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Application of citizen science in assessing temporal and spatial variations in fish populations in the wetlands of the Elephant Marsh in Malawi

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Abstract

Communities in the Elephant Marsh, located in Chikwawa and Nsanje districts in southern Malawi were actively involved in assessing temporal and spatial variations in fish populations. The study aimed to determine the catch composition, size distribution, diversity and conservation status of key fish species. To achieve this, the survey deployed several complementary sampling techniques from secondary and primary data sources. Eight landing sites with their corresponding fish conservation hotspots were targeted in the marsh. The key findings of this study indicated increased dependence of communities to fishing activities with corresponding increase in fish catches. The study results further noted significant differences in fish catches and the number of species across seasons. Contrary, there were no significant variations in fish catches and the number of species across the eight sampled sites. Overall, there were no significant temporal or spatial differences in the fish species diversity, highlighting similarities in the habitat characteristics and management. The study results also revealed the maturity and conservation status of key fish species in the marsh. It further revealed the extent of illegal fishing practices in the marsh. The study results therefore demonstrated the uniqueness of Elephant Marsh with respect to seasonally specific fish populations and distribution. For the effective management and conservation of the rich and unique fisheries resources, community conservation area management plans for the respective hotspots should be developed and implemented. Policy makers should also consider reviving input control measures like closed season and fishing gear licensing for Elephant Marsh fishery.

1 Introduction

Wetlands with numerous ecological, economic, and social benefits are among the most productive ecosystems, providing unique environments that are critical habitats for a wide range of plants and animals [1, 2]. These environments are known for self-purification, naturally filtering and trapping sediments, nutrients, and pollutants thereby improving water quality [1, 2, 3, 4]. Wetlands are further known for their role in minimising climate change impacts as they are crucial in the global carbon cycle and flood control by absorbing excess rainfall subsequently reducing flooding events [2, 5]. It is therefore through these attributes that communities around the wetlands heavily rely on them for their livelihoods and other opportunities.

In Malawi, several wetlands with varying magnitudes exist and Elephant Marsh, located in the Chikwawa and Nsanje districts at the southern end of Malawi is one of them [1, 5, 6]. Elephant Marsh is a second Ramsar site No. 2308 established on 1st August 2017. The name Elephant Marsh was given by Dr. David Livingstone, following a vast wetland area hosting a large number of wild animals, such as elephants, buffalos, hippos and antelopes [7]. Currently, only hippopotamus population is reported to be available estimated to be less than 100, which is one-tenth of what was expected to have occurred under more natural conditions. Furthermore, Elephant Marsh had thousands of crocodiles in the 1980s however, several factors dominated by the anthropogenic activities have reduced the numbers to less than 200, according to Government of Malawi Report (2023). The unique biodiversity of Elephant Marsh provides

several ecosystem services to aquatic ecology and surrounding communities. Traditionally, human beings have been connected to the marsh socially, economically and culturally [1]. The marsh provides readily available fish to the communities through subsistence fishing which has been there since time immemorial [1, 4]. Fish production is dominated by African catfish, *Clarias gariepinus* and tilapias, *Oreochromis mossambicus*, and is currently estimated to be slightly above 2,000 metric tons per year against 5,100 metric tons reported between 1977 and 1993 [6]. The marsh further provides readily available water for irrigation farming [5, 8]. The marsh directly employs approximately 3,340 people through fishing activities (Malawi Department of Fisheries, unpublished data, 2025).

Despite all the benefits, the marsh is facing serious threats primarily driven by habitat destruction and modifications [1, 4, 5]. The opening of new gardens for cash crops, upscaling and settlement, brick making, cultivating along river banks, grazing and cutting down of trees in catchment areas of rivers have all been blamed for the habitat degradation in the marsh. The ecosystem has further experienced the emergence of aquatic invasive species, habitat fragmentation, increased human populations and unsustainable fishing practices [1, 5, 9]. These challenges are occurring in the face of impactful climate changes coupled with weak governance systems, rendering monitoring control and surveillance less effective [8]. Despite acknowledging depletion of fisheries resources, it is worrisome to note that conservation efforts are not clearly outlined in the Socio-economic Profile 2022–2030 reports for Chikwawa and Nsanje Districts. The reports largely attribute the aquatic environmental damage to lack of environmental awareness, weak environmental information system, inadequate institutional support to environmental management, weak environmental legislation, vulnerability of the district to poverty and natural disasters and a fragmented approach towards environment and natural resource management.

Despite the challenges, the ecosystem has attracted a number of research and development interests. Researchers have documented the fish species richness of Elephant Marsh while identifying threats to the unique ecosystem [1, 4, 7]. Studies assessing the socio-economic and governance dynamics of the communities around the marsh have previously been conducted [8, 9]. Factors that influence fish production in the entire Shire Valley were also examined [6]. Other authors applied an eco-social model to assess options for managing ecological status of the Elephant Marsh [10]. The recent study looked at the vulnerability of the ecosystem services and functions in Elephant Marsh and suggested coping strategies for the communities [5]. Recent agriculture development intervention in the region is the World Bank-funded Shire Valley Transformation Programme II (SVTP II). The project aims to increase agricultural productivity, commercialise and promote the sustainable utilisation and management of natural resources in the Shire Valley Region. These components respond to several Pillars/Enablers in the Malawi vision document called Malawi 2063 Agenda.

One of the project components, The Natural Resources Management, supports environmental activities such as strengthening the participatory protection and management of natural resources in the Elephant Marsh (STVP-II Project. Communities identified fish conservation hotspot and are geared towards the development of community conservation area management plans (CCAMPs). Considering the complexity of the Elephant Marsh ecosystem, an in-depth baseline assessment of the fish population

was conducted by researchers. Communities were actively engaged in the assessments for them to appreciate the current status of their resources and be part of the solution. Specifically, the study aimed to estimate current levels of catch and fishing effort. The study also aimed to monitor unique fish diversity and distribution; assess the population distribution and conservation status of the key fish species in the Elephant Marsh. The study therefore expects to generate usable information that will lead into streamlined and effective conservation and exploitation initiatives of Elephant Marsh fisheries resources for the present and future generations.

2 Methods

2.1 Study Area Description

The study was conducted in the Elephant Marsh located between latitudes 14°25'–17°50'S and longitudes 35°15'–35°15'E and ranges from the Kamuzu Bridge at Dyeratu in Chikwawa to Chiromo in Nsanje District (Fig. 1). The total catchment area of the region varies from 500 km^2 in the dry season to 2,700 km^2 at peak rainy season [9]. The Elephant Marsh is characterised by many kinds of vegetation, such as rooted emergent, submerged and free-flowing vegetation [5, 9]. The marsh is interspersed with islands with saline soils and palm trees (Chikwawa Socio-economic Profile 2022–2030). They are known to trap sediment that would otherwise cause flooding downstream [2, 9]. Elephant Marsh has distinct weather patterns similar to tropical savanna climate [5]. The mean annual rainfall revolves around 700 mm, mostly from November/December to February/March. The Elephant Marsh is located in a lowest part of Malawi hence is reported to have the highest temperatures which reaches 49°C, while minimum is around 10°C (Chikwawa Socio-economic Profile 2022–2030).

2.2 Data Sources

Two data sources were used in the study: (1) secondary data from Chikwawa and Nsanje Districts and (2) primary data collection through seasonal field surveys.

