Research Article

Fish Diversity and Abundance of Lake Tanganyika: Comparison between Protected Area (Mahale Mountains National Park) and Unprotected Areas

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1. Introduction

High biodiversity is the most remarkable characteristic of Lake Tanganyika including vertebrates, invertebrates, and plants [1–3]. It contains more than 1300 species of fish, invertebrates, and plants among which 500 species do not exist anywhere else on earth (endemic species) making it an important contributor to global biodiversity [4, 5]. The lake has received relatively less human impact than many other African lakes [6] and could serve as an example of managing lakes in other developing countries. The complex ecosystem of the lake in terms of number of species as well as their complex interactions is without any doubt unique in the world [5].

The fishery of Lake Tanganyika is of great importance to the surrounding region where protein is scarce [1, 7]. Fishing is the greatest simple economic activity depended upon by the communities surrounding the lake and it is perceived to be one of the greatest threats to biodiversity. The removal of large quantities of fish (app. 130,000 to 170,000 tons of fish−year−1) might be expected to have a direct impact on the biodiversity of the fish (and other aquatic organisms) in the lake [8]. The productivity of an ecosystem promotes its quality whereby living organisms are manufactured through interactions of community and environment. Standing crop, rate of removal of resources, and rate of production are the measures of the quality of an ecosystem, [9, 10] recommended strengthening of prohibition of fishing activities within the park to enhance biodiversity and biomass within park boundaries.

The reputation for high biodiversity in Lake Tanganyika is best demonstrated by fish of the family cichlidae and the mollusks. Both of these groups have a high number of species with a substantial proportion of endemic species [1] and a considerable genetic variability within species.

The lake, however, is vulnerable to pollution [11–13] and there are currently few efforts being made to conserve
its biodiversity. The most immediate threats to the lake’s unique environment and biota are pollution from various sources [14] and intensive fishing with illegal methods. These problems and their effects are increasing and immediate attention is required to assess and control these problems and conserve the biodiversity. One of the methods of conserving biodiversity of the lake is to control human activities by establishing protected areas [10, 15, 16]. Mahale Mountains National Park (MMNP) is one of the no-take zones in the lake. Establishment of protected areas is a proactive measure of mitigation, ensuring that some essentially unmodified sites exist within the lake for buffering against uncertainty [17, 18].

Paley et al. [19] reported that 53% of all the species known to inhabit Lake Tanganyika are found in MMNP. However, there are limited studies on fish abundance and diversity carried out in the region [19, 20]. Such studies need to be carried out on a spatial and temporal scale to determine the change in diversity and abundance. In addition, they can assist to ascertain the degree of anthropogenic influence and pollution in such critical ecosystems. The aim of this study was to assess and compare spatial pattern of fish abundance and biodiversity within and outside MMNP in order to verify effectiveness of the protected area and provide reference information as a baseline for such a critical habitat.

2. Materials and Methods

The study was conducted in May to June 2008 and the sampling sites were located within Mahale Mountains National Park (Figure 1) and areas outside the park. The MMNP is located at the southern edge of Kigoma (North North West to South South East), with an elevation ranging from 2,000 to 2,400 m [21]. The MMNP was put in place in 1985, and it covers an area of 1,613 km² of which 96 km² is aquatic covering a strip of water along the shore of Lake Tanganyika and extends 1.6 km into the lake [22] with many bays and few small rocky outcrops [21]. Of all the areas along Lake Tanganyika, Mahale is one of the richest in the topographical variation [21]. The park is one of the four national parks or natural reserves bordering the lake; the others are Rusizi River Nature Reserve (Burundi), Gombe River National Park (Tanzania), and Nsumbu National Park (Zambia) [15].

