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SHIFT IN SIZE AT FIRST MATURITY OF NILE PERCH (*LATES NILOTICUS*) IN LAKE VICTORIA

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ABSTRACT

Nile perch (*Lates niloticus*) in Lake Victoria plays a critical role as it provides resources for millions of people in Tanzania, Uganda, and Kenya. Concerns about the sustainability of fisheries have emerged because of fluctuations in catch rates and changes in population structure. This study investigates whether the size at which Nile Perch reaches maturity (L50) has changed over the years and whether it is linked to overall stock size. The regional acoustic survey data collected between 2015 and 2022 were analysed using R. The analysis revealed a significant decrease ($p < 0.05$) in the size at maturity (L50) for Nile perch, with females maturing at a larger size (46.9 cm total length) compared to males (41.6 cm total length). This indicates the potential threats to fishery sustainability and lake ecosystems. Additionally, L50 differed significantly ($p < 0.05$) between the quadrants of the lake. Areas with a higher estimated biomass had larger L50 values, suggesting a potential link between food competition and maturity patterns. The study also found a larger Nile perch concentrated in the middle and along the coastline, suggesting that these areas provide better growth conditions. The observed decrease in the L50 highlights the need for further research to understand the causes and potential consequences for the fishery and lake ecosystems.

Keywords: Lake Victoria, Nile perch, Size at maturity, Acoustic survey, Quadrants.

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1 INTRODUCTION

1.1 Background Information

Lake Victoria is the largest lake in Africa, with a surface area of 68,800 km^2, and the second-largest lake in the world. The lake supports the largest inland fisheries in Africa which are shared by three nations bordering it: Uganda, Kenya, and Tanzania (Natugonza et al., 2022). It also plays a pivotal role in providing other essential ecosystem services to the three countries, including supplying water for domestic and industrial needs, facilitating transport, hydropower generation, and providing food/protein for over 42 million people (Nyamweya et al., 2020). Furthermore, its fisheries contribute to employment and income and serves as a source of export earnings for countries along its shores (Njiru et al., 2018).

Lake Victoria is a tropical lake inhabited by diverse flora and fauna (Sayer et al., 2018). Despite the diverse fauna, the fishery is dominated by only four fish species: two native species, silver cyprinid (*Rastrineobola argentea*) and haplochromines, and two introduced species, Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) (Njiru et al., 2018). Nile perch was introduced in 1954 and is today the most valuable fishery because it provides the highest export earnings, with an annual value of USD 600 – 850 million (Mkuna & Baiyegunhi, 2020). In recent years, the state of Nile perch stocks in Lake Victoria has become a pressing issue. This is because of the varying catch rates between years, changes in population size structure, and the recovery of haplochromine cichlid populations, their main prey (Sayer et al., 2018). This situation poses a threat to the long-standing benefits that the lake perch fishery has provided to the three countries during the last several decades.

Studies on Nile Perch biology have suggested that size at maturity can be used as a biological indicator to track changes in stock size (Kayanda et al., 2010). The size at maturity has fluctuated since the stock was introduced into Lake Victoria. Previous studies, for the period from 1964 to 2007, suggest that perch matures at a smaller size when its population is small and that size at maturity increases with increasing population size (Kayanda et al., 2010). This study investigates changes in Nile perch size at maturity in recent years, from 2015 to 2022, and explores the effects of stock size on size at maturity.

1.2 Statement of the Problem

Nile perch was introduced to Lake Victoria in 1954 to make it a commercial fish species. The introduction was successful, and its presence greatly increased the availability of fish protein, revenue, and job opportunities for local communities (Pringle, 2005). Since then, annual catches have ranged from 150 thousand to 350 thousand metric tonnes (Kayanda et al., 2010). In recent years, concerns have arisen that fishing pressure on Nile perch stock is above sustainable levels due to the decline in catch per unit effort (Njiru et al., 2018). One of the methods used as an indicator of stock size fluctuations is size at maturity (LVFO, 2007). Previous studies on Nile perch size at maturity suggest a positive relationship between stock size and size at maturity, *that is*, a larger stock results in a larger size at maturity (Kayanda et al., 2010). The previous size at maturity was conducted before the survey index time series for Nile perch abundance began. The current study examines the relationship between annual size at maturity and the survey index, aiming to establish another index to track changes in Nile perch stock size. To ensure responsible fisheries management and effective conservation plans for Nile perch, it is crucial to investigate and understand the causes and consequences of changing size at maturity and its correlation with stock size.

1.3 Significance of the Study

This research will contribute to sustainable fishing of Nile perch in Lake Victoria by examining whether annual variability in size at maturity is correlated to a stock size index, which is calculated from hydroacoustic backscatter from Nile perch measured during an annual acoustic research survey. By understanding the relationship between Nile perch stock biomass and changes in size at maturity, this study seeks to contribute to the development of evidence-based policies and practices, fostering sustainable management approaches for Nile perch fisheries in the region. Ultimately, it aims to ensure the ongoing well-being of both the lake ecosystem and communities relying on its resources.

1.4 General Objectives

To assess whether Nile perch size at maturity in Lake Victoria varies between years from 2015 to 2022 and to research the effects of stock size on size at maturity. Furthermore, to investigate if size at maturity varies between lake quadrants within a year and if it is impacted by Nile perch density.

1.4.1 Specific Objectives

i. Determine the biomass and distribution of Nile perch in Lake Victoria from 2015 to 2022, both for the entire lake and the four quadrants of the lake.

ii. To determine the size at maturity of Nile perch in Lake Victoria for the years 2015 to 2022, both for the entire lake and the four quadrants of the lake.

iii. Examine the spatial variation of maturity stages within the four main quadrants of Lake Victoria in relation to Nile perch density.

2 LITERATURE REVIEW

2.1 Biology, Growth and Maturity of Nile perch

The Nile perch is recognised for its remarkable growth potential, ranking among the largest freshwater fish species. They exhibit rapid size increase during their early life stages. Studies have documented individuals reaching a total length (TL) of up to 200 cm (approximately 6 feet 7 inches) and attaining weights exceeding 200 kg (over 440 pounds) (Froese & Pauly, 2024). However, it is important to note that these are exceptional maximum sizes.

Furthermore, Nile perch exhibits sexual dimorphism, with females generally achieving larger body sizes than males. This distinction is crucial for the sustainability of the population, as Nile perch typically reaches sexual maturity at a smaller size than its maximum potential. This allows for reproduction to occur before reaching their full growth, ensuring the continuation of the population.

Nile perch size at maturity varies between sexes, with females maturing at a greater size than males (Kayanda et al., 2010), due to differential resource allocation. This means that females prioritise growing bigger to create more eggs and store energy reserves for reproduction, whereas males can invest more resources into earlier maturity and competing for mates.

Previous studies in Lake Victoria have shown that the size at maturity ranges from 45 cm to 93 cm for females and from 32 cm to 62 cm for males (Table 1). For comparison, the global estimate of Nile perch size at maturity is 85 cm for females and 53 cm for males (Froese and Pauly, 2024).

Table 1: Size at maturity (total length, cm) in male and female Nile perch in Lake Victoria, results from studies 1964 and 2007 (Kayanda et al., 2010).

	Females	Males	Source
1964-67	45.3	32.2	Okedi (1970)
1968-77	54.7	41.9	Ogutu-Ohwayo (2004)
1982	93.3	46.8	Ogutu-Ohwayo (2004)
1988-92	93.3	62.2	Ogutu-Ohwayo (2004)
2001	75.8	57.7	UNECIA (2001)
2007	58.0	52.5	LVFO (2007a)

Nile perch are primarily piscivorous, and their preference leans towards smaller fish species, particularly silver cyprinids such as dagaa (*Rastrineobola argentea)* and Alestes species. These smaller fish species provide a readily available and abundant source of energy for Nile perch growth. However, Nile perch is an opportunistic feeder, and its diet can vary depending on prey availability (Nyamweya et al., 2020). Smaller individuals, especially juveniles, also consume larger crustaceans and insects as they grow and their gape size increases (Yongo et al., 2018). This adaptability allows Nile perch to exploit various food resources in the lake ecosystem.

2.2 Nile perch Distribution

Nile perch inhabits various aquatic environments, including rivers, lakes, and irrigation canals (Pringle, 2005).

Nile perch exhibits variations in distribution and density throughout Lake Victoria. Their presence and density are highest in open waters at depths ranging from 10 m to 40 m, but they can be located down to a depth of 60 m in specific parts of the lake. For instance, water temperature fluctuations might cause them to seek refuge in deeper, cooler areas during warmer periods (Njiru et al., 2014). Water clarity is crucial for vision-based predation. They favour clearer waters for efficient hunting, and increased turbidity can affect their distribution. Human activities such as fishing pressure can also play a role.

The distribution and density of Nile perch varies across different quadrants (northwest, northeast, southeast, and southwest) of the lake. This variation could be attributed to several factors. Prey availability plays a major role (Taabu-Munyaho et al., 2014). If a particular quadrant experiences a surge in prey such as dagaa, Nile perch might concentrate there to capitalise on the abundant food source. Prey availability also impacts juvenile distribution. Studies in the Mwanza Gulf have revealed higher juvenile densities in areas with abundant zooplankton, their primary food source (Sayer et al., 2018).

Water temperature is another key factor influencing Nile perch distribution in Lake Victoria. While previous studies have suggested a preference for deeper, cooler regions (Cornelissen et al., 2015), Nile perch may occasionally venture into shallower, warmer areas. This behaviour could be driven by two potential benefits. Warmer water may enhance metabolic activity, leading to increased energy levels. Additionally, warmer shallows may offer richer prey availability, attracting adult Nile perch (Mkumbo and Ligtvoet, 2017).

Lake Victoria is not a uniform environment. Local factors, such as depth, inflows, and coastal habitats, create spatial varieties that influence Nile perch distribution. For example, the Nyanza Gulf exhibits seasonal shifts in the presence of Nile perch owing to variations in prey availability and fishing pressure (Cornelissen et al., 2015). The interaction between temperature and oxygen availability shapes the vertical and horizontal distribution of Nile perch such that during cold environments, they tend to move into deeper water, and during warm periods, they move into shallow waters (Goudswaard et al., 2007).

2.3 Nile perch fishery in Lake Victoria

Nile perch is a large predatory fish that was introduced into Lake Victoria around 1954 from lakes Albert and Turkana to boost fishery production following the collapse of the native haplochrominie fishery (Goudswaard et al., 2007). Its introduction has led to a change from the original subsistence fishing to commercial-oriented fishing, resulting in a large increase in annual landings from the lake, the landing increased from 20 metric tons in 1992 to 92 metric tons in 2005 (Njiru et al., 2018). Before the introduction of the Nile perch, Lake Victoria had a very diverse fish fauna comprising 28 genera with approximately 500 species. Over 90% of these species were haplochromine cichlids (Sayer et al., 2018).

The increased fishing of Nile perch in Lake Victoria can be attributed to several interconnected factors. The substantial increase in overall fishing effort and consistent reduction in gear mesh sizes have led to higher catches of Nile perch (Aura et al., 2020). Unlike fisheries management strategies worldwide that emphasise property rights and collective responsibility (Everson et al., 2013), Lake Victoria's fisheries remain open access (Aura et al., 2020). To address the increasing fishing pressure and safeguard the adult spawning stock, the East African Council of Ministers, in collaboration with the Lake Victoria Fisheries Organization (LVFO), implemented a slot size regulation for Nile perch. This regulation permits the catching and landing of Nile perch only within the size range of 50–85 cm TL, aiming to protect juvenile fish and ensure sustainable harvesting practices. This regulation aims to safeguard immature fish, allow for the harvest of mature individuals, and simultaneously protect larger female fish (Kammerer, 2020) because Nile perch which exceeds 85 cm TL, is not allowed to be caught. Control measures, such as restrictions on gear types and mesh sizes, have been implemented, but have proven largely ineffective. The lack of surveillance and monitoring limits the effects of slot-size regulation (Yongo et al., 2018). The fishing effort on perch of all sizes remains high in the lake.