2.3 Secondary Data

2.3.1 Fishing effort indicators

To understand fish population dynamics, the study needed to establish the status of the fishing effort indicators that are associated with the sites. These indicators are collected through an annual frame survey, annual census of fishing effort indicators, conducted in the months of February or March. The surveys provide a systematic and standardised approach for capturing such indicators by, among others, providing the trends and current status of the fishers; fishing units; sex and age profiles; levels of illegal fishing practices and any emerging issues associated with fishing operations. The annual frame survey data collection is undertaken via digitised survey instruments deployed through the KoboCollect mobile application. District Fisheries Officers (DFOs) are responsible for the data collection with supervision

from the research institutions. The study provides recent figures and trends of fishers comprising gear owners and crew members. It has further provided a snapshot of the status of illegal fishing that threatens the biodiversity of the Elephant Marsh.

2.3.2 Fish production estimates

Fish production data in the Elephant Marsh was collected to supplement the survey data. The catch and effort data are collected monthly at predetermined landing sites within a minor stratum. Minor strata (plural) are administrative constituencies within Malawi capture fisheries districts for the attainment of effective fisheries conservation and development. There are four minor strata in the Elephant Marsh with varying geographical sizes.

The fish production data covered five years, from 2021–2025 corresponding to the project implementation period. Unlike, the annual census of the fishing effort indicators, catch assessment survey (CAS) is yet to migrate to digital platforms. The migration process has however started elsewhere in Lake Malawi. The survey team therefore collected copies of the data and took them to the Monkey Bay Capture Fisheries Centre for consolidation and analysis.

2.4 Primary Data Collection

This study complement science with local knowledge in fish identification and distribution. Community representatives from community conservation area (CCAs) committees and beach village committee (BVCs) were actively involved in the data collection process.

2.4.1 The Sampling design

The study was conducted from June 2024 to March 2025, targeting three seasons namely cool dry (May-August), hot dry (August-October) and rainy season (November-April). It was conducted by monitoring two hotspots/landing site per minor stratum (Table 1). One minor stratum was sampled for two days, resulting in a total of 8 survey days per season. Specific locations were identified by the fishing community representatives and extension workers. All the hotspots and landing sites were georeferenced via handheld Etrex 20 GPS receivers.

Table 1
List of sampled hotspots and landing sites within Elephant Marsh

District	Minor Stratum Name	Hotspot	Landing Site
Chikwawa	Northwest Elephant Marsh	Mchere	Mchere
		Namicheni	Namicheni
	Northeast Elephant Marsh	Lisuli	Lisuli
		Mthyola	Thedzi
Nsanje	Southeast Elephant Marsh	Gongómkulu	Chisamba
		Nyangóna	Chibvuli
	Southwest Elephant Marsh	Msambo	Msambokulira
		Mphanda	Chinzeti

2.5 Fishery Independent Data Collection

Fishery independent surveys are techniques that allow researchers to design and implement a sampling plan by applying all scientific sampling principles [11]. Some examples of such techniques include trawl surveys, underwater censuses, mark and recapture, etc. [12]. During the recent surveys, a standardised seine net measuring 150m long and 15m deep with 1.2mm meshes was operated by at least five experienced local fishers. Fishing was achieved through a paddled plank boat. Fish sampling was performed at three predetermined sampling stations at each conservation hotspot.

2.5.1 Handling of the sampled fish

Before fishing, the fishers were informed and oriented on the best handling techniques of the sampled fish. Fishers were further advised against hiding the fish, as that would significantly affect the results. The survey aimed to collect data while minimising fish mortality and unintended catching of organisms. Fish caught per station were separately kept in well-marked containers with water and immediately processed at the nearest landing site. After all the necessary data were recorded, live and strong fish were returned to the water, while the few dead fish were handed over to the BVC/CCA representatives to determine their disposal.

2.5.2 Data collection

Once the fish sampling was completed, data collection process commenced. The fish catch data were collected following the modified guidelines of Pauly [11] and Sparre and Venema [12], as outlined;

i. All non-fish materials and organism (frogs, debris, weeds, logs, etc) were removed and recorded
ii. Where necessary, the sampled fish were washed with clean water
iii. All the fish were then weighed to determine the weight of the catch
iv. To improve representativeness, all large fish species were separated from smaller ones

v. At least a 30% sample size was randomly collected as a representative of the total catch
vi. When the catch was too small to be sampled, all the fish were processed

2.5.3 Fish identification and data recording

The fish were identified by experienced fish taxonomists at the Monkey Bay Capture Fisheries Centre, together with the seasoned fishers and the CCA representatives. Published identification keys by Paul Skelton [1, 4] were used for verification. Both scientific and local names were captured during the exercise. After the fish were sorted to the species level, individual length in millimetres and weight in grams were recorded using structured data collection forms. Extra caution was taken to minimise stress to the fish through handling by speeding up the process (10 minutes), working under a shelter and handling the fish with moist hands. Fish sampling was also purposively conducted in the morning when fish are less active.

2.6 Beach Sampling

Beach sampling also known as fishery-dependent surveys, was conducted to complement the fishery-independent sampling. Unlike fishery independent surveys, beach sampling is not flexible in standardising the time/period or location of fishing. Everything depends on the fishers. The CCA and BVC representative were key in introducing the research team to the fishers.

Two landing sites per minor stratum were selected for sampling. The sampling targeted all the existing fishing gear and methods at each landing site. Like with fishery-independent sampling, the sample size varied according to the size of the catch. In some cases, all the landed catch was measured, whereas in other cases, at least 30% of the catch was sampled. Once the sample was determined, the sampling procedure recommended by Pauly [11] and Sparre and Venema [12] previously outlined in Section 2.5.2 was followed.

2.7 Fish Size Structure and Selectivity

Using the gamma distribution, numerically dominant fish (top 4) were selected for length frequency distribution modelling. The gamma distribution function is one of the most preferred data simulation tools by fisheries scientists [14, 15]. Eq. 1 is the modified gamma distribution function used in the study [14].

$$L\left\{x|c,b\right\} = \frac{\left(\frac{x}{b}\right)^{(c-1)\frac{-x}{e^b}}}{b\Gamma(c)} \quad \text{Eq. 1}$$

where x is the value of the variate, b is the scale parameter, c is the shape parameter, and $\Gamma(c)$ is the gamma function for the c parameter. The values for b and c were hypothesised and solver in Microsoft Excel 2021 was used to generate the values for the best fit through iteration with the Generalized Reduced Gradient (GRG) nonlinear approach, which 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 top 4 fish species were also modelled using the logistic model for seine nets [16]. Selectivity comprises vulnerability of fish to the fishing gear and availability of the targeted fish [17]. The logistic model shown in Eq. 2 was used to determine the probability of capture for the selected fish species.

$P_{(L)} = 1/(1 + e^{(-k(L-L_{50}))})$ Eq. 2

Where P is the probability of capture of the gear on a fish of size L and ranges from 0 to 1, k is a parameter related to the size range which changes from values between 0 and 1, L is the observed total length and L_{50} pronounced as the Length-at-50%, is the mean length at first capture. The values for L_{50} and k were hypothesised and the best fit was achieved using Solver package installed in Microsoft Excel 2021.

2.8 Estimation of Fish Diversity

Fish species diversity was determining by calculating fish species diversity indices. The diversity indices were derived by integrating the Shannon-Weiner, Simpson and Pielou's evenness indices. Eq. 3–5 shows the formula used in calculating the three indices.

2.8.1 Shannon–Weiner Diversity Index

$H = -\sum_{i=1}^{n} n \left(\frac{n_i}{N}[log_2]\left(\frac{n_i}{N}\right)\right)$ Eq. 3

where H = Shannon–Weiner index of diversity, n_i = total number of individuals of a species and N = total number of individuals of all species.

