Research Article

Comparing the Performance of Protected and Unprotected Areas in Conserving Freshwater Fish Abundance and Biodiversity in Lake Tanganyika, Tanzania

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Marine protected areas have been shown to conserve aquatic resources including fish, but few studies have been conducted of protected areas in freshwater environments. This is particularly true of Lake Tanganyika, Tanzania. To better conserve the lake's biodiversity, an understanding of the role played by protected areas in conserving fish abundance and diversity is needed. Sampling of fish and environmental parameters was performed within the Mahale Mountains National Park (MMNP) and nearby unprotected areas at depths between 5 m and 10 m. Twelve replicates of fish sampling were performed at each site using gillnets set perpendicularly to the shore. Mann-Whitney tests were performed, and the total amount of species turnover was calculated. A total of 518 individual fish from 57 species were recorded in the survey. The fish weight abundance was fivefold greater in the MMNP than in the unprotected areas. Fish abundance and diversity were higher in the MMNP than in the unprotected areas and decreased with distance from it. Our findings confirmed the importance of the protected area in conserving fish resources in Lake Tanganyika. The study provides baseline information for management of the resources and guiding future studies in the lake and other related ecosystems. Management approaches that foster awareness and engage with communities surrounding the MMNP are recommended for successful conservation of the resources in the region.

1. Introduction

The complexity of the Lake Tanganyika (Figure 1) ecosystem makes it unique in the world [1], and it notably contributes to global biodiversity [2, 3]. About 58% of the animal species that inhabit the lake are endemic [4], and fish of the family Cichlidae and Molluscs are very diverse; that is, both of these groups have a high number of species with a substantial proportion of endemic species [5] and show considerable genetic variability within species. However, the lake's biodiversity is vulnerable to anthropogenic threats including fishing [5–10].

Conservation researchers have advocated controlling human activities by establishing protected areas as one of the methods of conserving biodiversity in an ecosystem [9, 11, 12]. This mitigation approach ensures that some essentially unmodified sites exist for buffering against uncertainty such as overfishing [13, 14]. It is well documented that protected areas nurse and harbor many more species compared with unprotected areas [11, 12, 15]. Additionally, studies of freshwater ecosystems have revealed that fish in protected areas are larger than those in unprotected areas [16–18]. Unfortunately, many protected areas are designed to conserve terrestrial
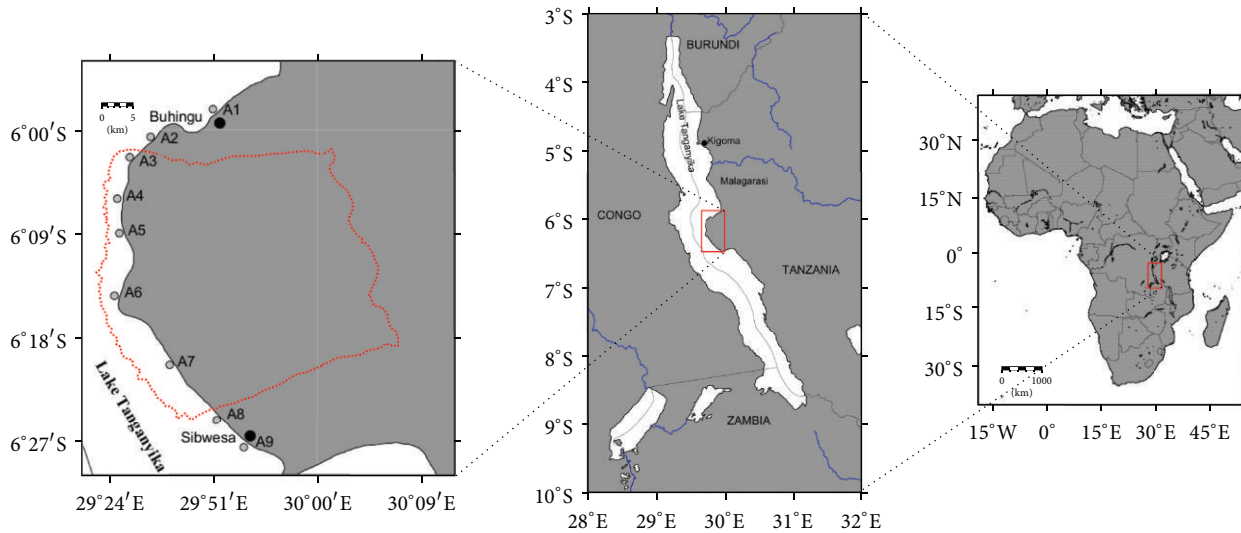
FIGURE 1: Map of Lake Tanganyika showing study sites within protected area (MMNP: A3–A7) and in unprotected areas (Buhingu: A1-A2 and Sibwesa: A8-A9) during 2008 gillnet survey. The large red polygon in the first frame shows sketch boundaries of MMNP (terrestrial and water strip in grey color and white color, resp.). The blue lines in the middle frame represent rivers.