The sampling design of the study was categorized into three factors: (1) status of the area with two levels (protected and unprotected); (2) habitat with two fixed and orthogonal levels (rocky and sandy), and (3) sampling site. A total of twelve sampling sites (8 sites within the protected area, that is, MMNP and 4 sites in unprotected areas) were selected. Of these twelve sites six (4 within MMNP and 2 in unprotected areas) were sandy and the other six (4 within MMNP and 2 in unprotected areas) were rocky habitats. The four outermost sites (i.e., the first two and last two) were located in unprotected areas (Buhingu and Sibwesa villages) and the rest were within MMNP. The sampling sites were selected at least 5 km apart. In the survey, we noted that rocky and sandy habitats were not equally interspersed within and outside the protected areas. The geographical positioning system (GPS) locations of the sites were recorded (Table 1).

Environmental parameters, namely, dissolved oxygen (DO), temperature, and transparency, were also recorded at 5 m and 10 m depths (Table 1). Water transparency was measured using a Secchi disc while DO and temperature were recorded using a multiparameter analyser WTW 340i [23].

Fish abundance and diversity data were collected in the near shore zone using stationary visual census (SVC) technique which involved SCUBA diving. A pair of divers conducted censuses of fish population within a quadrant of 8.5 m by 5 m which was laid on a lakebed. The divers first sampled at the deeper point (10 m) and then moved towards the shore to 5 m water depth. At each depth, two points located 10 m apart were sampled. The species present in the column of water were identified and individuals of each species were counted and recorded on slates. It took about 45–50 minutes for divers to count and record fish in the quadrant. Fish were identified to the species level as per Konings [24]. The data obtained were used to calculate fish diversity by the Shannon-Wiener diversity index.

Data were recorded in Microsoft excel packages and further analyzed in STATISTICA (version 8, Inc., 2010). The mean values of water transparency, dissolved oxygen concentration, and temperature were tested independently with one-way ANOVA for each parameter at a significant level (P = 0.05). In addition, species diversity and richness were derived by using Shannon-Weiner diversity index (H') formula as shown below:

\[
H' = -\sum_{i=1}^{S} P_i \ln P_i, \tag{1}
\]

where \(S\) is number of species in the sample, and \(P_i\) is relative importance values obtained as the squared ration of the importance values of \(S\) individual value for all species to \(N\) the total importance.

3. Results

There was no significant variation (P > 0.05) in water parameters tests between sampling sites in protected area and unprotected areas; water transparency (ANOVA, \(F_{1,22} = 0.12, P = 0.73\)), DO (ANOVA, \(F_{1,22} = 3.67, P = 0.07\)), and temperature (ANOVA, \(F_{1,22} = 0.16, P = 0.69\)) (Table 1). In MMNP, five sampling sites (63%) had relatively flat beds, two (25%) had inclined beds, and one site (12%) showed a mixture of flat and inclined bed. However, as one moves from the shore towards the open waters, there was a sharp increase in depth. Purely flat rocky bottom was not encountered in the survey. Riverine was another type of habitat found in the park although survey could not be conducted due to crocodiles’ menace.

There was a large degree of overlap between fish species found in protected area (inside MMNP) and unprotected areas (outside MMNP) (Table 2). A total of 70 and 55 fish species were recorded inside MMNP and outside MMNP, respectively.

Generally, dominant fish species (with their percentage of individuals on the total individuals counted in the survey in parentheses) included *Lepidiolamprologus***
Table 1: Environmental parameters mean (±SD) of the sampled sites in Lake Tanganyika during May to June 2008 survey. Sites S1, S2, S11, and S12 are within unprotected areas and sites S3–S10 are within the protected area (Mahale Mountains National Park).

