0353	0511	
	75	DH	50		NW	SI	Ug	0511	0520	
	76	TI	51		NW	SI	Ug	0520	0613	
	77	CTD		14	NW	SI	Ug	0613	0626	
	78	NB		10	NW	SI	Ug	0630	0730	
	79	TC	52		NW	SI	Ug	0748	0849	
	80	DH	53		NW	SI	Ug	0849	0954	
	81	TC	54		NW	C	Ug	0954	1119	
	82	CTD		15	NW	C	Ug	1119	1132	
	83	NB		11	NW	C	Ug	1136	1206	
	84	DH	55		NW	C	Ug	1224	1251	
	85	DH	56		NW	SI	Ug	1251	1257	End of the day-Mpata Bay
17/11/2022	86	DH	57		NW	SI	Ug	0111	0113	Left Mpata Bay
	87	TD	58		NW	D	Ug	0113	0610	
	88	CTD		16	NW	D	Ug	0610	0622	
	89	NP		3	NW	D	Ug	0701	0742	
	90	DH	59		NW	D	Ug	0747	0938	
	91	TD	60		NW	D	Ug	0938	1341	
	92	TC	61		NW	C	Ug	1341	1602	
	93	TI	62		NW	SI	Ug	1602	1724	End of day Kalangala

18/11/2022	94	TI	63		NW	SI	Ug	0355	0437	Left Kalangala
	95	NB		12	NW	I	Ug			Forgot CTD and NB at the beginning
	96	CTD		17	NW	I	Ug	0340	0444	
	97	TI	64		NW	I	Ug	0444	0458	
	98	TI	65		NW	I	Ug	0458	0527	
	99	DH	66		NW	I	Ug	0527	0558	
	100	CTD		18	NW	I	Ug	0601	0609	
	101	NB		13	NW	I	Ug	0623	0723	
	102	TI	67		NW	I	Ug	0732	0859	
	103	DH	68		NW		Ug	0859	1045	
		CTD		19				1045	1057	
	104	TI	69		NW	I	Ug	1057	1151	
	106	TI	70		NW	I	Ug	1151	1232	
	107	TI	71		NW	I	Ug	1232	1354	
		TI	72		NW	I	Ug	1354	1435	
	109	TI	73		NW	I	Ug	1435	1522	End of the day Muvo Bukafu bay
19/11/2022	117	DH	74		NW	I	Ug	0338	0339	Left Muvo Bukafu bay the engine went off unexpectedly. To check the end time on the echogram
	118	TI	75		NW	I	Ug	0339	0421	Possibly not recorded
	119	TI	76		NW	I	Ug	0421	0516	
	119	TI	77		NW	I	Ug	0516	0602	
		CTD		20				0602	0609	
	120	NB		14	NW	I	Ug	0617	0718	
	121	DH	78		NW	I	Ug	0718	0748	
	122	TI	79		NW	I	Ug	0748	0841	
	123	DH	80		NW	I	Ug	0841	0910	
	124	TI	81		NW	I	Ug	0910	0937	
	125	CTD		21	NW	I	Ug	0937	0950	
	126	TI	82					0950	1019	End of the day Jinja pier
20th to 21st/11/2022	Rest day in Jinja									
22/11/2022	127	DH	83		NE	I	Ug	0800	0818	Left Jinja late at 11:00
	128	DH	84		NE	I	Ug	0818	0855	
	129	TI	85		NE	I	Ug	0855	1019	
	130	TI	86		NE	I	Ug	1019	1147	
	131	CTD		22	NE	C	Ug	1147	1157	
	132	DH	87		NE	C	Ug	1157	1253	
	133	TC	88		NE	C	Ug	1253	1431	
	134	TC	89		NE	C	Ug			Omitted due to time
	135	CTD			NE	C	Ug			Omitted due to time
	136	DH	90		NE	D	Ug			Omitted due to time
	137	TC	91		NE	C	Ug			Omitted due to time
	138	CTD		23	NE	C	Ug	1431	1444	
	139	DH	92		NE	C	Ug	1444	1528	End of the day Kojja Bay
23/11/2022	140	DH	93		NE	I	Ug	0201	0236	Left Kojja Bay
	141	TI	94		NE	I	Ug	0236	0328	

	142	TI	95		NE	I	Ug	0328	0418	
	143	CTD		24	NE	I	Ug	0418	0427	
	144	TI	96		NE	I	Ug	0427	0615	
	145	CTD		25	NE	C	Ug	0615	0624	
	147	TC	97		NE	C	Ug	0624	0750	
	148	DH	99		NE	C	Ug	0750	0849	
	149	TC	100		NE	C	Ug	0849	1000	
	150	TC	101		NE	C	Ug	1000	1100	
	151	CTD		26	NE	C	Ug	1100	1111	
	152	NB		15	NE	C	Ug	1118	1217	
	153	TI	102		NE	I	Ug	1231	1242	
	154	DH	103		NE	I	Ug	1242	1308	
	155	TI	104		NE	I	Ug	1308	1347	
	156	TC	105		NE	I	Ug	1347	1451	
	157	DHa	106a		NE	I	Ug	1451	1500	
	158	DHb	106b		NE	I	Ke	1500	1517=	End of day, Port Victoria
24/11/2022	159	DHa	107a		NE	I	Ke	0431	0448	Left Port Victoria
		DHb	107b		NE	I	Ug			NB on this transect
	160	CTD		27	NE	I	Ug	0448	0501	
	161	NB		16	NE	I	Ug	0501	0601	
	162	NB		17	NE	I	Ug	0637	0830	
	163	TC	108		NE	C	Ug	0941	1112	
	164	DH	109		NE	C	Ug	1112	1217	
	165	CTD		28	NE	C	Ug	1217	1229	
	166	TC	110		NE	C	Ug	1229	1353	
	167	TC	111		NE	C	Ug	1353	1459	
	168	CTD		29	NE	D	Ug	1459	1507	
	169	DH	112		NE	D	Ug	1507	1523	End of day Lolwe
25/11/2022	170	TD	113		NE	D	Ug	0213	0742	Leaving Lolwe
	171	CTD		30	NE	D	Ug	0743	0815	Engineer working on the hydraulic system.
	172	DH	114		NE	D	Ug	0816	0928	The GPS went off shortly
	173	TD	115		NE	D	Ug	0928	1319	
	174	CTD		31	NE	D	Ug	1319	1330	
	175	TC	116a		NE	C	Ug	1330	1449	
	176	TC	116b		NE	C	Ke	1449	1557	
	179	DH	117		NE	C	Ke	1557	1654	
	180	TI	118		NE	C	Ke	1654	1705	End of day Luanda Kotieno
26/11/2022	181	CTD		32	NE	C	Ke	0319	0342	Left Lwanda Kotieno
	182	NB		19	NE	I	Ke	0342	0419	
	183	TI	119		NE	I	Ke	0440	1512	
	184	TI	120		NE	NG	Ke	1512	0546	
	185	NB		20	NE	NG	Ke	0553	0527	
	186	NB		21	NE	NG	Ke	0701	0751	
	187	TI	121		NE	NG	Ke	0805	0827	
	188	CTD		33	NE	NG	Ke	0827	0839	
	189	TI	122		NE	NG	Ke	0839	1103	
	190	CTD		34	NE	NG	Ke	1103	1112	Arrival At Kisumu
27/11/2022	191									Rest day Kisumu
28/11/2022	192	DH	123		NE	NG	Ke	0433	0702	Left Kisumu Pier
	193	TI	124		NE	NG	Ke	0702	0819	
	194	CTD		35	NE	NG	Ke	0819	0832	
	195	DH	125		NE	NG	Ke	0832	0928	
	196	DH	126		NE	NG	Ke	0928	0947	

	197	DH	127		NE	C	Ke	0947	1010	
	198	DH	128		NE	C	Ke	1010	1105	
	199	TC	129		NE	C	Ke	1105	1148	
	200	CTD		36	NE	C	Ke	1148	1159	
	201	TD	130		NE	D	Ke	1159	1336	
	202	DH	131		NE	D	Ke	1336	1453	
	203	TC	132		NE	C	Ke	1453	1604	
	204	DH	133		NE	C	Ke	1604	1640	End day at Sori
29/11/2022	205	DH	134		NE	C	Ke	0413	0431	Left Sori/not recorded
	206	NB		22	NE	C	Ke	0450	0610	
	207	CTD		37	NE	C	Ke	0625	0637	
	208	DH	135		NE	C	Ke	0637	0735	
	209	TC	136a		NE	C	Ke	0735	0750	
	210	TC	136b		NE	C	Ug	0750	0849	
	211	CTD		38	NE	C	Ug	0849	0904	
	212	DH	137		NE	C	Ug	0904	0928	
	213	TC	138a		NE	C	Ug	0928	1030	
		TC	138b		SE	C	Tz	1030	1103	
	215	CTD		39	SE	C	Tz	1103	1118	
	214	NB		23	SE	C	Tz	1121	1229	
	216	DH	139		SE	C	Tz	1235	1255	End of Day, Shirati
30/11/2022	222	DH	140		SE	D	Tz	0153	0329	Left Shirati
	223	TD	141		SE	D	Tz	0329	0759	
	224	CTD		40	SE	D	Tz	0759	0811	
	225	DH	142		SE	D	Tz	0811	0932	
	226	TD	143		SE	D	Tz	0932	1349	
	230	DH	144		SE	C	Tz	1349	1444	End of day Musoma
01/12/2022										Rest day
02/12/2022	231	DH	145		SE	I	Tz	0357	0408	Left Musoma
	232	TI	146		SE	I	Tz	0408	0532	
	233	TC	159		SE	C	Tz	0532	0613	
	234	CTD		41	SE	C	Tz	0613	0626	
	235	TC	160		SE	C	Tz	0626	0710	
	236	TC	161		SE	C	Tz	0710	0801	
	237	CTD		42	SE	C	Tz	0801	0813	
	238	NB		24	SE	C	Tz	0823	0859	
	239	TC	162		SE	C	Tz	0912	0947	
	240	DH	163		SE	C	Tz	0947	1035	
	241	CTD		43	SE	C	Tz	1035	1051	
	242	TC	164		SE	C	Tz	1051	1253	
	243	TC	165		SE	I	Tz	1253	1338	Changed from TI to TC as depth was btn 40-30m
	244	CTD		44	SE	I	Tz	1338	1353	
	245	DH	166		SE	I	Tz	1353	1440	
	246	TC	167		SE	C	Tz	1440	1516	End of day Una bay (no connection)
03/12/2022	247	DH	168		SE	C	Tz	0313	0319	Left Una
	247	TD	169		SE	D	Tz	0319	0523	
	248	DH	170		SE	D	Tz	0523	0631	
	249	CTD		45	SE	D	Tz	0631	0647	
	250	TD	171		SE	D	Tz	0647	0927	
	251	TI	172		SE	I	Tz	0927	0957	
	252	CTD		46	SE	I	Tz	0957	1338	CTD and calibration at off Sizu island
	253	NB		25	SE	I	Tz	1346	1417	

	254	DH	173		SE	C	Tz	1430	1444	End at Ukara
04/12/2022	255	DH	174		SE	I	Tz	0306	0328	Left Ukara (Bwisya)
	255	TD	175		SE	D	Tz	0328	0444	From TC to TD >53 m
	257	CTD		47	SE	C	Tz	0444	0457	
	257	TC	176		SE	C	Tz	0457	0654	
	258	TC	177		SE	C	Tz	0654	0829	
	259	TC	178		SE	C	Tz	0829	0905	
	260	CTD		48	SE	C	Tz	0905	0922	
	261	NB		26	SE	C	Tz			Fishing abandoned due to bad weather
	262	TI	179		SE	I	Tz	0937	1112	
	263	TI	180		SE	I	Tz	1112	1241	
	264	CTD		49	SE	I	Tz	1241	1254	
	265	NB		27	SE	I	Tz	1300	1401	
	266	DH	181		SE	I	Tz	1412	1432	End of day Nansio
05/12/2022	267	DH	182		SE	SG	Tz	0315	0345	Left Nansio
	268	TI	183		SE	SG	Tz	0345	0449	
	269	TI	184		SE	SG	Tz	0449	0556	
	270	DH	185		SE	SG	Tz	0556	0609	
	271	NB		27	SE	SG	Tz	0618	0748	
	272	CTD		5~~0~~6	SE	SG	Tz	0748	0819	
	273	DH	186		SE	SG	Tz	0819	0939	
	274	DH	187		SE	SG	Tz	0939	1029	
	275	CTD		5~~1~~7	SE	SG	Tz	1029	1042	
	276	NB		28	SE	SG	Tz	1048	1148	
	277	TI	188		SE	SG	Tz	1203	1212	
	278	DH	189		SE	SG	Tz	1212	1252	
	279	TI	190		SE	SG	Tz	1252	1319	
	280	NB		NB029	SE	SG	Tz	1325	1400	
	281	DH	191	58	SE	SG	Tz	1410	1435	End of day and survey at Nyamikoma pier
06/12/2022										Travel to TAFIRI pier, Mwanza

Appendix III: Detailed results from net bottom hauls

A1.3.1. Catch composition

Fish catch composition for November 2022 survey recorded twelve fish species through 25 net hauls the same as in 2021 and 2020, compared to thirteen fish species recorded during October-November 2019 surveys respectively. During the current survey, *Lates niloticus* with 67.16% dominated the catch by weight, followed by haplochromines with 23.14%. The dominance of 67.16 % for Nile perch in 2022 catches seems to be smaller compared to the dominance of the last three years since 2019 where Nile perch dominated the catch by 91.97% after that there was a progressive decline in dominance. The composition for Haplochromines group of cichlids species in 2022 observed to be significantly higher when compared to the catch composition for the last five years (2017-2021). This is an index of prey-predator's relationship whereby Nile perch as predator seems to decline and give more room for haplochromines to increase in catches. Haplochromines species which shows to improve from 23.00% (2015) to 25.5% (2016) then observed to decline to progressively to 1.95% (2019). The rest fish species insignificantly contributed the other portion of the composition as presented in (Figure A1.1a & 1b).

In the order of dominance, the species recorded were *Lates niloticus*, Haplochromines sp, *Rastrineobola argentea, Oreochromis niloticus, Caridina nilotica, Synodontis victoriae, Protopterus aethiopicus, Clarius gariepinus Barbus profoundus, Synodontis afrofischeri. Schilbe intermedius, and Bagrus docmak.* other fish species which are common and were found in the previous surveys were not encountered in this survey. These included, *Labeo victorianus, Brycinus sadleri, Afromastercemblus frenatus, Brycinus* jacksonii, *Tilapia rendali*, and *Tilapia zillii.* These two organisms *Caridina nilotica*, and Molluscs were recorded because are ecologically very important as food for fish.