The primary factor contributing to the high fishing effort in Lake Victoria is the open-access nature of the fishery, in which most fishermen operate without limitations. Several studies have shown that the proportion of small fish (< 50 cm) has increased in the catch in recent years (Mkumbo and Marshall, 2015). This suggests that fishing of smaller and immature fish is increasing. Increasing catches of small and potentially immature fish jeopardises fishery sustainability (Yongo et al., 2018).

3 MATERIALS AND METHODS

3.1 Study Area

The survey was conducted in Lake Victoria, the largest lake in Africa, which encompasses a vast surface area of 68,800 square kilometres. The lake plays a crucial role in the ecological and economic well-being of the East African regions of Tanzania, Kenya, and Uganda. Our research focused on the Nile Perch within the lake.

Figure 1: Map showing Lake Victoria (https://www.britannica.com/place/Lake-Victoria).

3.2 Methods

The current research project uses data collected through a well-established regional scientific survey conducted annually across Lake Victoria from 2015 to 2022 (Nyamweya, Natugonza, Mangeni-Sande, et al., 2020). This collaborative effort involves research Institutes from Kenya, Tanzania, and Uganda, ensuring a comprehensive approach to understanding Nile perch dynamics within the entire lake.

The survey methodology includes standardized methods for hydroacoustic measurements and trawling along predetermined transects surveyed by the three nations (Nyamweya, Natugonza, Mangeni-Sande, et al., 2020). Standardised methods allow for a consistent and reliable assessment of Nile perch abundance and distribution across the lake over time. To ensure accurate species identification of acoustic backscatter and to gather additional data on catch rates and Nile perch biological samples, trawl sampling is conducted at frequent intervals along the acoustic transects. The location of the transects was the same for the years 2015–2017 and was changed in 2018 and has remained the same since (*Figure 2*). All three countries conduct the survey using the research vessel Lake Victoria Explorer which is equipped with a SIMRAD EY500 echosounder featuring hull-mounted transducers operating at frequencies of 120 kHz and 70 kHz.

3.2.1 Biological Data Acquisition

In addition to hydroacoustic surveys, regional research surveys incorporate opportunistic bottom trawling into the ground truth species composition of acoustic backscatter, gather biological measurements, and assess catch rates of Nile perch. A specific bottom trawl net with a cod-end mesh size of 4 mm is deployed for this purpose (Nyamweya, Natugonza, Mangeni-Sande, et al., 2020). Information on trawl operation details, such as trawl duration, size, sweeps length, and speed, can be found in Table (Table 2).

Table 2: Trawl details and operation settings.

No. Trawl	Trawl length	Head rope	Opening	Trawl speed	Trawl time
20 per survey	17 m	24.4 m	3.5m	2.9-3.2 knots	30 minutes

The survey strives for consistency, aiming for an average of 20 trawl hauls per year, as detailed in Table 2. Following each haul, the entire catch is sorted and identified to species level, excluding haplochromines, (Nyamweya, Natugonza, Mangeni-Sande, et al., 2020).

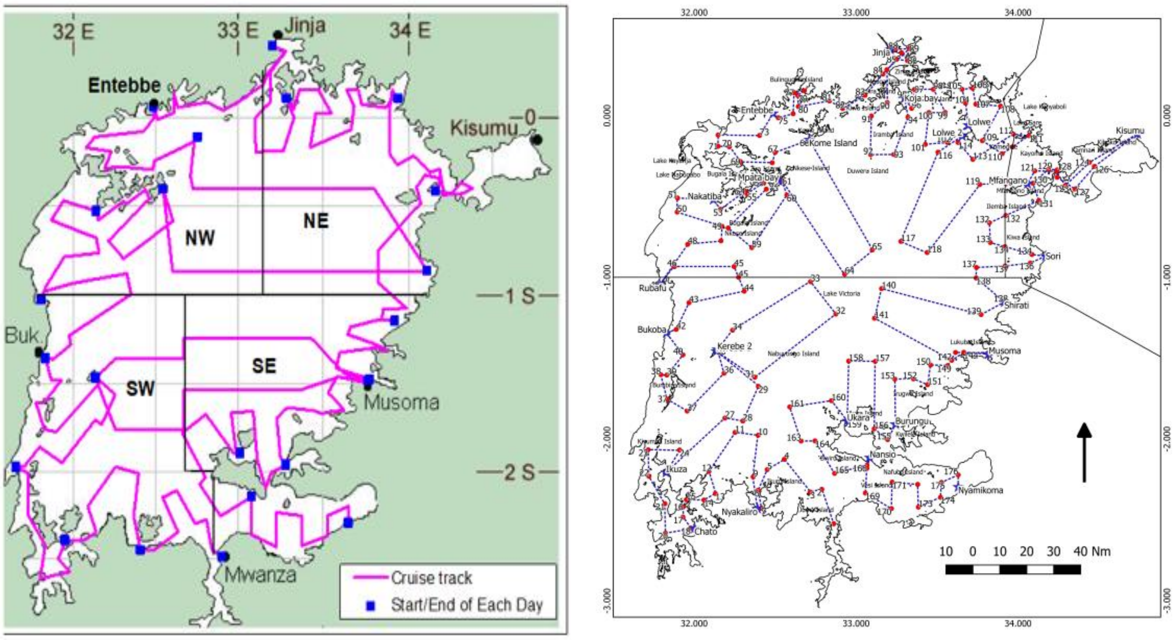
To ensure accurate population estimates, the catch is then separated by species and total length (TL) before further processing. For Nile perch, all individuals exceeding 30 cm TL are measured individually, while smaller fish are measured from a representative subsample (Nyamweya, Natugonza, Mangeni-Sande, et al., 2020).This stratified approach optimises the data collection efficiency.

For each sampled Nile perch, the total length, total weight, sex, maturity stage, and stomach content are recorded. Finally, to account for potential biases in subsampling smaller fish, the results are proportionally adjusted based on the weight of the total catch (excluding large fish) compared with the subsample weight. Sample size of approximately 200 fish per year (total n = 3600).

Incomplete data across Lake Victoria can significantly affect our understanding of Nile Perch maturity. Fewer data points in specific quadrants or years mean a smaller sample size, making it difficult to accurately estimate the overall proportion of mature fish. In addition, missing data that are not evenly distributed can skew the results. For example, if areas with typically high maturity rates have missing data, the overall size at which 50% of the population reaches maturity (L50) could be underestimated. These limitations make it challenging to identify the real trends in L50 variations. To address this, we excluded quadrants with very little data (n<45), thus acknowledging the need for more comprehensive data collection in future studies. It is worth noting that there was a small sample size in 2020 due to the coronavirus pandemic. Hence, 2020 data points were excluded.

3.2.2 Acoustic Data Acquisition

The survey utilises a cross-lake design (Figure 2a) and radial design (Figure 2b) for its cruise survey tracks. The design efficiently divides the lake into four quadrants: southeast (SE), southwest (SW), northwest (NW), and northeast (NE), as shown in Figure 2a. The research vessel maintained a constant speed of approximately 9 knots (*Table 2*) while following predetermined transects. This consistent approach allows for reliable comparisons of fish abundance and distribution across different quadrants of the lake over time.



(a) (b)

Figure 2: Map of Lake Victoria showing the survey design of acoustic tracks; design (a) was used in 2015 – 2017 and design (b) was used in 2018 - 2022 (LVFO, 2008).

Acoustic data files were processed using the Echoview software (v. 8.0, GPO Box 1387 Hobart TAS 7001 Australia).

Four analysis lines (checked bottom, test bottom, Dagaa and top lines) were set with specifications as detailed in the acoustic SOPs (LVFO 2018). For the analysis of Nile perch, the Single Target 70 Khz was used, where the threshold for Nile perch was -50 dB. Regions were defined by four quadrants: northeast (NE), northwest (NW), southeast (SE), and southwest (SW) and strata according to the events in the event log. Removal of the bottom was conducted by checking between the “checked bottom” and “test bottom” lines according to the standards procedures in the SOPs (Nyamweya et al., 2019).

Nile perch densities were estimated using single-target detections (split beam Method 2, with no TVG range correction; LVFO (2018)) in the Echoview software. Data interpretate was exported by lines and regions (constituting to the individual Surveyed Areas). Only data from the 120 kHz transducer were used for standing stock biomass estimation in this study. Single targets were thresholder at -50 dB, equivalent to a minimum detection length for Nile perch of ca. 10 cm (Nyamweya et al., 2019).

The survey area was estimated by acoustic cells with depth layers were set at 2 m intervals with a horizontal grid of 1 km (Elementary Distance Unit - EDSU). The standing stock of Nile perch was estimated per EDSU. Each cell was exported by line and region. The estimated cell distances were of 1 km, in cases that these distances were below 1 km they were included in the analysis weighted by their length.

The acoustic backscatter or single target data were exported within a 2 m depth layer in two parts from the top line to the dagaa line and from the dagaa line to the bottom, and converted to mean numerical density (units) and mean biomass using equations 1 and 2, respectively:

Density = (*NTargets/VBeam*) (1)

where *NTargets* and *VBeam* are the number of targets detected and the cell beam volume, respectively. The beam volume is estimated by:

Biomass = Density × Mean weight (2)

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

This study builds on previous surveys conducted under the Integrated Fisheries Management Plan (IFMP) by employing the same well-established length-weight relationship for Nile perch in Lake Victoria. This approach ensures consistency and facilitates comparisons across datasets.

For the TS/size relationship, we utilised the equations established by Kayanda et al. (2012) (Equations 3 and 4). These equations provide a reliable method for converting Total Stock (TS) estimates into size units, complementing the existing length-weight relationship.

TL=10((TS+84.14)/30.15) (3)

Total weight = 0.0042 x TL3.26 (4)

3.2.3 Estimation of Standing Stock

The mean density of Nile perch for each EDSU was calculated within the respective quadrant in a manner similar to that in the LVFO (2018) report. The mean density of all surveyed areas within a stratum and their 95% confidence interval (CI) were calculated through bootstrapping (n=5000) in the R statistical package, version 4.0.2 (R Core Team, 2023).

The biomass of Nile perch for each stratum was determined by multiplication of the mean densities and stratum area.

4 DATA ANALYSIS

The data were analysed based on the following hypotheses:

4.1 Hypotheses

i. There is no significant change in biomass and distribution for Nile perch in Lake Victoria from 2015 to 2022, neither between years nor quadrants within year.

ii. Size at maturity in 2015 to 2022 is the same between years and the same as recorded in previous studies conducted from 1964 to 2007 (Kayanda et al., 2010).

iii. There are no significant spatial differences in size at maturity among quadrants (I, II, III, and IV) within Lake Victoria.

Data were analysed using R (R Core Team, 2023), and the initial stage involved importing the data into R, followed by data cleaning and preparations focusing on specific variables of project interest for further statistical procedures. Sex categories were standardised to include "Female," "Male," and "Juvenile." Maturity stages were categorised from stage I to VI for consistency. Data formats were adjusted to ensure uniformity. Missing values can introduce errors in the analysis; hence, entries with missing data for sex, maturity stage, and regional notes were removed.

New variables were derived from the existing variables to enhance the analysis. A "Maturity" variable was created, classifying fish as "Immature" (stages I and II) or "Mature" (stages III to VI) based on the original maturity stage data. Latitude and Longitude data were often presented in degrees and seconds' format. We converted these coordinates to a more standard "Lat" and "Lon" format for easier analysis.

Data Analysis and exploration were performed, which involved some calculations. A key aspect of the analysis involved calculating the "proportional maturity" of the Nile perch population from the maturity variable, which was calculated as (proportional maturity = mature / (mature + immature). A generalised linear model (GLM) was used to determine the length at which 50% of the fish population reached maturity (L50), based on the calculated proportion of maturity. This metric provides valuable insights into the reproductive potential of the population. For the acoustic data, we performed calculations to estimate the density, weight, and biomass of the Nile perch across the lake, the calculation was done as described in the methodology section. These calculations provided information on the abundance and distribution of fish within the lake.

Descriptive statistics were used to determine the overall characteristics of the data. The mean, median, and standard deviation were calculated for various parameters such as total fish length, weight, density, and biomass. This provided a foundational understanding of the central tendencies and variability within the data.