2.8.2 Simpson Diversity Index

$D = 1 - \sum\left(\frac{ni}{N}\right)^2$ Eq. 4

where D = Simpson's diversity index, n_i = number of individuals of a species and N = total number of individuals in the community.

2.8.3 Pielou's Evenness Index

$J = \frac{H'}{lnS}$ Eq. 5

where J represents Pielou's evenness index, H represents the Shannon–Wiener diversity index and S represent the total number of species in the community.

2.9 Fish Conservation Status

All the sampled fish species were subjected to the International Union for Conservation of Nature (IUCN) Red List Assessment. The fish species were initially checked in Paul Skelton [1, 4] and on official websites of the IUCN and FishBase for the scientific name verification and conservation status. The

conservation status approach divides species into nine categories [13], namely, not evaluated (NE), data deficient (DD), least concern (LC), near-threatened (NT), vulnerable (VU), endangered (EN), critically endangered (CR), extinct in the wild (EW), and extinct (EX).

2.10 Data Processing

Microsoft Excel 2021 was used for data entry, cleaning, merging and descriptive statistics. Jupyter notebook V 7.0.8 (Python 3) was used for plotting and arranging size structure graphs, fish diversity and statistical analysis while ArcGIS 10.5 was used to produce the map of the study area.

Data analysis followed data entry and cleaning. As per requirement, the data had to initially undergo a pretreatment before conducting statistical tests. The fish catch data were initially tested for normality and homoscedasticity ($p = 0.05$). Following the preliminary results, spatial and temporal variations across sites and seasons were tested through the application of analysis of variance (ANOVA) or the Kruskal–Wallis test. The choice of the statistical test relies on satisfying a fundamental requirement for parametric data, which is to pass the normality and homoscedasticity tests [17]. If the data fail the tests, nonparametric tests that use ranks to arrive at the same conclusions are used [18]. A Dunn's test, a post hoc analysis approach for heterogeneous variances, was applied to the results that indicated significant variations.

3 Results

3.1 Fishing effort and fish production trends

The Elephant Marsh directly employs over 4,458 people as gear owners and fishing crew members (Fig. 2). For the many years, the fishery continues to be dominated by males, with a contribution of 97% against 3% females. The current annual fish production is estimated at 2,146 metric tons. The amount has increased by 10% between 2024 and 2025. In general, there has been an increase in fish production corresponding with a similar pattern in the number of fishers.

3.2 Extent of illegal fishing

The Elephant Marsh is currently experiencing domination of illegal gillnets over legal gillnets (Fig. 3). The results of the 2025 annual frame survey reported increased dominance of illegal gillnets which are under-meshed and made of environmentally destructive monofilament materials. Within the same period, the fishery has further faced a continued occurrence of Mosquito nets being used as fishing gear or forming a part of a gear as lining.

3.3 Total catch from the surveys

A total catch of 1,033 kg was recorded across the three seasons. With significant differences ($P = 0.009$), the rainy season reported the highest catch of 501 kg, which was 28% and 17% greater than that of the

cool dry and hot dry seasons, respectively. The study revealed that passive gears, namely, gillnets, fishtraps and longlines, dominated the catch across the seasons. There was a minimal contribution to the catches by other fishing gears like castnets, handlines, batting (a risky catching of fish with bare hands), panga knives and seine nets.

3.4 Spatial distribution of catches

Among the eight sites, Msambokulira had the highest catch of 33%, followed by Thedzi, 19% (Fig. 4). Chisamba, Chinzeti, Chibvuli, Lisuli, and Mchere recorded a catch range between 5% and 14%. Namicheni had the lowest contribution of 2.5%. No significant partial variations (*p = 0.187)* were reported among the sites. Seasonally, there was a significant difference in the number of fish caught between the cool dry season and the rainy season. (*P = 0.007*).

3.5 Catch Composition

The study registered fish that belong to twelve (12) fish families, namely, Alestidae, Anabantidae, Anguillidae, Cichlidae, Clariidae, Cyprinidae, Gobiidae, Malapteruridae, Mochokidae, Mormyridae, Protopteridae, and Schilbeidae. Such categorisation is not available in the local fish identification. Approximately 50% of the total landings were from the Clariidae family. The Cichlidae family was the second highest with 29% contribution. Mochokidae, Protopteridae, Mormyridae, Malapteruridae, Schilbeidae, Cyprinidae, and Alestidae reported catch rates ranging from 1–6%. The families Anguillidae, Anabantidae, and Gobiidae had a least combined contribution of less than 1%.

The study results identified a total of thirty-one (31) fish species (Table 2). Compared across the three seasons, the difference was significant *(P = 0.015)*. The study reported 12 (39%) common species across the seasons, 19% between hot dry and rainy seasons, and 10% amid the cool dry and rainy seasons. A total of 26% of the identified fish species were exclusively reported in the hot season, whereas the rainy and cool dry seasons presented one unique species each.

Compared with the 2023 Elephant Marsh Diversity Baseline Report, the 31 species reported by the current study is a notable increase from the 15 species and 8 families documented in the baseline biodiversity report. Across both surveys, a cumulative total of 34 distinct fish species was recorded, with 12 fish species shared between the surveys. The current assessment generated 19 fish species that were not present in the baseline report. Conversely, three species registered were not found in the current study.

Table 2
Fish species sampled during the current study against the 2023 baseline survey

No	Scientific Name	Local Name	Cool dry	Hot dry	Rainy	Baseline
1	*Brachyalestes imberi*	*Mamberi*	+	+	+	+
2	*Clarias gariepinus*	*Mlamba*	+	+	+	+
3	*Clarias ngamensis*	*Mlamba*	+	+	+	+
4	*Mormyrus longirostris*	*Samwamowa*	+	+	+	+
5	*Oreochromis mossambicus*	*Makakana*	+	+	+	+
6	*Oreochromis shiranus*	*Makumba*	+	+	+	+
7	*Protopterus annectens*	*Dowe*	+	+	+	+
8	*Schilbe intermedius*	*Dande*	+	+	+	+
9	*Synodontis zambezensis*	*Nkholokolo*	-	+	+	+
10	*Glossogobius callidus*	*Kafulamchenga*	-	+	-	+
11	*Opsaridium tweddleorum*	*Mpasa*	-	-	+	+
12	*Astatotilapia calliptera*	*Kambuzi*	+	+	+	-
13	*Coptodon rendalli*	*Ngunduwe*	+	+	+	-
14	*Enteromius paludinosus*	*Gangafodya*	+	+	+	-
15	*Marcusenius macrolepidotus*	*Mphuta*	+	+	+	-
16	*Ctenopoma multispine*	*Dambulu*	+	-	+	-
17	*Heterobranchus longifilis*	*Nyume*	+	-	+	-
18	*Malapterurus shirensis*	*Nyesi*	+	-	+	-
19	*Labeo mesops*	*Ntchira*	+	-	-	-
20	*Enteromius radiatus*	*Gangafodya*	-	+	+	-
21	*Labeo altivelis*	*Njole*	-	+	+	-
22	*Labeobarbus cylindricus*	*Ningwi*	-	+	+	-
23	*Mormyrops anguilloides*	*Mkupe*	-	+	+	-
24	*Petrocephalus catostoma*	*Gundamwala*	-	+	+	-
25	*Anguilla labiata*	*Nkunga*	-	+	-	-
26	*Cyphomyrus discorhynchus*	*Mphuta*	-	+	-	-

Note: + means present and - means absent

No	Scientific Name	Local Name	Cool dry	Hot dry	Rainy	Baseline
27	*Enteromius trimaculatus*	*Gangafodya*	-	+	-	-
28	*Malapterurus shirensis*	*Khopokopo*	-	+	-	-
29	*Opsaridium microcephalus*	*Sanjika*	-	+	-	-
30	*Opsaridium microlepis*	*Mpasa*	-	+	-	-
31	*Enteromius macrotaenia*	*Gangafodya*	-	+	-	+
32	*Labeo congoro*	*Ntchila*	-	-	-	+
33	*Oreochromis placidus*	*Makakana*	-	-	-	+
34	*Synodontis nebulosus*	*Nkholokolo*	-	-	-	+
Note: + means present and - means absent						

Among the sites, Thedzi registered the highest number of species (25) in all three seasons. Chinzeti reported the lowest species number during cool dry and hot dry periods, while Chibvuli recorded the fewest. Despite the differences in the spatial distributions of fish species, there was no significant difference among the sites (*P = 0.343*).