| Site ID | Habitat | GPS location | Water transparency (m) | Water DO (mg/l) 5 m depth | Water DO (mg/l) 10 m depth | Water temperature (°C) 5 m depth | Water temperature (°C) 10 m depth |
|---------|---------|--------------|------------------------|---------------------------|---------------------------|-------------------------------|-------------------------------|
| S1      | Sandy   | 08 58.40 50.39'E | 9.00 ± 0.15            | 7.35 ± 1.90               | 7.75 ± 1.10               | 27.00 ± 0.00                  | 26.80 ± 0.20                  |
| S2      | Rocky   | 08 00.53 45.09'E | 9.00 ± 0.24            | 6.30 ± 1.80               | 6.50 ± 1.80               | 26.85 ± 0.10                  | 26.95 ± 0.10                  |
| S3      | Sandy   | 08 02.39 43.89'E | 10.00 ± 0.30           | 7.25 ± 1.70               | 6.70 ± 2.40               | 26.85 ± 0.30                  | 26.90 ± 0.40                  |
| S4      | Rocky   | 08 05.26 43.051'E | 10.00 ± 0.21           | 7.80 ± 0.40               | 6.95 ± 0.90               | 27.35 ± 0.30                  | 27.30 ± 0.80                  |
| S5      | Sandy   | 08 08.05 42.839'E | 10.00 ± 0.16           | 7.25 ± 0.70               | 6.70 ± 0.80               | 26.90 ± 0.40                  | 26.85 ± 0.30                  |
| S6      | Rocky   | 08 10.46 43.699'E | 10.00 ± 0.13           | 6.50 ± 2.00               | 6.45 ± 1.90               | 27.15 ± 0.70                  | 26.80 ± 0.40                  |
| S7      | Rocky   | 08 13.95 42.915'E | 10.00 ± 0.11           | 7.35 ± 0.10               | 6.95 ± 0.30               | 27.00 ± 0.40                  | 26.95 ± 0.50                  |
| S8      | Rocky   | 08 17.15 45.323'E | 10.00 ± 0.12           | 7.45 ± 0.70               | 7.00 ± 1.20               | 25.55 ± 0.50                  | 25.40 ± 0.40                  |
| S9      | Rocky   | 08 19.73 46.983'E | 10.00 ± 0.14           | 8.05 ± 0.10               | 7.50 ± 1.40               | 26.60 ± 0.00                  | 26.60 ± 0.20                  |
| S10     | Rocky   | 08 23.34 49.702'E | 10.00 ± 0.20           | 6.60 ± 1.00               | 6.60 ± 1.20               | 26.40 ± 0.20                  | 26.30 ± 0.00                  |
| S11     | Rocky   | 08 25.18 51.359'E | 10.00 ± 0.18           | 7.25 ± 0.30               | 6.70 ± 0.80               | 26.00 ± 0.00                  | 26.00 ± 0.00                  |
| S12     | Sandy   | 08 27.39 53.934'E | 10.00 ± 0.30           | 7.40 ± 0.60               | 6.35 ± 1.90               | 26.25 ± 0.10                  | 26.25 ± 0.10                  |

Figure 1: Map showing study sites (labeled S1–S12) along the shore of Lake Tanganyika during May to June 2008 survey. S1–S2 and S11–S12 represent study sites in unprotected areas and S3–S10 are study sites inside the protected area (Mahale Mountains National Park).

Species diversity was high in rocky habitats as compared to sandy habitats ($F = 16.71, df = 537, P = 0.001$) (Figure 2).
Table 2: Species composition (%) and mean abundance (±SE) of fish species in rocky and sandy habitats within protected area and unprotected areas in Lake Tanganyika during May to June 2008 survey.

