# Changes in fish species diversity, size structure and distribution in the trawlable demersal zones of Lake Malawi, Malawi

**Mwamad S. M'balaka** ( ms.mbalaka@gmail.com )
Department of Fisheries, Monkey Bay Capture FIsheries Research Station https://orcid.org/0000-0001-9956-5922
**Emmanuel Kaunda**
Lilongwe University of Agriculture and Natural Resources
**Geoffrey Kanyerere**
Department of Fisheries Head Office
**Daniel Jamu**
The University of Rhode Island, Graduate School of Oceanography
**Amulike Msukwa**
Lilongwe University of Agriculture and Natural Resources

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# Abstract

A study was conducted to assess temporal and spatial changes in the trawlable demersal zones of Lake Malawi. Data from surveys conducted in 1998 and 2020 targeting 120 stations covering a surface area of 9,647.97km$^2$ was used. Trawling speed of *Research Vessel Ndunduma* was restricted to 4.6km/hr. Length frequency distribution was modelled with the probability density function for determining the likelihoods in the gamma distribution. Parameters for modal length and logistic modelling were guessed and Solver in Microsoft Excel 2021 was used to generate the best of fit values through iteration with GRG Nonlinear approach. The study determined fish diversity using the Shannon and Weiner relationship. The recent survey recorded fewer fish species (149) against 158 sampled in the previous survey. The overall catch rates in 2020 and 1998 ranged from 3.8kg/0.5hr to 2003.8kg/0.5hr and 28.7 kg/0.5 to 1,884.3 kg/0.5hr, respectively. Overall fish density in the 2020 and 1998 surveys was calculated at 11.7tons/km$^2$ and 7.5tons/km$^2$, respectively representing a 35.6% drop. The study has revealed temporal and spatial shifts in the fish stock composition, distribution and abundance which necessitates urgent management interventions to prevent further fisheries resource losses. Efforts to regulate mesh sizes of the cod-ends of trawlers are encouraged just like the initiative of introducing a closed season for the commercial operators.


# Introduction

Lake Malawi has the most diverse freshwater fishes in the world with over 800 fish species (Konings, 2007; Stauffer, et al., 2018) and more are yet to be discovered. The latest addition to the known fish species was made by Stauffer et al., (2018) where two deep-water *Diplotaxodon* fish species were described. Lake Malawi fisheries provide essential socio-economic and ecosystem services to the country (Weyl, et al., 2010). Nationally, fish and fisheries products contribute 4% to the Gross Domestic Product (GDP) while nutritionally about 70% of the animal protein and 40% of the total protein are derived from fish (Annual Economic Report, 2021). With the current annual fish landings of 170,844 metric tons with an average “beach” value of US$1.3/kg, fisheries of Malawi are estimated at a landed value of MK184 billion or US$ 230 million. Over 80,000 people are directly employed in both small-scale fishery and commercial trawl fishery as gear owners and crew members while over 500,000 are employed in ancillary activities like fish processing, marketing, trading, boat building, boat repairing, net mending and fishing gear suppliers (Annual Economic Report, 2021).

Lake Malawi fisheries are mainly distinguished by their level of mechanization hence, are classified into small-scale/artisanal, commercial (trawlers and aquarist) components, (Kanyerere, 1999; Banda, 2001). The traditional fishery is known for its low investment cost, low production per unit effort, labour intensive, and wide spreading across all waterbodies (FAO, 2005; Kolding, et al., 2019). Selected small-scale fishing gears namely gillnets, open water seines, and beach seines are licensed to fish in Malawi whereas smaller gears like hooks, fish traps, cast nets and scoop nets are not licensed (Weyl, et al., 2010). The commercial trawl fishery on the other hand was introduced in 1968 after successful trawl trials in 1965 in the southern part of Lake Malawi (Turner, 1977; Banda, 2001). This fishery is categorised based on the number of trawl units, engine sizes and fishing preference along the water column. Based on the number of trawl units and water depth, they are stern and pair trawlers. Stern trawlers operate in waters deeper than 50m while pair trawlers operate in water depths range of 18m to 50m (Banda, 2001). Currently, there are three trawling techniques used in Lake Malawi namely; semi-pelagic stern trawling; demersal stern trawling and semi-pelagic pair trawling (Kanyerere, et al., 2018). Entry into the fishery is controlled by area specific permits and the Department of Fisheries is mandated to issue annual permits to the fishers upon meeting the minimum requirements (Fisheries Conservation and Management Act of 1997).

A substantial change in the species composition as a result of the introduction of trawl fishing was observed by Banda & Tomasson(1997) and Turner et al., (2005). It was noted that large demersal fish species were being replaced by smaller haplochromine species. Of particular concern was the significant decline in one of the commercially important fish, Chambo which significantly reduced the overall economic value of the Malawi fishery (Weyl, et al., 2010). The decline in the bigger fish was attributed to a number of factors but the paramount reason was the increased fishing effort and non-compliance to set out management regulations (Bulirani, 2005). Fisheries management regulations have generally been ignored by the sector as reported by Turner et al.(2005) and M'balaka and Kanyerere (M'balaka & Kanyerere, 2019a). It had been observed that vessels particularly pair trawlers routinely fish within one nautical mile (1.8km) from the shore or in less than 18m water depth; mesh sizes have been reduced from the legal minimum size of 38mm to less than 20mm. The fishery has also experienced mechanical modification where engine horse powers have largely been increased so are the sizes of the trawl nets while fishing hauls last more than the recommended aggregated duration of 8hrs/Day. High yields have therefore been maintained only by the continued adoption of these ecologically damaging practices (Turner, et al., 2005; Weyl, et al., 2010).

Efforts to assess the status of the fish stocks of the lake have partially been conducted without any distinct pattern. Kanyerere and M'balaka (Kanyerere & M'balaka, In Press) assessed the demersal zone of the central part of Lake Malawi and made some investment recommendations in an attempt to decongest the over-capacitated southern part of the lake as observed by Tweddle et al., (2010). Kanyerere et. al., (2018) recently assessed the status of commercial fisheries in southern Lake Malawi using time series data. The latest attempts to assess the fish stocks in the demersal zones were made by M'balaka *et. al.*, (M'balaka, et al., 2019) in the southeast arm of Lake Malawi. Based on the recent efforts, it is clear that Lake Malawi has not been comprehensively covered to assess the status of its stocks since the last 1998 survey. Of great importance to the fisheries diversity which requires regular and systematic monitoring is the threat of an exotic *Oreochromis niloticus* that has already colonised the northern Lake Malawi catchment (Weyl, et al., 2010). A number of works by Bootsma and Hecky (2003) equally paint another gloomy picture of the fishery with respect to the status of water quality. It is imperative therefore that an assessment of the status of fish stocks was conducted to generate new information for a renewed perspective of the fisheries resources in Lake Malawi.

## Materials And Methods

Study area and data sources

The study used data from biomass assessment surveys that were conducted in 2020 and 1998 in the demersal zones of Lake Malawi. The two surveys covered the following districts which were categorised in regions as follows; Karonga, Nkhata Bay, central (Nkhotakota and Salima), Southwest Arm (SWA) covering Dedza and Mangochi and the Southeast Arm (SEA) in Mangochi district.

Fish species composition, size structure and distribution

Size Structure and Distribution

Fish composition for the two surveys was compared through cross-tabulation using pivot tables in Microsoft Excel. Graphs of the catch composition at family and genus levels were produced in SigmaPlot 12.5. The two data sets achieved internal validity as they both used the same sampling transects, fishing gear operated by the same vessel and the key technical personnel were involved in both surveys.

To determine size structure, length frequency distribution was modelled with probability density function for determining the likelihoods for the gamma distribution (Hastings & Peacock, 1975). Parameters *b* and *c* were guessed and the solver in Microsoft Excel 2021 was applied to generate the values for best fit through iteration with GRG Nonlinear approach which only uses smooth nonlinear data. The set objective for the Solver was to minimise the residual sum of squares (RSS) by adjusting the variables, *b* and *c*. The results from the solver were then exported to SigmaPlot 12.5 for production of the modelled length frequency graphs. The choice of Gamma distribution function was based on the flexibility of the function as it follows the behaviour of the size distribution hence, most biological scientists working with size structure data prefer to use it. It is one of the most powerful simulation tools in fisheries science (Haddon, 2011).