For effective data exploration, different visualisations were applied. Plots were created to illustrate the distribution of maturity stages, total length, maturity, and biomass for each year (2015-2022) and within each quadrant (I-IV) of the lake. These plots allowed us to identify the patterns and trends in the data.

To visualise the spatial distribution of female and male Nile perch in relation to their maturity stage, we generated maps for each quadrant across the study years (2015-2022). These maps offer valuable insights into the spatial dynamics of the population.

Specific data points were excluded from the analysis due to limitations. The year 2020 was omitted from the size-at-maturity (L50) analysis owing to the low number of data points. Similarly, certain quadrants within specific years were excluded because of a high proportion of missing values and complete absence of data. The excluded data were quadrant NE in 2015, quadrant SE in 2017, quadrants NE and SW in 2019, quadrant SW in 2021(there was a completely missing value in this quadrant), and all quadrants in 2020.

The null hypotheses were validated using inferential statistics. Normality tests were performed to ensure that the data met the assumptions of the subsequent analyses. The normality of the data was confirmed, and Analysis of Variance (ANOVA) was employed to assess whether there were significant differences in the data between years and quadrants. Post-hoc analysis was conducted to pinpoint the specific years or quadrants that differed significantly.

By following these analysis steps, valuable information was extracted from the collected data and insights were gained into Nile perch population dynamics within Lake Victoria.

5 RESULTS

5.1 Size at maturity of Nile perch in Lake Victoria

The present analysis revealed a statistically significant difference in size at maturity (L50) between male and female Nile perch ($p < 0.05$). The results indicated a temporal decline in Nile perch L50 from 2015 to 2022, with female L50 declining from 58.0 to 46.9 and for males from 52.5 to 41.6 (Figure 4). A comparison of the current results with previous studies shows that L50 is lower in the current study than in previous studies, except for 1967 (Figure 5).

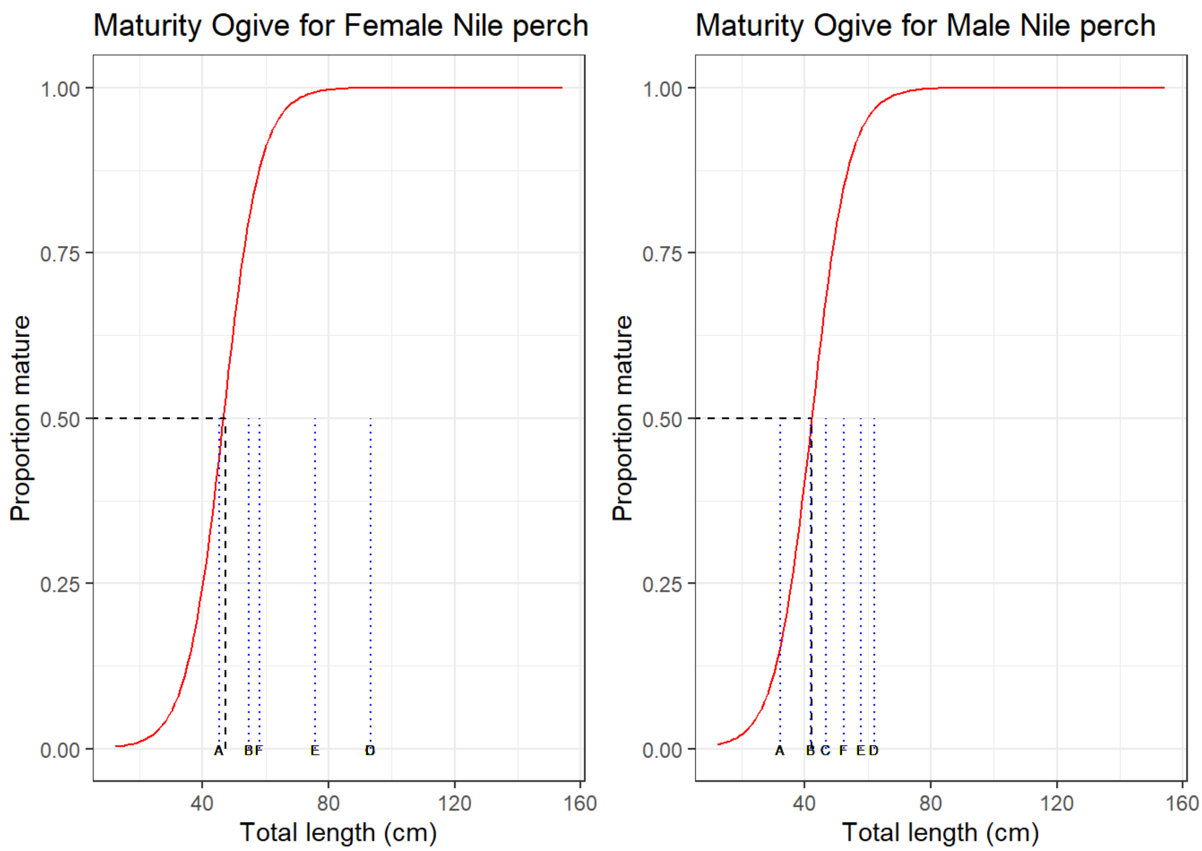


Figure 3: Maturity ogive (red solid line) and estimated L50 (black dashed line) of Nile perch in Lake Victoria for the current study, average for years 2015-2022, and reported L50 from previous studies (blue dotted line; A: 1967, B: 1977, C: 1982, D: 1992, E: 2001, and F: 2007, respectively). Results reported separately for females and males.

5.2 Interannual and variability between quadrants of size at maturity of Nile perch (2015 - 2022)

Significant variations ($p < 0.05$) in the size at maturity (L50) of Nile perch were found between sexes, years, and quadrants.

There is a significant difference between male and female L50, which aligns with established scientific knowledge about sexual dimorphism in Nile perch. The L50 values differed significantly across the seven years investigated (2015-2022). L50 was large Post – hoc test revealed significant differences ($p < 0.05$) in L50 between 2015, 2016, 2017, 2018, and 2019.

The data also indicated a statistically significant difference ($p < 0.05$) in L50 between the four quadrants of the lake (NE, NW, SE, and SW). This highlights a spatial dimension to the variations in size at maturity, suggesting that the Nile perch in different lake regions mature at different sizes.

Figure 4: Size at maturity (L50, TL) for female (right panel) and male (right panel) Nile perch per quadrant in Lake Victoria from 2015 to 2022.0. Year 2020 was excluded from the analysis due to few data.

5.3 Maturity Frequency of Nile perch in Lake Victoria

The frequency of the proportion of age at maturity (mature and immature) from length sampling recorded from the bottom trawl sampling showed that the number of immature fish was greater than that of mature fish in most quadrants in all years. In quadrant SW, for 2018 and 2019, the proportions of maturity and immaturity were similar.

Figure 5: Maturity frequency of Nile perch in Lake Victoria for eight years

5.4 Biomass of Nile perch in Lake Victoria

The overall annual biomass in the lake ranged from 533,770 to 1,127,774 tons. It was highest in 2021 and lowest in 2016 (*Figure 6*). A significant difference in the mean biomass of Nile perch between the four quadrants of the lake was observed ($p < 0.05$). This indicates an uneven population distribution with northeast (NE) and northwest (NW) quadrants. The Southeast (SE) quadrant shows the highest overall Nile perch biomass (~180000 tonnes) in 2021, followed by the southwest (SW) quadrant, and the northeast (NE) quadrant exhibits the lowest Nile perch biomass in 2019, followed by the northwest (NW) quadrant in 2018.

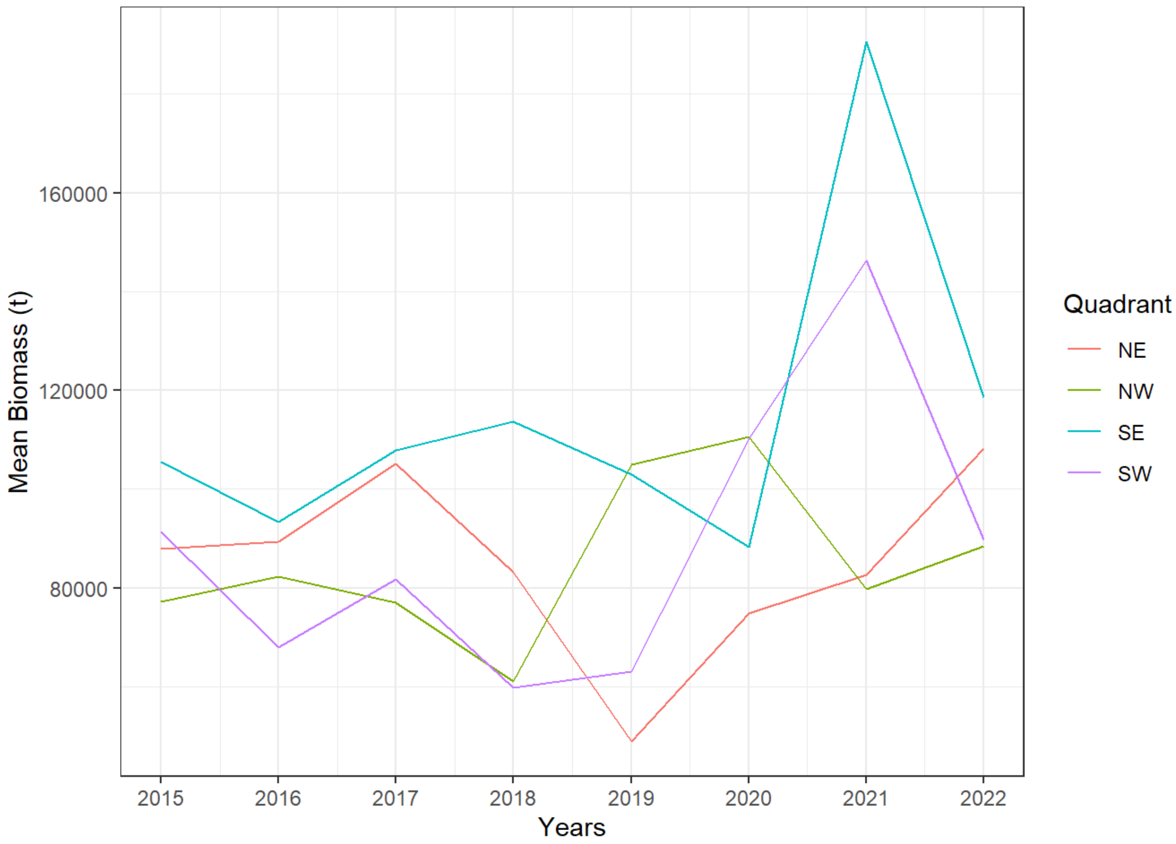


Figure 6: Total biomass of Nile perch in L. Victoria for the period of eight years (2015 - 2022)

5.5 Spatial and Temporal Distribution of Nile perch in Relation to Maturity Stages in Lake Victoria

The spatial and temporal distributions of Nile perch from trawl samples are shown in Figures 9, 10, and 11. Marked fluctuations were observed in the Nile perch maturity stage distribution. The analysis revealed a significant difference in maturity stages between the years and quadrants ($\chi^2 = 75.783$, df = 7, $p < 0.001$). These results highlight the importance of considering temporal variations when studying the maturity-stage dynamics of Nile perch populations in Lake Victoria.

The provided (*Figure 7*) shows a significant difference in the spatial and temporal distribution of the female Nile perch in years and across the four quadrants (NE, NW, SE, and SW) of Lake Victoria. Stages III, IV, V, and VI are mature, whereas stages I and II are immature. The larger maturity stages of females were mainly found along the northwest coast. In some years (e.g. 2018), some large stages have been found in the middle of the lake.