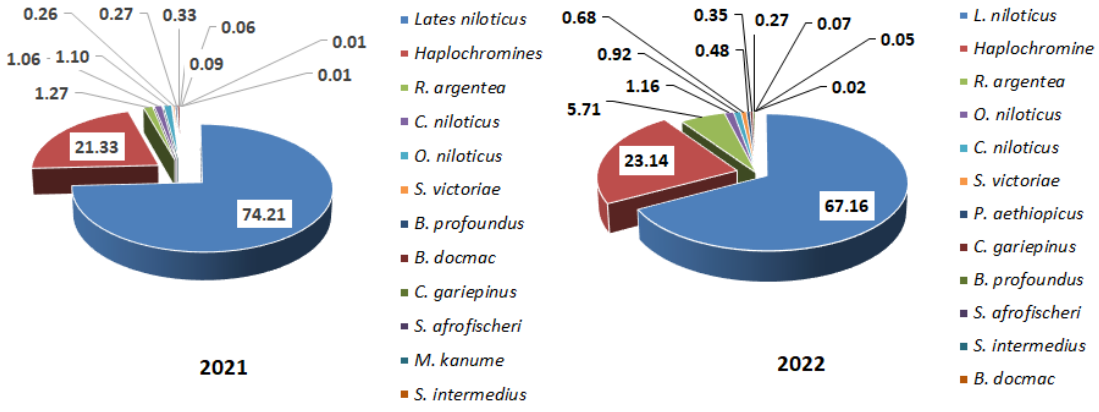


Figure A1. 1a: Catch composition for the 2021 and 2022 survey

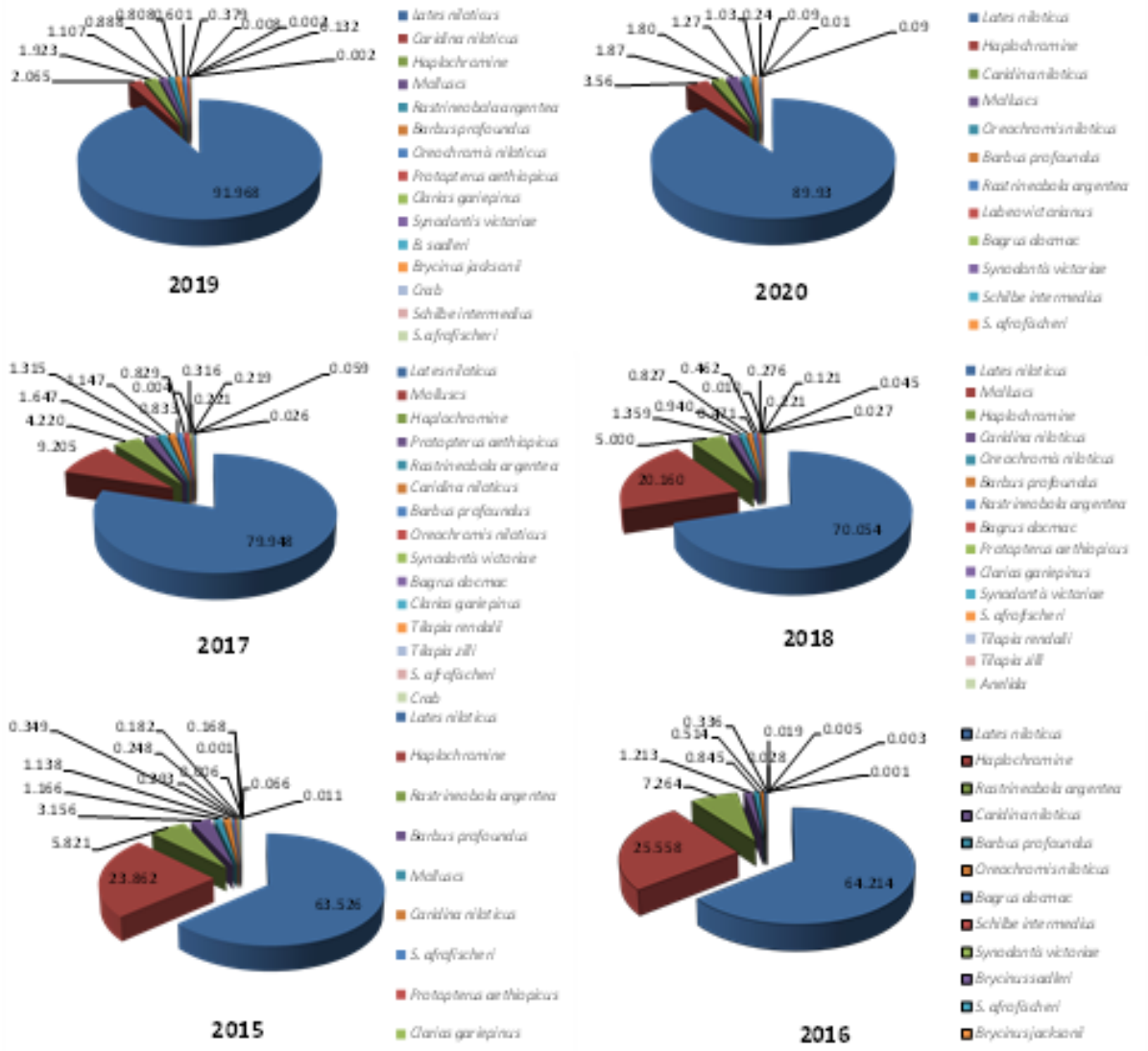


Figure A1. 21b: Catch composition for the survey period of 2015-2020

Table A1. 1: Changes in % catch composition by weight in Lake Victoria

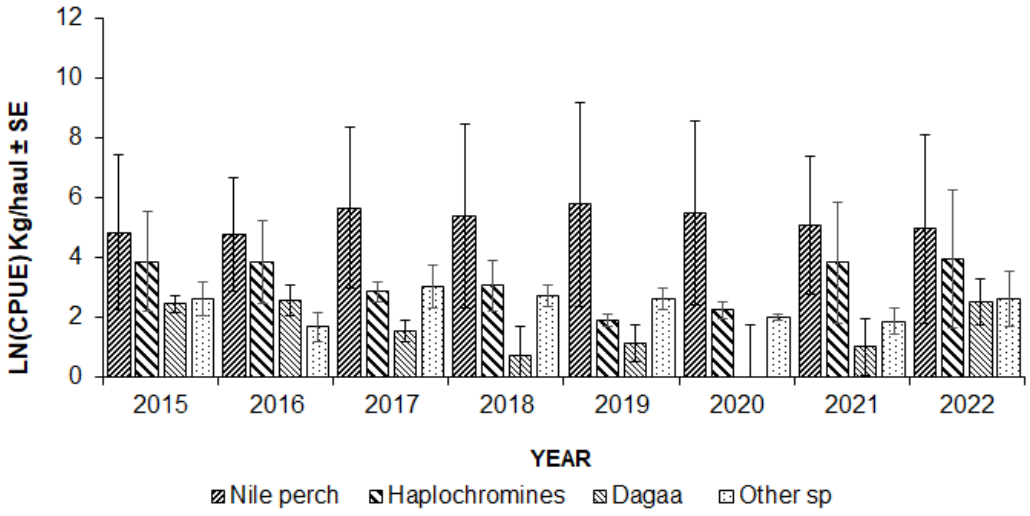
Species	Nov 2015	Sep 2016	Sep 2017	Sep 2018	Sep 2019	Oct 2020	Oct 2021	Nov 2022
Nile perch	64.27	64.210	87.08	83.85	93.12	89.93	74.21	67.16
Haplochromines	24.14	25.56	5.29	8.19	1.95	3.56	21.3	23.1
Dagaa	5.89	7.26	1.42	0.77	0.90	0.24	1.27	5.71
Others	5.7	2.97	6.21	7.19	4.03	6.27	3.19	3.99

AI.3.2. Catch per Unit Effort as an index of Relative abundance

The relative abundance stated as Catch per Unit Effort (CPUE) for eight consecutive years expressed as Kg/haul has been shown in the Table 2 for the Nile perch, Haplochromines, Dagaa were observed to increase progressively from 2.43±0.83 in 2019 to 18.40±9.99 in 2022 (Table A1.2). The changes in the Haplochromine and the Nile perch CPUE in the whole lake could be as a result of the ecosystem dynamics in addition to any other drivers. Despite the gear used such as the bottom trawl net, Dagaa catches indicated an increase almost four-fold as compared to November with

Table A1. 2: Changes in CPUE (Kg/haul) (Kg ± SE) since 2015 to 2022

Period	n	Nile perch	Haplochromines	Dagaa	Other sp
Nov 2022	25	51.08±23.62	18.40±9.99	4.54±2.14	4.92±2.52
Oct 2021	31	58.13±9.83	16.71±7.61	0.99±0.39	2.35±0.65
Oct 2020	24	85.67±21.71	3.39±1.35	0.23±0.11	2.71±1.10
Sep 2019	24	116.36±29.69	2.43±0.83	1.12±0.54	5.05±1.43
Sep 2018	25	79.88±21.40	7.81±2.32	0.73±0.37	5.52±1.42
Sep 2017	30	103.55±14.71	6.29±1.40	1.69±0.71	7.58±2.07
Sep 2016	24	42.16±6.72	16.78±3.94	4.77±1.66	1.95±0.62
Nov 2015	25	46.03±13.55	17.29±5.25	4.22±1.32	4.92±1.77



A1.3.3 Catch per unit effort of Nile perch in different quadrants

Catch per unit effort (CPEU) of all the commercial species in different quadrants behave differently. CPUE for six successive years expressed as Kg/haul in both quadrants is shown in

(Table A1.3). The Overall CPEU for Nile perch which observed to increases from 79.88±21.40 Kg/haul (2018) to 116.36±29.69Kg/haul (2019), this time decreased significantly by (-12.03%) with 51.08±23.62Kg/haul (2022) (Table A1.3). Information from the quadrant strata for the Nile perch continued to fluctuate in the areas of Northeast, Northwest and Southwestapart from the Southwest that had an increase in the relative indices (Table A1.3). The highest catch rate was observed in SW quadrant strata with 78.23±27.34 Kg/haul, however, this value dropped by 46.91% from 147.35±35 Kg/haul (2020) and then 140.37±87.37 kg/haul (+79.43%) in 2022 survey. Except for NE where there are significant increases in CPUE from 29.14±16.82 (2021) to 32.57±7.01 (2022) to) equivalent to 11.59% a slight increase in the catch rates. The lowest catch rates were observed in the SE with (-76.29%) at 13.38±6.53 kg/haul in 2022 compared to the 2021 (Table A1.3). Then for the haplochromines CPUE which shows to decrease tremendously from 7.81±2.32 Kg/haul in 2018 to 2.43±0.83 Kg/haul in 2019 increases tremendously to 17.740±9.99 Kg/haul in overall catch rates, this is a good sign for the survival of Nile perch. However, haplochromine CPUE behaves in inversely correlated with Nile perch. Unlike last year of 2021, The NW quadrants, haplochromine increased, tremendously from 0.42±0.18 Kg/haul (2020) to 34.18±27.83 Kg/haul in 2021. Then for the 2022-year samplings recorded 62.82±38.12 kg/haul as compared to 20.63±8.49 kg/haul in 2021 in SW quadrant. Dagaa catches from the last two surveys do not differ much except for the NW where the drop is higher from 5.39±3.33 Kg/haul in 2017 to 1.06±0.60 Kg/haul in 2019 then decreased slightly to 0.54±0.18 Kg/haul for 2021 survey and an increase in the 2022 that recorded 12.02±7.32 kg/haul. Then for the overall catch rates of all quadrants of all other fish species combined as others indicated a slight increase overall catch rates from 4.92±2.52 Kg/haul in 2022 as compared to 2.35±0.65 Kg/haul in 2021 samplings, however, generally the same trend of declining observed in all other quadrant.

Table A1 3: Changes in CPUE (Kg/haul) (Kg ± SE) of major fish species based on Quadrants

Quadrant	YEAR	Nile perch	Haplochromines	Dagaa	Other species
Overall	2022	51.08±23.62 (-12.13%)	18.40±9.99	4.54±2.14	4.92±2.52
Overall	2021	58.13±9.83 (-32.15%)	16.71±7.61	0.99±0.39	2.35±0.65
	2020	85.67±21.71	3.39±1.35	0.23±0.11	2.71±1.10
	2019	116.36±29.69	2.43±0.83	1.12±0.54	5.05±1.43
	2018	79.88±21.40	7.81±2.32	0.73±0.37	5.52±1.42
	2017	103.55±14.71	6.29±1.40	1.69±0.71	7.58±2.07
SW	2022	140.37±87.35 (+79.43%)	62.82±38.12	0.19±0.15	5.02±3.42
SW	2021	78.23±27.34 (-46.91%)	20.63±8.49	1.37±0.99	4.11±1.82
	2020	147.35±68.70	2.03±1.14		0.56±0.56
	2019	45.26±26.91	3.55±2.29	1.53±1.29	8.39±4.05

	2018	24.197±5.35	8.12±3.13	1.31±1.17	9.80±3.23
	2017	134.50±26.97	4.82±1.99	1.55±1.33	8.94±4.72
NW	2022	30.82±24.34 (-44.52%)	6.92±4.48	12.02±7.32	0.52±0.46
	2021	55.55±11.34 (-35.93%)	34.18±27.83	0.54±0.18	0.41±0.30
	2020	86.70±30.67	0.42±0.18		1.93±1.90
	2019	181.36±102.44	3.04±2.42	1.06±0.60	0.75±0.47
	2018	153.83±55.89	4.75±2.57	0.01±0.01	2.97±1.24
NW	2017	101.62±28.17	4.16±1.37	5.39±3.33	9.62±5.05
NE	2022	32.52±7.07 (+11.59%)	1.97±0.73	4.05±3.79	3.66±1.57
NE	2021	29.14±16.82 (+93.37%)	4.75±4.43	1.82±1.76	3.75±1.12
	2020	15.09±7.24	1.86±0.68		3.36±0.48
	2019	93.46±33.41	1.09±0.31	1.77±1.75	7.59±3.59
	2018	38.86±16.62	6.43±4.76	0.92±0.55	3.88±2.76
	2017	59.67±19.99	6.45±2.48	0.71±0.59	4.19±2.03
SE	2022	13.38±6.53 (-76.29%)	4.63±1.76	1.98±1.21	0.37±0.31
SE	2021	56.44±14.58 (-46.49%)	3.91±1.54	0.56±0.29	1.55±0.85
	2020	105.48±35.35	9.00±4.79		1.70±0.41
	2019	145.37±41.95	2.05±0.92	0.14±0.09	3.45±0.72
	2018	103.52±55.33	13.30±9.01	0.71±0.59	5.07±3.83
	2017	132.23±38.75	9.26±4.36	0.63±0.23	9.43±5.85

Table A1 3: CPUE (Kg/haul) (Kg ± SE) of major fish species per Country per Strata per Quadrants

Strata	Nile perch	Haplochromines	Others
TzSEDeep	2.41±0.00	0.26±0.00	0.099±0.00
TzSECoastal	19.39±11.23	3.08±1.98	1.38±0.84
TzSEInshore			
TzSESpekeGulf	15.81±12.66	9.16±1.10	4.93±2.78
TzSWDeep	3.81±0.06	0.28±0.28	0.013±0.013

TzSWCoastal	42.17±9.19	2.54±2.24	0.04±0.03
TzSWInshore	42.99±0.00	32.29±0.00	21.59±0.00
TzSWEminPasha	342.21±231.88	168.51±68.51	4.79±4.03
UgNWDeep	2.84±0.45	1.03±1.03	0.04±0.04
UgNWCoastal	7.56±3.08	0.01±0.01	3.58±3.45
UgNWInshore	12.65±272	14.03±13.46	33.9±11.1
UgNWSesse	154.30±0.00	11.39±0.00	0.24±0.00
UgNEDeep			
UgNECoastal	42.96±13.98	2.74±1.45	1.19±0.95
UgNEInshore			
KeNECoastal			
KeNEInshore	21.49±0.00	1.29±0.00	32.79±0.00
KeNENyanzaGulf	29.49±9.38	1.43±1.03	5.87±3.13

A1.3.3.2. Length frequency distribution of Nile perch (Lates niloticus)

Nile perch are large predator fish in Lake Victoria. The size structure of Nile perch caught during the November December 2022 surveys ranged from 1cm TL to 110 cm TL, compared to 130 cmTL for the year 2021 and 1cm TL to 150 cm TL for 2020 survey, while total mean length shows slightly decrease from 20.86 cm TL (2021) to 19.27 cm, TL (Table 4). The overall mean size for Nile perch is still low compared to the historical one of 25.17 cm TL recorded in the year 2018. The mean length for Nile perch during the 2022 survey was 19.27 cm, TL, this is a slight decrease from the previous survey of 2021 (Figure 2). Generally, mean size for Nile perch observed to fluctuate up and down whereby it increases by 58.3% from 15.9 cm TL (2017) to 25.17cm TL (2018) before dropping to 18.46 cm TL in 2020 and raised gradually to 20.86 cm TL in 2021 (Figure 2). Moreover 94.73 % of the Nile perch caught were below the lower limit of slot size (50 cm TL). This means out of 9150 Nile perch caught (2022) only 413 equivalents to 5.27% by number were above the lower limit 50.0 cm TL of Slot size (Table 4).