Unlike in previous studies where weight was used to determine the importance of fish species (Banda & Tomasson, 1997; Kanyerere & M'balaka, In Press), this study used numerical importance of the fishes to conduct further length-based analyses. The advantage of this approach is that it considers conservation-related aspects of smaller fishes that might otherwise not significantly contribute to the total catches. Mindful of the fact that Lake Malawi is dominated by cichlids most of which are smaller in sizes, it was therefore imperative that assessment approaches are selected to provide chances for such particular fish species in order to come up with meaningful fisheries diversity conservation recommendations.

Length frequency distributions for the five selected fish species were modelled using the logistic model (Holt, 1963) which is similar to gear selectivity models in principle. The logistic model was used to determine the probability of a fish being retained by the encountered trawl net. Parameters $L_{50}$ and $k$ were guessed and solver in Microsoft Excel 2021 was used to generate the best fit values through iteration with GRG Nonlinear approach which was applied on smooth nonlinear data. The set objective for the solver was to minimise the residual sum of squares (RSS) by adjusting the variables, $L_{50}$ and $k$. The results from the solver were then exported to SigmaPlot 12.5 for production of the sigmoid shaped graphs. The logistic function differs from knife-edge selection as it provides a chance to any fish to be retained by the gear regardless of their sizes. Hence, any fish has a chance of being retained by the net and this chance is cumulative with an increase in the fish sizes (Holt, 1963). This is the reason why the logistic curve is sigmoid shape and its steepness is controlled by the value of $k$.

Fish species diversity

Fish species richness and abundance have been used widely to describe and assess the status of fisheries ecosystems (Hewitt, et al., 2008). This study determined fish diversity in two ways; Species richness (number of species in the study area) and species abundance (relative number of species) (Gorman & Karr, 1978). Species diversity indices for the two time periods were calculated and compared using the Shannon and Weiner (1963) relationship.

# Results

Catches sampled

Table 1 provides a summary of the total recorded catches by region for both 2020 and 1998 biomass assessment surveys. The 2020 biomass assessment survey recorded 27,261.6kg of fish against 37,853.2kg registered in the 1998 survey thereby representing a decrease of 28%. At regional level, the recent survey recorded 713.3kg of fish in Karonga which represented a drop of 58.1% from 1,700.6kg reported in 1998. Another big decline was recorded in the SEA where catches of 9,233.1kg were registered in 2020 against 17,912kg recorded in the previous survey translating into a 48.5% drop. The central part and the SWA reported declines of 13.4% and 4.6%, respectively. Nkhata Bay was the only site that reported an increase of 12.3% between the two surveys.

Table 1
Comparative results of total fish catch and mean catch rates between 2020 and 1998 surveys

| | **2020** | | | **1998** | | |
|---|---|---|---|---|---|---|
| Region | No of Stations | Total Catch (kg) | Mean Catch Rates (kg/0.5Hr) | Total Catch (kg) | Mean Catch Rates (kg/0.5Hr) | Change (%) |
| Karonga | 7 | 713.3 | 101.9 | 1,700.6 | 242.9 | -58.1 |
| Nkhata Bay | 14 | 4,267.7 | 304.8 | 3,800.9 | 271.5 | 12.3 |
| Central | 29 | 7,130.0 | 245.9 | 8,234.0 | 283.9 | -13.4 |
| SWA | 27 | 5,917.5 | 219.2 | 6,205.6 | 229.8 | -4.6 |
| SEA | 39 | 9,233.1 | 236.7 | 17,912.0 | 459.3 | -48.5 |
| **Overall** | **116** | **27,261.6** | **235.0** | **37,853.2** | **326.3** | **-28.0** |

Fish species composition

The 2020 survey recorded fishes comprising 7 families, 45 genera and 149 species. The catch from the 1998 survey on the other hand consisted of 7 families, 45 genera and 158 species. The family Cichlidae that contributed 86% in 2020 and 83% in 1998 survey was dominant in both surveys (Fig. 2). The Cichlidae dominance, was followed by Clariidae, Bagridae, Mormyridae and Mochokidae with 7.1%, 3.4%, 1.4% and 1.2%, respectively in the 2020 survey. The family Cyprinidae had smaller contribution of less than 1%. In the former survey, family Bagridae Clariidae, Mochokidae and Cyprinidae with 6%, 5%, 5% and 1%, respectively followed the dominant display of the Cichlids. Family Mastacembelidae and Mormyridae had insignificant contributions of less than 1% each in the earlier survey.

At genus level, Fig. 3 shows fish that contributed to more than 1% of the total sampled catches. The recent survey recorded *Lethrinops* (23%) *Copadichromis* (9%), *Placidochromis* (9%), *Aulonocara* (8%), *Otopharynx* (7%) and *Diplotaxodon* (7%), as the most common with a combined contribution of more than 60%. In the former survey, *Lethrinops* (22%) *Otopharynx* (10%), *Copadichromis* (9%), *Aulonocara* (8%), *Diplotaxodon* (7%), *Rhamphochromis* (6%) *Alticorpus* (5%) and *Bagrus* (4%) were the most important genera in the sampled catches. The genera *Taeniolethrinops*, *Stigmatochromis* and *Placidochromis* were the least in the 1998 survey.

In the category of fish genus that contributed less than 1% in the recent survey, the genera *Synodontis* (0.71%) and *Sciaenochromis* (0.57%) contributed more than 0.5% each (Fig. 4). The least were the genera *Barbus, Corematodus, Docimodus* and *Labeo* with 0.013%, 0.011%, 0.011 and 0.002%, respectively. The 1998 survey recorded *Pallidochromis* (0.86%), *Chilotilapia* (0.84%), *Engraulicypris* (0.79%), *Ctenopharynx* (0.74%), *Nimbochromis* (0.65%) and *Hemitaeniochromis* (0.62%) having contributions of more than 0.5% each. The genera *Labeo, Lichnochromis* and *Clarias* with 0.01%, 0.002% and 0.002%, respectively were the least.

From the 149 fish species recorded in the recent survey, the SEA dominated with 119 species followed by central with 113 species. The trend was similar to the one reported in 1998 survey. The third highest number of fish species (92) was also registered in SWA while Nkhata Bay and Karonga on the other hand recorded 62 and 46 species, respectively. In terms of number of sampled specimens recorded in the recent survey, SEA with 14,890 was again dominant followed by SWA and central with 10,075 and 8,713 individuals, respectively. Nkhata Bay and Karonga were the last two with 3,305 and 1,104, respectively. A further assessment of the 38,037 spacemen indicated that *Otopharynx argyrosoma* (2,541), *Copadichromis virginalis* (2,051), *Lethrinops oliveri* (2,011), *Aulonocara minutus* (1,675) and *Placidochromis longimanus* (1,607) had a numerical advantage from the rest.

The 1998 survey reported a total of 49,223 specimens which comprised 2,170 in Karonga, 5,882 in Nkhata Bay, 10,244 in the central, 13,987 in the SWA and 16,940 in the SEA. At regional level, the highest number of fish species was recorded in the SEA with 125 which was closely followed by the central part with 120. The third highest was SWA with 110 species whereas Nkhata Bay and Karonga were the last two with 70 and 43 species, respectively. A numerical assessment of the 158 fish species indicated that *Otopharynx argyrosoma* (3,899), *Bagrus meridionalis* (2,282), *Copadichromis virginalis* (2,136), *Diplotaxodon limnothrissa* (1,984) and *Synodontis njassae* (1,812) were among the top five fish species.

Size Structure and selectivity of selected fish species

The top most abundant fish species were subjected to length-based analyses and Table 2 provides a summary of the parameters used. The top five dominant fish species were subjected to further length-based analyses to determine their size structure. The fishes were analysed at two levels; using the gamma distribution function and logistic model for gear selectivity. Table 2 shows the solver fitted parameters that this study used to plot length frequency graphs and selection ogive.