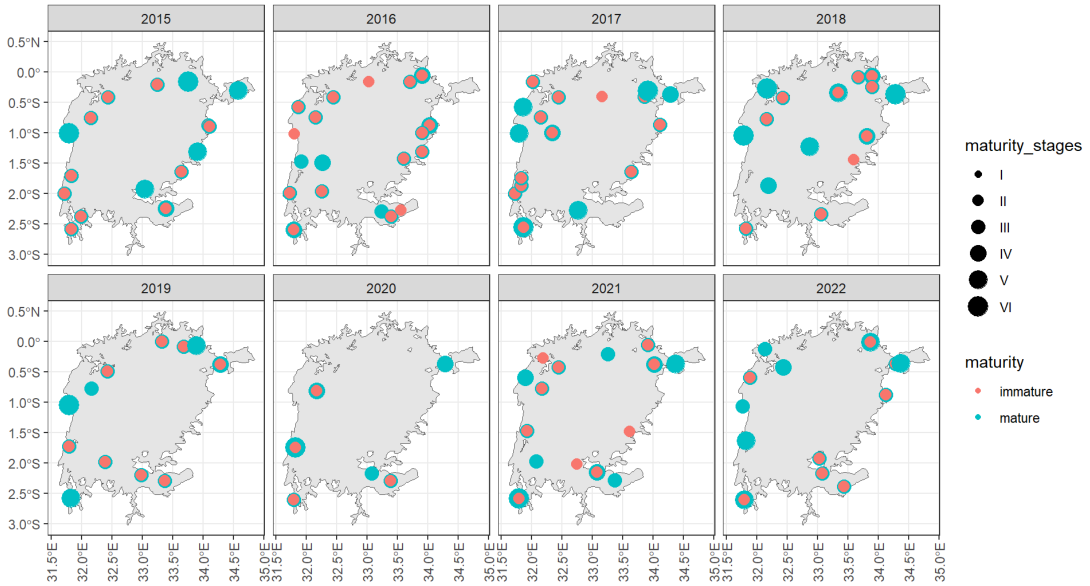


Figure 7: Spatial and temporal distribution of female Nile perch in Lake Victoria over the past eight years based on their maturity stages (2015 - 2022). Different size of bubbles indicates the different maturity stages.

The provided (*Figure 8*) shows that there is a significant difference in the spatial and temporal distribution of male Nile perch in years and across the four quadrants (NE, NW, SE, and SW) of Lake Victoria. The distribution shows that most males are mature; however, there is a difference in size; the larger maturity stage males are mainly found along the cost northwest. Although in some years (e.g. 2018), some large stages were found in the middle of the lake as females, as shown in *Figure 7*.

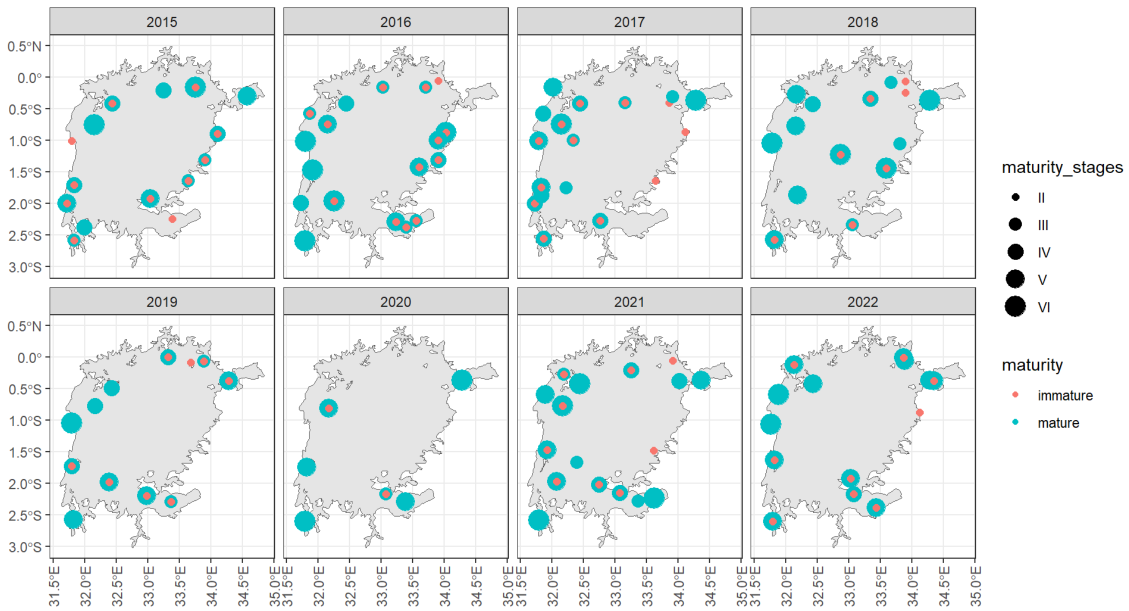


Figure 8: Spatial and temporal distribution of male Nile perch in Lake Victoria over the past eight years based on maturity stages (2015–2022).

6 DISCUSSION

This study showed a clear shift in maturity size from 1960 to 2022. A decrease in size at first maturity in Nile perch was found to be more profound in recent years, 2015-2022, and it is discussed here that this may be linked to the variability in stock size. Additionally, there were significant differences in Nile perch L50 (the length at which 50% of a population becomes sexually mature) between males and females, as well as years and spatial differences between quadrants. The analysis revealed a statistically significant difference ($p < 0.05$) in L50 between male and female Nile perch in Lake Victoria. As shown by Dadebo et al. (2006), we also found that females exhibited a larger size at maturity (L50 = 46.93 cm) than males (L50 = 41.94 cm). This finding aligns with observations of sexual dimorphism in the Nile perch and supports the concept that females prioritise larger body sizes for increased reproductive potential (Hüssy et al., 2012).

The findings revealed significant variations ($p < 0.05$) in size at first maturity (L50) across the four quadrants of Lake Victoria (Figure 4). Interestingly, a positive relation emerged between the L50 and the estimated Nile perch biomass within each quadrant (Figure 6). Fish in quadrants with higher estimated biomass (e.g., 2021, Southeast and Southwest) displayed a larger L50 compared to those in quadrants with lower biomass (Northeast and Northwest). This observation aligns with the idea that increased competition for resources, particularly food, in areas with higher biomass may lead to delayed maturity in Nile perch (Godbold et al., 2012). These findings suggest a potential interplay between population density and size at maturity, highlighting the need for further investigation of density-dependent effects on Nile perch reproduction.

Furthermore, the study revealed a concentration of larger Nile perch, likely in later maturity stages, along the coastline (Figures 7 and 8). These areas appear to offer more favourable conditions for the growth and survival of the Nile perch. This could be because of factors such as abundant food sources or specific habitat characteristics that support their development. Notably, previous research by Cornelissen et al. (2015) suggested that Nile perch populations tend to be higher in shallower, warmer regions of the lake than in deeper areas. These shallower regions might be more conducive to egg production and development of healthier offspring.

A decrease in L50 across the entire lake or in specific quadrants could have significant ecological and economic consequences. Fluctuations in Nile perch catch over the years, which peaked at 560,000 tons in 1999 from a mere 30,000 tons in the late 1970s, highlight this potential impact (Ogutu-Ohwayo, 1990). Reduced reproductive output due to a smaller size at maturity could lead to population decline, impacting the overall health of the lake ecosystem and sustainability of the Nile perch fishery (Gullberg et al., 2019). Conversely, a stable or increasing L50 could indicate a healthy and productive population.

While this study provides valuable insights, it is important to acknowledge limitations due to missing data in certain quadrants and years. This could potentially affect the strength of our size estimates at the first maturity (L50). Future research aiming for a more comprehensive understanding of the variations in L50 across the lake should prioritise consistent data collection across all quadrants and years. Ideally, a minimum of 400 fish per quadrant should be measured annually. Additionally, incorporating alternative methods for maturity assessment, such as histological analysis, could offer complementary data and strengthen overall findings.

These findings highlight the importance of considering spatial and temporal variations when assessing Nile perch size at maturity. The observed differences in L50 based on sex, quadrant, and year suggest intricate interactions between biological and environmental factors that influence reproductive strategies in Nile perch. By acknowledging these spatial and temporal variations in L50, this study sheds light on the complexities of Nile perch reproductive strategies within Lake Victoria. Further research on the underlying mechanisms driving these variations can inform the development of more effective management practices. Such practices would be crucial for the sustainable conservation of the Nile perch population and overall health of the lake ecosystem.

7 CONCLUSION AND RECOMMENDATIONS

This eight-year analysis using hydroacoustic and biological data provided valuable insights into the maturity patterns of Nile perch in Lake Victoria for eight years. Our research in Lake Victoria uncovered a surprising trend: Nile perch are maturing at a smaller size. While this might initially seem beneficial, potentially leading to larger catches, it presents a complex challenge for the fishery's long-term health. Smaller fish tend to produce fewer eggs (Yongo et al., 2018), which could lead to a decline in overall offspring numbers, despite a larger spawning population. The smaller Nile perch might collectively produce fewer offspring than larger, more fecund fish.

Unregulated fishing targeting smaller, recently matured fish can inadvertently favour this smaller-maturing trait. Over multiple generations, with the continued targeting of smaller fish, the genes for smaller size at maturity become more dominant in the population. This can lead to a genetic shift in which the average size at maturity shrinks. If only smaller Nile perch were caught, the population could become dominated by fish with this characteristic.

To address these concerns, we recommend implementing stricter fishing regulations with increased minimum size limits to protect smaller immature fish, allowing them to grow larger and contributing significantly to future reproduction.

1. Regulating fishing gear types can be beneficial. Promoting the use of a more selective gear that targets larger fish, such as gillnets with larger mesh sizes, can help reduce the capture of immature individuals.

2. Establishing periods during the peak spawning season as closed seasons offers crucial protection for spawning fish, allowing them to reproduce successfully and replenish their population.

3. Ensuring healthy spawning and nursery grounds for the Nile perch is essential. This might involve measures, such as controlling pollution or protecting specific breeding areas within the lake. A healthy environment, with clean water and protected breeding grounds, promotes successful reproduction.

Sustainable management of the Nile perch fishery requires a multipronged approach. Continuous research and monitoring of the population size, age structure, and reproductive success are essential. These data, such as regularly checking the health of Nile perch, allow authorities to adapt fishing regulations and management strategies. For instance, regulations, such as minimum size limits, can be adjusted based on observed growth and distribution patterns to protect smaller, immature fish and ensure a healthy mix of sizes within the population. Additionally, further research is crucial to understand the root causes of the observed shift towards smaller maturing perch. Collaborative efforts between fishermen, local communities, and researchers can lead to more effective solutions. By working together and leveraging research findings, we can develop sustainable management strategies that benefit both the fishery and communities that depend on it. By implementing these recommendations, we can ensure the long-term sustainability of Nile perch in Lake Victoria and promote a future in which both fish and fishermen can thrive.

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REFERENCES

Aura, C. M., Nyamweya, C. S., Owili, M., Gichuru, N., Kundu, R., Njiru, J. M., & Ntiba, M. J. (2020). Checking the pulse of the major commercial fisheries of Lake Victoria Kenya, for sustainable management. *Fisheries Management and Ecology*, *27*(4), 314–324. https://doi.org/10.1111/fme.12414

Cornelissen, I. J. M., Van Zwieten, P. A. M., Peter, H. K., & Nagelkerke, L. A. J. (2015). Nile perch distribution in southeast Lake Victoria is more strongly driven by abiotic factors, than by prey densities. *Hydrobiologia*, *755*(1), 239–255. https://doi.org/10.1007/s10750-015-2237-x

Dadebo, E., Ahlgren, I., & Ahlgren, G. (2006). Maturation, sex ratio and fecundity of the Nile perch (*Lates niloticus, L.)* (Pisces: *Centropomidae*) in Lake Chamo, Ethiopia. *SINET: Ethiopian Journal of Science*, *28*(2), 151–160. https://doi.org/10.4314/sinet.v28i2.18251

Everson, I., Taabu-Munyaho, A., & Kayanda, R. (2013). Acoustic estimates of commercial fish species in Lake Victoria: Moving towards ecosystem-based fisheries management. *Fisheries Research*, *139*, 65–75. https://doi.org/10.1016/j.fishres.2012.09.019

Froese, R., & Pauly, D. (2024). *FishBase* [Computer software]. World Wide Web electronic publication. www.fishbase.org

Goudswaard, K. (P. C.), Witte, F., & Katunzi, E. F. B. (2007). The invasion of an introduced predator, Nile perch *(Lates niloticus, L.*) in Lake Victoria (East Africa): Chronology and causes. *Environmental Biology of Fishes*, *81*(2), 127–139. https://doi.org/10.1007/s10641-006-9180-7

Hüssy, K., Coad, J. O., Farrell, E. D., Clausen, L. W., & Clarke, M. W. (2012). Sexual dimorphism in size, age, maturation, and growth characteristics of boarfish (*Capros aper*) in the Northeast Atlantic. *ICES Journal of Marine Science*, *69*(10), 1729–1735. https://doi.org/10.1093/icesjms/fss156

Kammerer, J. (2020). *Size selective fishing: The effect of size selectivity on the equilibrium yield in the Nile perch fishery of Lake Victoria*. Alfred-Weber-Institut for Economics. Heidelberg University.