Overall mode distribution for the 2022 length distribution pattern of the Nile perch dropped from 12 cm TL to 10 cm TL. The maximum and minimum length of *Lates niloticus* for the sampled period fluctuate but with no significant difference in maximum size of Nile perch ranging which range from 103 in (2019), to 150 in 2020 while for 2022 survey the maximum Nile perch caught was 110 cm TL. However, the minimum size for different years ranges from 1 to 3 cmTL. The population structure for Nile perch within the different sampled period has no differences (Figure 2). In general, the population structure for all sampled periods were dominated with juvenile fish (small sized fishes) ranges between 12.32 cmTL to 25.17 cm TL (Figure A1. 2)

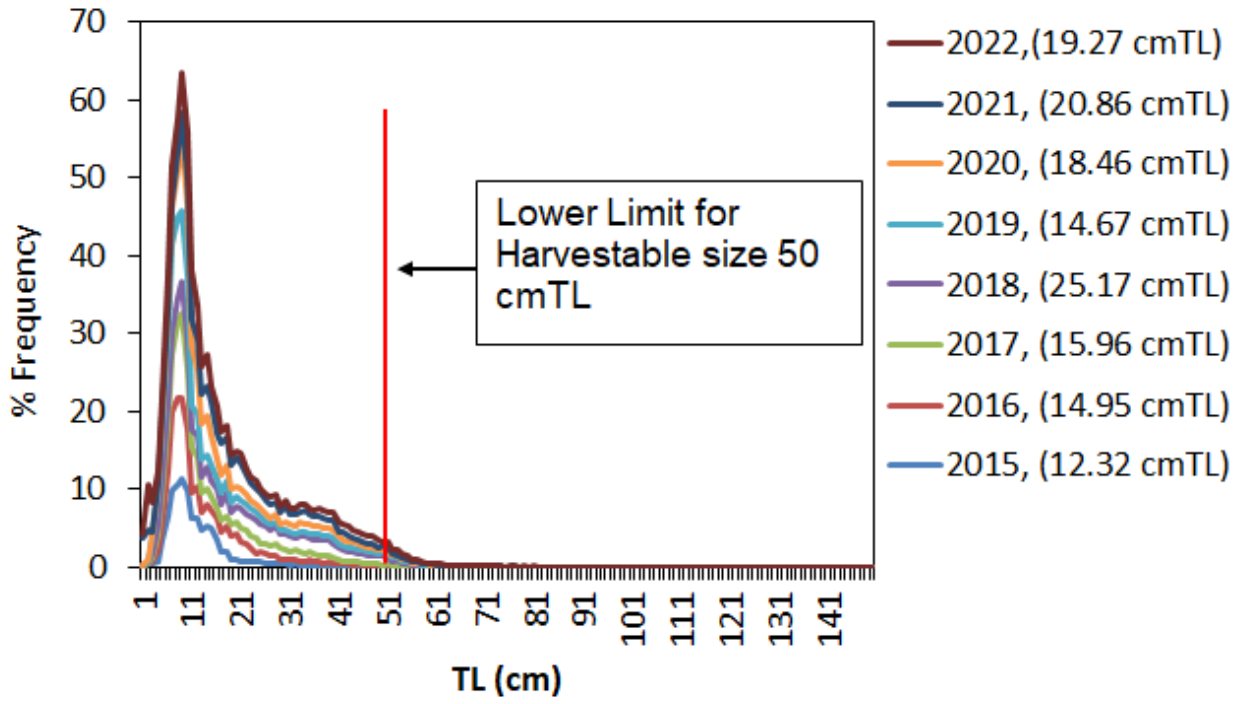


Figure A1. 2: Overall population structure of *Lates niloticus* based percentage length frequency from 2015 – 2022 with their mean size in (cm TL)

Table AI. 4: Size characteristics of Nile perch in Lake Victoria for the period of 2015-2022

Year	n	Mean Size (cm TL)	Mode Size (cm TL)	% Within Slot size	% Above (>50 cm TL)	% Below (<50 cm TL)	Max. Size (cm TL)
2022	9,150	19.27	10.0	5.15	5.27	94.73	110
2021	14,114	20.86	12.0	2.99	3.13	96.87	130
2020	17,644	18.46	9.0	2.83	2.93	97.07	150
2019	22,686	14.67	7.0	2.97	2.99	97.01	103
2018	12,202	25.17	9.0	4.98	5.06	94.94	104
2017	29,514	15.96	9.0	0.9	0.94	99.06	120
2016	11,100	13.95	8.0	1.13	1.19	98.81	124
2015	23,166	12.3	9.0	0.43	0.45	99.55	119

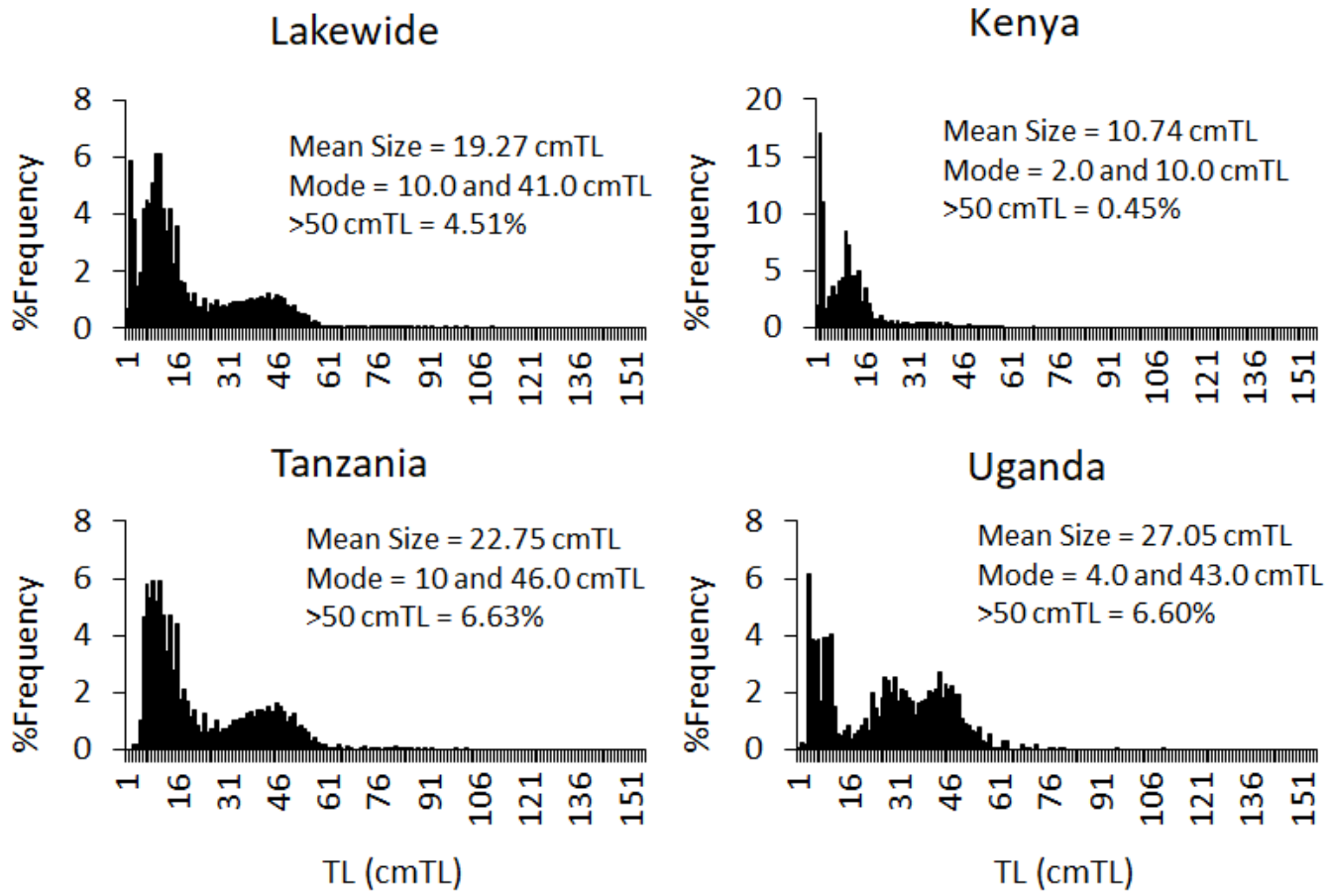


Figure A1. 3: Population structure of *Lates niloticus* in partner states for the 2022 survey.

General size characteristics of Nile perch including the mean size for the consecutive eight years is shown in Table 4 above. Whereby, the mean size of 19.27 cm TL was observed in the current survey of 2022. However, there were two phases of an increasing trend between 12.3 cm TL (2015) to 25.17 cm TL (2018), and 14.67 cm TL (2019) to 20.86 cm TL (2021). The highest mean size for 2022 survey is observed in Ugandan water with 27.05 cm TL (Figure 3) which increased progressively from 17.37 cm TL (2020) and 20.21 cm TL (2021) in Uganda (Figure 3 and 4). When compared to other partner states, Kenyan water is 10.74 cm TL which dropped from 18.16 cm TL (2021), and in Tanzanian water is 22.75cmTL which shows to drop from 24.59 cm TL in 2021 (Figure A1. 3).

Table A1. 5: Size characteristics of Nile perch by quadrants in Lake Victoria

Quadrant	Year	Mean T L (cm)	n	%>50.0 cm TL
SW	2022	23.10	4183	8.25
SW	2021	24.27	4566	6.77
	2020	22.0	2575	14.50
	2019	10.18	4200	2.00
	2018	29.89	2386	5.87
	2017	21.8	4570	2.16
	2016	18.6	1336	2.17
NW	2022	24.75	865	4.86
NW	2021	16.27	4949	1.17
	2020	16.0	2630	4.53
	2019	15.12	5277	6.78
	2018	32.58	2596	7.01
	2017	17.3	3366	0.86
	2016	25.13	274	0.36
NE	2022	13.37	3580	4.02
NE	2021	18.19	1790	0.6
	2020	23.0	1351	1.8
	2019	15.81	576	1.99
	2018	18.62	3249	2.00
	2017	20.70	5678	0.53
	2016	15.39	2289	0.92
SE	2022	19.97	522	4.02
SE	2021	25.09	2809	2.28
	2020	15.0	5754	3.09
	2019	15.52	9373	1.79
	2018	22.85	3971	2.04
	2017	12.3	15900	0.48
	2016	12.2	7201	0.71

A1. 3.3.3. Size characteristics of Nile perch in the relation to their weight for different year

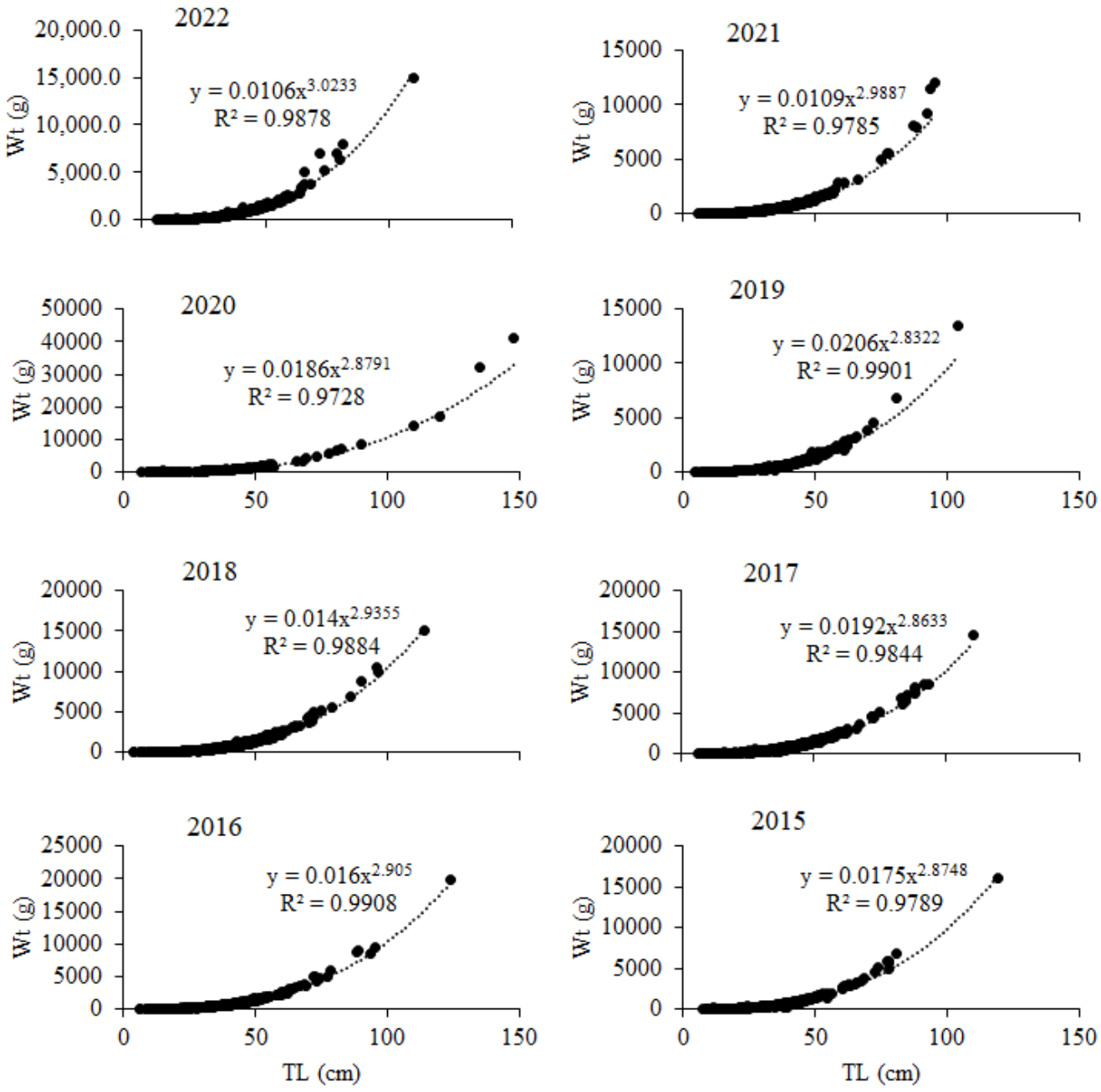


Figure A1. 5: Length Weight Relationship of *Lates niloticus* for different period from 2015 to 2022

Table A1. 6: Characteristics of the L-W-Coefficient of Nile perch for different sampling year

YEAR	a	b	r2	n
2022	0.0106	3.0233	0.9878	375
2021	0.0109	2.9887	0.9888	327
2020	0.0186	2.8791	0.9884	163
2019	0.0206	2.8322	0.9864	342
2018	0.0140	2.9355	0.9900	502
2017	0.0192	2.8633	0.9932	523
2016	0.0160	2.9050	0.9931	529
2015	0.0175	2.8748	0.9869	513
Average	0.0159	2.9127	0.9893	

Length weight relationship of the Nile perch has been shown in figure 5 above while the length weight coefficient for the sampled period of 2015 -2022 are presented in Table 6 above.

A1. 3.4. Food and feeding for Nile perch

A1. 3.4.1. Food composition

A total of 375 Nile perch specimens were analyzed for gut contents in the present survey. 36.8% (138) of the dissected specimen had full stomachs with 41% having extruded guts. The proportion of empty stomachs was 21% (80 specimen) of the sampled fish. Relative proportion of fullness was determined at 13%, 8.8%, 3.4% and 4.4% for ¼, ½, ¾ and Full stomachs respectively (Table A1. 7 below)

Table A1. 7 Stomach content characteristics of *Lates niloticus*

Stomach fullness	**Numbers**	**% Composition**
Specimen with gut contents	138	36.8
Empty stomachs	80	21.33
Extruded	157	41.87
¼ Full stomachs	49	13.07
½ Full stomachs	33	8.8
¾ Full stomachs	13	3.47
Full stomachs	43	11.47

Seven (7) prey items were identified from gut content analysis during the present survey. These include: Haplochromines, caridina, dagaa, mollucs, B. profundus, Bagrus docmak and juvenile Nile perch. Haplochromines and caridina ramain the two major food items for Nile perch accounting for 62.88% and 20.37% respectively in 2022, this is a slight variation from previous years where caridina had dominated the diet of Nile perch from 2016 to 2021(Figure 6) . During the present assessment, fish and fish remains were more prevalent in the prey items for size classess above TL 26cm while cardina was most preferred among lower size classess (Figure A1.7). Canibalism has been low among the Nile perch with the highest rate observed in 2017 (5.59%). This characteristic was most prevalent among larger size classes (>30cm TL) with the highest canibalism oberved at size 60cm TL in 2021.