Table 2
Solver fitted parameters for Gamma distribution and Logistic Models for the top 5 fish species

| | | | *Gamma Model Parameters* | | | *Logistic Model* | | *Literature* | *Management Implication* |
|---|---|---|---|---|---|---|---|---|---|
| | *Fish Species* | *Sample (n)* | *Phi* | *Sigma* | *Modal Length (mm)* | $L_{50}$ | $\sum$ | *Length-at-Maturity ($L_m$)* | |
| 2020 | *Otopharynx argyrosoma* | 2,541 | 0.81 | 105.30 | 85 | 81 | 0.14 | 92 | |
| | *Copadichromis virginalis* | 2051 | 0.95 | 115.38 | 109 | 97 | 0.08 | 80 | Mature |
| | *Lethrinops* ‘sp oliveri’ | 2011 | 0.80 | 105.44 | 83 | 81 | 0.13 | 120 | Immature |
| | *Aulonocara minutus* | 1675 | 0.72 | 100.40 | 72 | 67 | 0.20 | 42 | Mature |
| | *Placidochromis longimanus* | 1607 | 0.83 | 93.45 | 77 | 74 | 0.20 | Unknown | NA |
| 1998 | *Otopharynx argyrosoma* | 3,899 | 0.70 | 118.59 | 82 | 85 | 0.14 | 92 | |
| | *Bagrus meridionalis* | 2,282 | 2.95 | 101.97 | 298 | 290 | 0.014 | 330 | Immature |
| | *Copadichromis virginalis* | 2,136 | 1.02 | 118.46 | 120 | 114 | 0.08 | 80 | Mature |
| | *Diplotaxodon limnothrissa* | 1,984 | 0.98 | 93.40 | 90 | 132 | 0.04 | | |
| | | | 2.06 | 78.65 | 160 | | | 150 | Mature |
| | *Synodontis njassae* | 1,812 | 1.1 | 118.54 | 130 | 122 | 0.11 | 120 | Mature |

Figure 5 and Table 2 show modelled size structure for *O. argyrosoma, C. virginalis, L.* ‘sp oliveri’, *A. minutus* and *P. longimanus* sampled in the recently survey. The study registered the smallest *O. argyrosoma* of 51mm and the largest being 121mm with a mean total length of 83.3 ± 0.25mm. The model predicted a modal length of 85mm for the fish. The smallest *C. virginalis* measured 40mm and the largest was 160mm with a mean total length of 97 ± 1.02mm. The model estimated a value of 108mm as the modal length for the fish. The 2020 survey recorded sizes of *L.* ‘sp oliveri’ that ranged from 32mm to 155mm with an average total length of 83.9 ± 0.35mm. The predicted modal length was estimated at 83mm. Length for *A. minutus* ranged from 40mm to 80mm with a mean total length of 67.7 ± 1.08mm. The sampled fish had a length distribution estimate of 72mm as modal length. The sizes of *P. longimanus* ranged from 42mm to 135mm with an average total length of 75.6 ± 0.85mm. The predicted modal length of *P. longimanus* was 77mm.

Table 2 and Fig. 6 show the selection ogive of the five fish species. The length at which *O. argyrosoma* had 50% chance of being retained by the 38mm cod-end meshes was 81mm. The values of $L_{50}$ for *C. virginalis, L.* ‘sp oliveri’, *A. minutus* and *P. longimanus* were estimated as 97mm, 81mm, 67mm and 74mm, respectively.

The modelled size structures for *Otopharynx argyrosoma, Bagrus meridionalis, Copadichromis virginalis, Diplotaxodon limnothrissa* and *Synodontis njassae* for the former survey are shown in Fig. 7. The survey registered the smallest *O. argyrosoma* of 35mm and the largest being 155mm. The modelled length frequency distribution clearly indicated that the study sampled most of the fish species with a total length ranging from 75mm to 115mm having a mean total length of 88 ± 1.01mm. The model predicted a modal length value of 82mm for the fish. According to this study that recorded a total of 2,282 individual *B. meridionalis*, the smallest fish measured 50mm and the largest was 980mm. The modal length of the fish species was estimated at 298mm with a mean total length of 306.7 ± 2.11mm. The smallest *C. virginalis* measured 45mm and the largest was 195mm having a mean total length of 114.6 ± 0.89mm. The sampled fish had a modal length estimate of 120mm. The study that registered a total of 1,984 *D. limnothrissa* specimens reported the smallest fish of 30mm and the largest being 195mm. The modelled length frequency distribution showed that the sampled fish belonged to two length peaks; the first one was at 90mm while the second one was at 165mm. Because of this, the model generated two separate parameters with the first modal length at 90.2mm followed by another one at 160.2mm. The sizes of *S. njassae* ranged from 40mm to 205mm with an average total length of 123.3 ± 1.11mm. The predicted modal length from the model was 129.8mm.

Figure 8 and Table 2 show the $L_{50}$ values for *O. argyrosoma, B. meridionalis, C. virginalis, D. limnothrissa* and *S. njassae*. The length at which *O. argyrosoma* had 50% chance of being retained by the 38mm cod-end meshes was 85mm. The value for $L_{50}$ for *B. meridionalis* was estimated at 290mm while for *C. virginalis, D. limnothrissa* and *S. njassae* were 114mm, 131.8mm and 122mm, respectively.

Fish species diversity

An assessment of the fish diversity between the two surveys was conducted and the results indicated diversity indices of 3.84 and 4.06 for 2020 and 1998 surveys, respectively. Building on the estimated indices in both surveys, the effective number of species (ENS) was estimated as 47 for the 2020 survey and 58 for the 1998 survey. Besides reporting differences in the total number of fish species, the two surveys further differed on a number of fish species in that some species were appearing either in the 1998 or the 2020 survey.

The 2020 biomass assessment survey reported fish species amounting to 36 that were not there in the 2020 survey whereas the 1998 survey registered a total of 43 fish species that were not recorded in the recent survey (Table 3). Within the fish species that were only available in the recent survey, a total of 16 genera originating from Cichlidae and Mormyridae families were recorded. Out of the 43 fish species that were exclusively available in the 1998 survey, a total of 20 fish genera formed from 3 families namely Cichlidae, Clariidae and Cyprinidae were recorded. The study recorded unusually significant quantities of Mormyrids during the 2022 biomass assessment survey. A total of 18 specimens of the rare *Mormyrops anguilloides* (Linnaeus, 1758) measuring 1,110mm to 1,215mm with an average weight of 12.4kg were caught around Luweya River mouth in Nkhata Bay.

Table 3
Fish species that appeared in either the 2020 or 1998 survey

| No | Fish Species | 2020 | 1998 | Fish Species | 2020 | 1998 |
|---|---|---|---|---|---|---|
| 1 | *Aulonocara brevinidus* | - | + | *Lethrinops micrentodon* | - | + |
| 2 | *Aulonocara brevirostris* | - | + | *Lethrinops microdon* | - | + |
| 3 | *Aulonocara macrochir* | - | + | *Lethrinops* sp blue - orange | + | - |
| 4 | *Aulonocara maylandi* | + | - | *Lethrinops* sp long | - | + |
| 5 | *Aulonocara* sp blue-nose | + | - | *Lethrinops* sp matumbae | - | + |
| 6 | *Aulonocara* sp deep | - | + | *Lethrinops stridei* | - | + |
| 7 | *Aulonocara* sp gold | + | - | *Lichnochromis acuticeps* | - | + |
| 8 | *Aulonocara* sp long | - | + | *Metriaclima aurora* | - | + |
| 9 | *Aulonocara* sp maleri | + | - | *Metriaclima zebra* | - | + |
| 10 | *Aulonocara* sp rostratum deep | - | + | *Mormyrops anguilloides* | + | - |
| 11 | *Aulonocara* sp yellow | - | + | *Mylochromis ericotaenia* | - | + |
| 12 | *Barbus litamba* | - | + | *Mylochromis formosus* | + | + |
| 13 | *Bathyclarias atribranchus* | - | + | *Mylochromis lateristriga* | + | - |
| 14 | *Buccochromis* sp eucinostomus | + | - | *Mylochromis melanotaenia* | - | + |
| 15 | *Champsochromis spilorhynchus* | - | + | *Mylochromis plagiotaenia* | + | - |
| 16 | *Copadichromis borleyi* | + | - | *Mylochromis* sp cf balteatus | - | + |
| 17 | *Copadichromis chrysonotus* | + | - | *Mylochromis* sp silver torpedo | + | - |
| 18 | *Copadichromis cyaneus* | - | + | *Otopharynx inornatus* | - | + |
| 19 | *Copadichromis pleurostigmoides* | - | + | *Oreochromis karongae* | - | + |
| 20 | *Copadichromis prostoma* | - | + | *Otopharynx argyrosoma* | + | - |
| 21 | *Coptodon rendalli* | + | - | *Otopharynx heterodon* | - | + |
| 22 | *Dimidiochromis dimidiatus* | - | + | *Otopharynx selenurus* | + | - |
| 23 | *Dimidiochromis strigatus* | - | + | *Otopharynx tetraspirus* | + | - |
| 24 | *Diplotaxodon argenteus* | + | + | *Otopharynx tetrastigma* | + | - |
| 25 | *Diplotaxodon macrops* | + | - | *Placidochromis acuticeps* | - | + |
| 26 | *Diplotaxodon* sp big - eye | - | + | *Placidochromis hennydaviesae* | + | - |
| 27 | *Docimodus evelynae* | + | - | *Placidochromis milomo* | + | - |
| 28 | *Exochromis annagens* | + | - | *Protomelas lobochilus* | - | + |