Kayanda, R., Taabu, A., Tumwebaze, R., Muhoozi, L., Jembe, T., Mlaponi, E., & Nzungi, P. (2010). Status of the Major Commercial Fish Stocks and Proposed Species-specific Management Plans for Lake Victoria. *African Journal of Tropical Hydrobiology and Fisheries*, *12*(1). https://doi.org/10.4314/ajthf.v12i1.57366

Mkumbo, O. C., & Ligtvoet, W. (2017). *The biology of Nile perch - condition factor. Growth, reproduction and food/feeding in Mwanza Gulf - Lake Victoria*. TAFIRI.

Mkumbo, O. C., & Marshall, B. E. (2015). The Nile perch fishery of Lake Victoria: Current status and management challenges. *Fisheries Management and Ecology*, *22*(1), 56–63. https://doi.org/10.1111/fme.12084

Mkuna, E., & Baiyegunhi, L. (2020). Impact of Nile perch (Lates niloticus) overfishing on fishers' income: Evidence from Lake Victoria, Tanzania. *African Journal of Agricultural and Resource Economics*, *15*(3), 213–229. https://doi.org/10.53936/afjare.2020.15(3).14

Natugonza, V., Nyamweya, C., Sturludóttir, E., Musinguzi, L., Ogutu-Ohwayo, R., Bassa, S., Mlaponi, E., Tomasson, T., & Stefansson, G. (2022). Spatiotemporal variation in fishing patterns and fishing pressure in Lake Victoria (East Africa) in relation to balanced harvest. *Fisheries Research*, *252*, 106355. https://doi.org/10.1016/j.fishres.2022.106355

Njiru, J., Van Der Knaap, M., Kundu, R., & Nyamweya, C. (2018). Lake Victoria fisheries: Outlook and management. *Lakes & Reservoirs: Science, Policy and Management for Sustainable Use*, *23*(2), 152–162. https://doi.org/10.1111/lre.12220

Njiru, M., Van Der Knaap, M., Taabu-Munyaho, A., Nyamweya, C. S., Kayanda, R. J., & Marshall, B. E. (2014). Management of Lake Victoria fishery: Are we looking for easy solutions? *Aquatic Ecosystem Health & Management*, *17*(1), 70–79. https://doi.org/10.1080/14634988.2014.881220

Nyamweya, C. S., Natugonza, V., Mangeni-Sande, B. K. R., Kagoya, E., Mboni, V. E., Shaban, S., Ongore, C., Mlaponi, E., Kosieny, D., & Magezi, G. (2020). *Hydro-acoustics Regional Working Group*.

Nyamweya, C. S., Natugonza, V., Mangeni-Sande, B. K. R., Kagoya, E., Mziri, V., Ongore, C., Mlaponi, E., Wabeya, U., Odada, E., & Magezi, G. (2019). *Hydro-acoustics Regional Working Group*.

Nyamweya, C. S., Natugonza, V., Taabu-Munyaho, A., Aura, C. M., Njiru, J. M., Ongore, C., Mangeni-Sande, R., Kashindye, B. B., Odoli, C. O., Ogari, Z., & Kayanda, R. (2020). A century of drastic change: Human-induced changes of Lake Victoria fisheries and ecology. *Fisheries Research*, *230*, 105564. https://doi.org/10.1016/j.fishres.2020.105564

Ogutu-Ohwayo, R. (1990). The decline of the native fishes of lakes Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, Lates niloticus, and Nile tilapia, Oreochromis niloticus. *Environmental Biology of Fishes*, 27(2), 81–96.

Pringle, R. M. (2005). The Origins of the Nile Perch in Lake Victoria. *BioScience*, *55*(9), 780. https://doi.org/10.1641/0006-3568(2005)055[0780:TOOTNP]2.0.CO;2

R Core Team. (2023). *_R: A Language and Environment for Statistical Computing_. R* [Computer software]. Foundation for Statistical Computing.

Sayer, C. A., Máiz-Tomé, L., & Darwall, W. R. T. (2018). *Freshwater biodiversity in the Lake Victoria Basin: Guidance for species conservation, site protection, climate resilience and sustainable livelihoods* (1st ed.). IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2018.RA.2.en

Taabu-Munyaho, A., Nyamweya, C. S., Sitoki, L., Kayanda, R., Everson, I., & Marteinsdóttir, G. (2014). Spatial and temporal variation in the distribution and density of pelagic fish species in Lake Victoria, East Africa. *Aquatic Ecosystem Health & Management*, *17*(1), 52–61. https://doi.org/10.1080/14634988.2014.876886

Yongo, E., Agembe, S., Outa, N., & Owili, M. (2018). Growth, mortality and recruitment of Nile perch (*Lates niloticus*) in Lake Victoria, Kenya. *Lakes & Reservoirs: Science, Policy and Management for Sustainable Use*, *23*(1), 17–23. https://doi.org/10.1111/lre.12203

APPENDICES

Appendix 1

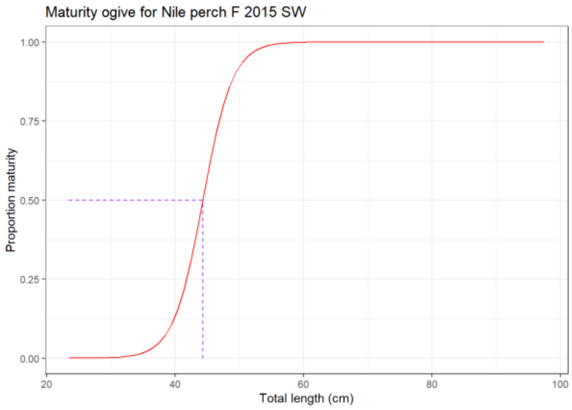
The table below shows the number of fish which were measured for biological parameters during regional hydroacoustic survey in Lake Victoria. This number were obtained after cleaning the data and removing the missing values in sex variable.

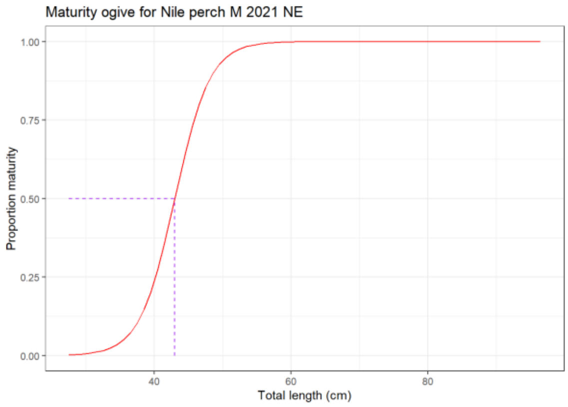
Year	Quadrant	Sex	Number of fish
2015	NE	F	97
2015	NE	M	55
2015	NW	F	27
2015	NW	M	26
2015	SE	F	56
2015	SE	M	33
2015	SW	F	45
2015	SW	juvenile	1
2015	SW	M	56
2016	NE	F	57
2016	NE	M	15
2016	NW	F	40
2016	NW	M	43
2016	SE	F	76
2016	SE	M	50
2016	SW	F	44
2016	SW	M	40
2017	NE	F	75
2017	NE	juvenile	17
2017	NE	M	41
2017	NW	F	56
2017	NW	juvenile	47
2017	NW	M	65
2017	SE	F	35
2017	SE	juvenile	6
2017	SE	M	28
2017	SW	F	95
2017	SW	juvenile	42
2017	SW	M	64
2018	NE	F	44
2018	NE	M	26
2018	NW	F	58
2018	NW	M	44
2018	SE	F	26
2018	SE	M	21
2018	SW	F	66

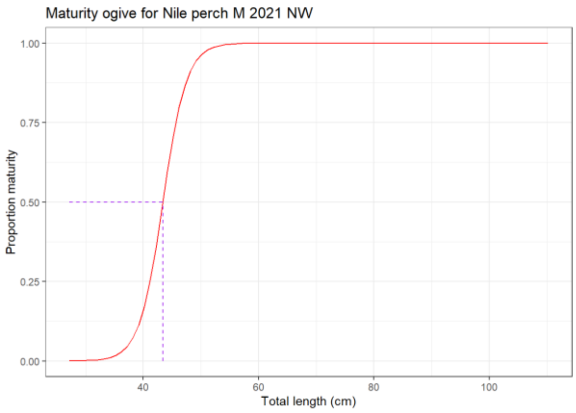
2018	SW	juvenile	23
2018	SW	M	65
2019	NE	F	54
2019	NE	juvenile	1
2019	NE	M	43
2019	NW	F	24
2019	NW	M	26
2019	SE	F	23
2019	SE	M	21
2019	SW	F	62
2019	SW	M	58
2020	NE	F	1
2020	NE	M	7
2020	NW	F	12
2020	NW	juvenile	3
2020	NW	M	14
2020	SE	F	20
2020	SE	juvenile	3
2020	SE	M	24
2020	SW	F	38
2020	SW	juvenile	14
2020	SW	M	16
2021	NE	F	17
2021	NE	M	17
2021	NW	F	35
2021	NW	M	50
2021	SE	F	48
2021	SE	M	69
2022	NE	F	46
2022	NE	M	44
2022	NW	F	29
2022	NW	M	35
2022	SE	F	38
2022	SE	M	38
2022	SW	F	26
2022	SW	M	51

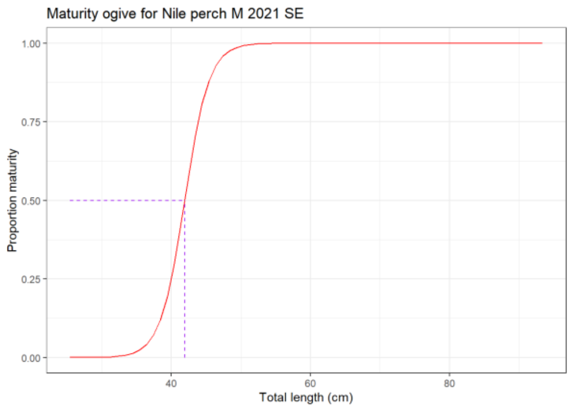
Appendix 2

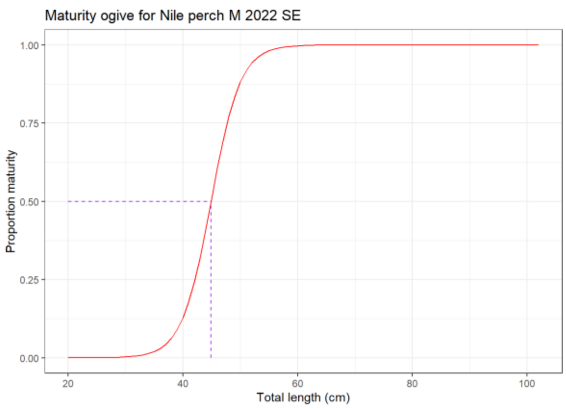
The graphs below show the proportional maturity and the length at maturity (L50) of females and males Nile perch in Lake Victoria from 2015 to 2022.