3.6 Fish Size Distribution

Numerically, the four dominant fish species in the present study were the African catfish *Clarias gariepinus (*Mlamba*);* Mozambique tilapias, *Oreochromis mossambicus (*Makakana*);* straightfin minnow, *Enteromius paludinosus* (Gangafodya), and the Lower Zambezi bulldog, *Marcusenius macrolepidotus (*Mphuta*).* Figure 5 and Fig. 6 present the length frequency distributions and gear selectivity for the top four fish species. Table 3 compares the length at capture values with the length at first maturity data from the literature searches (https://fishbase.se/search.php). The length distribution of *C. gariepinus* peaked between 200 and 400mm. *O. mossambicus* showed two strong size classes in the rainy season while peaking between 100 and 150mm in the other two seasons. Lots of *E. paludinosus* were recorded between 20 and 50mm. Two distinct size classes were also reported in *M. macrolepidotus* and this pattern was observed in all seasons. Based on the length-at-capture values, Only *M. macrolepidotus* species were sexually mature during the surveys ($L_c > L_m$) (Table 3).

Table 3
Length at capture and the length at first maturity for *C. gariepinus*, *O. mossambicus*, *E. paludinosus* and *M. macrolepidotus*

Fish Species	***Cool Dry***	***Hot Dry***	***Rainy***	***Literature***	***Maturity***		
	Lc (mm)	***Lc (mm)***	***Lc (mm)***	***Lm (mm)***	***Cool Dry***	***Hot Dry***	***Rainy***
C. gariepinus	***216***	***319***	***315***	***308***	***Immature***	***Mature***	***Mature***
O. mossambicus	*154*	*121*	*37,128*	*144*	*Mature*	*Immature*	*Immature*
E. paludinosus	*98*	*42*	*36*	*64*	*Mature*	*Immature*	*Immature*
M. macrolepidotus	*147*	*126,230*	*102,174*	*130*	*Mature*	*Mature*	*Mature*

3.7 Fish species diversity

The results revealed that the Shannon ($p = 0.181$), Simpson ($p = 0.164$) and Evenness ($p = 0.122$) indices were statistically not different across sites. Despite the insignificant spatial and temporal variations, the rainy season generated the highest fish diversity index among the three seasons (Fig. 7).

3.8 Fish Conservation Status

Among the 31 identified fish species, *Labeo mesops* is listed as critically endangered (CR), *Oreochromis mossambicus* and *Opsaridium microlepis* are vulnerable (VU), and *Opsaridium tweddleorum is listed* as data deficient (DD) (Table 4). *Anguilla labiata* and *Ctenopoma multispine* are yet to be evaluated. The rest of the species are of least concern (LC).

Table 4
Conservation status for all the fish species sampled by the study (IUCN 2022)

No	Species Name	IUCN Red List Assessment
1	*Labeo mesops*	Critically Endangered (CR)
2	*Oreochromis mossambicus*	Vulnerable (VU)
3	*Opsaridium microlepis*	Vulnerable (VU)
4	*Astatotilapia calliptera*	Least Concern (LC)
5	*Brachyalestes imberi*	Least Concern (LC)
6	*Clarias gariepinus*	Least Concern (LC)
7	*Clarias ngamensis*	Least Concern (LC)
8	*Coptodon rendalli*	Least Concern (LC)
9	*Enteromius paludinosus*	Least Concern (LC)
10	*Enteromius radiatus*	Least Concern (LC)
11	*Enteromius trimaculatus*	Least Concern (LC)
12	*Glossogobius callidus*	Least Concern (LC)
13	*Heterobranchus longifilis*	Least Concern (LC)
14	*Hydrocynus vittatus*	Least Concern (LC)
15	*Labeo altivelis*	Least Concern (LC)
16	*Labeobarbus cylindricus*	Least Concern (LC)
17	*Malapterurus shirensis*	Least Concern (LC)
18	*Marcusenius macrolepidotus*	Least Concern (LC)
19	*Mormyrops anguilloides*	Least Concern (LC)
20	*Mormyrus longirostris*	Least Concern (LC)
21	*Opsaridium microcephalus*	Least Concern (LC)
22	*Oreochromis shiranus*	Least Concern (LC)
23	*Petrocephalus catostoma*	Least Concern (LC)
24	*Protopterus annectens*	Least Concern (LC)
25	*Schilbe intermedius*	Least Concern (LC)
28	*Synodontis zambezensis*	Least Concern (LC)

No	Species Name	IUCN Red List Assessment
29	*Opsaridium tweddleorum*	Data Deficient (DD)
30	*Anguilla labiata*	Not Evaluated (NE)
31	*Ctenopoma multispine*	Not Evaluated (NE)

4 Discussion

The Elephant Marsh continues to boast unique fish species not commonly found in other water bodies in Malawi. The study results have just confirmed this while also reporting increased trends of fish catches. However, the increase in the catches corresponded with escalation in the population of fishers (Government of Malawi 2025). Subsequently, there is a reduced catch per unit of effort, which translates to reduced incomes from fishing activities, assuming that hyperdepletion scenarios are not at play [12, 20]. The fishery has further been hit by domination of illegal fishing activities through the use of illegal fishing gear and methods. Lack of alternative sources of livelihoods is one of the drivers of fisheries resource depletion in the region [5, 9]. However, it is strongly believed that any conservation efforts in the marsh must always build on strong and motivated local leaders who are willing to protect the interests of communities as resource users [9]. It was noted that community conservation efforts have also been made in marsh through the establishment of CCAs especially for hotspots of Mthyola in North of Elephant Marsh; and Gong'o wamkulu, Nyang'ona, Msambokulira and Mphanda hotspots in South of the marsh. These interventions are reported to enhance community participation in management of wetland resources. CCA committees jointly with BVCs conduct patrols to combat illegal activities. Citizen science was successfully applied in Lakes Chilwa and Chiuta, two shallow water lakes in the southeastern part of Malawi, where communities were engaged in the identification, mapping, and monitoring of fisheries resources in fish spawning sites [21]. In southern Lake Malawi, the revamping of local management structures such as BVCs and Fisheries Associations was attributed to the rejuvenation of shallow-water fish stocks such as Chambo [22, 23].