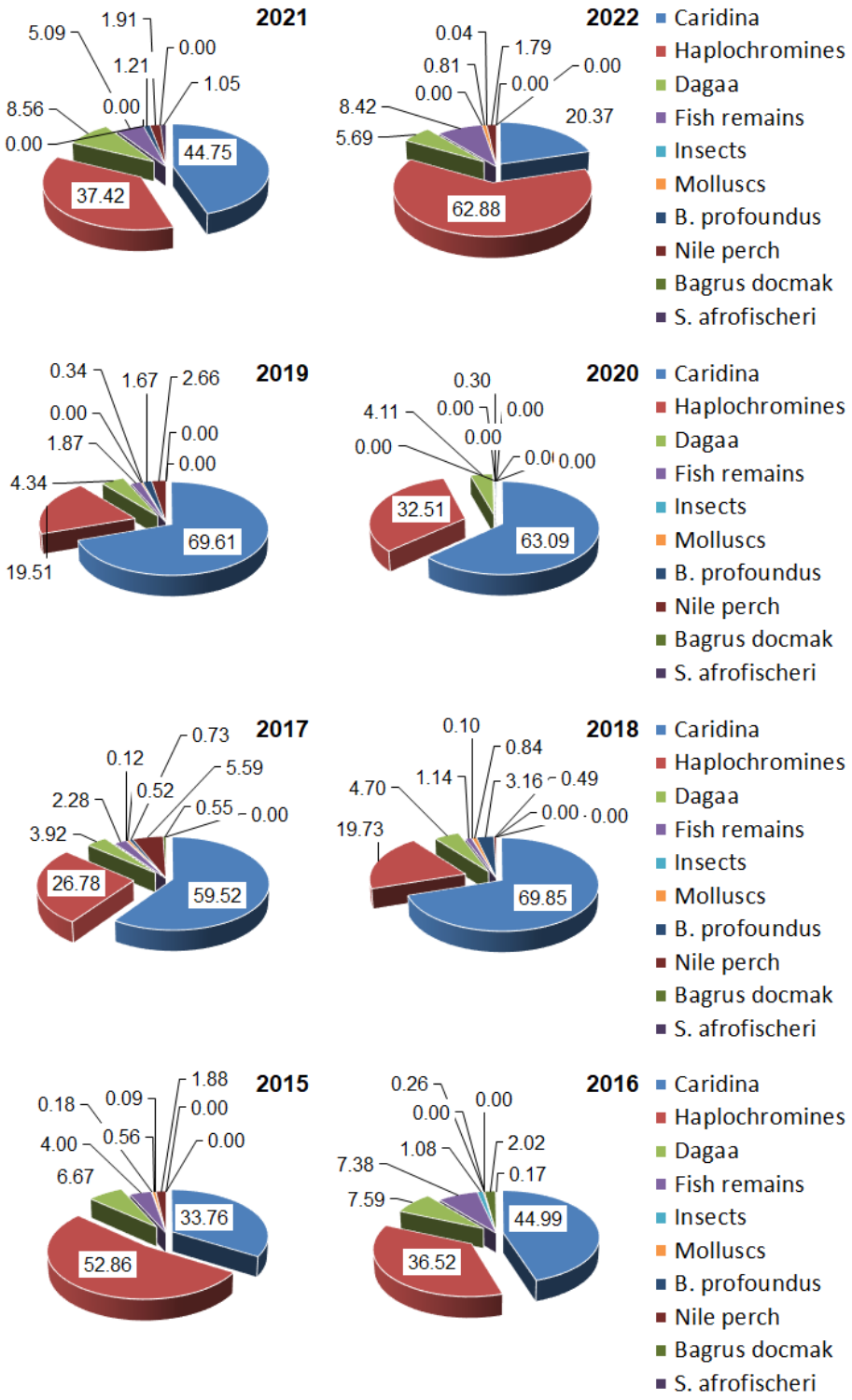


Figure A1. 6: Percentage contribution of different prey items to the diet of *Lates niloticus*

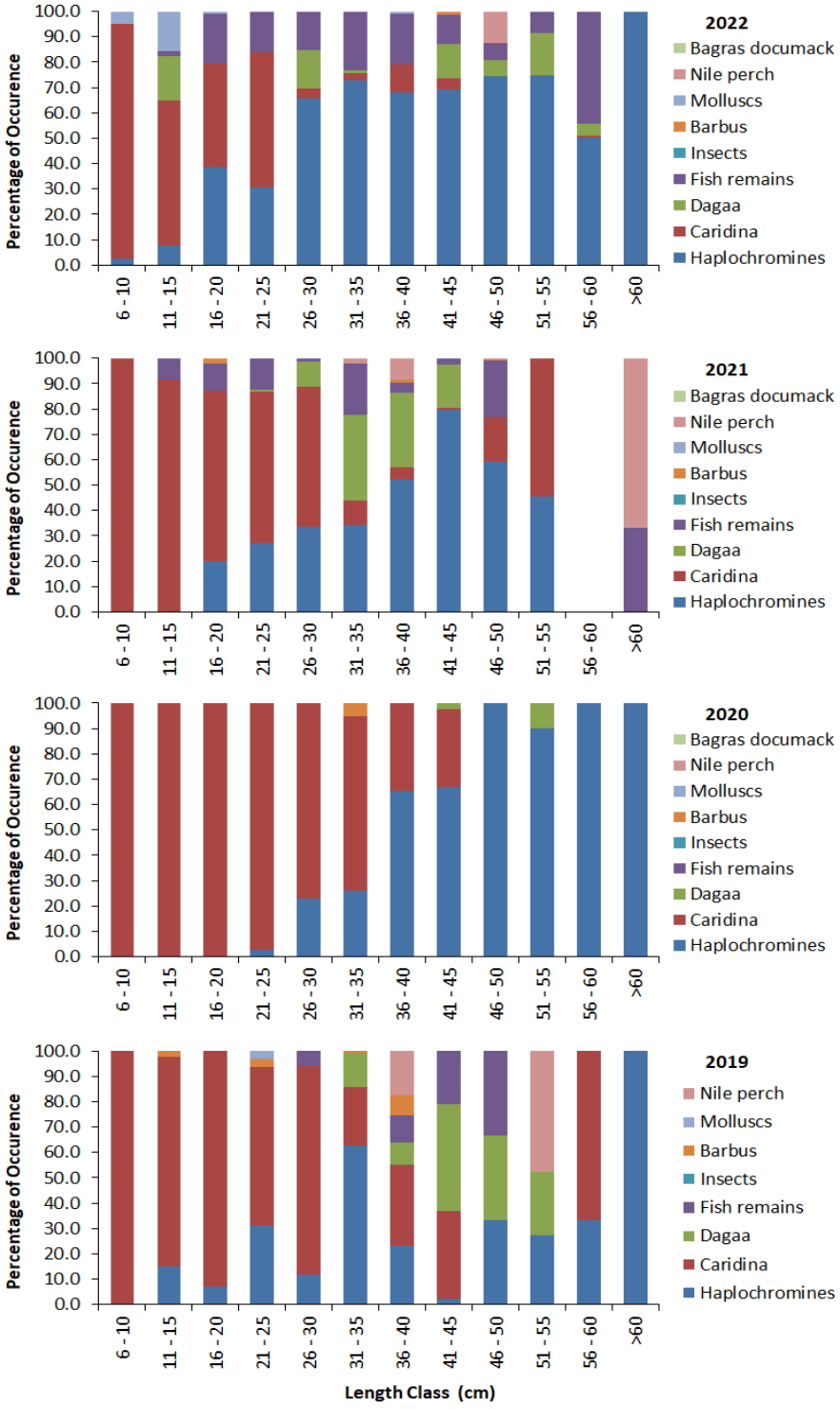


Figure A1. 7: The ontogenic shift of *Lates niloticus* for its prey

A1. 4.0. Discussion

A1. 4.1.0. Fish species composition

A total of 25 hauls in November 2022 as compared to 31 net hauls in 2021 and 30 net hauls in 2017. The sampling net hauls were less compared to the previous surveys such as March 2009 where 41 net hauls were registered. Overall, the survey of November 2022 registered a decrease in percentage composition by weight with 67.17% as compared to 74.21% in 2021. In addition, the decrease was progressively from 98.12% in 2019 to 67.16 % for the current 2022 survey. (Figure 1 and 2) (Table 1). The changes in the Nile perch in terms of low trends percentage composition could be attributed to an increase in the Haplochromine and Caridina species that are ecologically important as feed for Nile perch (Figure A1.1b & Table A.1). Hence, this increase of other species apart from *Lates niloticus* could be attributed to the natural oscillation between prey-predator relationships since haplochromines are preferred food item for Nile perch whose abundance reduced.

The current high fishing pressure on Nile perch fisheries targeting big Nile perch fish, is triggered by the current expansion of the fish maw industry in East Africa and Asia due to fish maw value. This may be the cause for the diminishing percentage composition by weight of *L. niloticus*. Most fishermen target big Nile perch because big fish have higher-valued maws. Large Fish maw has higher value, and this drives most of the fishers to target big Nile perch. According to the study conducted by TAFIRI in 2017 and 2018. Understanding the trade of fish maw and its implications for fisheries and aquatic ecosystems will reduce the declining of the large Nile per h in the lake. Studies done by TAFIRI reported that there is a direct proportionality between the swim bladder length and the total length of Nile perch, as the fish length increases its swim bladder length also increases. (TAFIRI Report 2017 &2018) fishermen always tend to search for large specimens to fish. This will remove the large Nile perch from the Lake Victoria ecosystem. other reason why there is decline in Nile perch composition by weight could be changes in our fisheries regulation whereby removing the upper limit of slot size and allow fishers to harvest lager Nile perch beyond the upper limit of slot size 85 cm TL could be contributed to the decline significantly. , this stock of large Nile perch is the one considered as the brood-stock for the Nile perch. Removing the brood stock from the population will result in declining the population. Data of Nile perch from different survey and studies already justified that female Nile perch mature for the first time at a length 75-90 cm TL. (Taabu et al, 2005; Ogutu-Ohwayo, R. 2004; Wandera et al.2003).

A1. 4.2 Characteristics of the Major fish Species Stocks dynamics

A1. 4.2.1. Catch rates

Catch rates are an index of biomass for aquatic organisms, which can be used to tell the status of the fish stock in aquatic environment. Catch per unit effort (CPUE) of all the commercial species in different quadrants behave differently (Table 2). CPUE for six successive years expressed as Kg/haul in both quadrants is shown in Table 2 and Table 3. The Overall CPUE for Nile perch

which observed to increases from 79.88±21.40 Kg/haul (2018) to 116.36±29.69Kg/haul (2019), this time decreased significantly by 50.04% from 2019 to 58.13±9.83Kg/haul (2021), and 32.15% from 2020 results and the current survey of November was 51.08± 23.62 kg/haul with (-12.13%) in 2021. (Table 3). Then in terms of quadrant strata Nile perch has shown fluctuation trends. The recent studies indicated an increase in the CPUE by 140.37±37 kg/haul with (79.43%) in 2022 as compared to 78.23±27.34 Kg/haul of 2021 in the SW quadrant strata. Unlike in the previous year of NE where recorded the lowest CPUE from 15.09±7.24 (2020) to 29.14±16.82 (2021) equivalent to 93.37% this time it was the SE with 56.44±14.58 in 2021 as compared to 13.38±63 with 76.29% decrease in 2022 (Table 1).The with other species such as haplochromines CPUE indicated a decrease tremendously from 7.81±2.32 Kg/haul in 2018 to 2.43±0.83 Kg/haul in 2019 increases tremendously to 16.71±7.61 Kg/haul then in 2022 the recorded catches were 18.40±9.99 kg/haul hence this continues to be a good sign for the survival of Nile perch because, haplochromines are praying important role for the ecosystem of the lake and are most preferable feeds for Nile perch ad we need to protect them.

However, Haplochromine CPUE behaves in inversely correlated with Nile perch. In all the quadrants, Haplochromine the previous samplings NW had 0.42±0.18 Kg/haul (2020), this area the catches increased to 34.18±27.83 Kg/haul in 2021. In the 2022 hydroacoustic studies the SW had the highest CPUE recorded at 20.63±8.49kg/haul. Then for the Dagaa catches from the last two surveys do not differ much except for the NW where the drop is higher from 5.39±3.33 Kg/haul in 2017 to 1.06±0.60 Kg/haul in 2019 then decreased slightly to 0.54±0.18 Kg/haul for 2021; though for the 2022 survey recorded an increase of 12.02±7.32 kg/haul. The Catch rates for other fish species combined as others shows to decreases progressively for the overall catch rates from 7.58±2.07 Kg/haul in 2017 to 2.35±0.65 Kg/haul in 2021, then for the 2022 recorded 4.92±2.52 kg/haul, however, generally the same trend of declining observed in most of the quadrants apart from SW. Dagaa decline from 2017 to 2019 by almost 33.73%. Although it is not alarming yet, this should also be checked because of their importance as small pelagic fish species which are also ecologically important. However, Dagaa is also coming up as an important prey in the diet of large Nile perch especially those above 40 cm TL. Data has shown also a decline in catch rate for the group of other fish species by 13.28% from 2020 to 2021 survey, though there was an increase in the recent surveys of 2022 with 4.54±2.14 kg/haul.

The NW quadrant, which for the three years 2017 to 2019 was increasing with highest catch rates for Nile perch, continue to decrease progressively from 181.36±102.44 (2019) to 55.55±11.34 (2021), though the 2022 it was the Southwest quadrant that had the highest catches (Table 3.) This kind of trend may be due to the current high fishing pressure targeting large Nile perch, this is stimulated by the current growth of fish maw business in East Africa and Asia due to fish maw value. Large fish maw has higher value, and this drives most of the fishers to target large sized Nile perch. Another reason why there is decline in Nile perch composition by weight could be due to changes of our fisheries regulation by removing the upper limit of slot size which allows fishers to harvest lager Nile perch beyond the upper limit of slot size 85 cm TL, this stock of large Nile perch is the one considered as the brood-stock for the Nile perch. Removing the brood stock from the population will affect the size of the population.

Size of organisms is a central factor to key ecological processes, and changes in size distribution may have many causes, including environment-induced or genetic variability in life history characteristics predator-prey relationships or competitive interactions (Shin *et al.*, 2005). Most important in Lake Victoria, is that Nile perch fishing is selective, targeting large fish which are more valuable, modifies the size structure and functioning of fish assemblages, with consequences for productivity and resilience of some stocks especially the Nile perch. Although the catch rate for Nile perch declined, the overall mean size structure of Nile perch caught during the October-November 2021 survey observed to increases slightly from 18.46 cm TL (2020) to 20.86 cm TL (2021), yet for the 2022 recorded above 50.0 cm TL. However, the overall mean size for Nile perch is still low compared to the historical one of 25.17 cm TL recorded in the year 2018. The mean length for Nile perch observed to increases by 58.3% from 15.9 cm TL in 2017 to 25.17cm TL in 2018 before dropping to 18.46 cm TL in 2020. This time it rose gradually to 20.86 cm TL. Moreover, 96.87 % of the Nile perch caught were below the lower limit of slot size (50 cm TL). This means out of 14114 Nile perch caught only 423 equivalents to 2.99% by number were within the slot size of 50-85 cm TL. The mean size of the Nile perch indicated that the population of the Nile perch in the lake is dominated by the small sized Nile perch which is good if we will preserve this group to grow to recruitment. This could be attributed to the presence of many large individual Nile perches in 2020 which with high fecundity reproduced a quite number of offspring which letter on being caught during the 2021 survey and rise arithmetic mean size of the Nile perch. Size characteristics of the Nile perch for different years and their frequency have been shown in table 3. The mean size of Nile perch can be applied as a key indicator within the Ecosystem Approach to Fisheries which required the use of size-based indicators for the assessment of fisheries trends in exploited aquatic ecosystem. Most life history traits are correlated with size, which acts as a constraint on metabolic rates and energy assimilation, so influencing the entire lives of animals including their growth, reproduction and survival (Shin *et al.*, 2005; Reiss 1989). The overall mode for the Nile perch in 2022 was 10.0 cm Tl as compared to 12.cm TL in 2021 that was seen as the largest mode for the eight consecutive sampling periods, normally the most frequent total length for Nile perch ranges from 7-9 cm TL, so when you compared to the previously modal value the increases is significant. The maximum and minimum length of *Lates niloticus* for eight consecutive years fluctuate but with no significant difference in maximum size of Nile perch. The size ranges from 1 to 155 cm TL 2022 as compared to 1 to 130 cm TL for the 2021 survey, 2014 had the smallest maximum size of 95cm TL. This could be depicting a healthy population of the Nile perch fishery that may require the fisheries management to monitor and maintain the stock sizes of the Nile perch fishery in Lake Victoria.

A1. 4.3. Food and feeding for Nile perch

A1. 4.3.1. Food composition

The predatory Nile perch feeds on a variety of diets (Shin *et al.*, 2005) with diets shifts observed (Hughes 1986, Ligtvoet & Mkumbo1992 and Oguto-Ohwayo1990) from the dominant haplochromine cichlids in 1970's to shrimps, dagaa and their juvenile in the 1980's. Following the resurgence of haplochromine between 1998-2006, haplochromine become more prominent in the Nile perch diet (Kishe-Machumu et al., 2011). Prey preference is a factor of resource availability

(Mkumbo & Ligtvoet 1992). In 2022, results indicated that *Caridina niloticus* continue to dominate in the stomach of juvenile Nile perch of ≤20cm TL while, Haplochromines dominated the food of large size class (≥ 60cm TL). The trends still continue to indicate that the food for the Nile perch of size range between 5.0 to 30 cm TL was dominated by Caridina but again for the size class between 31 to 39 cm TL there was no clear dominance prey for the Nile perch, the observed prey items were Caridina, Haplochromine, Dagaa, unidentified fish remains and Insects. Cannibalism has also continued to be observed in the size class between 46.0 to 50 0 cm TL. Cannibalism contribution to diet was a bit significant with (8.42%) in 2022 in that size class compared to the one observed during 2021 survey (5.09%) in the same size class. Moreover for the specimen with the size above 60.0 cmTL, their stomach were dominated full with Haplochromines.. Other studies show that cannibalism increased only when Haplochromines were depleted (Oguto-Ohwayo 1993). Overcrowding and shortage of food are normally considered to be the major predisposing factors for cannibalistic mode of feeding (Adeosun 2016). The preference of Nile perch for Haplochromines rather than of their own young reduces cannibalism (Kishe-Machumu *et al* (2011). Studies show that an increase in gill rakers spacing with size of fish prevent large Nile perch from being effective prawn predator (Hughes 1992). From the above investigation, it is indicated that *Lates niloticus* from Lake Victoria fed on variety of diet mainly fish for adult Nile perch and shrimps for juvenile Nile perch (Adeosun 2016).