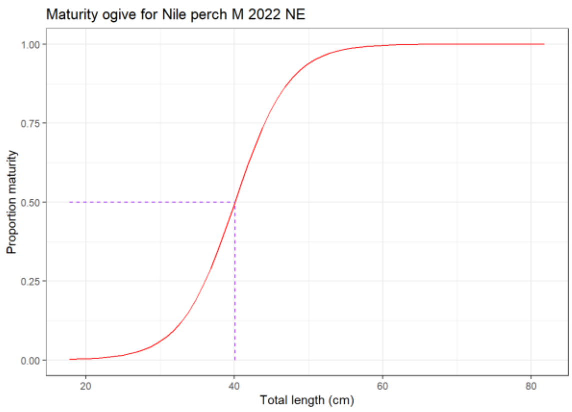









Maturity ogive for Nile perch M 2022 SE
Proportion maturity
Total length (cm)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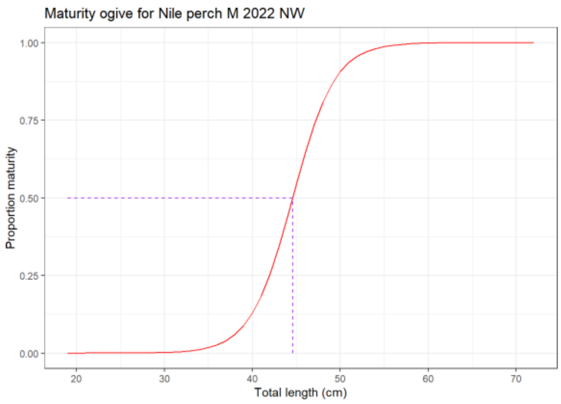
Total length (cm)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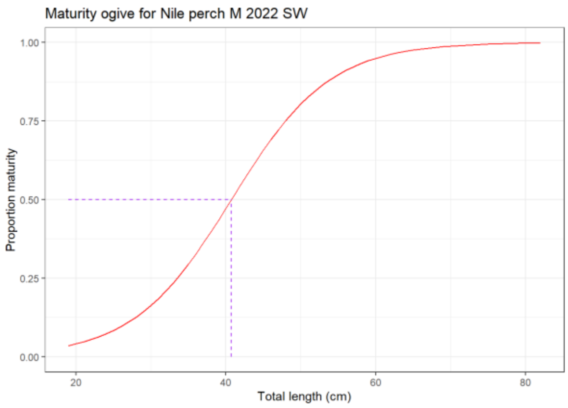
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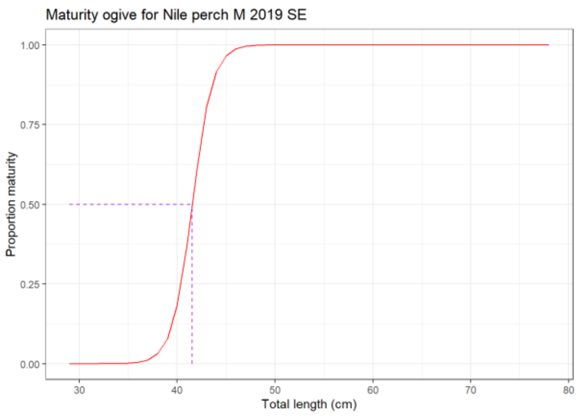
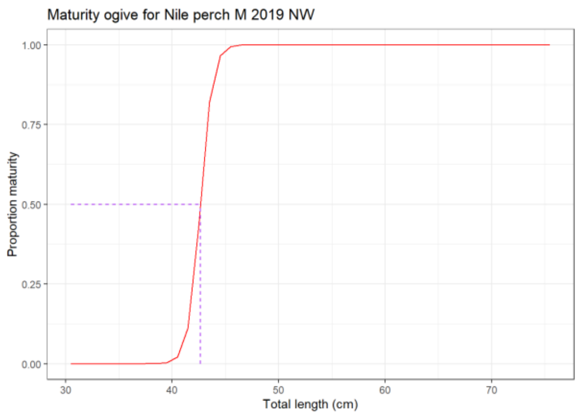
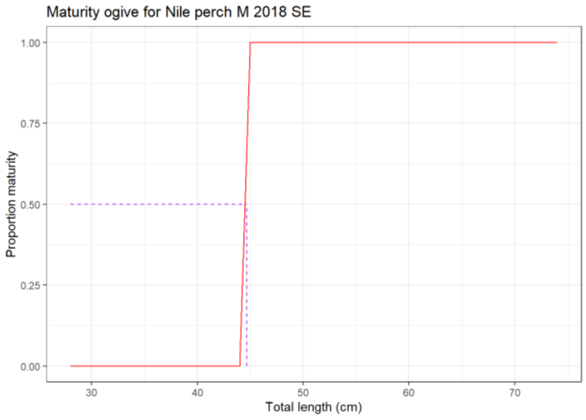

Maturity ogive for Nile perch M 2019 SE
Proportion maturity
Total length (cm)


Maturity ogive for Nile perch M 2019 NW
Proportion maturity
Total length (cm)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Proportion maturity
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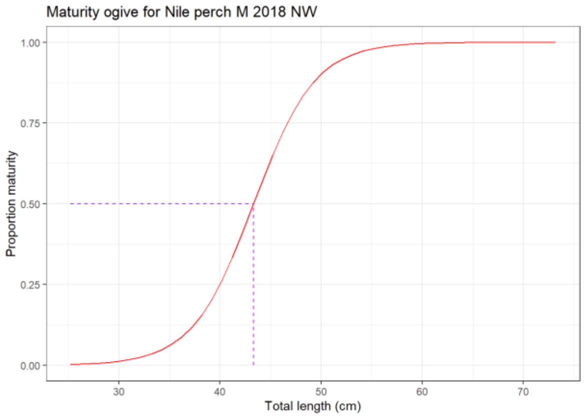
0.75
0.50
0.25
0.00
30
40
50
60
70
Total length (cm)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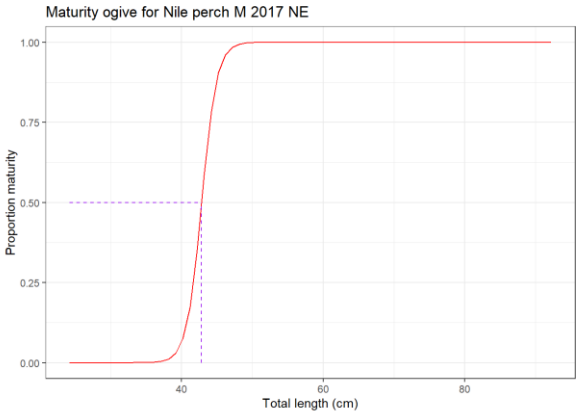
0.50
0.25
0.00
30
40
50
60
70
Total length (cm)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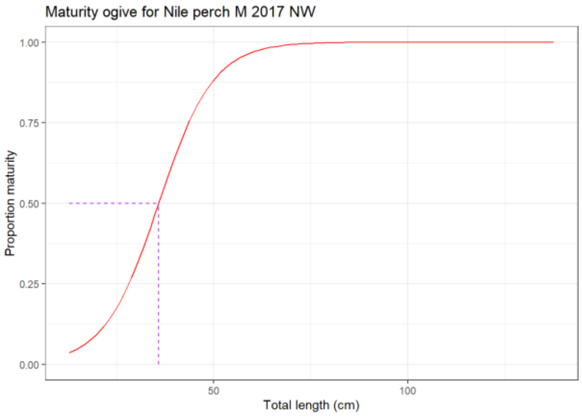
40
60
80
Total length (cm)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Proportion maturity
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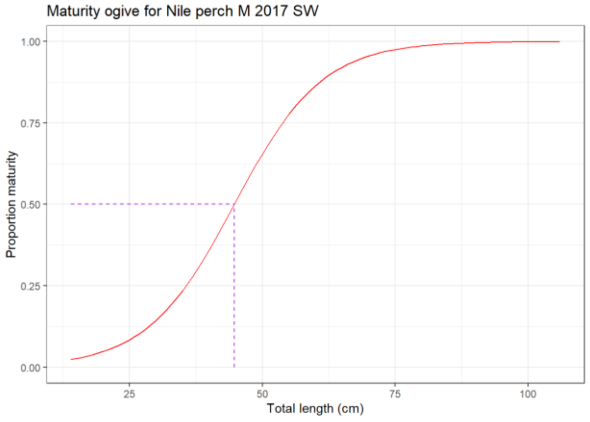
0.75
0.50
0.25
0.00
50
100
Total length (cm)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Proportion maturity
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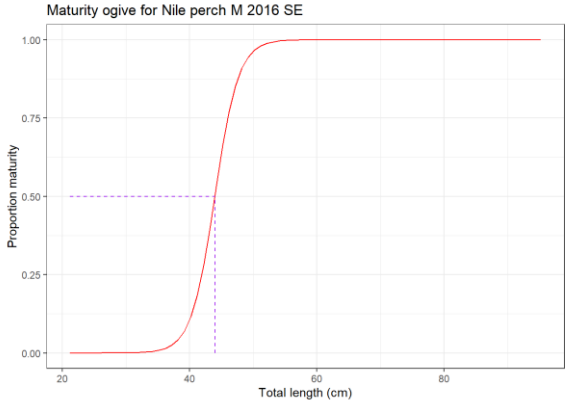
0.25
0.00
25
50
75
100
Total length (cm)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Proportion maturity
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0.75
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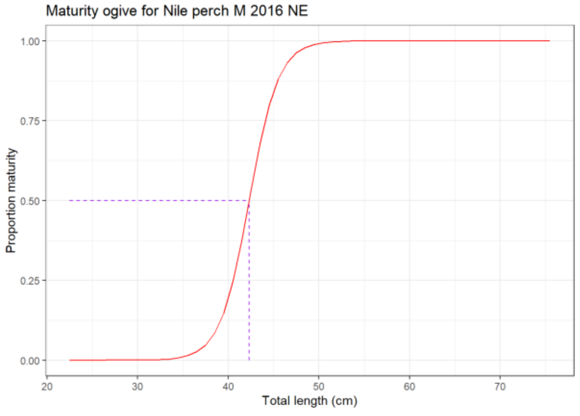
0.00
20
40
60
80
Total length (cm)