The findings of this study further reveal a fascinating temporal and spatial trend in species abundance and richness within the Elephant Marsh. This pattern confirms that the Elephant Marsh is a vital biodiversity hotspot for various fish species that are linked to seasonal and spatial differences in habitat characteristics and productivity [1, 5, 24, 25]. There is a direct relationship between habitat complexity and fish species richness [26]. Historical estimates for Elephant Marsh aquatic zones, spanning from the 1970s to 2016, suggest greater overall diversity, with approximately 52 species inhabiting the area [1, 6, 24, 25]. The current study could have missed some fish species because of study limitations in terms of scope and technical capacities. Despite that, the current survey identified Vundu, *Heterobranchus longifilis* (nyume) and Many Spined Climbing Perch, *Ctenopoma multispine* (Dambulu), which were reportedly missing in several recent field works (GoM 2023). The variations in fishing gear and methods also offer valuable insights as adaptive strategies by local fishers. However, the lack of closed fishing season and licensing of fishing gears as observed during the field works needs to be seriously

considered by the resource managers. Fisheries resource management and exploitation call for input control measures to ensure sustainability for both present and future generations [20].

The current study did not report any presence of a voracious piscivore, tigerfish, *Hydrocynus vittatus* in the sampled hotspots. The fish is not known to live in still and turbid waters, a characteristic of the Elephant Marsh [1, 27]. Tiger fish prefer warm and well oxygenated relatively larger water bodies and the pelagic zones [1, 4, 27]. It is therefore more likely to find the fish in the mainstream Shire River than in marshes, especially during the hot dry season. The study results therefore clear any fears that this predator fish will invade hotspots in the Elephant Marsh and negatively impact fish species diversity conservation and management efforts. However, the fish requires special attention and tracking, as they have been reported to travel upstream or downstream for more than 500 km [28] and issues of changes in the land use and land cover as previously reported [29] would facilitate the process. Issues of ecosystem adaptations can also lead to the possible introduction of the *H. vittatus* in the Elephant Marsh hence, continued monitoring remains key to achieve sustainability of the fish stocks in Elephant Marsh.

The dynamic populations of key fish species reported by the study results indicate that the study site serve as a crucial habitat for various aquatic life stages, encompassing breeding, nursing, growth and recruitment. The comprehensive utilisation of the area by the key fish populations underscores its ecological complexity and significance across different periodic seasons [26]. The presence of sexually immature fish species across seasons indicates continuous spawning and calls for targeted conservation and management strategies. The seasonal pattern of immaturity suggests specific periods during which these species are particularly vulnerable and require protection to avoid recruitment overfishing [20]. This information is especially critical and socially tricky for the Mozambique tilapia, *O. mossambicus*, which is classified as vulnerable species but popular around the marshes, highlighting an urgent need for focused conservation efforts that balances social needs. Understanding the optimal times for protecting these species can inform regulations on fishing practices and habitat preservation to ensure the long-term sustainability of fish resources in the Elephant Marsh, thereby responding to Pillar/Enabler No. 9—environmental sustainability—under the Malawi 2063 Agenda.

The study results demonstrated the uniqueness of Elephant Marsh with respect to seasonally specific fish species diversity and spatial distribution. By demonstrating significant variations in several essential population parameters, the dynamics and responses of fish to seasonal changes have been revealed. While acknowledging the important roles played by fishing communities, this study has equally exposed some existing biodiversity threats, such as increased fishing effort and continued adoption of ecologically destructive fishing gears and methods.

Building on the key findings, this study has suggested the following management and conservation recommendations for the marsh;

i. For effective management and conservation of rich and unique fisheries resources, the government and communities must develop management plans for their respective CCAs

ii. To achieve sustainability of the fisheries resources, decision makers are encouraged to operationalise the input control measures namely the closed season and licensing of legal fishing gears
iii. The increased use of illegal fishing gear and methods remains a major threat to fish stocks; hence, community-led monitoring, control and surveillance programs are highly recommended
iv. To minimise overdependence on fisheries resources, communities must be introduced to alternative sources of livelihoods and income-generating activities (IGAs), such as aquaculture, beekeeping and the carbon market.
v. To supplement the study results, an ecological status assessment study to look at the water quality, benthic macroinvertebrate, land use/land cover and the aquatic vegetation is highly recommended.
vi. There is a need to continue monitoring of the fish population as the project activities are being implemented

Declarations

Competing Interests

Financial interests: M.S.M., C.L.M., K.H.K, T.B.P., M.N., B.N., P.T., L.S., A.M. and W.K. declare that they have no financial interests. The SVTP-2 previously employed G.M., J.K.N. and C.M. Nonfinancial interests: L.Y.P. served as a desk officer of the SVTP-2.

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Author Contribution

All the authors contributed to the study conception and design. M.S.M., C.L.M, K.H.K., T.B.P, B.N. and P.T. performed material preparation, data collection, and analysis. M.S.M. wrote the first draft of the manuscript. M.N., L.S., A.M., L.Y.P., G.P., J.K.N., C.M. and W.K. commented on all the versions of the manuscript.

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Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Statement The study was ethically reviewed and approved by the University of Malawi Research Ethics Committee (UNIMAREC), Protocol No. P.05/24/451. Two committee members provided oversight during data collection by conducting spot checks.

Authorship

All the authors have read and approved that the final manuscript is in accordance with the journal policy

Ethics approval and Consent to Participate

The study was ethically reviewed and approved by the University of Malawi Research Ethics Committee (UNIMAREC) Protocol No. P.05/24/451. Two members of the committee further provided an oversight during the data collection by conducting spot-checks.

All procedures in dealing with human participants were performed in accordance with the Declaration of Helsinki. Relevant Basel Declaration Principles were adhered to during the fish handling processes.

The study consulted the Environmental Affairs Department in Malawi whether collection of dead fish by the communities would require the Access and Benefit Sharing (ABS) agreement. It was mentioned that the ABS would not apply in that case hence permission for collection was not required.

Written Ethical statement was obtained from all individual participants included in the study.

Consent to Publish

No identifiable personal data or images are included in the study hence a consent to publish is not applicable.