| No | Fish Species | 2020 | 1998 | Fish Species | 2020 | 1998 |
|---|---|---|---|---|---|---|
| 29 | *Hemitaeniochromis* sp urotaenia deep | - | + | *Protomelas taeniolatus* | + | - |
| 30 | *Hemitaeniochromis* sp urotaenia shallow | - | + | *Scienochromis ahli* | + | - |
| 31 | *Labeo mesops* | - | + | *Scienochromis benthicola* | + | - |
| 32 | *Lethrinops furcifer* | - | + | *Stigmatochromis* sp spilostichus | - | + |
| 33 | *Lethrinops leptodon* | - | + | *Stigmatochromis* sp woodi shallow | - | + |
| 34 | *Lethrinops machrochir* | + | - | *Stigmatochromis spilorhynchus* | - | + |
| 35 | *Lethrinops macracanthus* | + | - | *Tramitichromis intermedius* | + | - |
| 36 | *Lethrinops macrochir* | + | - | *Tramitichromis variabilis* | + | - |
| 37 | *Lethrinops macrophthalmus* | + | - | *Trematocranus intermedius* | + | - |
| 38 | *Lethrinops macrorhynchus* | + | - | *Tyrannochromis macrostoma* | - | + |
| 39 | *Lethrinops marginatus* | + | - | | | |
| *Total* | | | | | 36 | 43 |

Key: Available species is denoted by a positive symbol (+) while absence is denoted by a negative symbol (-)

# Discussion

The Cichlidae family continues to dominate the demersal zones of the Lake Malawi fishery. The dominance of cichlids has also been reported in Lake Victoria(Okaronon, et al., 2003; Masai, et al., 2022) while Lake Tanganyika(Kimirei, et al., 2008) equally reported significant contributions after Cyprinidae family. The small contribution of the larger Cyprinids points out to its overexploitation as it is highly targeted both in the open water seines and hooks (Department of Fisheries, Unpublished data). It is however important to mention that Usipa, *Engraulicypris sardella* which falls under the Cyprinids family currently contributes significantly to the total fish landings of the country (Kolding, et al., 2019; Annual Economic Report, 2021). Similar dominance of smaller cyprinids has been widely reported in many tropical lakes such as Lakes Kariba, Mweru, Kivu, Victoria and Tanganyika(Kolding, et al., 2019) with several social-economic and ecosystem benefits being highlighted. The increased presence of the smaller pelagic cyprinids provides hope for the resource poor fishing communities across the tropical lakes in achieving food and nutritional security (Kolding et al., 2019).

Significant presence of bigger genera like *Otopharynx, Rhamphochromis* and *Bagrus* was reported in the previous survey but very little in the latest survey. Instead, these were replaced by smaller Haplochromine species namely *Otopharynx* and *Placidochromis*. Similar results were reported by Banda and Tomasson (1997) and Turner et. al. (2005). Kolding et al.,(2019) reported of a complete takeover of smaller fishes in all inland water bodies in Africa. The scenario which primarily was created through overexploitation of larger fishes fits well with the concept of fishing down the food web(Pauly, et al., 2000) clearly demonstrating how fishers adjust their preferences in response to overfishing of particular large sized fish stock. Similar incidences of species shifts have widely been reported in Lake Victoria where a deliberate introduction of *Lates niloticus* brought about substantial changes in the fish species particularly the Haplochromines (Ogutu-Ohwayo, 1990; Ouma, et al., 2002; Njiru, et al., 2005). Fish species shifts are reported to disturb the tropical aquatic ecosystem by creating imbalances in the food web (Kolding et al., 2019). Elsewhere, selective fishing particularly targeting bigger fish is reported to have caused substantial structural adjustments to both marine fish stocks and the ecosystem(Kolding et al., 2016; Plank et al., 2017).

This study also reported an overall dominant contribution of smaller haplochromines, *Otopharynx argyrosoma.* The fish species, which is widely distributed in the southern part of Lake Malawi (Turner, 1996; Konings, 2016), was also reported in abundance in Lake Malombe and the Upper Shire River (Kanyerere & M'balaka, 2017). The substantial presence of the fish in Lake Malombe signifies the importance of the connection between the two waterbodies through the Shire River. It is therefore important to consider conservation interventions that insures that there is a free movement of the fish between these two water bodies. The fish is also reported to have an increased presence in deep waters (Turner, 1996) which are lightly exploited by both the artisanal and commercial trawl fishers because of insufficient capacity and other physical barriers such as lake bottom. The nature of bottom of Lake Victoria (muddy bottom) has been reported to restrict full use of bottom trawling (Okaronon, et al., 2003) while water depth in Lake Tanganyika is reported to serve the same purpose (Kimirei, et al., 2008).

A differential impact of fishing on different species has revealed how complex multi-species fisheries can be in respect to fisheries conservation and management. The study has revealed a mixture of sexual maturity status of the major fish species sampled where other species were reported to be sexually mature while other were not. This becomes a big challenge in coming up with fisheries management measures particularly on mesh size restriction. Decision on what type of fish to protect will therefore not only depend on the current study findings but also assess the catch and effort statistics from the Department of Fisheries which indicates dominant presence of *Diplotaxodon* and *Copadichromis* species (Department of Fisheries, Unpublished Data). The resilience of the two fishes has been noted indicating how buoyant the fish has been to all forms of environmental and fishing pressures coupled with environmental degradation in the lake and the catchment. The absence of trawlers in some parts of central and the northern region may also likely aid in the increased production of offshore fish stocks. The study further recognised the contribution of 13 rare fish species and among them were *Labeo cylindricus* and *Placidochromis milomo*. The unusual significant appearance of fully grown *Mormyrops anguilloides* (Linnaeus, 1758) in the recent survey in Nkhata Bay was also observed. The adult fish are reported to prefer deep and quiet waters between boulders and overhangs that are away from strong water currents (Skelton, 2001). This habitat preference concurs with where the fish were sampled as the site was characterized by the presence of artificial reefs (*Zilundu*) submerged by the communities to act as fish aggregating devices.