Maturity ogive for Nile perch M 2016 NE
Proportion maturity
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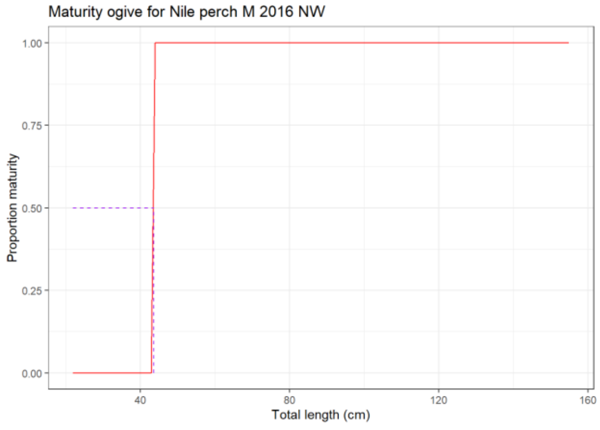
0.00
20
30
40
50
60
70
Total length (cm)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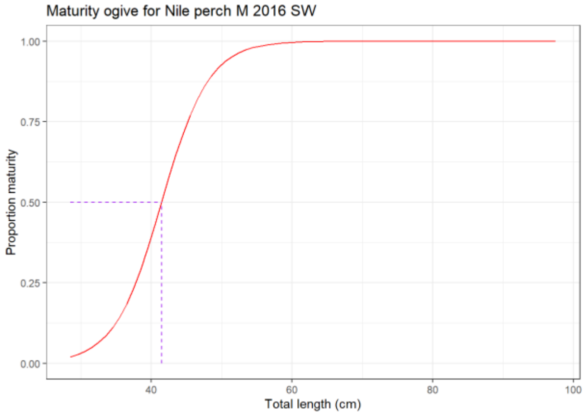
0.00
40
80
120
160
Total length (cm)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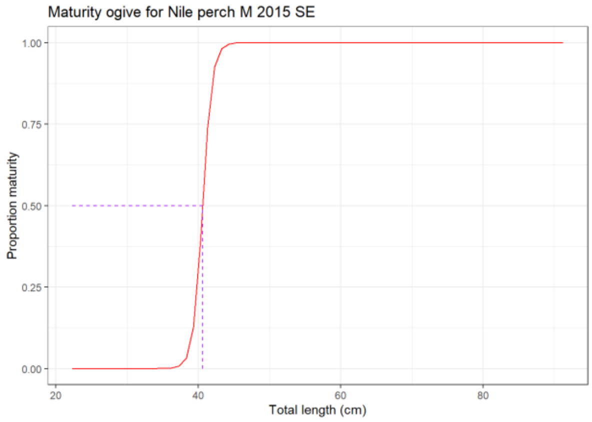
40
60
80
100
Total length (cm)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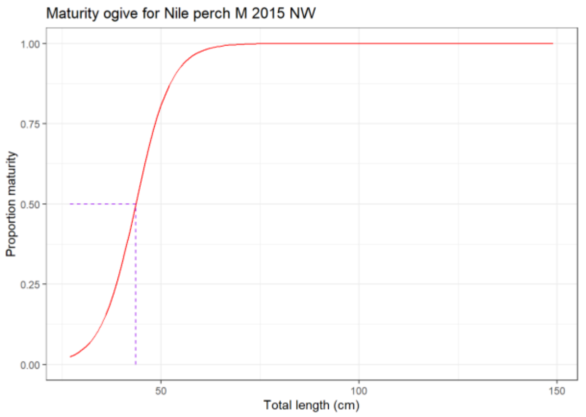
0.00
20
40
60
80
Total length (cm)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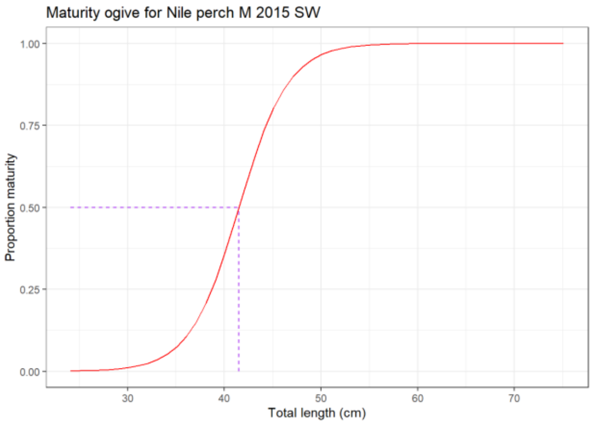
50
100
150
Total length (cm)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Proportion maturity
1.00
0.75
0.50
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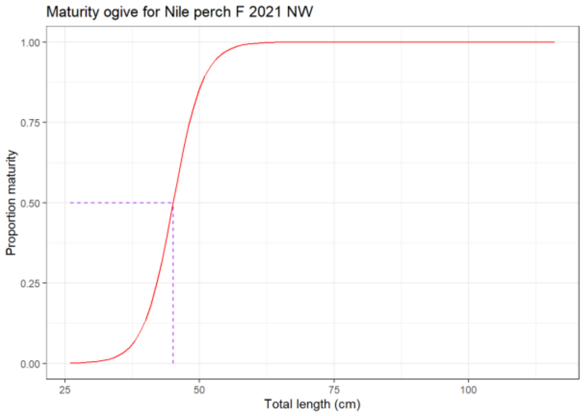
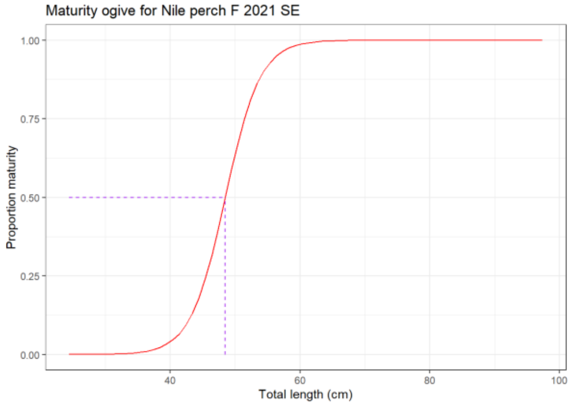
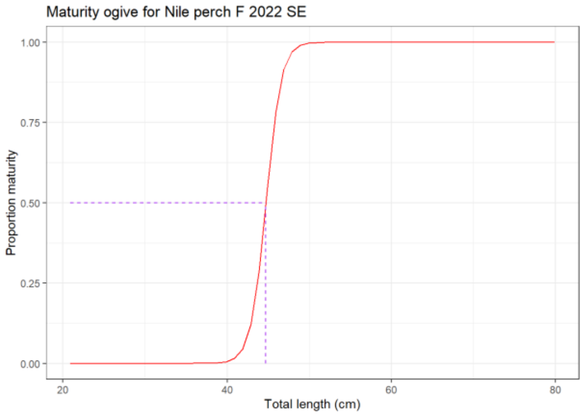
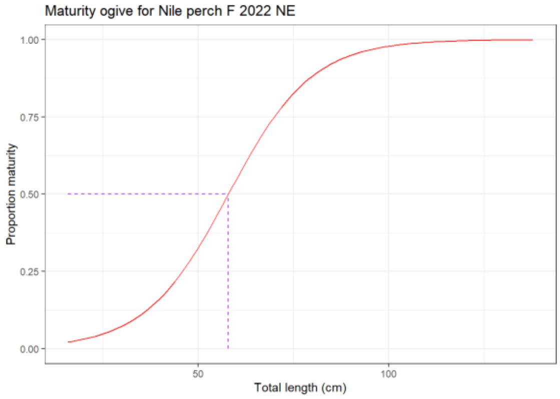
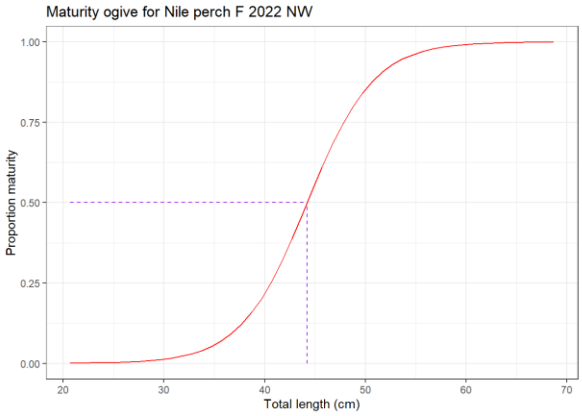
70
Total length (cm)

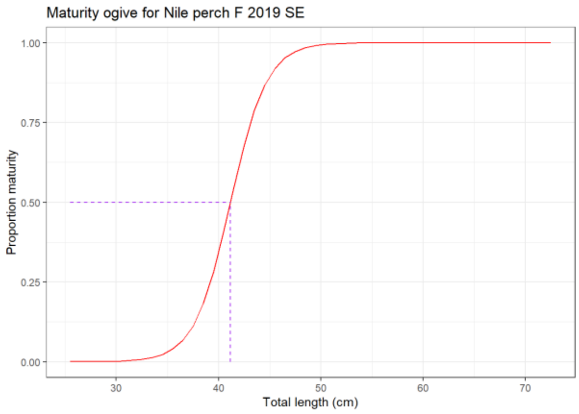

Maturity ogive for Nile perch F 2021 NW
Proportion maturity
1.00
0.75
0.50
0.25
0.00
25
50
75
100
Total length (cm)

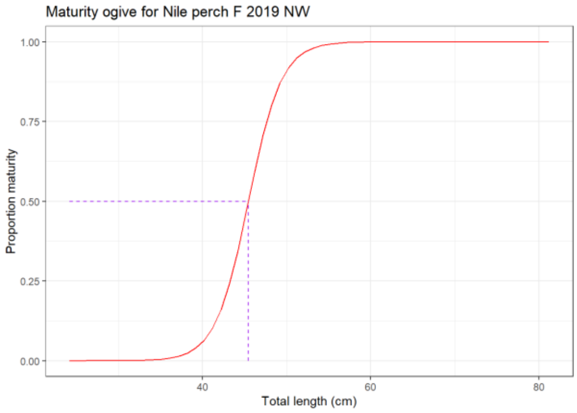

Maturity ogive for Nile perch F 2021 SE
Proportion maturity
1.00
0.75
0.50
0.25
0.00
40
60
80
100
Total length (cm)

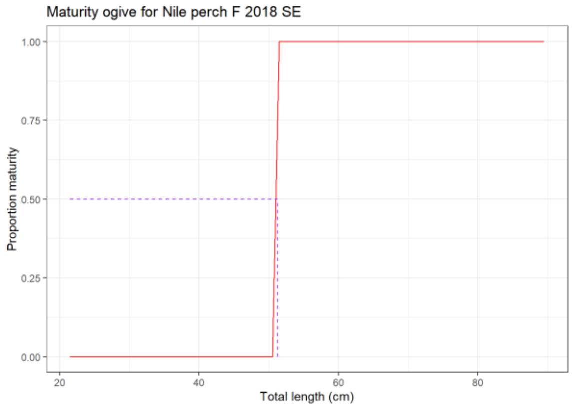

Maturity ogive for Nile perch F 2022 SE
Proportion maturity
1.00
0.75
0.50
0.25
0.00
20
40
60
80
Total length (cm)

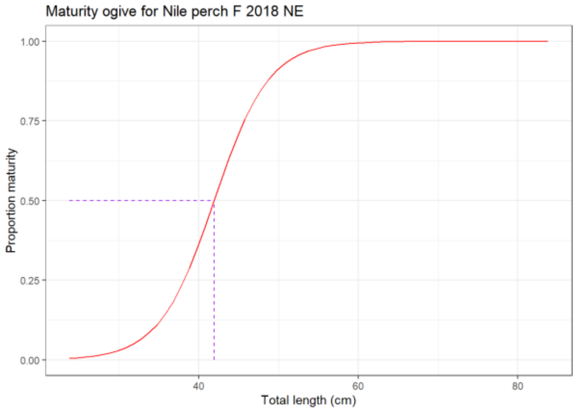

Maturity ogive for Nile perch F 2022 NE
Proportion maturity
1.00
0.75
0.50
0.25
0.00
50
100
Total length (cm)

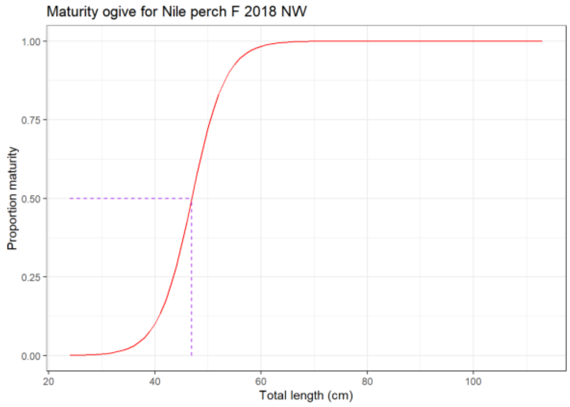

Maturity ogive for Nile perch F 2022 NW
Proportion maturity
0.00
0.25
0.50
0.75
1.00
20
30
40
50
60
70
Total length (cm)

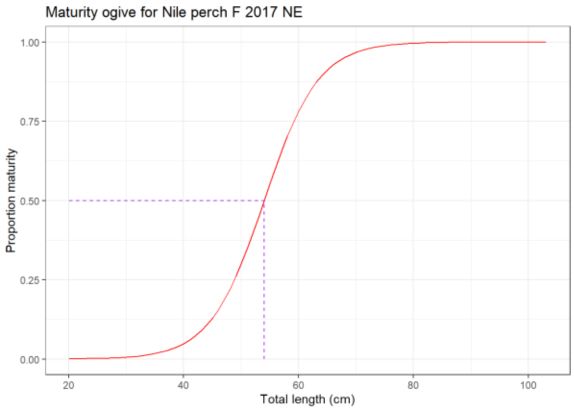

Maturity ogive for Nile perch F 2019 SE
Proportion maturity
0.00
0.25
0.50
0.75
1.00
30
40
50
60
70
Total length (cm)