Clinical Trial Number

Not Applicable

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Figures

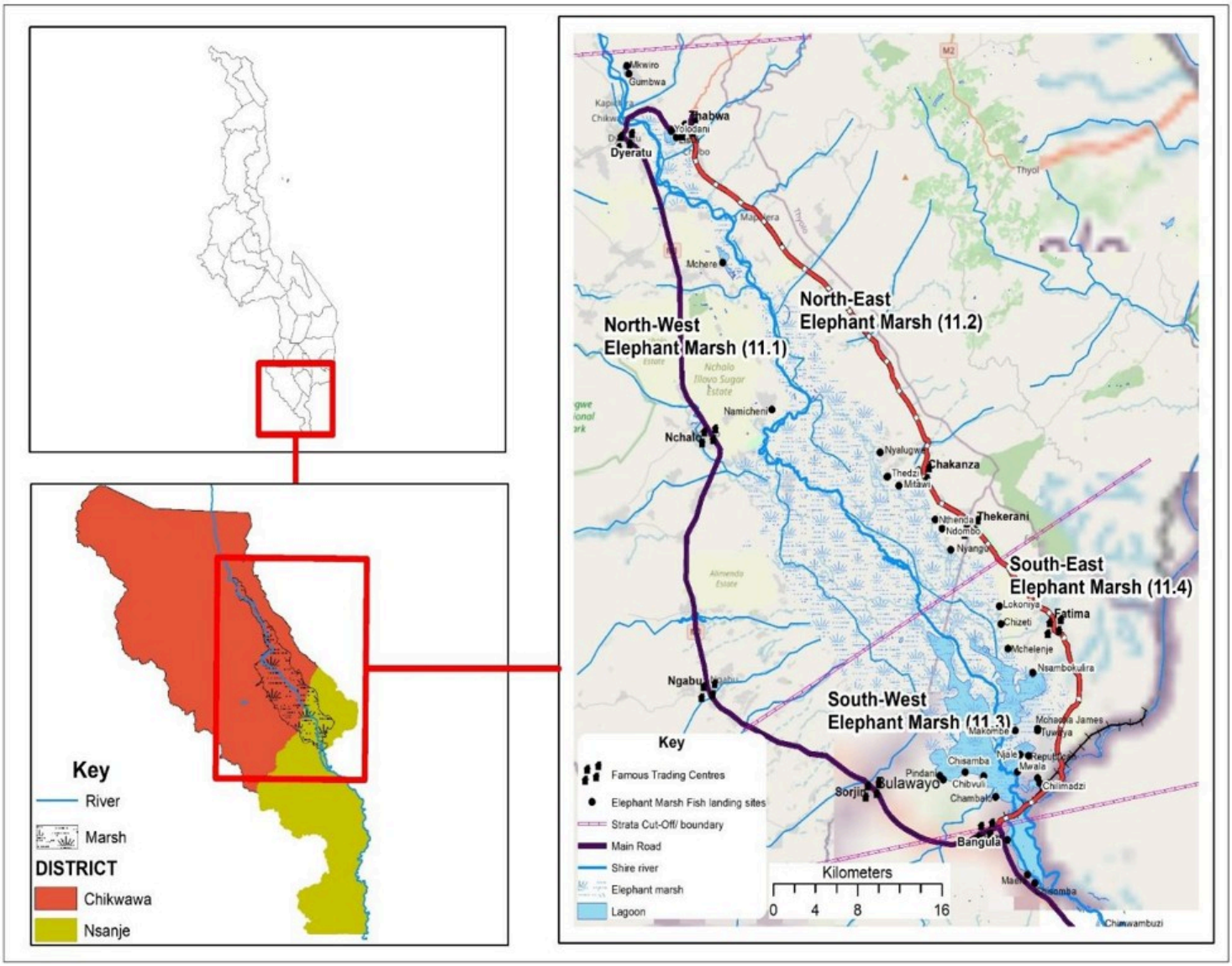


Figure 1

Map of the study area showing the Elephant Marsh and the four administrative boundaries

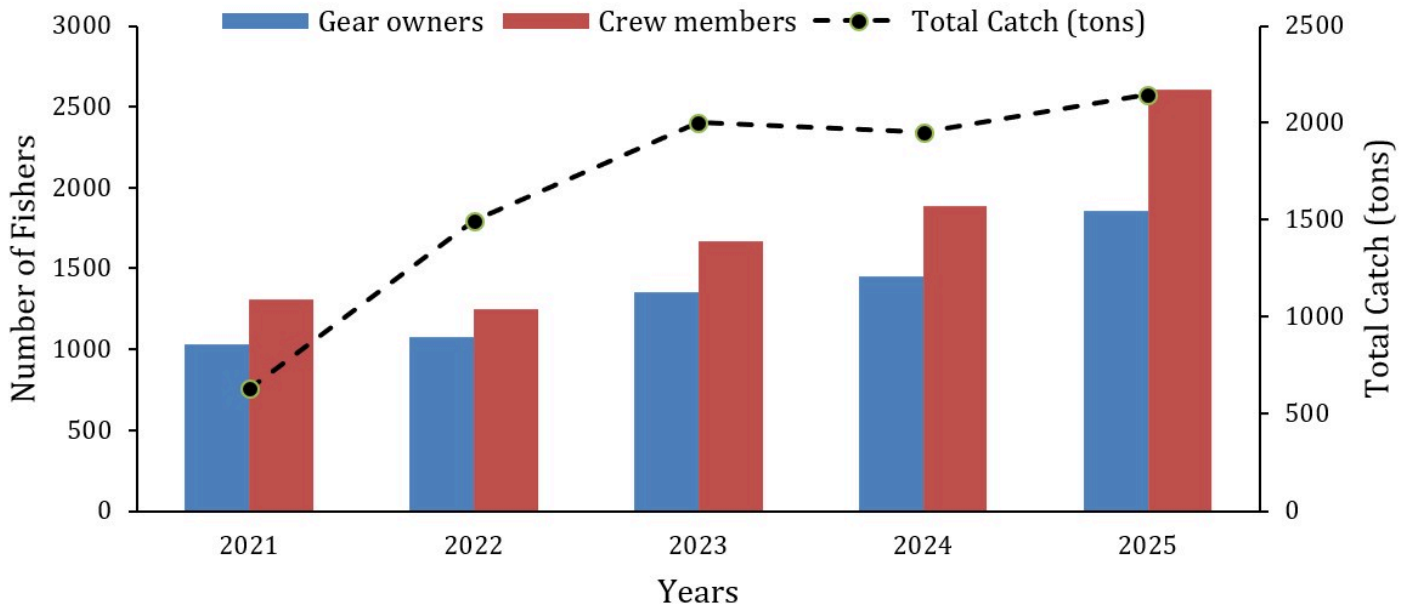


Figure 2

Number of gear owners, crew members and fish catch in Elephant March between 2021 and 2025