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Appendix IV: Detailed results from limnology

LAKE VICTORIA FISHERIES ORGANIZATION

EAST AFRICAN COMMUNITY PARTNERSHIP FUND/ GIZ

LIMNOLOGICAL REPORT

HYDROACOUSTIC SURVEY OF LAKE VICTORIA

FROM 5Th November to 5TH December 2022

Hydro-acoustic Survey Limnology and Environment Team

Email: collongore@gmail.com, congore@kmfri.co.ke

March 2023

Abbreviations and Acronyms

µS/cm	Micro-Siemens per Centimetre
APHA	American Public Health Association
Chloro a	Chlorophyll-*a*
Cond	Conductivity
CTD	Conductivity Temperature Disolved Oxygen
DO	Dissolved Oxygen
EP	Emin Persha
FTU	Formazin Turbidity Units
mg/L	Milligrams per Litre
NB	Net Bottom
NE	Northeast
NG	Nyanza Gulf
NTU	Nephelometric Turbidity Units
NW	Northwest
^{o}C	Degrees Celsius
ORP	Oxidation Reduction Potential
PCA	Principal Component Analysis
pH	$-\log_{10}[H^{+}]$ (Negative Log_{10} of Hydrogen Ions Concentration
SE	Southeast
SG	Speke Gulf
SI	Sesse Islands
SW	Southwest
TDS	Total Dissolved Solids
Temp	Temperature
YSI	Yellow Springs Instruments

SUMMARY

Limnological studies conducted in conjunction with Lake Victoria's lake-wide acoustics surveys seek to characterise the aquatic environment in terms of physical, chemical, biochemical, and ecological attributes that influence fish stocks. Limnological data explains observed fish abundance trends at various spatial delimitations considered for the survey, which will be conducted in November and December 2022 with the goal of generating data on stock densities of commercially and ecologically important fish species. For in-situ logging of the vertical profile data of the water physical, chemical, and biochemical attributes, a previously calibrated depth-profiling system; a submersible Seabird® SBE 19plus V2 SeaCAT was used. Observations from 56 sampling points across the lake show shifts in thermal regimes and dissolved oxygen concentration patterns. The lake-wide mean temperature was 25.03±0.85 ^{o}C, an increase from the previous year's measurements. The lake-wide mean of dissolved oxygen (DO) was 5.39±0.87mgL^{-1}, a slight decrease from previous years. As a result, this study finds a continuum of temporal trends and spatial patterns in environmental conditions observed over the last decade, with notable occurrences of dramatic stratification patterns in most regions. More fish are expected to appear in the pelagic zones, but there is a risk of catastrophic overturn events.

INTRODUCTION

Background

Lake Victoria (Fig. 1) is the world's second largest freshwater lake and Africa's largest lake, with a surface area of 68,000 km2 (Hamilton, 2017), shared by three East African countries: Tanzania (51%), Uganda (43%), and Kenya (6%). Its 193,000 km^2 catchment area is shared by five East African states: Tanzania (44% (85,448 km^2), Kenya (22% (42,724 km^2), Uganda (16% (31,072 km^2), Rwanda (11% (21,362 Km2), and Burundi (7% (13,594 km^2) (LVBC, 2007). It has a long shoreline, estimated at 7360 km using high resolution satellite data (Hamilton 2017). The heavily indented shoreline is defined by bays and gulfs, as well as ecotone riparian wetlands, rocky cliffs, and open beaches, all of which provide access to ecosystem service seekers. A large human population of about 42 million people, which is growing at a rate of about 3.8% per year, lives in its basin, relying on its resources for a living (Nyamweya et al., 2020). The catchment area also includes the Nile Basin, which runs through Sudan and Egypt via the Nile River (Penn, 2001).

Changes induced by local direct human impacts and global climate change trends have resulted in phenomenal changes to the lake environment over the last century (Nyamweya et al., 2020). For example, with observed increases in surface temperatures, the mixing pattern has been disrupted and is no longer predictable (Hecky, 1993), frequently deviating from its earlier classification of oligotrophic monomictic type. The thermocline, according to neolimnological data (Graham, 1929), frequently occurred at 30-40 m depth, with periodic partial thermal mixing between the epilimnion and hypolimnion (Payne, 1986), and complete annual mixing between the months of June and August. According to recent observations, the lake experiences very different thermal regimes, characterised by increasing physical thermal stability and shallower mixing depths, which may have an impact on fish productivity (Sitoki et al., 2010). Nyamweya et al., (2020) depict the temporal scenes in the life of this lake over the last century and observes large-scale changes in the lacustrine environment and fisheries that are characterised and influenced by increased fishing pressure, biomanipulation, and catchment processes.

The lake's ecosystem stressors have been shown to originate in four distinct geographical realms: the lake itself, the littoral zone, within the basin, and outside the basin. Stressors from these sources interact to degrade the lake, reducing its resilience (Mugidde, 2001, Kolding et al. 2008, Hecky et al. 1996). Such stressors, the majority of which are anthropogenically sustained and of such complexity, have been identified as being driven by the ever-changing physical infrastructure surrounding the lake, human population explosion, and advances in fishing efficiency (Balirwa et al., 2003; Goudswaard et al., 2011; Goldschmidt et al., 1993; Nyamweya et al., 2016). Human population growth, on the other hand, has been linked to nutrient over-enrichment of lake waters via nutrient streams from domestic waste and intensive agricultural practices (Verschuren et al., 2002).

The goal of limnological studies in Lake Victoria that are integrated with acoustics surveys is to characterise the lake's aquatic environment by physical, chemical, biochemical, and ecological attributes that influence fish stocks. The environmental conditions of a body of water have a direct impact on fish stocks, influencing abundance, species composition, stability, productivity, and physiological conditions (APHA, 1985). Measurements of such parameters

along acoustic transects not only provide a clear understanding of habitat quality and its spatiotemporal variations, but also provide insight into how such parameters influence fish stocks (Laevastu and Hayes, 1981, Laevastu, 1993). This leads to a better understanding of the aquatic system's ecosystem processes, which translates into better lake and its fisheries resources management approaches (Santoso and Toruan, 2020).

Thus, the hydro-acoustics studies on Lake Victoria, whose objective is to generate information on stock densities of commercially important fish species, particularly Nile Perch and the pelagic groups (Dagaa and the haplochromine cichlids), relies on limnological information to explain the observed fish biomass and abundance trends at different transects, strata and other spatial delimitations considered. This approach provides a holistic ecosystem perspective of the fisheries and an enhanced understanding of the performance of the acoustics equipment and ensuing data.

Thus, hydro-acoustics studies on Lake Victoria rely on limnological information to explain observed fish biomass and abundance trends at different transects, strata, and other spatial delimitations considered. This method provides a holistic ecosystem view of the fisheries as well as a better understanding of the performance of the acoustics equipment and resulting data.

Objective

To is to characterize the lake-wide aquatic environment by physical, chemical, biochemical and ecological attributes that influence fish stocks and their spatial-temporal trends.

MATERIALS AND METHODS

The sampling points (CTD stations) for measuring water physical and chemical attributes were located in accordance with the Standard Operating Procedures (SOPs) for Lake Victoria Hydro Acoustics Surveys. The fifty-six (56) points were selected by stratified random sampling to ensure even distribution and representation of all strata, special regions, countries, and quadrants while logically coinciding with bottom trawl (NB) sampling points. As a result, the sites occurred systematically and intermittently between acoustics cruise transects covering the entire lake and closely followed, with minor logistical deviations caused by local prevailing conditions such as weather and time of day. The spatial positions of the CTD stations are depicted in Figure 1. Annex 4 contains more detailed descriptions of the CTD stations.

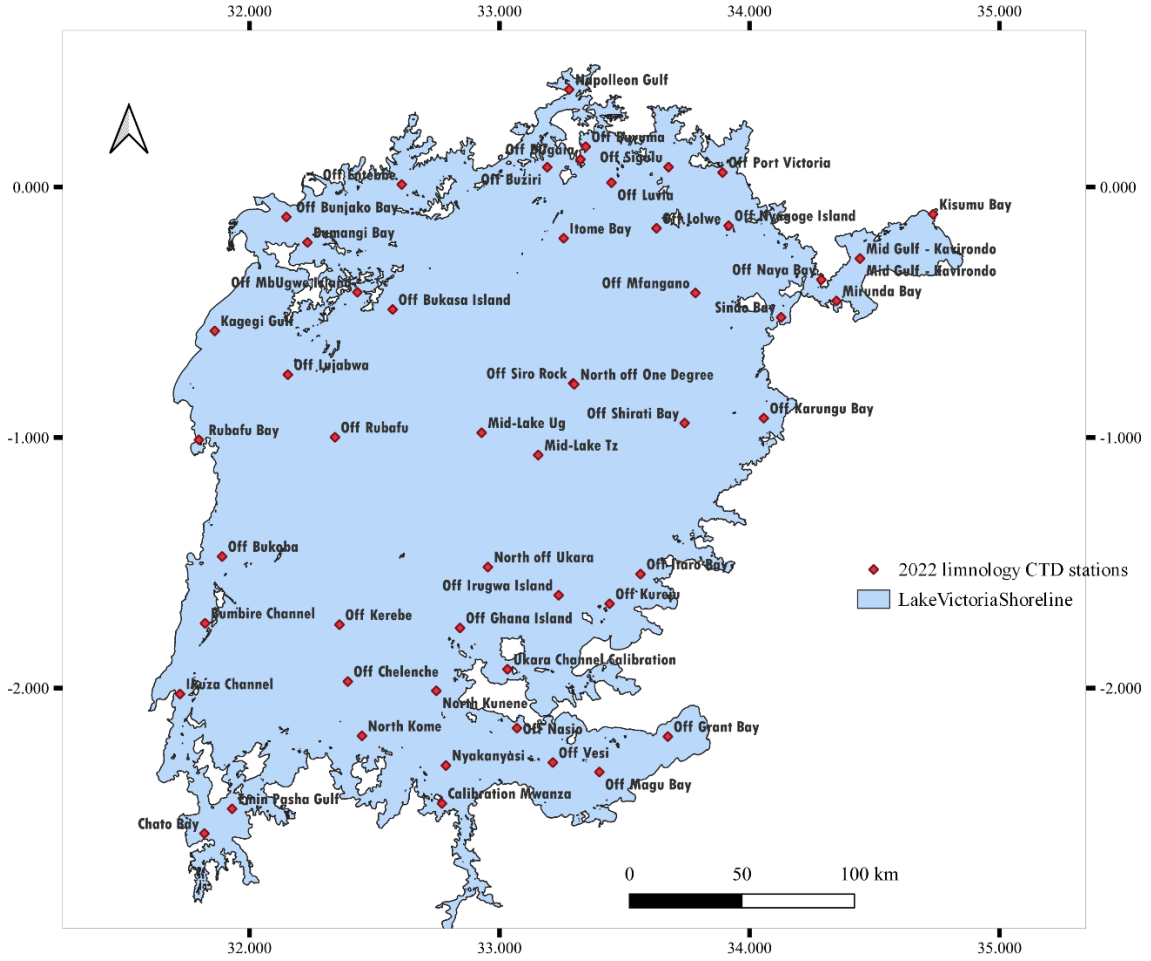

Fig. 1. Map of Lake Victoria showing the CTD stations, October- November 2022

Water environmental attributes were measured using standard methods for aquatic environmental studies (APHA, 2012). The vertical profile data of the water's physical and chemical parameters was logged using a depth-profiling system (CTD). Prior to the survey, the probe was calibrated by running analytical tests on sample waters for pH, DO, and turbidity and comparing the results to sensor logged values. Corrective calibration was then performed as needed. Temperature measurements were calibrated by comparing them to readings from different thermometric instruments on the same samples of water, and the mean deviation of temperature values was noted for future correction of field measured data. To prevent instrument malfunction, the instrument was serviced on a regular basis by clearing clogging debris from the conduits and pump orifices.

The main parameters which were measured and logged by the instrument are temperature= Temp (^{o}C), Dissolved Oxygen = DO (mgL^{-1}), water conductivity = Cond (µScm^{-1}), water turbidity = Turb (NTU), chlorophyll-a (ugL^{-1}), pH, salinity (PSU), Photosynthetically Active Radiation = PAR (nm), sound speed (ms^{-1}) and total depth (m).

Water transparency was measured as Secchi depth using a standard Secchi disc and standard procedures. CTD station locations (GPS Coordinates) were logged on a smartphone-phone phone application-based GPS system, Maps. Me, and compared to those displayed on the RV Explorer's on-board GPS and echo-sounder system. The habitat characteristics and

weather conditions at the CTD stations were detailed in a descriptive statement, which was used for data analysis and interpretation.

All data was compiled into comprehensive electronic datasheets, and the main summaries and statistical computing were completed with the R programming language (R Core team 2022), while GIS mapping and spatial visualization were completed with QGIS. The GIS base maps were obtained from Hamilton et al (2017).

K-means clustering analysis was performed to determine the possible associations between CTD stations in terms of their individual unique physico-chemical attributes based on the parameters temperature (^oC), Dissolved Oxygen (mgL^{-1}), water conductivity (μScm^{-1}), water turbidity (NTU), chlorophyll-a (ugL^{-1}), Photosynthetically Active Radiation (nm) and sound speed (ms^{-1}). The k- means clustering was performed in R by first determining the best number of clusters were estimated by optimum average silhouette and elbow analyses. Further the CTD stations were then grouped according to their respective clusters based on the centroid means.

RESULTS AND DISCUSSION

The results are presented in tables and figures that summarize all data points for each parameter by geographically delineated areas such as quadrants, strata, and special regions, as well as the depth strata and country boundary-derived acoustics regions of the lake, while focusing on the sites with notable physical, chemical, and biochemical properties. The parameters whose summaries are presented and graphically depicted are temperature= Temp (^oC), Dissolved Oxygen = DO (mgL^{-1}), water conductivity = Cond (μScm^{-1}), water turbidity = Turb (NTU), chlorophyll-a (ugL^{-1}), pH, salinity (PSU), Photosynthetically Active Radiation = PAR (nm), sound speed (ms^{-1}) and total depth (m).

Non- homogeneity of the Lake Victoria waters based on K-means cluster partitioning

The results of the k-means clustering showed that the data would cluster optimally in 2 clusters based on the considered parameters of temperature (^oC), Dissolved Oxygen (mgL^{-1}), water conductivity (μScm^{-1}), water turbidity (NTU), chlorophyll-a (ugL^{-1}), Photosynthetically Active Radiation (nm) and sound speed (ms^{-1}). Table 1 shows the cluster means for the 2 clusters woth a fit (Within cluster sum of squares by cluster) of between SS / total SS = 72.7 %.

Table 1: Cluster means for the CTD stations based on k-means of temperature (^oC), Dissolved Oxygen (mgL^{-1}), water conductivity (μScm^{-1}), water turbidity (NTU), chlorophyll-a (ugL^{-1}), Photosynthetically Active Radiation (nm) and sound speed (ms^{-1}) and Secchi depth (m)

Cluster	**Temp (^oC)**	**Cond (μScm^{-1})**	**Turb (NTU)**	**Chlr (ugL^{-1})**	**PAR (nm)**	**Sound (ms^{-1})**	**DO (mgL^{-1})**	**SD (m)**
1	25.47	99.31	0.76	1.18	866.01	1499.13	5.44	4.71
2	25.33	104.16	3.38	6.98	150.69	1498.71	5.65	2.05

Overall limnological conditions of the lake

Analysis of the observations from 56 CTD stations indicates a one-way ANOVA significant difference in temperatures among the quadrants ($p<0.05$) while a two-way ANOVA of temperatures between Quadrant and Strata also showed significant differences. Further examination of the temperature data reveals widespread active thermal stratification patterns, most notably in the Northwestern sites especially in the inshore and coastal stations. This was also evident in the dissolved oxygen (DO) profiles, with instances of anoxia or DO levels below critical levels occurring at the bottom depth zones. Fish would be expected to avoid the lake bottom in such conditions. The overall temperature (lake wide mean (±SD)) was 25.03±0.85 ^{o}C and the dissolved oxygen was 5.39±0.87 mgL^{-1} (Tables 1-4). Notably, these are not significant deviations from the previous year's (2021) temperatures and dissolved oxygen levels of 25.30±0.90 ^{o}C and .26±1.90 mgL^{-1}, respectively. However, it is important to note the slight increase in temperature and the slight drop in mean DO, which are consistent with recent decadal trends of limnological conditions (temperature and DO) indicating that the lake has been warming up with a corresponding drop in dissolved oxygen over the last decade, a possible response to global climate change and local anthropogenic stress. Most CTD stations had dissolved oxygen levels above 5 mgL^{-1} throughout the water column, but there were drastic shifts in concentrations down the column due to the apparent stratification (Figures 2-20).

Spatial variations in temperature by quadrant and strata

The Northeast (NE) quadrant was the warmest of the four quadrants, with a mean (±SD) temperature of 25.38±0.97+C (Table 2). The Northeast (SE), which had previously been the warmest quadrant, recorded a mean temperature of 25.32±0.66 ^{o}C. These observations suggest that the eastern zone of the lake remains the warmest, possibly because it has the greatest coverage of shallower depths and is associated with a higher proportion of influent waters from terrestrial drainage than the western parts. Mean temperatures of 24.69±0.72 ^{o}C were recorded within the Southwest quadrant. The Northwest remained the coldest, at 24.40±0.41 ^{o}C.

A comparison of the depth delineated strata and the special ecological areas revealed that the latter were the warmest, with Nyanza gulf retaining the warmest conditions and stable temperatures at 26.79±1.02 ^{o}C. Emin Pasha, and Speke Gulf recorded temperatures of 25.73±0.91 ^{o}C and 25.99±0.83 ^{o}C, respectively. The coldest waters were found in the Sesse Islands, which measured 24.44±0.02 ^{o}C, while the deep strata recorded 24.75±0.66 ^{o}C.