habitats than aquatic biodiversity, consequently limiting the assessment of spatial and temporal fish abundance and biodiversity in both protected and unprotected areas [19–22].

The Mahale Mountains National Park (MMNP) was established in 1985 to conserve terrestrial biodiversity, with a particular aim of protecting chimpanzees. The MMNP has a total area of 1,613 km^2, of which 96 km^2 is a 1.6 km wide aquatic strip extending along the shore of Lake Tanganyika [23]. All forms of exploitation including fishing are strictly prohibited in the MMNP. Trained park rangers conduct patrols to prevent poaching. However, fishing activities in surrounding waters remain unregulated. The ecological performance of protected areas has been assessed by comparing it with that of nearby unprotected areas [24, 25]. However, studies on the MMNP's biological conservation efficacy and loss of fish abundance and diversity in adjacent areas are scarce.

The purpose of this study was to assess and compare the differences in fisheries resources between protected and unprotected areas. To achieve this, we compared fish abundance and diversity between the MMNP and nearby unprotected areas. Such studies are vitally important to ascertain the spatial and temporal extent of human influence in variations in abundance and diversity in the ecosystem. This baseline information also could contribute valuable knowledge to the global debate concerning the relevance of freshwater protected areas in conserving fisheries resources.

2. Methods

2.1. Study Area Description. The study was conducted in Lake Tanganyika, Tanzania, during May and June 2008. Sampling sites were located within and outside the MMNP (Figure 1). The MMNP is located at the southern edge of the Kigoma region, with an elevation ranging from 2,000 to 2,400 m [26].

2.2. Data Collection. For comparison purposes, the sampling sites were selected based on area status, that is, protected and unprotected, Table 1. Eight sampling sites (four within the protected area (MMNP) and four in unprotected areas) at least 5 km apart were randomly selected. The four outermost sites (i.e., two northernmost and two southernmost) were located in unprotected areas (Buhingu and Sibwesa villages, resp.).

2.3. Environmental Parameters. Four samples for dissolved oxygen (DO) and temperature were taken at each site at 5 m and 10 m water depths using a multiparameter analyzer WTW 340i [27]. The mean values of environmental parameters were statistically analyzed using a one-way ANOVA.

2.4. Sampling of Fish. The sampling of fish was performed at depths between 5 m and 10 m using gillnet set perpendicularly to the shore. Twelve replicates of gillnets, each with a width of 1.37 m and 45 m total length (before mounting), were joined end to end to form one panel of 360 m. The mesh sizes ranged from 1″ to 5″ (inches) (i.e., 25.4 mm to 127.0 mm), at an interval of 0.5″ except for the large mesh sizes (i.e., 1″, 1.5″, 2″, 2.5″, 3″, 3.5″, 4″, and 5″). The first 4 mesh size nets (1″ to 2.5″) were used in pairs. Each net had a length of 30 m after mounting at a hanging ratio of 0.66. Nets of different mesh sizes were used to increase the variability of sizes of fish and minimize sampling errors. The nets were set in the evening and hauled in the following morning. After hauling, the samples were sorted and identified to species level at the shore according to Konings [28]. Total catch, species, and wet weights of fish were recorded at each site. After the experiments, some of the fish samples were used for human consumption and representatives of some species were preserved for reference.