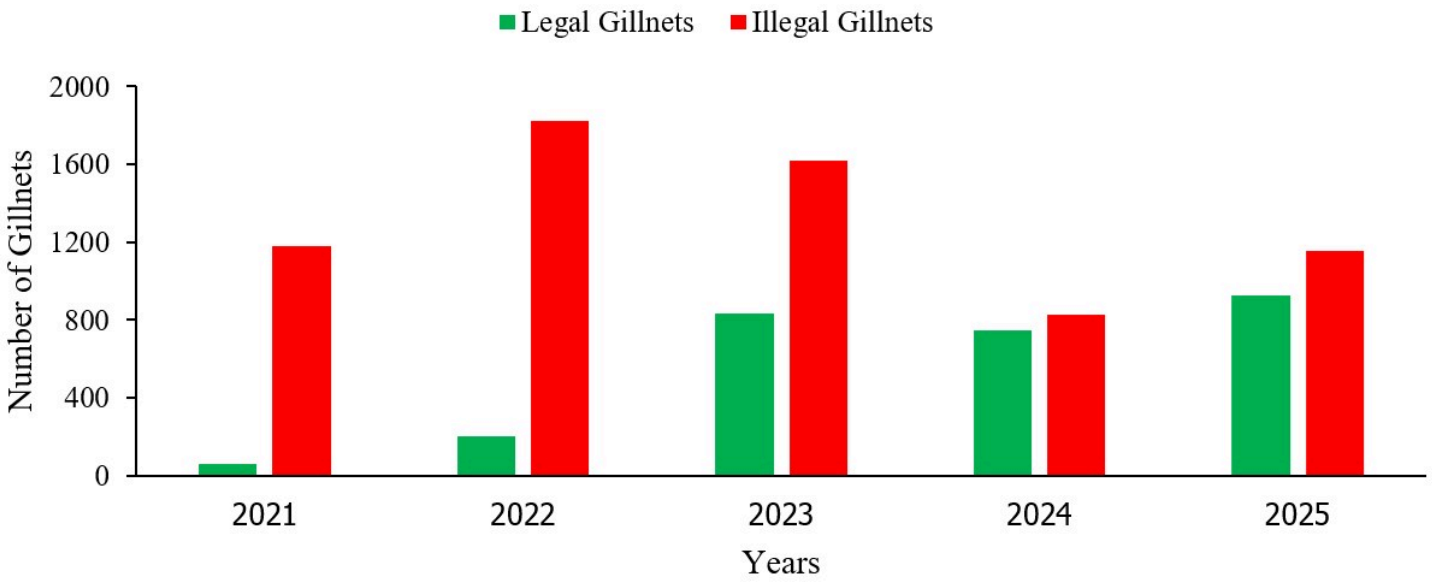


Figure 3

Trend of legal and illegal gillnets from 2021 to 2025 in the Elephant Marsh

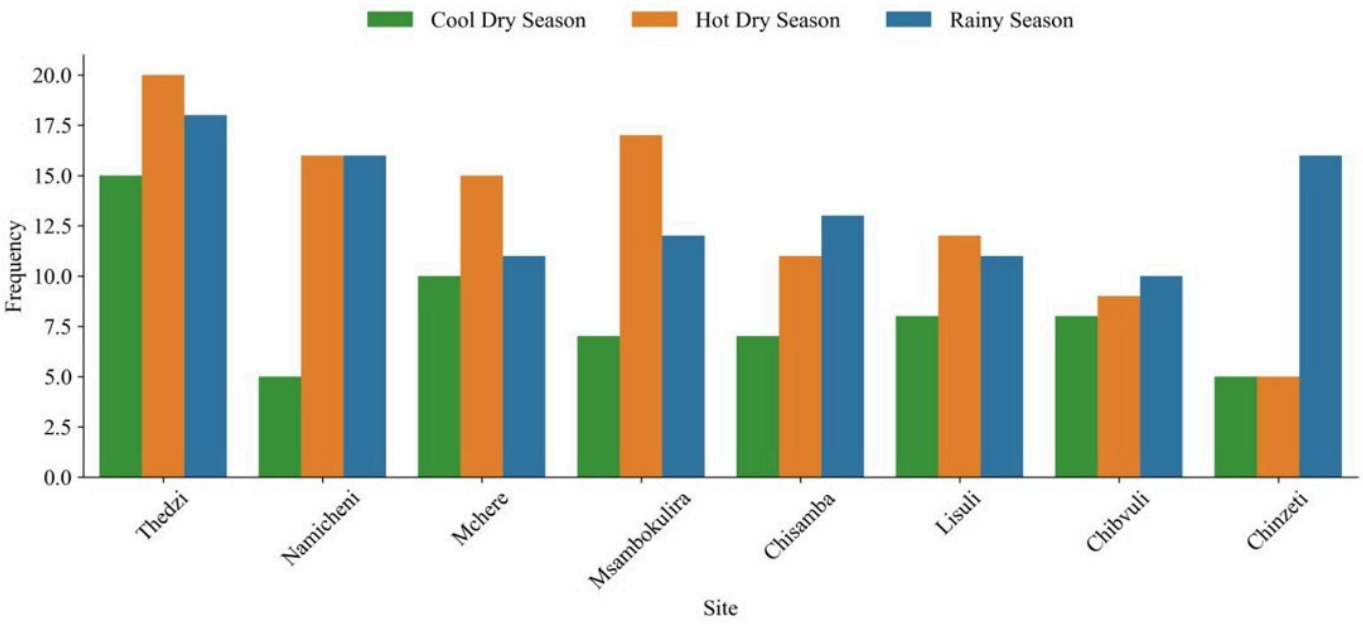


Figure 4

Number of fish species per landing site during cool dry, hot dry and rainy seasons in the Elephant Marsh

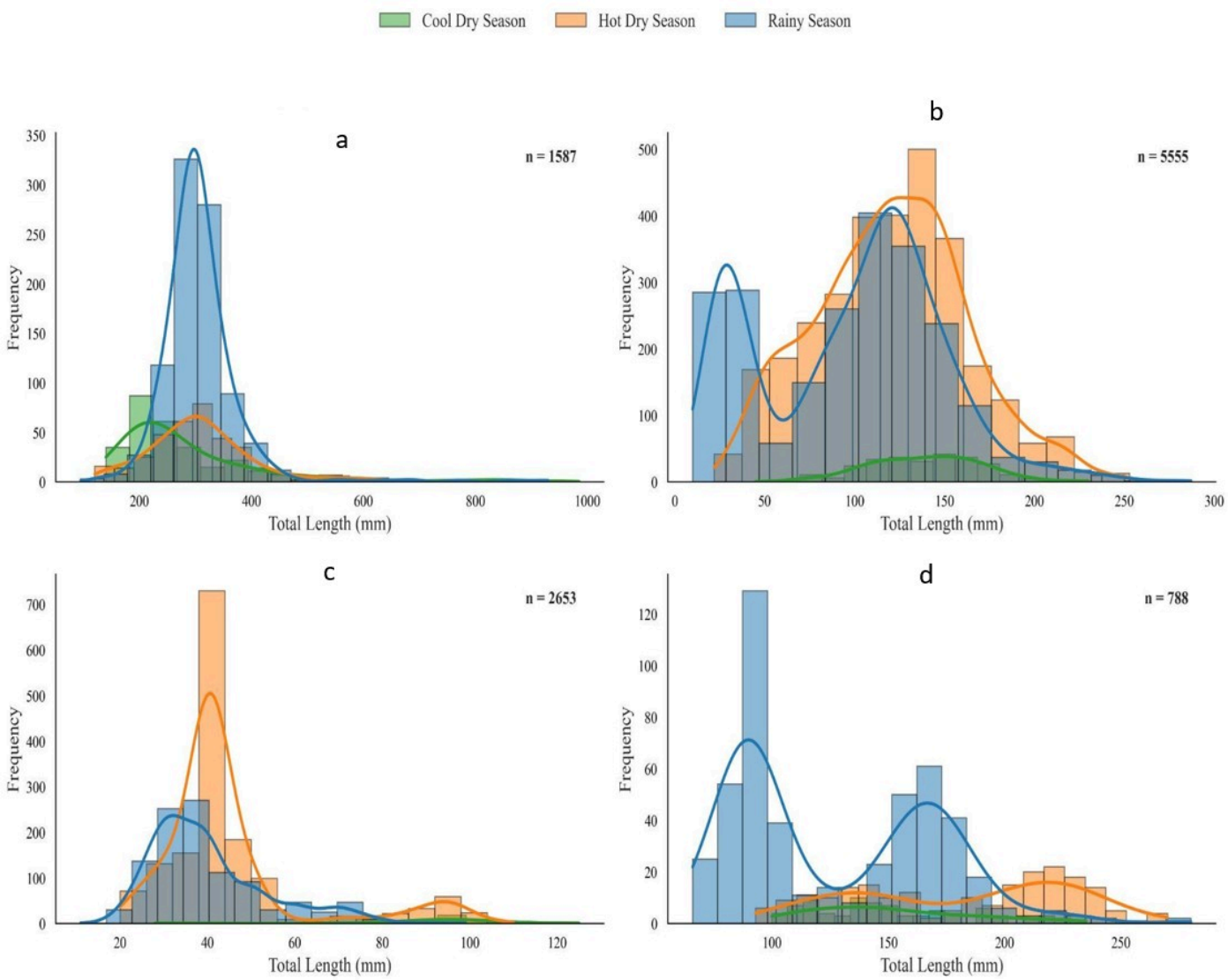


Figure 5

Modelled length frequency distributions of *C. gariepinus* (a), *O. mossambicus*(b), *E. paludinosus* (c) and *M. macrolepidotus* (d) sampled during the surveys