The lake has undergone noticeable changes in the fish species diversity and this could be attributed to the overexploitation of the fish stocks through increased fishing pressure. Of great concern is the overexploitation of shallow water fish species like the *Oreochromis species* whose preference for shallow waters for breeding and nursery is further threaten by their slow growth and low fecundity (Weyl et al., 2010). The observation of overexploitation in the shallow water zones was previously reported by Banda and Tommason (1997), Kanyerere and M’balaka (In Press). Illegal fishing and destruction of spawning and nursery grounds have been blamed for the fisheries resource destruction in many tropical waterbodies (Kimirei et al., 2008; Kolding et al., 2019; Masai et al., 2004). Lake Malawi submerged and emergent aquatic vegetation is routinely cleared for easy operations of beach seining and lakeshore real estate development while poor farming practices upstream have equally brought about siltation and chemical overload in similar systems (Ogutu-Ohwayo, 1990; Bootsma & Hecky, 2003; Kolding, et al., 2019). Of late, overfishing is not only occurring in the shallow waters, as the deeper water species are also threatened. The threat being caused to the deeper water demersal fish species is huge since these fishes are confined to particular environments with minimum mobility (Weyl, et al., 2010)). The restricted movements pose threat to their existence because of potential locality-specific overfishing (Weyl, et al., 2010).

Fish biodiversity is associated with a number of biophysical characteristics of the habitats (Patrick & Thomas, 2001; Sayer, et al., 2019). The area sampled in Karonga which reported the lowest fish diversity is characterized by shallow sandy habitats stretching from Kaporo to Chilumba (Turner, 1996). The central region (Salima and Nkhotakota) which had high fish diversity is characterized by rocky areas extending from the Chia River mouth to around Benga. The Nkhotakota District is also known to have artificial reefs installed by communities around the Nkhotakota Boma. Mbenji Island in Salima which is still managed by local leaders (Njaya, 2007) could be another site of higher fish diversity in the region. The central region is also well connected to three major tributary rivers namely Dwangwa, Bua and Linthipe (Sayer, et al., 2019). Rivers in Lake Tanganyika are reported to provide escape routes for overfished stocks of the lake (Kimirei, et al., 2008) and it is therefore believed that similar cases occur in Central Lake Malawi. The high diversity in both SWA and SEA is accredited to the increased productivity of the regions, partly because of the shallowness of the regions (Ribbink, 2001; Weyl, et al., 2010). The two regions are also known for having many outcrops, islands and aquatic vegetation particularly the northern part of Malindi (Turner, 1996). Community initiated fish protected areas (fish sanctuaries) established around 2017 are also reported to increase fish diversity through spillover and recruitment effects (Center, Coastal Resources, 2016).

Despite several challenges being faced in the management of the fisheries resources, positive strides have recently been registered. These include an adoption of vessel monitoring system (VMS) to monitor compliance of vessels regarding fishing areas and fishing times. The system aims to monitor activities of all trawl vessels in the waters of Lake Malawi including fishing duration which directly provide accurate estimates of fishing effort; adherence to their designated fishing areas and depth zones. Another optimistic development is the introduction of 3-month closed season for the commercial trawl fishery from December to February which commenced in the 2020/2021 fishing season (Department of Fisheries, 2020). The local fisheries management authorities (LFMAs) like Beach Village Committees (BVCs), Fisheries Association (FAs) have also been resuscitated and local leaders' involvement in fisheries management has been enhanced as a way of operationalizing decentralised fisheries resource management. In line with the Chambo Restoration Strategic Plan (2005), the fisheries have also seen a rise in the establishment of community-owned fish protected areas. In most cases, these areas are installed with fish aggregating devices (FADs) and other barriers to deter any active fishing within those zones (FISH, 2018). Recently, the Government of Malawi has also banned the importation and use of the ecologically damaging monofilament gillnets.

All in all, Lake Malawi demersal fishery has not significantly changed in terms of fish species richness and abundance. As previously reported, the fishery continues to experience fish species shift where larger and commercially important fish species have been replaced by smaller haplochromines species. The fishery is also going through a growth overfishing as the dominant fish species have been harvested prematurely. To avert this trend, previous studies(Kanyerere, 1999; Duponchelle, et al., 2003) recommended an upward adjustment of the cod-end mesh-sizes from the current 38mm to 80mm. The small-scale and commercial trawl fisheries are harvesting the same fisheries resources and this was previously reported by Weyl et al., (2010), hence the need to revise the fisheries regulations that govern them particularly on the fishing areas and time of fishing.

### Limitations

This study recognizes the following limitations which may have impacted on the research results, conclusions and recommendations.

1. Bottom trawl surveys are always challenged by the nature of the lake bottom hence its sampling design and estimation of the fish diversity are to some extent negatively affected
2. Trawl net by design is selective based on the mesh-sizes of the cod-end hence the results on the fish stocks and species diversity may not be a full picture of the fishes in the study area
3. The research vessel Ndunduma used in both surveys has water depth limits as it cannot sample in waters of less than 5m because of its bigger size. This means that it leaves out fish species that are found in those habitats thereby affecting the results on biodiversity and abundance
4. Both studies were conducted during the day which means that fish species that migrate vertically during the day could have been missed thereby impacting both fish species diversity and abundance. Studies elsewhere have shown that some bottom-dwelling fish species move to the upper water column during the day for feeding and/or foraging.

## Declarations

Competing Interest: Mwamad S. M'balaka received financial support from the Restoring Fisheries for Sustainable Livelihoods in Lake Malawi (REFRESH) Project for his postgraduate research. Emmanuel Kaunda and Geoffrey Kanyerere by being supervisors have financial interest from the funders. Daniel Jamu is employed by the project as a Deputy Chief of Party hence, has a financial interest. Amulike Msukwa has no any financial interest in the study

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# Figures

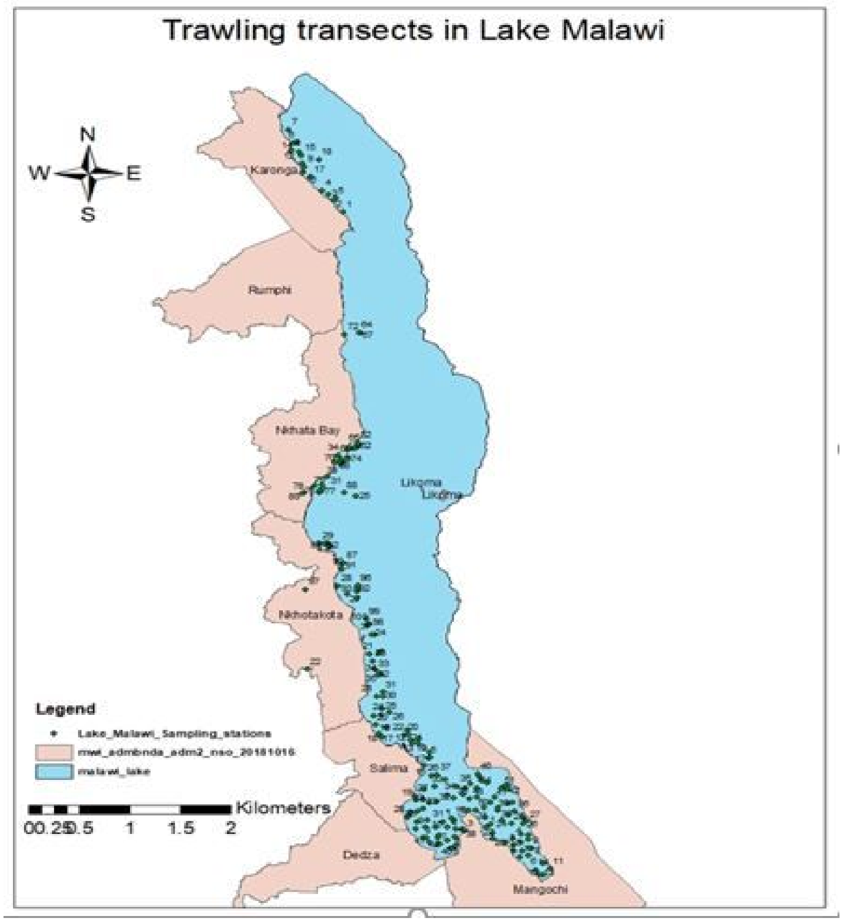
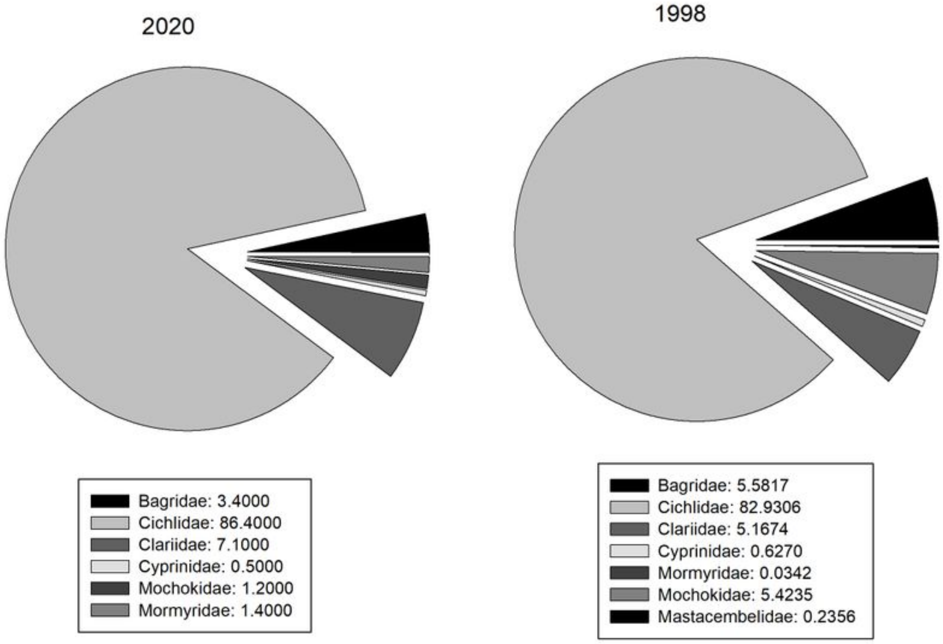