| Fish species                   | Species composition (%) | Mean abundance ± SE |
|--------------------------------|-------------------------|---------------------|
|                               | Protected area | Unprotected areas | Protected area | Unprotected areas |
|                               | Rocky Sandy | Rocky Sandy | Rocky Sandy | Rocky Sandy |
| Neolamprologus brichardi      | 8.83 0       | 0 0       | 17.25 ± 12.75 | 0 0 |
| Neolamprologus splendens      | 7.17 0       | 0 0       | 14.00 ± 14.00 | 0 0 |
| Neolamprologus savori          | 5.25 0       | 1.75 0    | 10.25 ± 3.68  | 0 0 |
| Lepidiolamprologus elongatus   | 4.99 2.46    | 3.86 0    | 9.75 ± 1.32  | 1.75 ± 0.63 |
| Lepidiolamprologus attenuatus  | 4.87 10.92   | 3.51 0    | 9.50 ± 1.85  | 7.75 ± 5.45 |
| Ophthalomolapia nasuta         | 4.87 0       | 8.07 0    | 9.50 ± 4.91  | 0 11.50 ± 7.50 |
| Paracyprichromis nigrinennis   | 3.84 0       | 0 0       | 7.50 ± 4.41  | 0 0 |
| Telmatocromis temporalis       | 3.46 0       | 1.75 0    | 6.75 ± 0.85  | 0 2.50 ± 2.50 |
| Plecodus paradoxus             | 3.33 4.58    | 0.35 0    | 6.50 ± 1.26  | 3.25 ± 1.80 |
| Cyathopharynx foai             | 3.33 0       | 7.72 0    | 6.50 ± 1.76  | 0 11.0 ± 7.00 |
| Petrochromis Moshi             | 3.33 0       | 2.81 0    | 6.50 ± 1.85  | 0 4.00 ± 1.00 |
| Lamprologus callipterus        | 2.82 1.76    | 2.81 0    | 5.50 ± 4.01  | 1.25 ± 0.75 |
| Lamprologus lemairi            | 2.82 0       | 0 0       | 5.50 ± 3.18  | 0 0 |
| Neolamprologus caudopunctatus  | 2.82 0       | 0 0       | 5.50 ± 2.47  | 0 0 |
| Petrochromis orthognathus      | 2.30 0       | 5.26 0    | 4.75 ± 0.25  | 0 7.50 ± 4.50 |
| Telmatocromis vittatus         | 2.30 0       | 1.75 13.68| 4.50 ± 1.85  | 0 2.50 ± 0.50 |
| Cyprichromis leptosoma         | 2.18 2.46    | 2.11 0    | 4.25 ± 2.66  | 1.75 ± 1.44 |
| Neolamprologus mustax          | 2.18 0       | 1.40 0    | 4.25 ± 1.70  | 0 2.00 ± 1.00 |
| Lobochilotes labiatus          | 2.18 0       | 4.56 0    | 4.25 ± 1.44  | 0 3.00 ± 3.00 |
| Xenotilapia spiloptera         | 1.79 0       | 2.11 0    | 3.50 ± 3.50  | 0 6.50 ± 6.50 |
| Trophus annectens              | 1.92 0       | 1.05 0    | 3.75 ± 2.25  | 0 1.50 ± 1.50 |
| Xenotilapia spilopterus        | 1.79 0       | 0 0       | 3.50 ± 1.32  | 0 0 |
| Petrochromis famula            | 1.79 0       | 0 0       | 3.25 ± 3.25  | 0 0 |
| Microdoncromis tenuidentatus   | 1.66 0       | 0 0       | 2.75 ± 1.89  | 0 0 |
| Xenotilapia sima               | 1.41 1.41    | 0 0       | 2.50 ± 0.87  | 0 2.50 ± 2.50 |
| Trophus brichardi              | 1.28 0       | 1.75 0    | 2.25 ± 0.95  | 0 0 |
| Barbus sp.                     | 1.15 0       | 0 0       | 1.75 ± 1.03  | 0 2.50 ± 2.50 |
| Neolamprologus toae            | 0.90 0       | 1.75 0    | 1.75 ± 1.03  | 0 2.50 ± 2.50 |
| Asprotilapia leptura           | 1.02 0       | 1.40 0    | 2.00 ± 1.08  | 0 2.00 ± 2.00 |
| Aflolamprologus compressiceps   | 0.90 0       | 0.70 1.05 | 1.75 ± 0.63  | 0 0 |