Inshore areas were the warmest among the water depth delineated strata, with mean temperatures of 24.92±0.91 ^{o}C which is consistent with the expectation that shallower areas would have the coldest waters due to maximized effect of irradiation and exposure to warmer terrestrial inflows as well as reduced retention times.

Spatial variations in dissolved oxygen (DO) by quadrants and strata

This year recorded a further oxygen fluctuation with the lake-wide mean Dissolved Oxygen (DO) of 5.39±0.87 mgL^{-1} compared to the previous year's 5.26±1.90 mgL^{-1}. The oxygen depletion was more pronounced within the Nyanza Gulf thereby making it to register the lowest column mean DO of 4.78±0.42 mgL^{-1}, which was a drastic fall from the 6.410.94 mgL^{-1} registered the previous year. This apparent oxygen depleted waters also reflect in the summary

of the data by Lake Victoria acoustic regions and quadrants, whereby the Northeastern areas of the lake registered the lowest DO with an indication of a general downward trend from the previous year (Table 1).

A comparison of the spatial trends by quadrants reveals that the Northwest remained the sector with the highest DO levels with a mean of 5.79±0.53 mgL^{-1}, followed by the Southeast with 5.52±0.73 mgL^{-1}, the Northeast 5.36±0.72 mgL^{-1} and the Southwest at 5.13±1.11 mgL^{-1} (Table 2). Due to its relative shallowest depth that would facilitate rapid mixing, it would be expected that the NE would have the highest DO levels, but the data suggests otherwise. This could be explained by the prevalence of eutrophication associated and potential oxygen depleting human activities within this sector of the lake, whose immediate impact is noticeable in the enhanced chlorophyll a levels and high phytogenic turbidity. Notable examples of these possible culprits are the expansive oil palm farms within the Sesse Islands as well as the proliferate fish cage farms within the Kenyan portion of the lake.

In descending order, the mean (SD) DO recorded within the depth strata and special regions were: Coastal (5.61±0.69mgL^{-1}), Inshore (5.58±0.81 mgL^{-1}), Speke gulf (5.37±0.49 mgL^{-1}), Emin Persha (5.28±0.55 mgL^{-1}), Sesse Islands (5.25±0.29 mgL^{-1}), Deep (5.01±1.10 mgL^{-1}) , Coastal (mgL^{-1}), and Nyanza gulf (4.78±0.42 mgL^{-1}) (Table 3). The pronounced oxygen depletion at the profundal depths registered in the previous year had apparently improved.

The gulfs and special regions had higher DO concentrations of 4.78±0.42 mgL^{-1}, 5.28±0.55 mgL^{-1}, 5.37±0.49 mgL^{-1}, and 5.25±0.29 mgL^{-1}, respectively, for Nyanza Gulf, Emin Persha, Speke Gulf, and Sesse Islands. This indicates that after Nyanza gulf, the deep strata were the most oxygen-depleted parts of the lake (Table 4).

Table 1. Mean (±SD) physical, chemical and biochemical attributes of water column compared among regions (strata defined by quadrants and countries). Temperature= Temp (°C), Dissolved Oxygen = DO(mgL^{-1}), Water conductivity = Cond (μScm^{-1}), Turbidity = Turb (NTU), Chlorophyll-a (ugL^{-1}), pH, Salinity (PSU), Photosynthetically Active Radiation = PAR (nm), Sound speed (ms^{-1}), Secchi depth (m) and Total depth (m).

Region	Temp (°C)	DO (mgL^{-1})	Cond (μScm^{-1})	Turb (NTU)	Chlorophyll (ugL^{-1})	pH	Salinity (PSU)	PAR	Sound speed (ms^{-1})	Secchi depth (m)	Total depth (m)
KeNECoastal	25.26±0.41	5.22±0.50	104.24±5.15	1.75±3.16	1.56±1.02	8.45±0.26	0.05±0.00	19.55±51.31	1498.83±1.09	2.17±0.64	34.00±4.24
KeNENyanzaGulf	26.79±1.02	4.78±0.42	143.87±19.24	16.37±6.59	13.95±19.02	8.02±0.18	0.07±0.01	4.74±16.95	1502.71±2.67	0.71±0.38	6.35±2.50
TzSECoastal	25.25±0.60	5.44±0.72	98.47±3.47	0.55±1.03	1.27±1.39	8.30±0.32	0.05±0.00	25.13±98.01	1498.95±1.48	2.74±0.77	50.75±15.55
TzSEDeep	24.87±0.16	5.34±0.65	93.53±1.90	0.44±0.29	0.48±0.50	8.09±0.28	0.05±0.00	36.81±131.43	1498.06±0.25	32.20±0	77.00±0
TzSEInshore	25.80±0.67	6.29±0.57	107.46±7.07	1.21±1.38	2.60±0.80	8.71±0.10	0.05±0.00	55.36±129.48	1500.18±1.76	2.24±0.43	25.00±8.89
TzSESpekeGulf	25.99±0.83	5.37±0.49	106.37±2.11	2.25±0.82	2.83±1.11	8.33±0.10	0.05±0.00	46.66±125.92	1500.68±2.17	1.85±0.37	22.35±6.15
TzSWCoastal	24.46±0.45	5.73±0.69	98.44±3.54	0.58±1.43	1.23±0.41	8.14±0.16	0.05±0.00	14.73±62.34	1496.78±1.28	3.66±0.25	59.83±4.92
TzSWDeep	24.45±0.42	4.56±1.29	97.00±1.91	0.15±0.16	0.62±0.62	7.84±0.45	0.05±0.00	25.67±106.32	1496.92±1.01	3.84±0.10	59.35±13.22
TzSWEminPasha	25.73±0.91	5.28±0.55	105.22±5.40	1.87±4.41	4.92±1.58	8.62±0.34	0.05±0.00	20.97±71.35	1500.00±2.51	1.50±0.36	20.21±9.54
TzSWInshore	25.16±0.85	5.42±0.65	103.67±8.14	1.04±5.78	2.16±1.53	7.83±0.65	0.05±0.00	49.43±162.18	1498.51±2.33	2.76±1.39	29.09±20.00
UgNECoastal	25.50±0.66	5.93±0.60	100.92±2.81	0.35±0.30	1.55±1.23	8.39±0.42	0.05±0.00	9.17±36.48	1499.54±1.86	1.86±0.10	40.67±18.15
UgNEDeep	25.36±0.81	5.42±0.70	99.34±2.45	2.02±3.59	0.74±0.66	8.22±0.31	0.05±0.00	9.62±44.83	1499.31±2.17	2.49±0.56	61.00±9.00
UgNEInshore	24.77±0.83	5.05±0.61	96.19±7.83	1.17±1.06	1.95±0.90	8.40±0.18	0.05±0.00	24.65±67.31	1497.42±2.27	2.14±0.45	25.33±10.07
UgNWCoastal	24.58±0.45	5.70±0.36	93.63±6.56	1.01±0.77	1.79±1.00	8.21±0.33	0.05±0.00	33.93±149.77	1497.07±1.31	2.45±0.37	46.98±13.83
UgNWDeep	24.35±0.08	5.60±0.35	94.66±0.64	0.61±0.23	0.83±0.62	8.10±0.23	0.05±0.00	4.10±14.68	1496.59±0.24	3.29±0	69.00±0
UgNWInshore	24.20±0.53	6.38±0.40	94.99±2.06	2.80±1.85	4.43±1.68	8.71±0.19	0.05±0.00	10.27±19.47	1495.73±1.50	1.63±0.30	15.25±6.08
UgNWSesseIslands	24.44±0.02	5.25±0.29	95.29±0.20	1.92±4.31	2.51±1.63	8.17±0.21	0.05±0.00	7.36±23.85	1496.59±0.14	2.21±	34.73±0
Lakewide	25.03±0.85	5.39±0.87	100.21±10.41	1.47±3.75	2.06±4.48	8.23±0.41	0.05±0.00	22.36±90.09	1498.30±2.25	2.82±4.25	35.85±21.09

The water column profiles of dissolved oxygen are visualized alongside those of temperatures in figures (Fig. 2-8).

Water salinity of Lake Victoria remained generally unchanged with a lake-wide mean of 0.05±0.01 PSU. Other physical chemical parameters like conductivity, turbidity, Secchi depth and Chlorophyll-*a* followed such sporadic patterns.

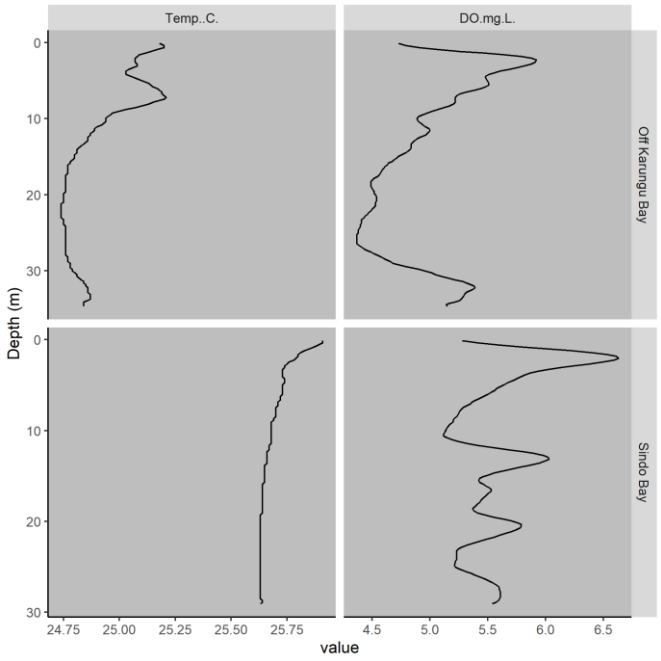

Fig. 2. Temperature and Dissolved oxygen (DO) profiles within the KeNECoastal CTD stations

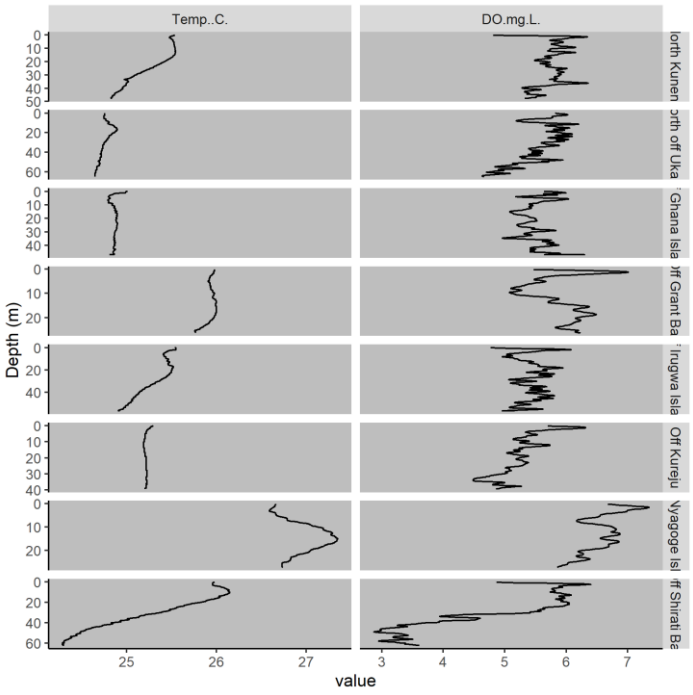

Fig. 4. Temperature and Dissolved oxygen (DO) profiles within the TzSECoastal CTD stations

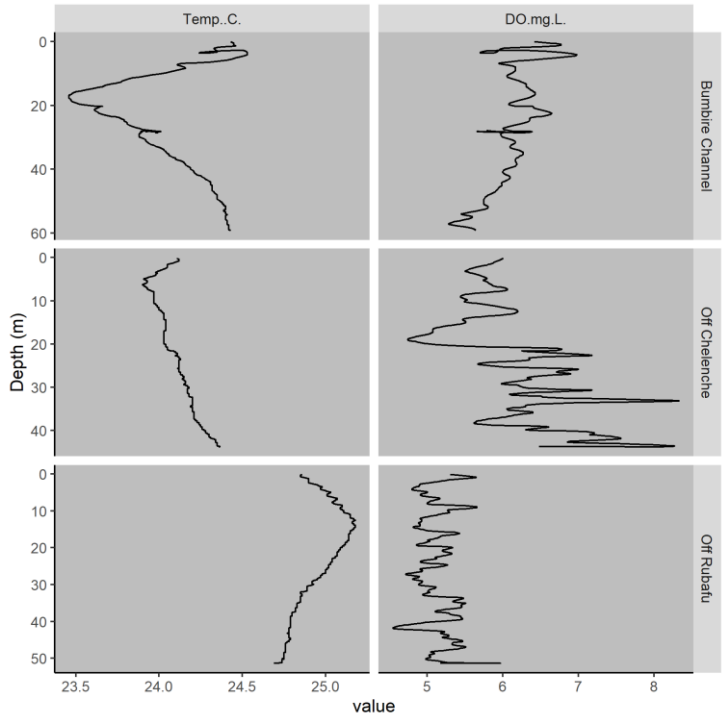

Fig. 6. Temperature and Dissolved oxygen (DO) profiles within the TzSWCoastal CTD stations

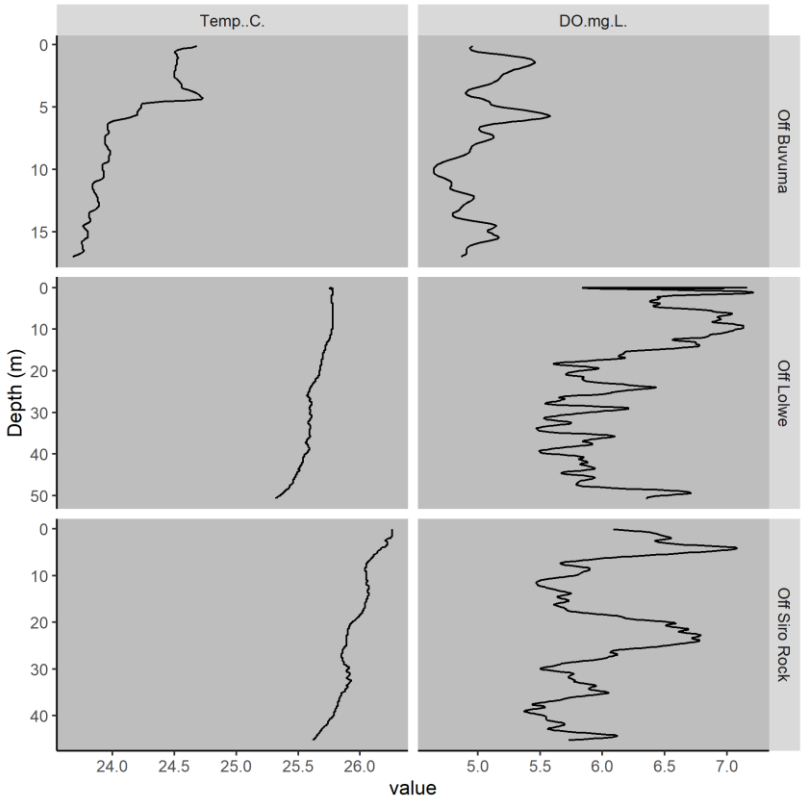

Fig. 7. Temperature and Dissolved Oxygen (DO) profiles within the UgNECoastal.