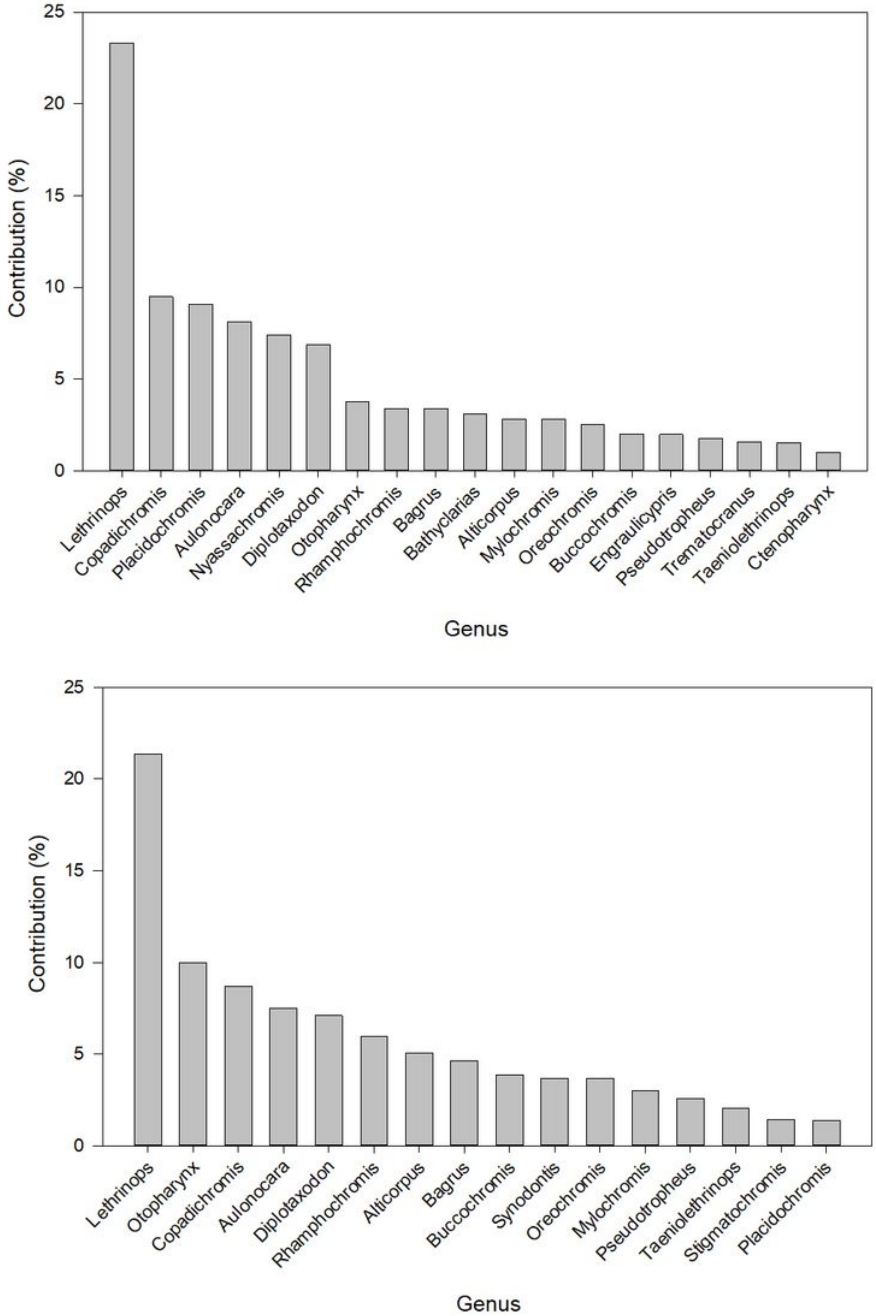

**Figure 1**

Sampling points used in the 2020 and 1998 demersal trawl surveys in Lake Malawi



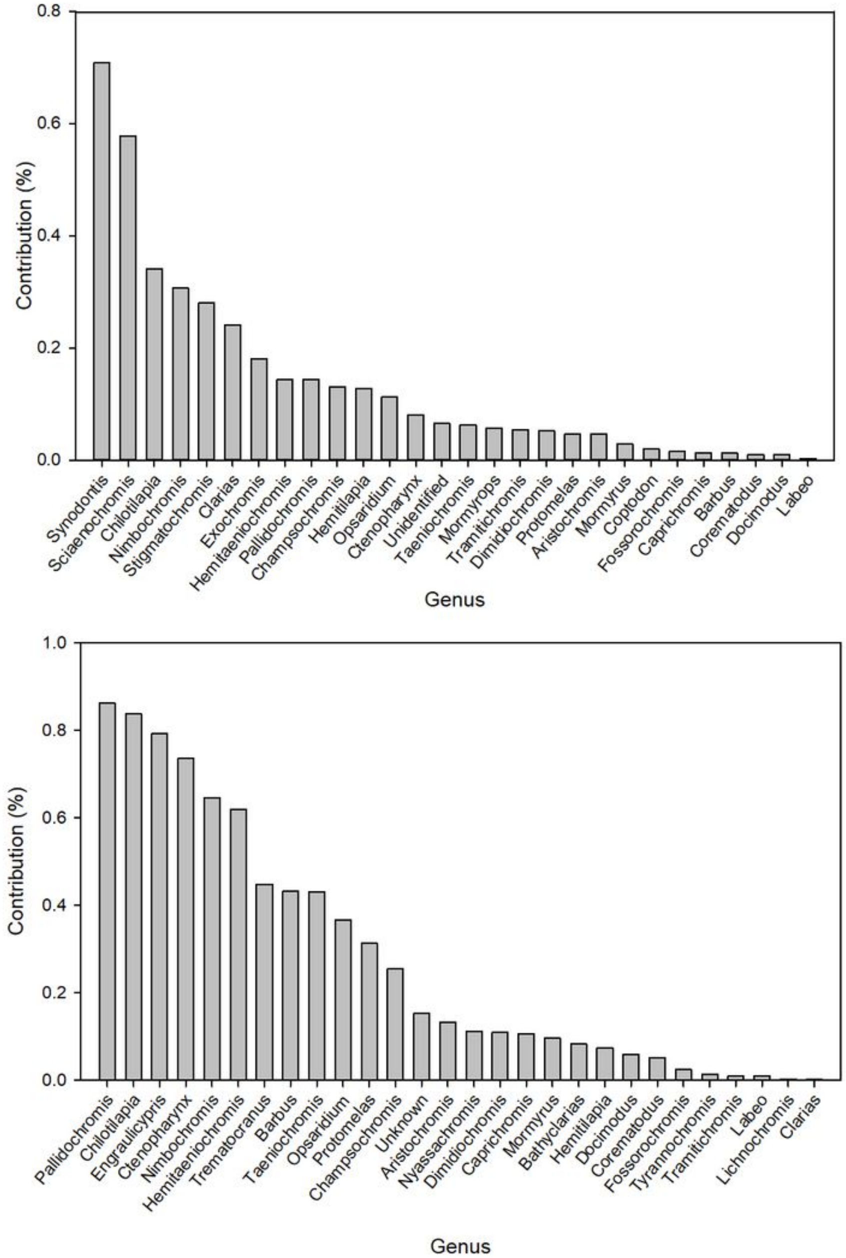

## Figure 2

Catch composition at family level between the 2020 and 1998 demersal trawl surveys