| Neolamprologus fasciatus       | 1.02 0       | 1.40 0    | 2.00 ± 0.82  | 0 0 |
| Neolamprologus gracilis        | 0.90 0       | 1.75 0    | 1.75 ± 1.75  | 0 0 |
| Plecodus straeleni             | 0.77 0.35    | 0.70 0    | 1.50 ± 0.87  | 0.25 ± 0.25 |
| Trophus moorii                 | 0.77 0       | 1.50 0    | 1.50 ± 1.19  | 0 0 |
| Petrochromis texas             | 0.64 0       | 0.35 0    | 1.25 ± 0.75  | 0 0.50 ± 0.50 |
| Neolamprologus tretocephalus   | 0.64 0       | 1.25 0    | 1.25 ± 0.48  | 0 0 |
| Lamprologus toae               | 0.64 0       | 1.25 0    | 1.25 ± 1.25  | 0 0 |
| Fish species | Protected area | Unprotected areas | Mean abundance ± SE |
|--------------|----------------|------------------|---------------------|
|              | Rocky | Sandy | Rocky | Sandy | Rocky | Sandy | Rocky | Sandy |
| Chalinochromis ndobhoi | 0.51 | 0 | 1.05 | 0 | 1.00 ± 1.00 | 0 | 1.50 ± 0.50 | 0 |
| Telmatocrinis brichardi | 0.51 | 0 | 0 | 0 | 1.00 ± 1.00 | 0 | 0 | 0 |
| Neolamprologus nigriventris | 0.51 | 0 | 0 | 0 | 1.00 ± 0.41 | 0 | 0 | 0 |
| Trophus duboisi | 0.51 | 0 | 0 | 0 | 1.00 ± 1.00 | 0 | 0 | 0 |
| Lates angustifrons | 0.51 | 0 | 0 | 0 | 1.00 ± 1.00 | 0 | 0 | 0 |
| Juridochromis regani | 0.38 | 0 | 0.35 | 0 | 0.75 ± 0.48 | 0 | 0.50 ± 0.50 | 0 |
| Limnotilapia dardennii | 0.38 | 0 | 0 | 0 | 0.75 ± 0.48 | 0 | 0 | 0 |
| Chalinochromis brichardi | 0.38 | 0 | 0 | 0 | 0.75 ± 0.48 | 0 | 0 | 0 |
| Haplochromis microlepis | 0.26 | 1.76 | 0 | 0.35 | 0 | 0.50 ± 0.50 | 1.25 ± 1.25 | 0.50 ± 0.50 |
| Gnathochromis pfefferi | 0.26 | 0 | 1.05 | 0 | 0.50 ± 0.50 | 0 | 1.50 ± 0.50 | 0 |
| Neolamprologus foai | 0.26 | 0 | 2.81 | 0 | 0.50 ± 0.50 | 0 | 4.00 ± 4.00 | 0 |
| Plecodus microlepis | 0.26 | 0 | 0.35 | 0 | 0.50 ± 0.50 | 0 | 0.50 ± 0.50 | 0 |
| Perissodus microlepis | 0.13 | 0 | 2.81 | 0 | 0.25 ± 0.25 | 0 | 4.00 ± 4.00 | 0 |
| Simochromis diagramma | 0.13 | 0 | 0.35 | 0 | 0.25 ± 0.25 | 0 | 0.50 ± 0.50 | 0 |
| Eretmodus cyanostictus | 0.13 | 0 | 0.35 | 0 | 0.25 ± 0.25 | 0 | 0.50 ± 0.50 | 0 |
| Variahitichromis moori | 0.13 | 0 | 0 | 0 | 0.25 ± 0.25 | 0 | 0 | 0 |
| Neolamprologus bifasciatus | 0.13 | 0 | 0 | 0 | 0.25 ± 0.25 | 0 | 0 | 0 |
| Tanganicodus irdscae | 0.13 | 0 | 0 | 0 | 0.25 ± 0.25 | 0 | 0 | 0 |
| Xenotilapia ochrogenys | 0 | 13.73 | 0 | 0 | 0 | 9.75 ± 7.88 | 0 | 0 |
| Enantioptus melanogenys | 0 | 11.97 | 0 | 0 | 0 | 8.50 ± 6.93 | 0 | 0 |
| Grammatotilapia lemaiarii | 0 | 10.21 | 0 | 0 | 0 | 7.25 ± 3.97 | 0 | 0 |
| Xenotilapia bathyphilus | 0 | 9.86 | 0 | 0 | 0 | 7.00 ± 7.00 | 0 | 0 |
| Lepidiolamprologus cunningtoni | 0 | 6.34 | 0 | 10.53 | 0 | 4.50 ± 2.25 | 0 | 5.00 ± 3.00 |
| Neolamprologus tetracanthus | 0 | 5.28 | 0 | 17.89 | 0 | 3.75 ± 2.59 | 0 | 8.50 ± 8.50 |
| Lepidiolamprologus boulengeri | 0 | 3.52 | 0 | 24.21 | 0 | 2.50 ± 2.50 | 0 | 11.5 ± 11.5 |
| Neolamprologus callipterus | 0 | 3.52 | 0 | 0 | 0 | 2.50 ± 2.50 | 0 | 0 |
| Ectodus descampsi | 0 | 3.17 | 772 | 0 | 0 | 2.25 ± 2.25 | 11.00 ± 11.00 | 0 |
| Neolamprologus kungwensis | 0 | 2.11 | 0 | 8.42 | 0 | 1.50 ± 1.19 | 0 | 4.00 ± 4.00 |