TABLE 1: Environmental parameters mean (±SD) of study sites in protected and unprotected areas in Lake Tanganyika, Tanzania, from gillnet survey during 2008. Samples from site A4 were omitted in the analysis.

Site ID	Site location	Status	DO (mg·L^{-1})	Temperature (°C)
A1	Buhingu	Unprotected	8.45 ± 0.21	26.95 ± 0.07
A2	Buhingu	Unprotected	7.30 ± 0.14	26.95 ± 0.07
A3	MMNP	Protected	8.00 ± 0.14	27.05 ± 0.07
A4	MMNP	Protected	7.70 ± 0.42	27.50 ± 0.00
A5	MMNP	Protected	7.35 ± 0.35	27.05 ± 0.07
A6	MMNP	Protected	7.25 ± 0.21	27.20 ± 0.00
A7	MMNP	Protected	8.15 ± 0.07	26.65 ± 0.07
A8	Sibwesa	Unprotected	7.25 ± 0.21	26.00 ± 0.00
A9	Sibwesa	Unprotected	7.50 ± 0.28	26.30 ± 0.00

2.5. Estimation of Abundance of Fish Species. To select appropriate statistical tests, fish mean abundance data and their residuals were tested for normality. The data were not normally distributed and variance groups were heterogeneous. This was followed by a log transformation, but the data still did not assume normal distribution patterns. Owing to this, we performed nonparametric tests after Mann-Whitney (MW) tests to determine pairs of areas with significant differences in fish abundance. The latter test was also performed to determine if habitat types affected fish abundance in the unprotected areas. Additionally, to avoid bias in the analysis, data from the rocky habitat in the MMNP was omitted; that is, data from 8 sites was used: four from within the MMNP and the 4 from the adjacent unprotected areas.

2.6. Calculation of Diversity of Fish Species. Fish biodiversity in both protected and unprotected areas was calculated as absolute species turnover, that is, the total amount of species turnover among the subunits in the dataset [29]:

$$\beta_A = (S_1 - c) + (S_2 - c) + \cdots + (S_n - c), \qquad (1)$$

where β_A is the absolute species turnover (diversity) for area A, S_1 is the total number of species recorded in the first site, S_2 is the total number of species recorded in the second site, S_n is the total number of species recorded in the nth site, and c is the number of species common to both sites.

Statistical tests for the environmental parameters and fish abundance were performed at significance level, $P = 0.05$, using STATISTICA (version 8, StatSoft Inc., 2010).

3. Results

3.1. Environmental Parameters. There were no significant differences in dissolved oxygen ($F_{1,16} = 0.73$, $P = 0.41$) and temperature ($F_{1,16} = 2.60 \times 10^{-3}$, $P = 0.96$) between the protected and unprotected areas (Table 1).

3.2. Abundance (Number) of Individual Fish. The mean number of individuals of fish in sites within the MMNP was higher than in the unprotected areas (Mann-Whitney, $P < 0.05$). In the survey, 518 individual fish from 57 species were recorded: 40 species were recorded in the MMNP and 39 were recorded
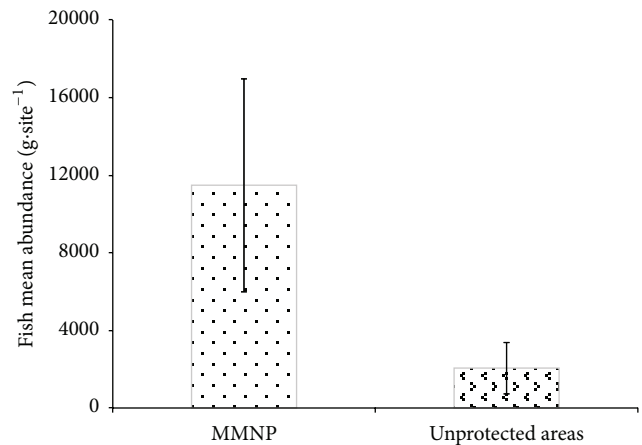

FIGURE 2: Mean fish abundance (wet weight ± SD) within protected area (MMNP) and unprotected areas (Buhingu and Sibwesa) in Lake Tanganyika, Tanzania, during 2008 gillnet survey.