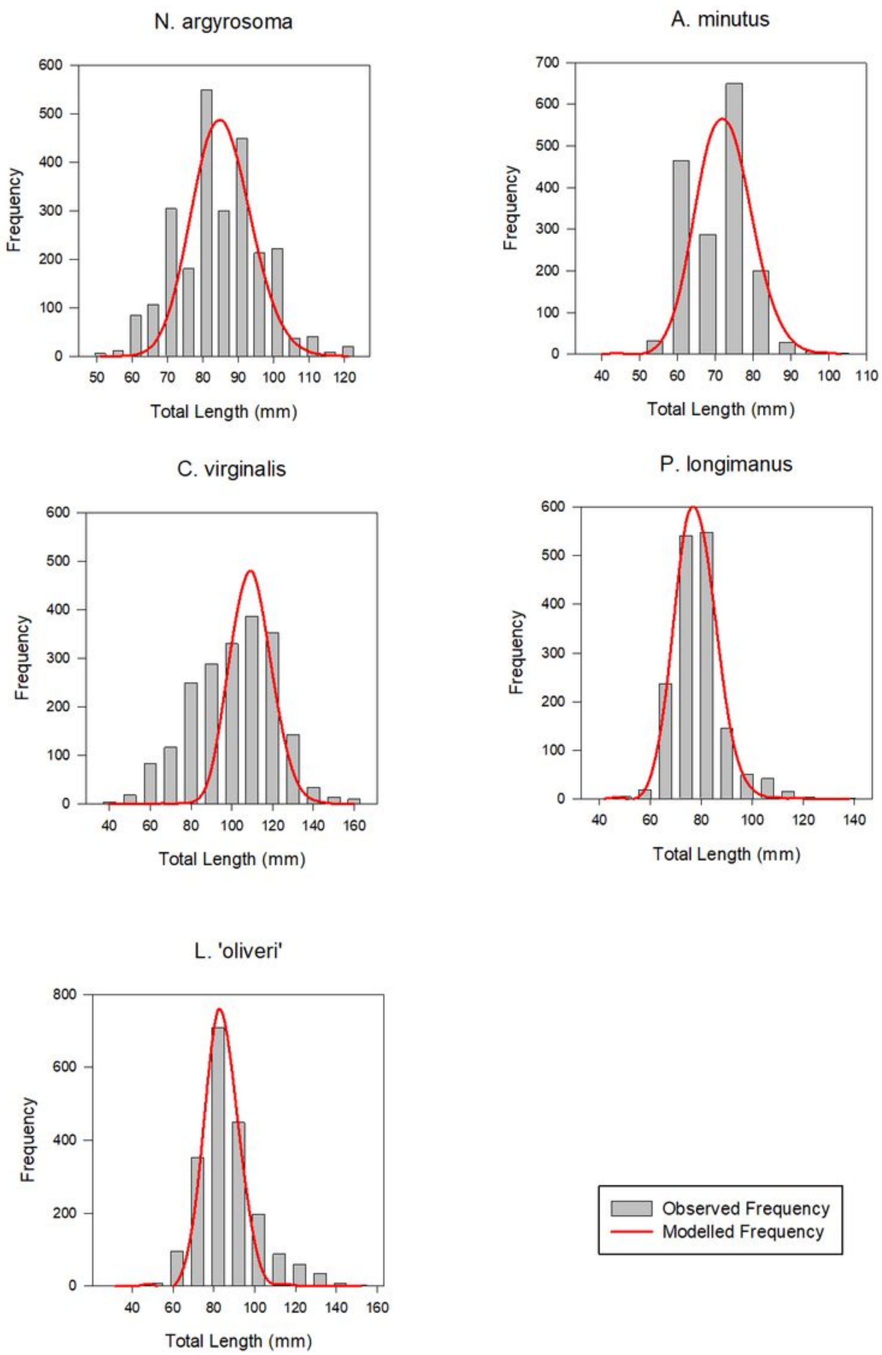

## Figure 3

Catch contribution by dominant fish genera that contributed more than 1% in the 2020 (top) and 1998 (Below) surveys



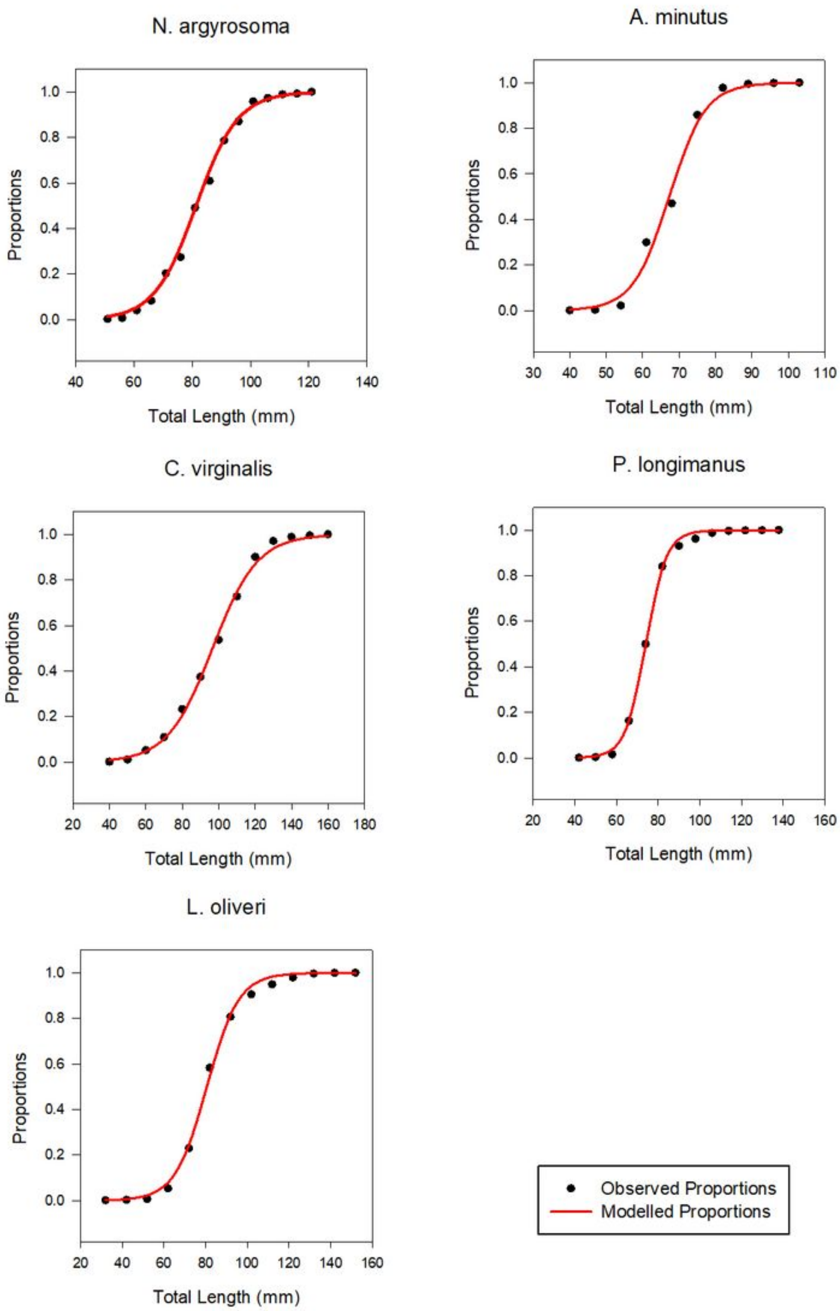

## Figure 4

Catch composition by fish genera with less than 1% contributions in 2020 (top) and 1998 (below) surveys