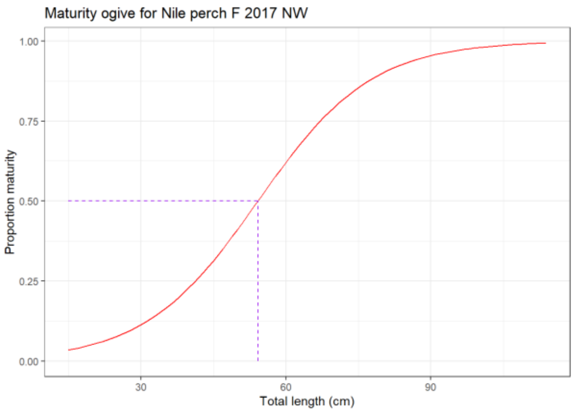

Maturity ogive for Nile perch F 2019 NW
Proportion maturity
0.00
0.25
0.50
0.75
1.00
40
60
80
Total length (cm)

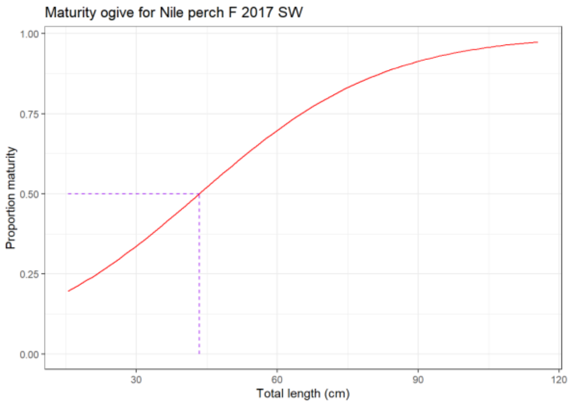

Maturity ogive for Nile perch F 2018 SE
Proportion maturity
0.00
0.25
0.50
0.75
1.00
20
40
60
80
Total length (cm)

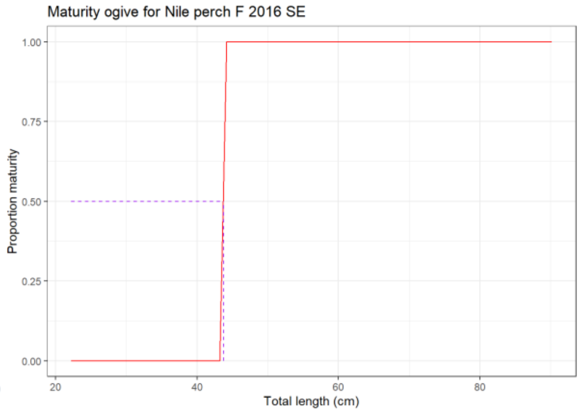

Maturity ogive for Nile perch F 2018 NE
Proportion maturity
0.00
0.25
0.50
0.75
1.00
40
60
80
Total length (cm)

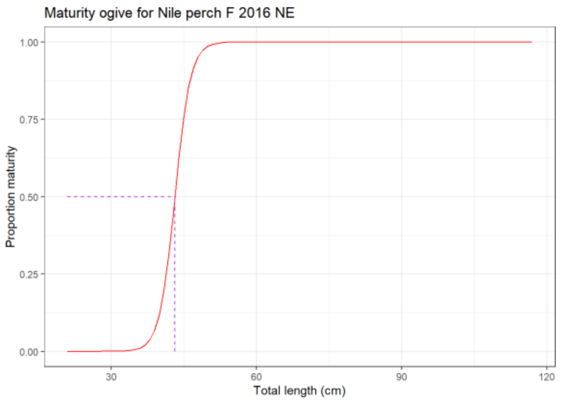

Maturity ogive for Nile perch F 2018 NW
Proportion maturity
0.00
0.25
0.50
0.75
1.00
20
40
60
80
100
Total length (cm)

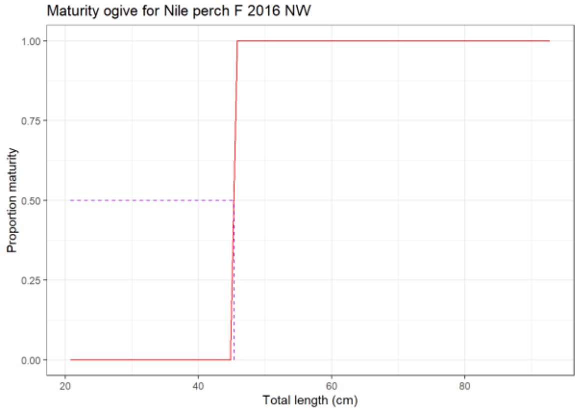

Maturity ogive for Nile perch F 2017 NE
Proportion maturity
0.00
0.25
0.50
0.75
1.00
20
40
60
80
100
Total length (cm)

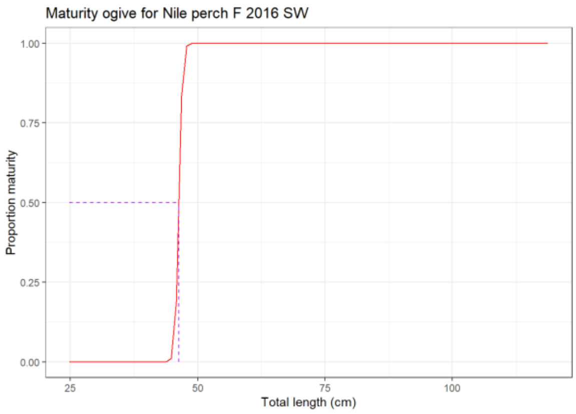

Maturity ogive for Nile perch F 2017 NW
Proportion maturity
0.00
0.25
0.50
0.75
1.00
30
60
90
Total length (cm)

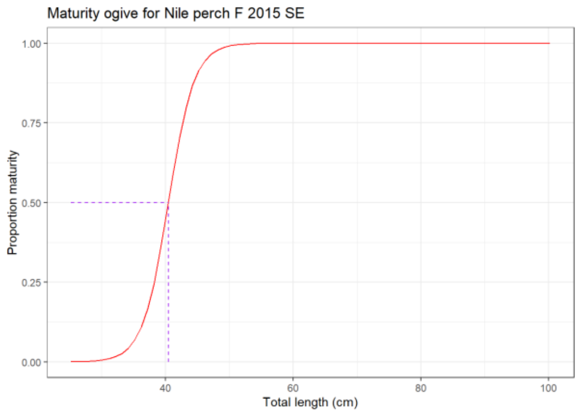

Maturity ogive for Nile perch F 2017 SW
Proportion maturity
Total length (cm)

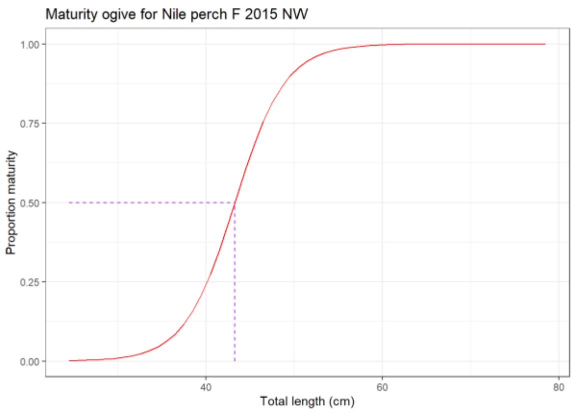

Maturity ogive for Nile perch F 2016 SE
Proportion maturity
Total length (cm)


Maturity ogive for Nile perch F 2016 NE
Proportion maturity
Total length (cm)


Maturity ogive for Nile perch F 2016 NW
Proportion maturity
Total length (cm)

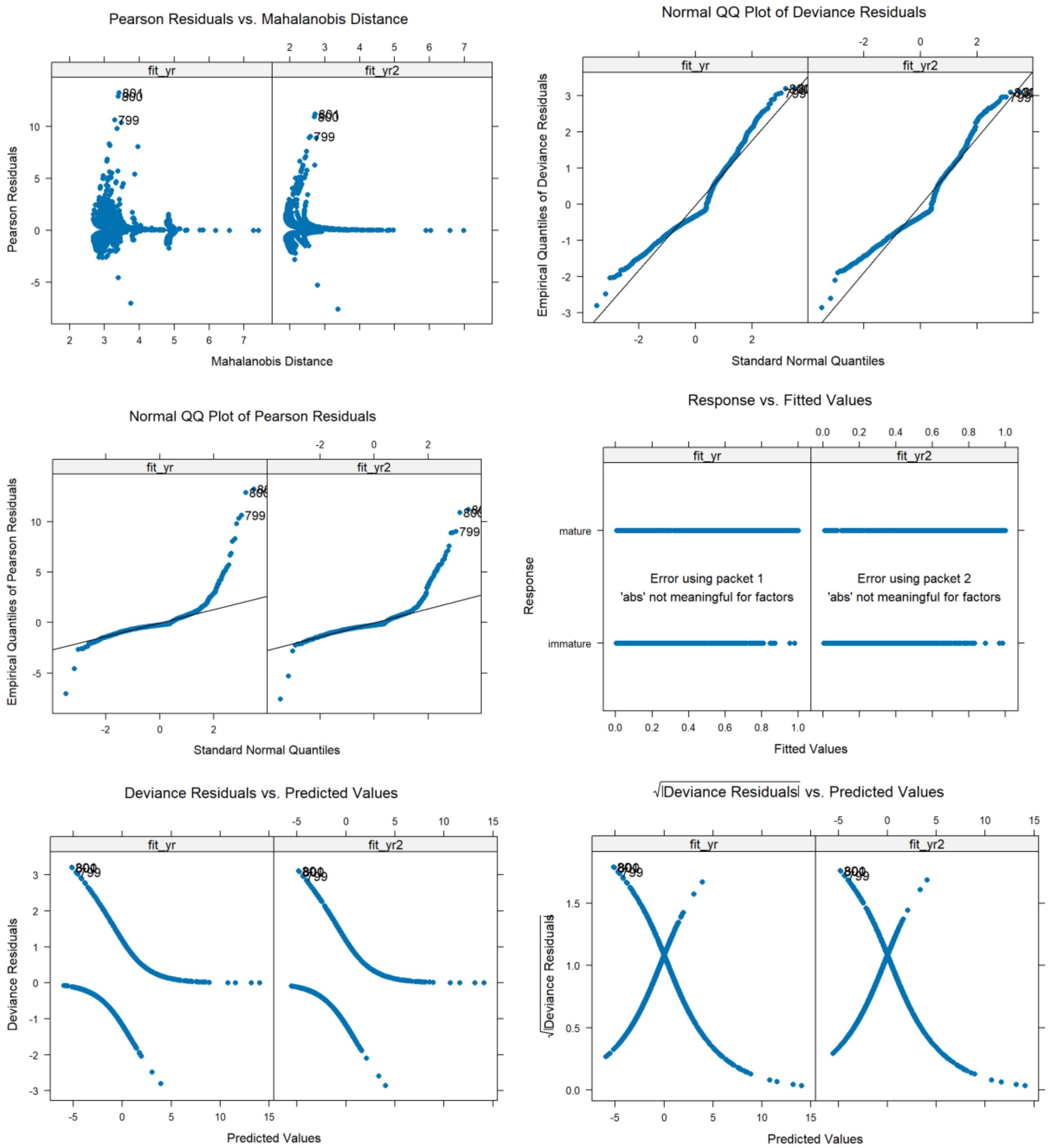

Maturity ogive for Nile perch F 2016 SW
Proportion maturity
Total length (cm)


Maturity ogive for Nile perch F 2015 SE
Proportion maturity
Total length (cm)


Maturity ogive for Nile perch F 2015 NW
Proportion maturity
Total length (cm)

Appendix 3

The graphs below, show the results of fit of the generalized linear model used in calculation of size at maturity (L50) of Nile perch in Lake Victoria.



Appendix 4

Provided figure below show spatial and temporal distribution of Juvenile Nile perch in years and across the four quadrants (NE, NW, SE, and SW) of Lake Victoria.