| Lamprologus microlepis | 0 | 1.76 | 0 | 0 | 0 | 1.25 ± 1.25 | 0 | 0 |
| Boulengerochromis microlepis | 0 | 1.06 | 0 | 0 | 0 | 0.75 ± 0.48 | 0 | 0 |
| Telmatocrinis dhonti | 0 | 0.70 | 0 | 0 | 0 | 0.50 ± 0.29 | 0 | 0 |
| Plecodus mustax | 0 | 0.70 | 0 | 0 | 0 | 0.50 ± 0.50 | 0 | 0 |
| Limnotilapia dardennii | 0 | 0.35 | 0 | 0 | 0 | 0.25 ± 0.25 | 0 | 0 |
| Ophthalmotilapia ventralis | 0 | 0 | 13.33 | 0 | 0 | 19.00 ± 19.00 | 0 | 0 |
| Lamprochromis tanangianus | 0 | 0 | 4.56 | 0 | 0 | 6.50 ± 6.50 | 0 | 0 |
| Lepidiolamprologus lemaiarii | 0 | 0 | 1.05 | 0 | 0 | 1.50 ± 1.50 | 0 | 0 |
| Aulonocranus dewindti | 0 | 0 | 1.05 | 0 | 0 | 1.50 ± 1.50 | 0 | 0 |
| Neolamprologus mondabu | 0 | 0 | 0.70 | 0 | 0 | 1.00 ± 1.00 | 0 | 0 |
| Fish species                      | Species composition (%) | Mean abundance ± SE |
|-----------------------------------|-------------------------|---------------------|
|                                   | Protected area | Unprotected areas | Protected area | Unprotected areas |
|                                   | Rocky          | Sandy             | Rocky          | Sandy             | Rocky          | Sandy             |
| *Tropheus moorii*                 | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Neolamprologus falcicula*        | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Neolamprologus furcifer*         | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Telmatochromis brichardi*        | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Lamprologus ledesi*              | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Mastacembelus platisoma*         | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Bathybates ferox*                | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Simochromis marginatus*          | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Simochromis pleurospilus*        | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Neolamprologus modestus*         | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Neolamprologus brevis*           | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Neolamprologus boukengeri*       | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Neolamprologus similis*          | 0              | 0                 | 0              | 0                 | 0              | 0                 |
| *Telmatochromis bifrenatus*       | 0              | 0                 | 0              | 0                 | 0              | 0                 |
Cichlids dominated in both areas. A small number of species \((n = 4)\) were recorded in the outermost sampling site of the unprotected area in Sibwesa. Of the sites inside the park, site 5 recorded few species diversity \((n = 7)\). Generally, percentage of individuals of fish species on the total individuals counted in a sampling site was higher in sites with low species richness than sites with high species richness. For instance in sampling site S12, \textit{X. ochrogenys} and \textit{N. tetracanthus} dominated by 50% and 47%, respectively.