in the unprotected areas (Table 2). The species belonged to nine families (number of species in parentheses): Cichlidae (41), Mastacembelidae (3), Mochokidae (3), Claroteidae (3), Latidae (2), Mormyridae (2), Clupeidae (1), Cyprinidae (1), and Poeciliidae (1). *Haplotaxodon microlepis* and *Bathybagrus graueri* were the most abundant species recorded in both the protected and unprotected areas (Table 2). The former ranked the first in abundance in both the MMNP and unprotected areas, and the latter was the sixth and fourth in the MMNP and unprotected areas, respectively. Five of the 10 most abundant species in the MMNP area were not recorded in the unprotected areas. On the other hand, only two species (*Synodontis* spp. and *Bathybates graueri*) which were among the most abundant ones in the unprotected areas were not recorded in the MMNP area. The two unprotected areas (Buhingu and Sibwesa) showed significant difference in the mean fish abundance (Mann-Whitney, $P < 0.05$). However, mean fish abundance was not significantly different between habitat types, particularly rocky and sandy types in the unprotected areas (Mann-Whitney, $P = 0.16$).

3.3. Weight Abundance. Figure 2 shows the mean wet weight of the fish samples in both the MMNP and the unprotected

Table 2: Mean abundance number of individuals (±SE) of fish species sampled in sites within the protected area (MMNP) and unprotected areas (Buhingu and Sibwesa) in Lake Tanganyika, Tanzania, during 2008 gillnet survey.

Fish species	Protected area	Unprotected areas
Haplotaxodon microlepis	9.00 ± 4.60	5.75 ± 4.42
Limnotilapia dardennii	7.75 ± 2.50	0.75 ± 0.48
Barbus sp.	7.75 ± 2.17	0
Lates angustifrons	6.50 ± 1.66	0
Bathybates hornii	6.00 ± 2.48	0.25 ± 0.25
Limnothrissa miodon	5.50 ± 4.52	0
Bathybagrus graueri	5.00 ± 1.78	3.00 ± 2.68
Lamprichthys tanganicanus	4.25 ± 1.93	0
Petrochromis moshi	3.50 ± 3.50	1.25 ± 1.25
Boulengerochromis microlepis	3.50 ± 0.87	0.25 ± 0.25
Lepidiolamprologus elongatus	3.25 ± 2.63	0
Plecodus paradoxus	3.00 ± 0.82	1.00 ± 0.71
Cyathopharynx foai	2.75 ± 1.80	0.50 ± 0.29
Lamprologus callipterus	2.00 ± 0.82	0.25 ± 0.25
Grammatotria lemairii	1.50 ± 1.19	0.25 ± 0.25
Petrochromis orthognathus	1.50 ± 0.96	0
Lepidiolamprologus cunningtoni	1.50 ± 0.87	0
Ophthalmotilapia nasuta	1.25 ± 1.25	1.75 ± 1.44
Synodontis petricola	1.25 ± 0.95	0.25 ± 0.25
Tropheus moorii	1.00 ± 1.00	0
Cyphotilapia frontosa	0.75 ± 0.75	0.50 ± 0.50
Lates mariae	0.75 ± 0.75	0.25 ± 0.25
Aulonocranus dewindti	0.75 ± 0.48	2.00 ± 2.00
Plecodus straeleni	0.75 ± 0.48	1.25 ± 0.95
Neolamprologus mustax	0.75 ± 0.48	0.50 ± 0.50
Tylochromis polylepis	0.75 ± 0.48	0.50 ± 0.50
Neolamprologus fasciatus	0.75 ± 0.48	0.50 ± 0.50
Perissodus microlepis	0.75 ± 0.48	0
Lepidiolamprologus profundicola	0.75 ± 0.48	0
Xenotilapia melanogenys	0.50 ± 0.50	0
Lobochilotes labiatus	0.50 ± 0.29	0
Xenotilapia sima	0.25 ± 0.25	1.25 ± 1.25
Lamprologus lemairii	0.25 ± 0.25	0.75 ± 0.75
Xenotilapia spiloptera	0.25 ± 0.25	0.25 ± 0.25
Petrochromis famula	0.25 ± 0.25	0
Bathybates ferox	0.25 ± 0.25	0
Mastacembelus cunningtoni	0.25 ± 0.25	0
Auchenoglanis occidentalis	0.25 ± 0.25	0
Tropheus annectens	0.25 ± 0.25	0
Simochromis diagramma	0.25 ± 0.25	0
Synodontis sp.	0	5.25 ± 4.61
Bathybates graueri	0	3.25 ± 3.25
Phyllonemus typus	0	2.00 ± 2.00
Ectodus descampsii	0	1.50 ± 1.50
Petrochromis fasciolatus	0	1.25 ± 1.25
Mastacembelus sp.	0	1.00 ± 1.00
Neolamprologus toae	0	1.00 ± 0.41
Telmatochromis brichardi	0	0.75 ± 0.75
Benthochromis tricoti	0	0.75 ± 0.75
Mormyrus sp.	0	0.25 ± 0.25
Mastacembelus moorii	0	0.25 ± 0.25