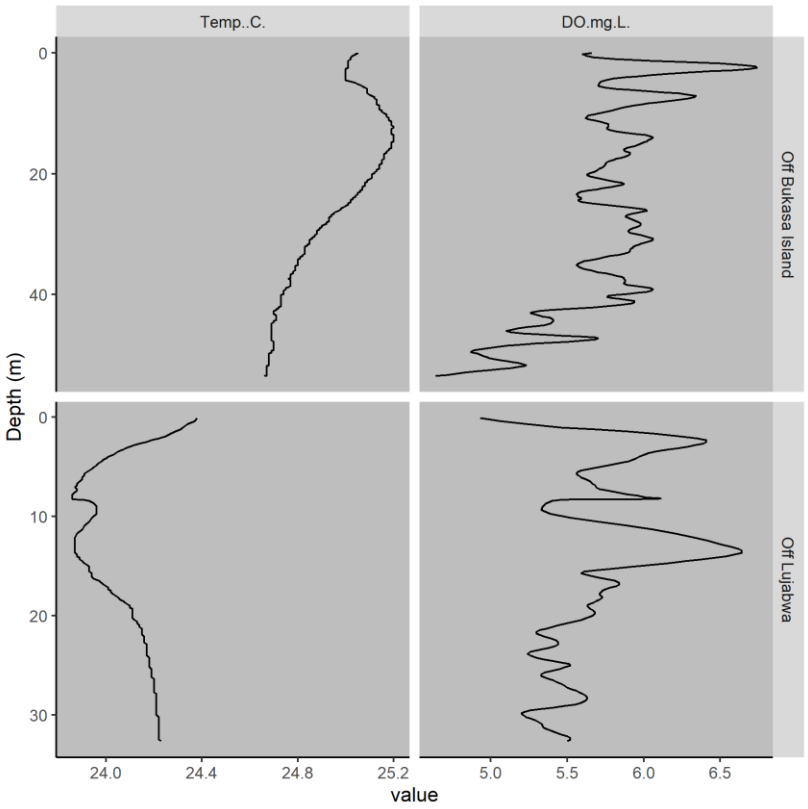

Fig. 8. Temperature and Dissolved oxygen (DO) profiles within the UgNWCoastal stations

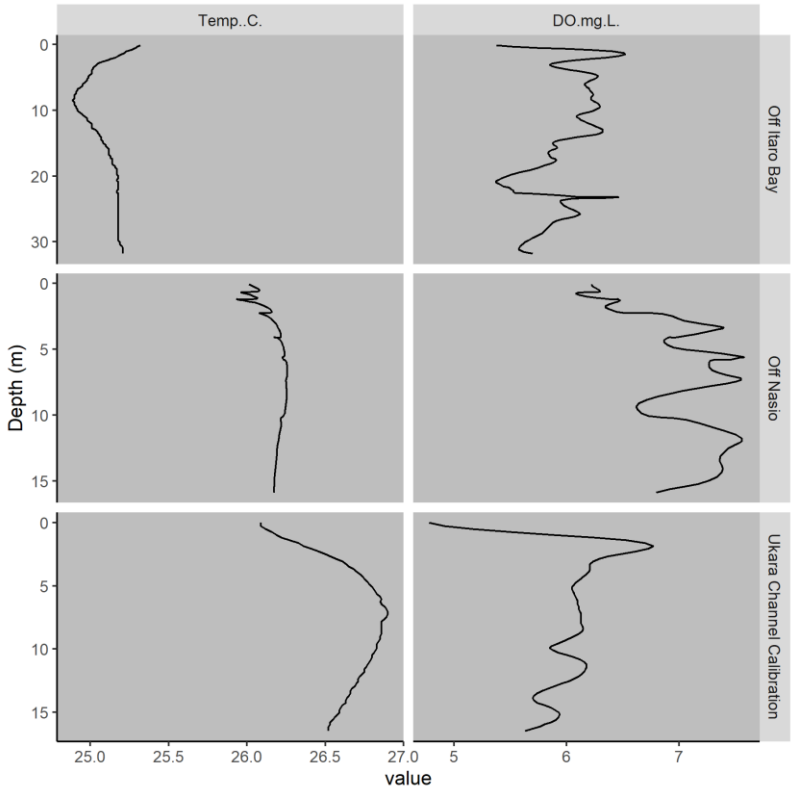

Fig. 9. Temperature and Dissolved oxygen (DO) profiles within the TzSEInshore stations

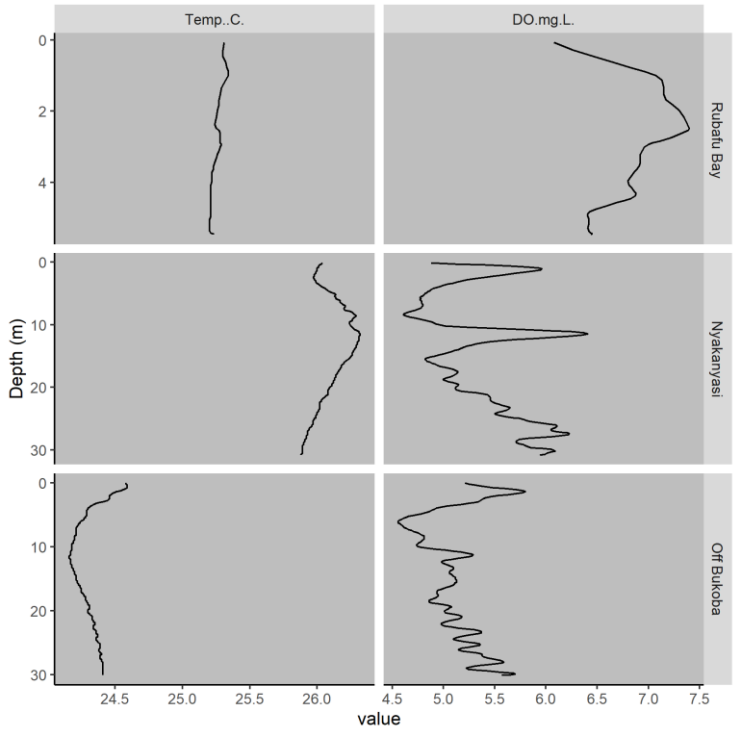

Fig. 10. Temperature and Dissolved oxygen (DO) profiles within the TzSWInshore stations

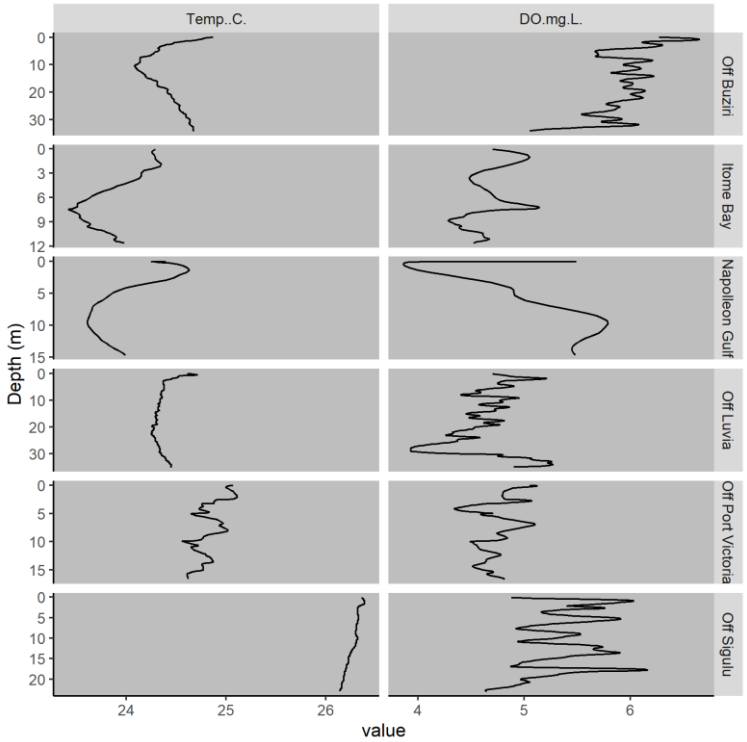

Fig.11. Temperature and Dissolved oxygen (DO) profiles within the UgNEInshore stations

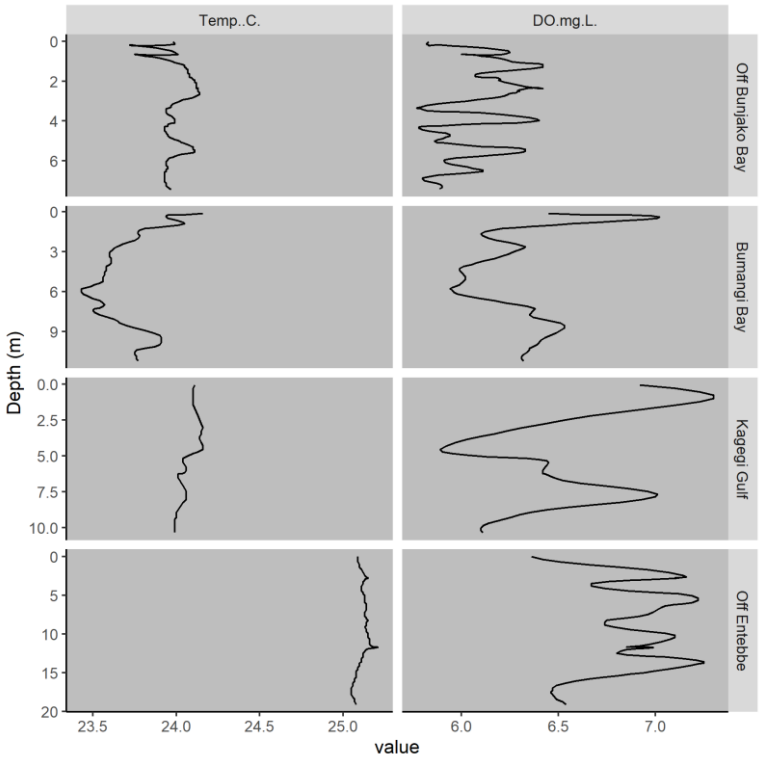

Fig. 12. Temperature and Dissolved oxygen (DO) profiles within the UgNWInshore stations

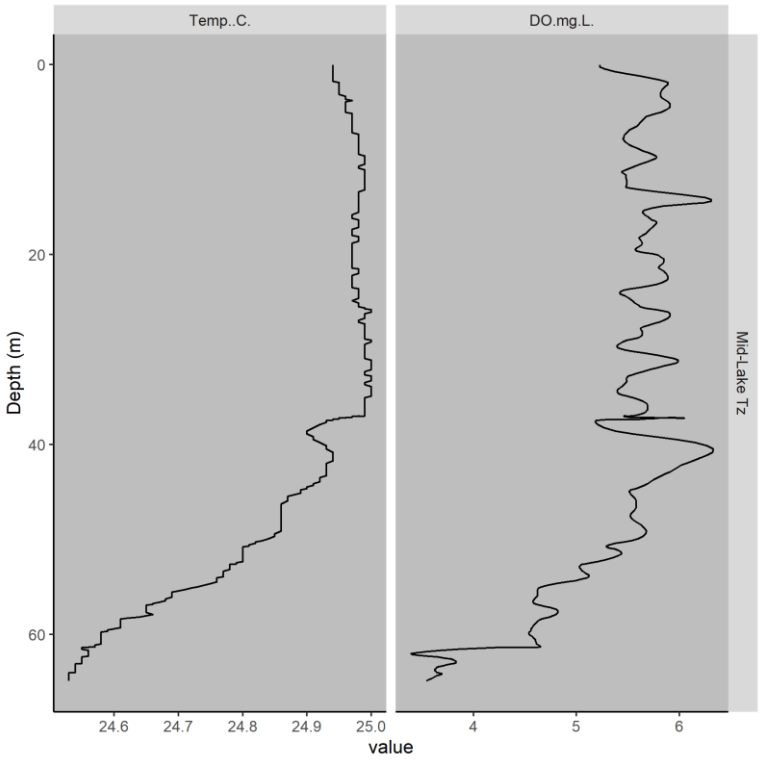

Fig. 13. Temperature and Dissolved oxygen (DO) profiles within the TzSEDeeep stations

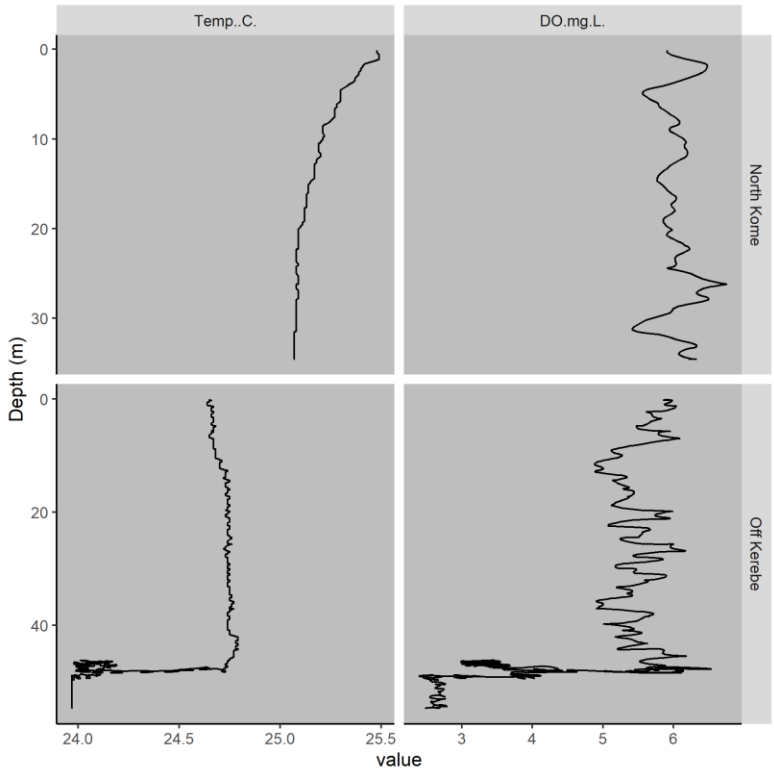

Fig. 14. Temperature and Dissolved oxygen (DO) profiles within the TzSWDeeep stations

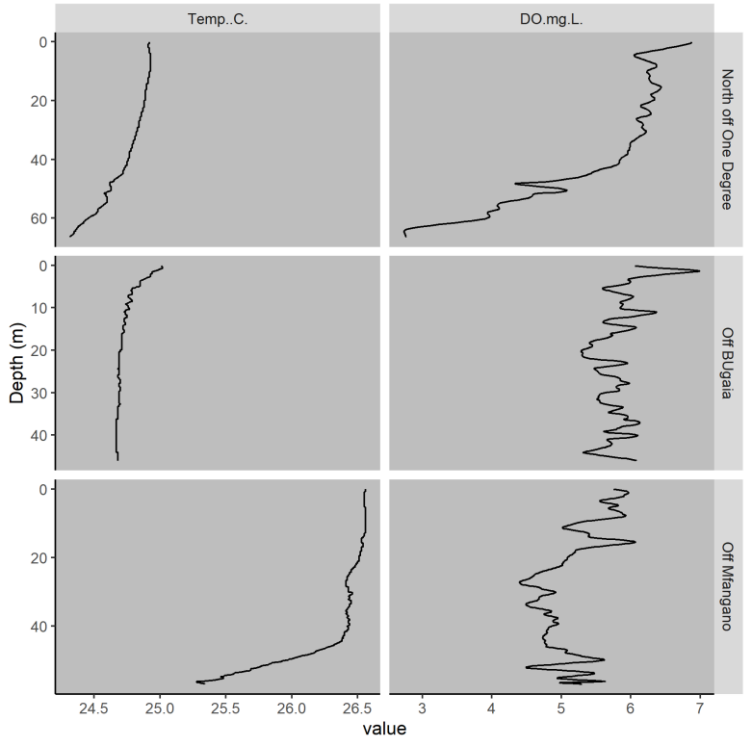

Fig. 15. Temperature and Dissolved oxygen (DO) profiles within the UgNEDeeep stations

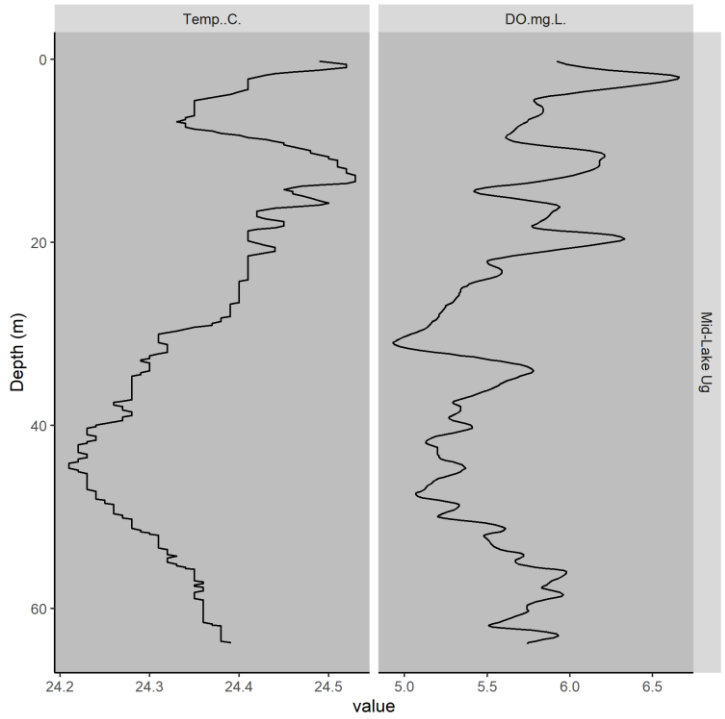

Fig. 16. Temperature and Dissolved oxygen (DO) profiles within the UgNWDeeep stations

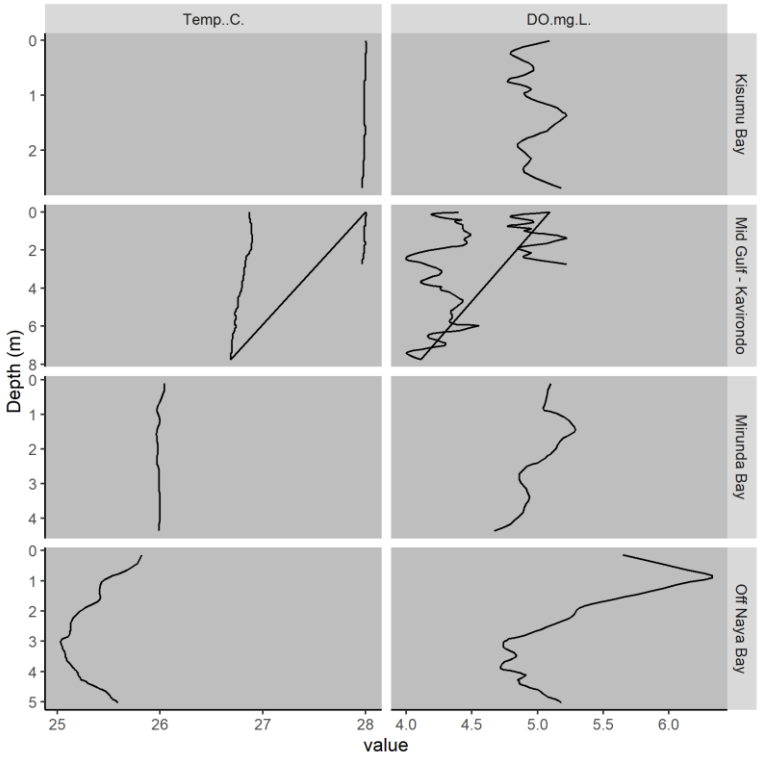

Fig. 17. Temperature and Dissolved oxygen (DO) profiles within the KeNENyanza Gulf stations