The area inside the park had higher fish biodiversity than areas in the unprotected areas (outside the park), \((P < 0.05)\) (Table 3). Comparison of rocky and sandy habitats showed that the former had high mean fish abundance per stationary visual census and 1 m\(^2\) in both protected and unprotected areas (Table 3).

Shannon-Wiener diversity index was used to describe the fish species diversity in rocky and sandy habitats within the protected area and unprotected areas (Table 3).

Although the two divers recorded many fish species in the protected area as compared to unprotected areas, there was no significant difference \((P > 0.05)\) in fish diversity between the areas. Nonetheless, pooling all data from both protected and unprotected areas showed that fish species diversity was significantly different \((P < 0.01)\) (Table 4). In addition, a significant variation \((P < 0.001)\) in species diversity between rocky and sandy habitats was evident in protected area, and vice versa for unprotected areas (Table 4).

**4. Discussion**

Environmental parameters, namely, dissolved oxygen, water temperature, and transparency, seemed to have no significant difference between areas inside and outside the park hence their influence on diversity and abundance of both areas was negligible. This could ascertain the fact that the variation in the fish abundance and diversity did not depend on the water quality parameters, but probably due to mainly other factors such as the management mechanism and the location of the sites.

Stationary visual census (SVC) employed in this study was noted to be size nondependent, unlike gillnet which relies on the mesh sizes and thereby affects the size of fish sampled; this method depends only on the visual capabilities of divers. In addition, the estimated sample of fish does not revolve around the captured and the noncaptured samples, but rather based upon the random throw of transects which appear to be representative of the study location. It was pointed out by Watson and Harvey [25] that SCUBA diver is likely to obtain accurate measures of species richness. However, the major setbacks of this method involved the look-alike of cichlids, mobility of fish [25, 26] due to disturbance, and the schooling phenomenon of fish which was minimized by throwing the transects randomly at least 5 m apart by the thoroughly trained experts on cichlids taxonomy. The avoidance of such sampling errors seemed to make the method robust.

Generally, rocky habitats recorded high fish species diversity than the sandy habitats (Figure 2 and Table 3). For example the Shannon-Weiner diversity index for sampling sites outside the park indicated that fish diversity in rocky habitats was twice that of sandy habitats. This could have been attributed to the favorable environment on the rocks for the growth of algae [27] which is the food of many herbivorous fish species. The same finding was reported by Paley et al. [19]. This implied that rocky areas had good biodiversity complexity hence attracted and harbored various aquatic organisms including fish [8]. Another reason could probably be the suitability of the rocks to provide hiding sites for cichlids to avoid predators. The hiding sites are mainly crevices which form microhabitats that are used as nests for breeding purposes. The fish species that use rocky habitats for breeding include many \textit{Neolamprologus} species [24] which were among the dominant species in the park. Therefore, variations in fish diversity among the habitats could be a result of differences in food availability and habitat preference of fish. On the other hand, sandy habitat defined as a predominantly sandy bottom with less than one tenth of the area covered with rocks is known to support relatively few cichlids [24]. Only those species capable of forming schools venture out over bare sandy bottoms. This could probably be the reason for school foraging species were infrequently recorded in the survey.

Protected area indicated high mean species richness than unprotected areas. Surprisingly, the protected area failed to show significant difference in fish species diversity under the Shannon-Weiner. This might be due to some reasons including relatively few species recorded in both protected and unprotected areas during the survey; the fact that protected areas do not present equilibrium points [28] hence other factors apart from human predation such as physicochemical properties of water can affect the biodiversity. In addition, nonvulnerable species could be negatively affected by the protection effect through their ecological relationship with other fishes, such as competition or predation [29]. Species richness and individuals within a species declined as one moves out of the park (Figure 2). This might have been contributed by intensive fishing [30] and environmental...
Lake Tanganyika during May to June 2008 survey. The sampling technique, that is, SVC whereas another two in the top ten dominant species of the report in the same

| Species | Outside MMNP | Inside MMNP |
|---------|--------------|-------------|
| X. flavipinnis | 2.47 | 1.0775 |
| L. elongates | 2.85 | 0.9817 |
| E. melanogenys | 1.31 | 3.13 |
| O. ventralis | 2.08 | 2.44 |