Fish species	Protected area	Unprotected areas
Synodontis multipunctatus	0	0.25 ± 0.25
Hippopotamyrus sp.	0	0.25 ± 0.25
Altolamprologus compressiceps	0	0.25 ± 0.25
Petrochromis ephippium	0	0.25 ± 0.25
Lepidiolamprologus attenuatus	0	0.25 ± 0.25
Neolamprologus pleuromaculatus	0	0.25 ± 0.25
Total number of individual fish	351	167
Average number of individual fish per site	87.75 ± 46.16	41.75 ± 37.47

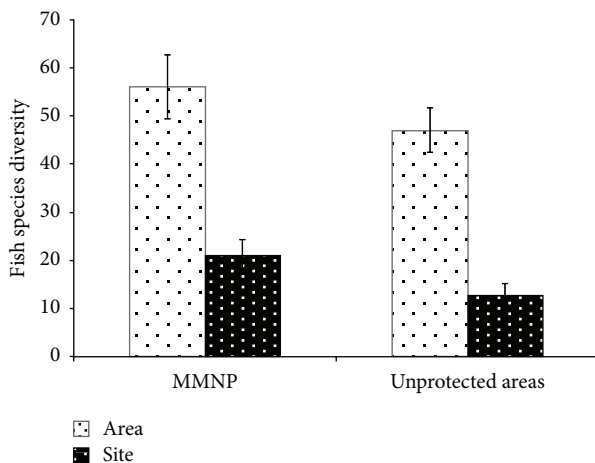FIGURE 3: Mean fish species diversity (±SD) calculated as absolute species turnover in protected area (MMNP) and unprotected areas (Buhingu and Sibwesa) in Lake Tanganyika, Tanzania, during 2008 gillnet survey.

areas. There was a significant difference (Mann-Whitney, $P < 0.05$) in weight abundance between the MMNP and the unprotected areas. The abundance in the MMNP was fivefold greater than in the unprotected area. The highest weight ($19,300 \, \text{g·site}^{-1}$) was recorded in the MMNP, whereas the lowest ($844 \, \text{g·site}^{-1}$) was recorded in unprotected areas (Buhingu).

3.4. Fish Species Diversity. The mean species diversity turnover was higher in the MMNP than in the unprotected areas (Figure 3). The number of species within the MMNP's sites was almost double that of the unprotected areas. The sites with the highest and lowest species diversity were recorded in the MMNP ($n = 30$) and unprotected areas ($n = 8$), respectively. The fish diversity decreased with distance from the MMNP where 23 and 16 species were recorded in Buhingu and Sibwesa, respectively.

4. Discussion

The main findings of this study are that there are higher fish species diversity and abundance of fish in the MMNP compared with the unprotected areas. We discuss these findings in the subsequent text, to illustrate the performance differences between the MMNP and the unprotected areas in conserving fish abundance and biodiversity in the lake.

4.1. Environmental Parameters. Insignificant differences in the environmental parameters between protected and unprotected areas ruled out their effects on fish species diversity and abundance in the areas. Upwelling driven by strong southeast winds that prevail during the sampling period (dry season, i.e., May–September) [30, 31] might have attributed to the similarity in the parameters.