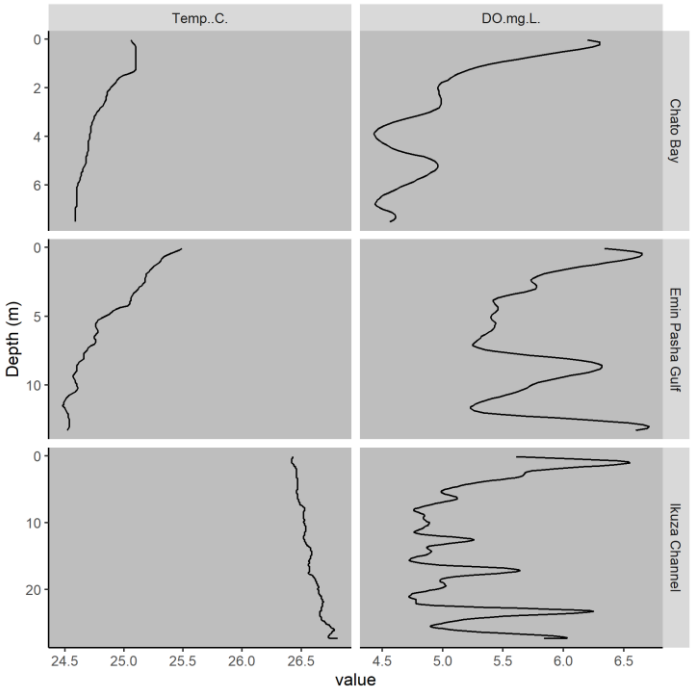

Fig. 18. Temperature and Dissolved oxygen (DO) profiles within the TzSWEmin Pasaha stations

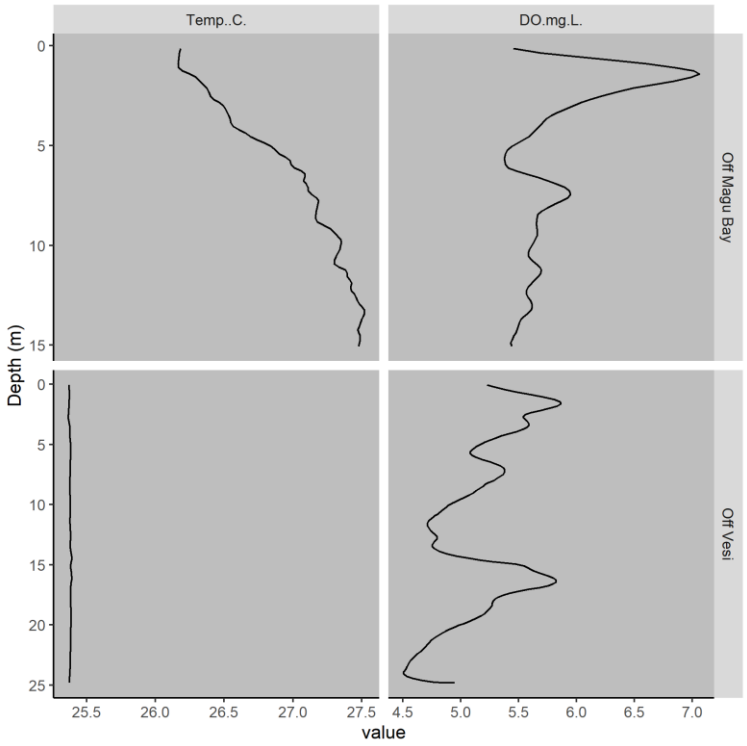

Fig. 19. Temperature and Dissolved oxygen (DO) profiles within the TzSESpekeGulf stations

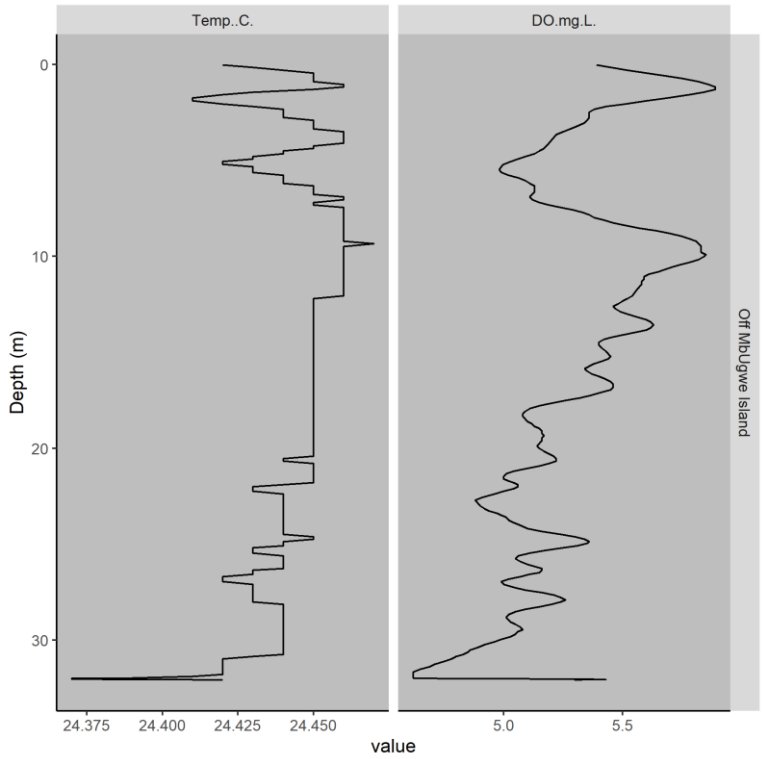

Fig. 20. Temperature and Dissolved oxygen (DO) profiles within the UgNWSseseIslands stations

Following evidence of widespread thermal stratification and the occurrence of oxygen-depleted waters within the coastal and inshore areas, most pelagic fish and crustaceans are expected to be found high above the lake bottom (pelagic zone). Furthermore, fish abundances would be lower in areas of the lake that recorded low to near anoxia. Such near anoxic conditions were only recorded in a few deep strata stations. Oxygen depletion may have developed as a result of a sustained anthropogenic input of oxygen-depleting and generally toxic compounds into the water, such as agriculturally derived nutrient over-enrichment, which is evident in the PAR, chlorophyl-a and turbidity data.

Evidence of eutrophication was also found in Ugandan waters near Napoleon Gulf, Ssese Islands, Murchison Bay, and further north around Sigulu and Sumba Islands. The Nyanza gulf and areas around Mfangano islands were also affected, with dense algal blooms exacerbating the stratification-driven anoxia. The presence of eutrophic conditions in the Rusinga Channel and elsewhere on Mfangano island could easily be linked to the presence and rapid expansion of caged fish farms in the area.

Spatial Variation in Chlorophyll-a by quadrant and strata

This year, a fluctuation was observed in the lakewide mean chlorophyll levels, which amounted to 2.06±4.48 ugL^{-1}, compared to the previous year's mean of 1.62±1.47 ugL^{-1}. A comprehensive examination of the spatial trends by quadrants uncovered that the Northeast quadrant exhibited the highest chlorophyll levels, with a mean of 2.93±7.71 ugL^{-1}, followed by the Northwest quadrant with 2.44±1.87 ugL^{-1}. Conversely, the Southeast quadrant showed the lowest chlorophyll levels of 1.46±1.40 ugL^{-1}. Additionally, a comparison between the depth delineated

strata and the special ecological areas revealed that the Nyanza gulf maintained the highest levels at 13.95±19.02 ugL^{-1}, representing a slight increase from the previous year's 8.73±5.51 ugL^{-1}.

Spatial Variation in Conductivity by quadrant and strata

This year there was a slight increase in the lakewide mean conductivity, which stood at 100.21 ±10.41 μScm^{-1}, as compared to the previous year's mean of 98.20 ±7.52 μScm^{-1}. Upon analyzing the spatial distribution of conductivity by quadrants, it was observed that the Northeast quadrant had the highest conductivity levels, with a mean of 104.30 ±16.43 μScm^{-1}, while the North West quadrant had the lowest levels at 94.54 ±3.93 μScm^{-1}. Additionally, upon examining the special ecological areas, Nyanza Gulf recorded the highest conductivity levels of 143.87 ±19.24 μScm^{-1}, followed by Emin Persha at 105.22 ±5.40 μScm^{-1}. The observed high conductivity levels in these areas correspond to the trend observed in the chlorophyll-a levels and may be attributed to the same underlying reasons.

Spatial Variation in Turbidity by quadrant and strata

The lakewide mean turbidity showed a slight decline this year, amounting to 1.47 ±3.75 FTU, as compared to the previous year's mean of 1.69 ±3.13 FTU. Upon examining the spatial distribution of turbidity by quadrants, the Northeast quadrant exhibited the highest levels, with a mean of 2.94 ±5.72 FTU. Furthermore, upon analyzing the special ecological regions, Nyanza Gulf recorded the highest turbidity levels at 16.37±6.59 FTU, followed by Speke Gulf at 2.25±0.82 FTU. In contrast, the coastal areas showed the lowest turbidity levels, with a mean of 0.64 ±1.30 FTU.

Spatial Variation in PAR by quadrant and strata

The lakewide mean Photosynthetically Active Radiation (PAR) was recorded at 22.36 ±90.09 nm. The South East quadrant exhibited the highest PAR levels of 31.61±109.28 nm, whereas the North East quadrant recorded the lowest levels of 14.14 ±49.68 nm. An examination of the data from the special ecological areas revealed that the Speke Gulf had the highest PAR levels of 46.66125.92 nm, while the Nyanza Gulf had the lowest levels of 4.7416.95 nm. However, no significant difference in PAR levels was observed between the coastal and deep areas, which recorded a mean of 20.40 87.56 nm and 20.39 91.87 nm, respectively.

Table 2. Mean (±SD) physical, chemical and biochemical attributes of water column compared among quadrants. Temperature= Temp (°C), Dissolved Oxygen = DO (mgL^{-1}), Water conductivity = Cond (μScm^{-1}), Turbidity = Turb (NTU), Chlorophyll-a (ugL^{-1}), pH, Salinity (PSU), Photosynthetically Active Radiation = PAR (nm), Sound speed (ms^{-1}), Secchi depth (m) and Total depth (m).

Quadrant	Temp (°C)	DO (mgL^{-1})	Cond (μScm^{-1})	Turb (FTU)	Chlorophyll (ugL^{-1})	pH	Salinity (PSU)	PAR	Sound speed (ms^{-1})	Secchi depth (m)	Total depth (m)
NE	25.38±0.97	5.36±0.72	104.30±16.43	2.94±5.72	2.93±7.71	8.31±0.33	0.05±0.01	14.14±49.68	1499.17±2.61	1.78±0.78	29.30±20.47
NW	24.40±0.41	5.79±0.53	94.54±3.93	1.58±2.27	2.44±1.87	8.32±0.36	0.05±0.00	15.89±86.89	1496.50±1.21	2.11±0.65	32.34±21.54
SE	25.32±0.66	5.52±0.73	99.44±5.53	0.74±1.11	1.46±1.40	8.33±0.32	0.05±0.00	31.61±109.28	1499.10±1.64	4.61±7.97	43.05±20.29
SW	24.69±0.72	5.13±1.11	99.27±5.16	0.61±2.72	1.56±1.63	8.02±0.48	0.05±0.00	24.76±101.48	1497.44±1.88	2.86±1.17	40.55±21.59
Lakewide	25.03±0.85	5.39±0.87	100.21±10.41	1.47±3.75	2.06±4.48	8.23±0.41	0.05±0.00	22.36±90.09	1498.30±2.25	2.82±4.25	35.85±21.09

Table 3. Mean (±SD) physical and chemical attributes of water column compared among countries. Temperature= Temp (°C), Dissolved Oxygen = DO(mgL^{-1}), Water conductivity = Cond (μScm^{-1}), Turbidity = Turb (NTU), Chlorophyll-a (ugL^{-1}), pH, Salinity (PSU), Photosynthetically Active Radiation = PAR (nm), Sound speed (ms^{-1}), Secchi depth (m) and Total depth (m).

Country	Temp (°C)	DO (mgL^{-1})	Cond (μScm^{-1})	Turb (FTU)	Chlorophyll (ugL^{-1})	pH	Salinity (PSU)	PAR	Sound speed (ms^{-1})	Secchi depth (m)	Total de (m)
Ke	26.13±1.11	4.97±0.51	126.75±24.65	10.06±9.03	8.66±15.66	8.21±0.30	0.06±0.01	11.14±36.78	1501.04±2.88	1.12±0.82	14.25±13
Tz	25.00±0.76	5.32±0.97	99.35±5.34	0.67±2.09	1.51±1.53	8.17±0.44	0.05±0.00	28.07±105.37	1498.24±1.95	3.84±5.98	41.95±20
Ug	24.92±0.81	5.57±0.69	97.28±5.41	1.31±2.23	1.80±1.49	8.33±0.34	0.05±0.00	15.23±66.41	1497.94±2.26	2.14±0.52	35.78±19
Lakewide	25.03±0.85	5.39±0.87	100.21±10.41	1.47±3.75	2.06±4.48	8.23±0.41	0.05±0.00	22.36±90.09	1498.30±2.25	2.82±4.25	35.85±21.

Table 4. Mean (±SD) physical, chemical and biochemical attributes of water column compared among strata. Temperature= Temp (^oC), Dissolved Oxygen = DO (mgL^{-1}), Water conductivity = Cond (μScm^{-1}), Turbidity = Turb (NTU), Chlorophyll-a (ugL^{-1}), pH, Salinity (PSU), Photosynthetically Active Radiation = PAR (nm), Sound speed (ms^{-1}), Secchi depth (m) and Total depth (m).

Strata	Temp (^oC)	DO (mgL^{-1})	Cond (μScm^{-1})	Turb (FTU)	Chlorophyll (ugL^{-1})	pH	Salinity (PSU)	PAR	Sound speed (ms^{-1})	Secchi depth (m)	Total depth (m)
C	25.06±0.68	5.61±0.69	98.80±4.51	0.641.30±	1.38±1.16	8.28±0.33	0.05±0.00	20.40±87.56	1498.40±1.83	2.65±0.78	48.30±14.64
D	24.75±0.66	5.01±1.10	96.93±2.76	0.77±2.07	0.66±0.63	8.00±0.41	0.05±0.00	20.39±91.87	1497.68±1.72	7.24±11.03	63.96±10.01
EP	25.73±0.91	5.28±0.55	105.22±5.40	1.87±4.41	4.92±1.58	8.62±0.34	0.05±0.00	20.97±71.35	1500.00±2.51	1.50±0.36	20.21±9.54
I	24.92±0.91	5.58±0.81	99.33±8.51	1.46±2.85	2.56±1.51	8.39±0.45	0.05±0.00	32.05±102.06	1497.78±2.49	2.15±0.72	23.45±11.46
NG	26.79±1.02	4.78±0.42	143.87±19.24	16.37±6.59	13.95±19.02	8.02±0.18	0.07±0.01	4.74±16.95	1502.71±2.67	0.71±0.38	6.35±2.50
SG	25.99±0.83	5.37±0.49	106.37±2.11	2.25±0.82	2.83±1.11	8.33±0.10	0.05±0.00	46.66±125.92	1500.68±2.17	1.85±0.37	22.35±6.15
SI	24.44±0.02	5.25±0.29	95.29±0.20	1.92±4.31	2.51±1.63	8.17±0.21	0.05±0.00	7.36±23.85	1496.59±0.14	2.21±0	34.73±0
Lakewide	25.03±0.85	5.39±0.87	100.21±10.41	1.47±3.75	2.06±4.48	8.23±0.41	0.05±0.00	22.36±90.09	1498.30±2.25	2.82±4.25	35.85±21.09

CONCLUSION AND RECOMMENDATIONS

As a result, this study observes a continuum of occurrence of dramatic stratification patterns in most regions. More fish occurrence in the pelagic zones is thus highly predicted prior to a catastrophic overturn event where widespread anoxia due to rapid column mixing column may cause fish deaths. There is immense evidence of eutrophication and potential DO depleting conditions resultant from adverse human catchment and off-shore practices. Deliberate efforts should be made to address negative catchment-based impacts, thereby providing long-term solutions to eutrophication problems.

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