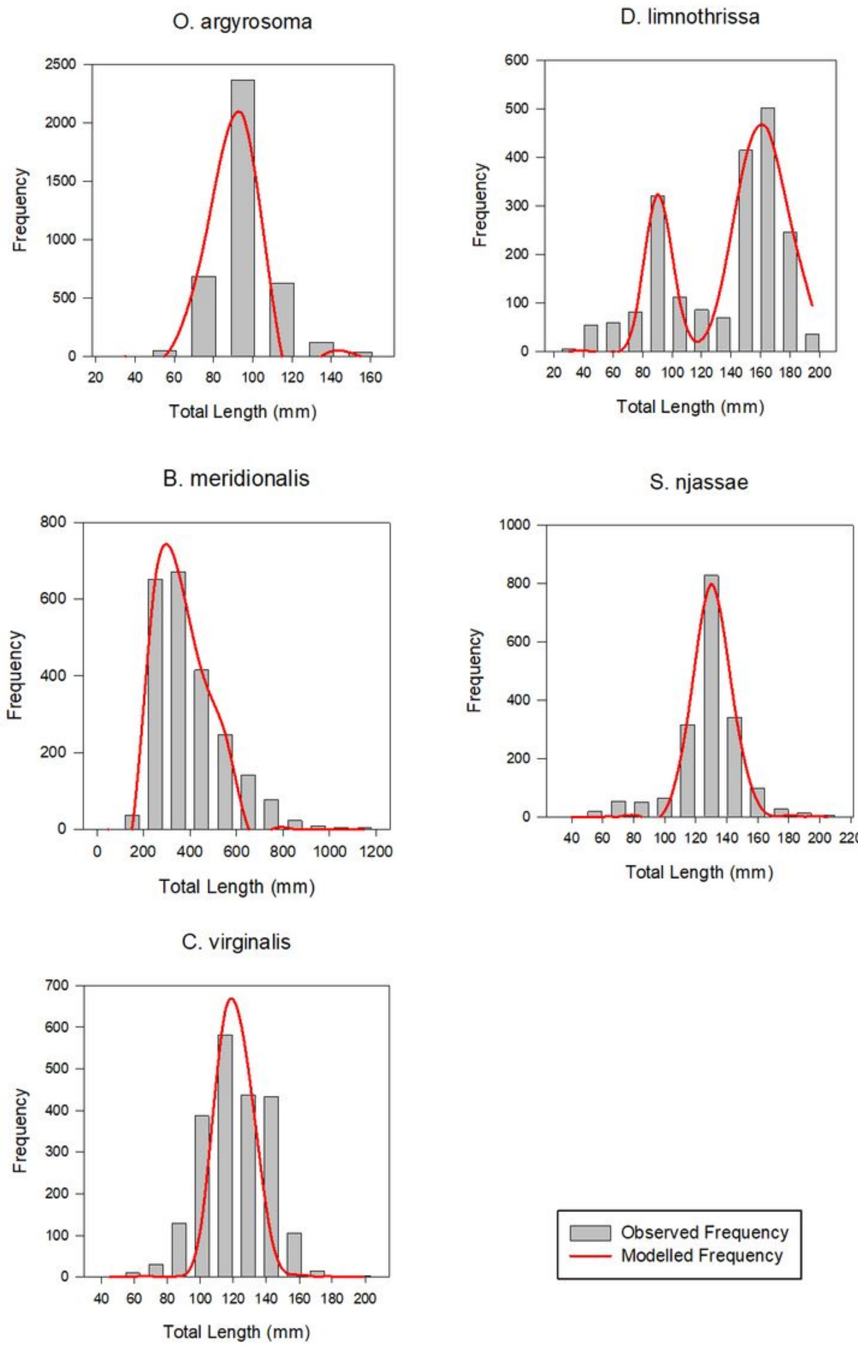

## Figure 5

Modelled size structure for top 5 fish species sampled during the 2020 survey



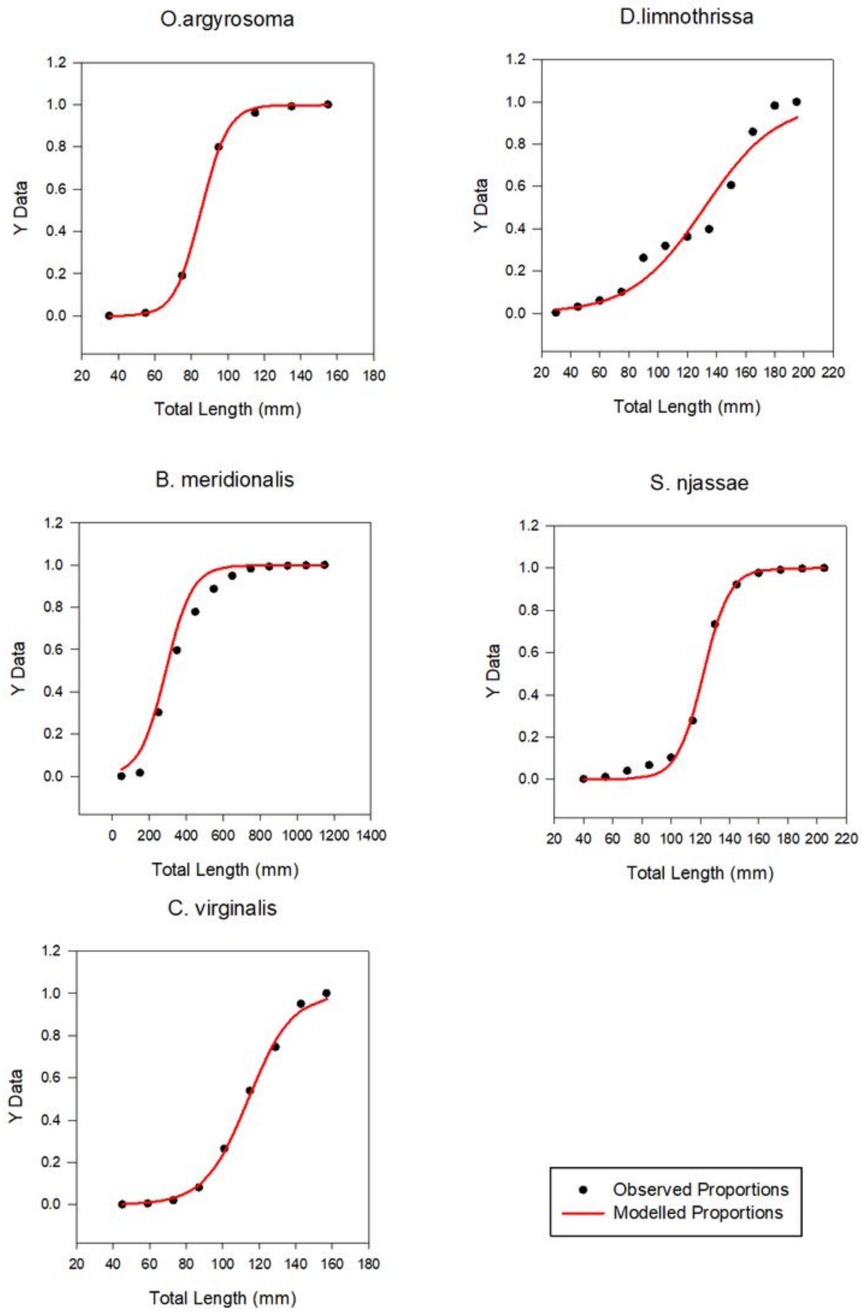

## Figure 6

Selective ogive for top 5 fish species sampled during the 2020 survey




## Figure 7

Modelled size structure for top 5 five species sampled during the 1998 survey




## Figure 8

Selection ogive for top 5 fish species sampled during the 1998 survey