4.2. Abundance (Number) of Individual Fish. The dominance of different fish species within the MMNP suggests that the area is richer in fish species than the adjacent unprotected areas. Fish species in the families Clupeidae, Cyprinidae, and Poeciliidae were recorded only in MMNP and were among the most abundant species. Conversely, sites in the unprotected areas were characterized by few species that notably contributed to the abundance in these areas. This was exemplified by the two most dominant species *Haplotaxodon microlepis* and *Aulonocranus dewindti* that (out of 17 species in the area) constituted about 50% of fish counts in Sibwesa.

4.3. Weight Abundance. The current findings affirm the assumed abundance of socially and economically important fish species such as *Lates angustifrons*, *Boulengerochromis microlepis*, and *Limnotilapia dardennii* in the protected area. There was higher mean abundance within the protected area than in adjacent unprotected areas (Figure 2), which suggests that the MMNP harbors larger individual fish compared to the unprotected areas. In other words, individuals of exploited species were relatively larger in protected areas than in open-access areas. Fish size is used as an indicator of fishing pressure; fish are likely to be smaller in areas that are more heavily fished [12, 15, 32]. These are some positive indications of the effectiveness of the MMNP in conserving fish abundance and diversity in the lake.

4.4. Fish Species Diversity. The differences in fish diversity between the MMNP and unprotected areas (Figure 3) were probably due to differences in management of the resources. Whereas all forms of exploitation including fishing are strictly prohibited in the MMNP, fishing activities in surrounding waters are high [8, 10]. Poor enforcement of existing fisheries regulations by the local and regional authorities may also

be attributed to low fish diversity in the unprotected areas. For instance, the use of prohibited beach seine nets was confirmed at Sibwesa during the survey. This could be one of the reasons why the sites in this area recorded the lowest fish species diversity. Identification of any signal of change in the ecosystem that will lead to taking immediate management and conservation measures is especially important [33].

5. Conclusions

Comparisons of fish abundance, especially of fish weight, and diversity showed that the MMNP plays an important role in conserving fisheries resources in the region. Extending the park or establishing more other protected areas could certainly enhance biodiversity in the region. However, this should be carefully considered because it might redirect fishing pressure to unprotected areas and cause more management challenges [34]. We believe that resources conservation approaches such as protected areas in the region cannot be successful through stringent laws and regulations but by creating awareness of the importance of protected areas among stakeholders. We advocate for socioecological studies, particularly on how communities surrounding the protected area should be engaged in enhancing sustainable fisheries resources management and conservation in the region.

Limitations of this study include inadequate sampling in rocky habitats in the MMNP, particularly in river mouths because they harbor dangerous animals such as Nile monitors, crocodiles, and hippopotamuses. Owing to this, we could not compare the influence of habitat types on fish abundance and diversity in the areas. Additionally, we could not find information on fish abundance and biodiversity before and after the addition of the water strip to the protected area. This precludes the comparison in a spatial and temporal basis of the variables in the areas. A similar paradox has been reported in other studies in freshwater protected areas [19–22]. Importantly, therefore, our work provides baseline information for the management of fisheries resources in Lake Tanganyika and guides future studies in the area.

Ethical Approval

The authors declare that the study was carried out in accordance with research ethical guidelines of the institutions and animal welfare including using environmentally friendly methods (i.e., gillnets).

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.
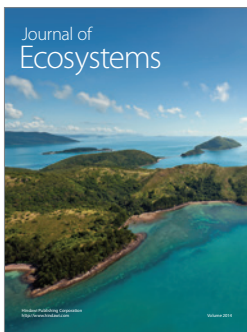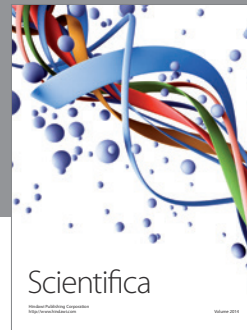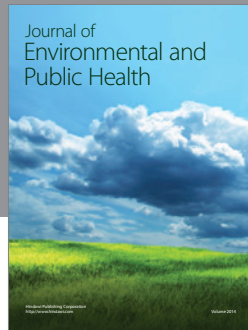
Acknowledgments

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