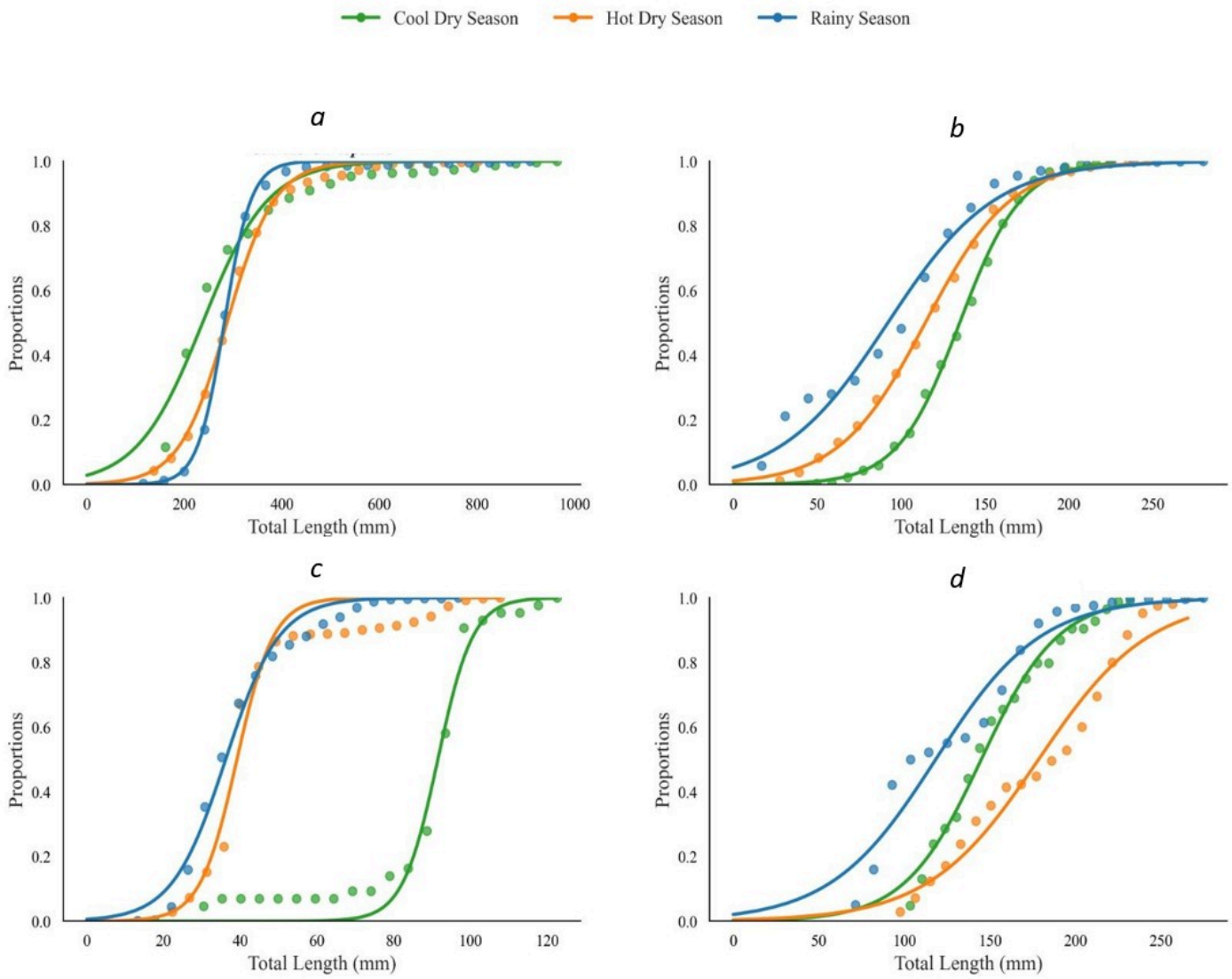


Figure 6

Selection Ogive of C. gariepinus (a), O. mossambicus (b), E. paludinosus (c) and M. macrolepidotus (d) sampled during the surveys

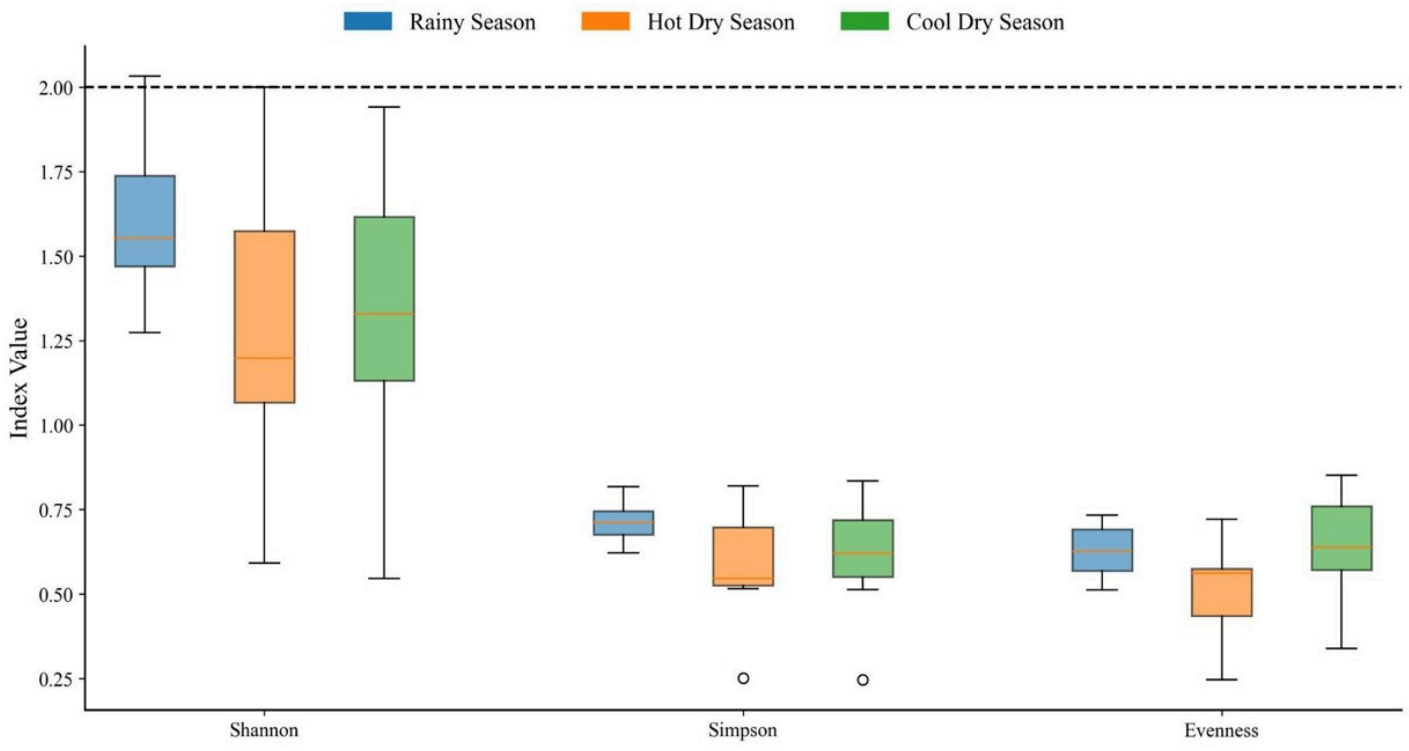


Figure 7

Fish diversity indices of Shannon, Simpson and Evenness across cool dry, hot dry and rainy seasons