Fish abundance was unevenly distributed between species in habitats, inside MMNP, and outside MMNP. All the dominant fish species (Table 2) reported to be present in the park by Paley et al. [19] were recorded in the current study except X. flavipinnis which was recorded neither inside MMNP nor outside MMNP. Almost all the dominant species are endemic to Lake Tanganyika [33]. Four of the current most dominant species, namely, L. attenuates, N. brichardi, L. elongates, and E. melanogenys, were recorded in the top ten dominant species of the report in the same sampling technique, that is, SVC whereas another two species, *P. paradoxus* and *X. ochrogenys* were recorded in gillnets. That is to say, three species of the current top 10 dominant species are reported for the first time by this study. Furthermore, 5 of the 10 top dominant species inside MMNP were not recorded outside MMNP, the rest were recorded in relatively low numbers. In contrast, only 2 of the top 10 abundant species outside MMNP were not recorded in areas within MMNP. Therefore, fish species dominated inside MMNP were not dominant outside MMNP and the vice-versa except for *O. nasuta* which was the second dominant species in areas outside MMNP and ranked eighth inside MMNP. Interestingly, the most dominant fish species *O. ventralis* outside MMNP was not recorded inside MMNP. It was recorded in high numbers probably because it was in aggregation [34] or low abundance of its predator, *Plecoderus straeleni* (0.53%) [35]. Furthermore, species from some families such as Mastacembelidae and Bagridae which are highly endemic [19] were recorded in the park only justifying that the park serves as a “safety valve” in fisheries resource conservation.

High diversity of fish species indicated by the Shannon-Wiener diversity index and abundance in the park especially in rocky habitats means that the park continues to nurse and serve as a “gene pool” for many fish species of Lake Tanganyika as compared to its neighborhood unprotected areas.

### 5. Conclusion

Fish abundance and diversity in the protected area were higher than in unprotected areas. Restriction of any fishing activities within the protected area seemed to contribute much to availability of such good stock of fish. However, there were some variations in biodiversity within the park and habitats. There were higher species abundance and diversity in rocky habitats than in sandy habitats. The aquatic environment in unprotected areas seemed to be threatened by many factors such as siltation due to uncontrolled agricultural activities and illegal fishing methods that could have resulted into reduced fish species diversity. There is a need to create awareness on the importance of the MMNP aquatic component and its conservation to the riparian communities to avoid conflict of interest between the stakeholders. Because of limited studies on fish biodiversity and abundance in the region, the findings of the current study serve as baseline information for future references as an attempt to revive the fisheries resources in the area and the lake at large. Further regular and comprehensive studies are required to verify the efficacy of the protected area in conservation of aquatic biodiversity and propose sound management practices.

### Table 3: Fish mean abundance (individual m\(^{-2}\) ± SE) and Shannon-Wiener diversity index (H\(^{\prime}\)) for protected area and unprotected areas in Lake Tanganyika during May to June 2008 survey.

| Test | Protected area | Unprotected areas | Protected and unprotected |
|------|----------------|------------------|---------------------------|
| Mean abundance (ind. m\(^{-2}\)) | Rocky | Sandy | Total | Rocky | Sandy | Total |
| H\(^{\prime}\) | 4.59 ± 2.44 | 1.67 ± 1.28 | 3.13 ± 2.01 | 3.35 ± 2.60 | 1.13 ± 1.08 | 2.24 ± 1.98 |

### Table 4: One-way ANOVA tests for species diversity in protected area and unprotected areas in Lake Tanganyika during May to June 2008 survey.

| Test value | Protected area | Unprotected areas | Protected and unprotected | Site |
|------------|----------------|------------------|---------------------------|------|
| F | 1.4362 | 1.4362 | 1.0775 | 0.9817 | 1.8534 | 1.4848 | 3.1271 |
| P | 0.0002*** | 0.0151* | 0.3631 | 0.5342 | 2.83E\(^{-5}\)*** | 0.0056** | 0.0004*** |
| df | 355 | 355 | 177 | 177 | 533 | 533 | 1067 |

*P < 0.05, **P < 0.01, ***P < 0.001.
Conflict of Interests

The authors declare that there is no relation with the mentioned software enterprises (Microsoft and STATISTICA) which might lead to conflict of interests with the companies therein. In addition, they are trained researchers with the information herein meant merely for scientific rationale and therefore they account their output based on research and information dissemination.

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