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Can a Protected Area Help Improve Fish Populations under Heavy Recreation Fishing?

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Abstract: Freshwater protected areas are designated parts of the inland waters that restrict human activities. They were created as a mechanism to combat the decline of fauna and flora of the world. Some authors have questioned their actual effectiveness in terms of the purpose of protecting endangered fauna and flora. We conducted an experiment in Lipno reservoir in the Czech Republic to evaluate the impact of protection against angling pressure on the fish community. We selected data from two years of gill netting and analyzed the difference between areas of low anthropogenic impact (LAI) and those of high anthropogenic impact (HAI) in terms of abundance, biomass, standard length, and diversity indices. Three groups of fish were found to prefer protected areas with low anthropogenic pressure: 1. YOY (Young-of-the-year) perch (*Perca fluviatilis*), the dominant of the young-of-the-year fish community. 2. Pike (*Esox lucius*), wels catfish (*Silurus glanis*) and rudd (*Scardinius erythrophthalmus*), which were not found in HAI areas at all. 3. Larger individuals of pikeperch (*Stizostedion lucioperca*), which survived better in LAI areas. Some factors may affect LAI, such as illegal poaching or setting out food bait to attract the fish outside. Another factor that can be considered is the migration of fish, either to forage or to reproduce, since the LAI areas are open to the reservoir. The areas of LAI act as protective habitats for heavily exploited predatory fish species and increase fish diversity indexes. The example of the protected and low-impact areas of Lipno should be followed in other water bodies with high fishing pressure and anthropogenic impact.

Keywords: protected areas; anthropogenic impact; angling; recreation pressure; exploitation; CEN gillnets; recreation fishing

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1. Introduction

Humans are intimately linked to freshwater ecosystems, and both humans and nature benefit when the risks to the health of these habitats are managed [1–3]. Among all ecosystems, inland waters are one of the most affected, and freshwater fishes have been one of the most threatened vertebrate groups in the world in recent decades [4–7]. Moreover, they are unique, and their loss could have irreparable consequences for global biodiversity [3,8]. Despite the economic and cultural value of freshwater fishes, the threat from anthropogenic impacts is still quite high [9]. Habitat degradation and loss, hydrological modifications, construction of instream barriers, excessive water abstraction, overexploitation and intensification of agricultural activities, introduction and spread of alien species and pollution have been identified as the main threats to freshwater ecosystems and their biodiversity [10–15]. Due to these multiple impacts and threats, increasing attention is being paid to freshwater ecosystems worldwide to find effective ways to restore lost habitats and important sites for endangered species [3,15–17].

Habitat overexploitation may be associated with declining populations. These declines have been linked to several factors, including overfishing and littoral habitat destruction [10,18]. Some studies have shown a widespread recruitment deficit in species that use the shallows as spawning grounds for reproduction, and increased mortality during the early stages due to loss of protective habitats has been suggested as one the causes of declines of adult fish populations [15,19–22]. For example, Ljunggren [23] showed that populations of top predators (such as pike (*Esox lucius*) and Eurasian perch (*Perca fluviatilis*)) had a continuous decline in density and abundance of coastal areas in parts of the Baltic Sea; Kubečka [24] showed that the populations of pike-perch (*Stizostedion lucioperca*) in the Lipno reservoir, Czech Republic had been declining sharply since 2004, recovering partly only after 2017. The relationships between the size of adult fish populations and the availability and quality of recruitment habitats, along with the other types of pressures facing littoral areas, may be the cause of declines in fish recruitment in diverse types of freshwater habitats [18,25]. Moreover, changes in the abundance and diversity of large piscivorous fishes can trigger community-wide trophic cascades that have far-reaching, detrimental consequences for ecosystem functioning and stability, as well as human livelihoods [26–28].

According to the IUCN definition, a protected area (hereafter PA) is a defined geographical space recognized, dedicated and managed by legal or other effective means to achieve the long-term conservation of nature with associated ecosystem services and cultural values [26]. In the past, protected areas were established to protect endangered species with the expectation that the community would have an increase in biomass, abundance, and species diversity [27]. The study of PAs in freshwater systems is far less developed than in marine environments. Research on marine PAs began to be studied nearly a decade before freshwater Pas and currently includes nine times more scientific papers than freshwater PAs. Given that freshwater environments are more vulnerable than marine environments and that scientific knowledge of freshwater ecosystems is much less than that of marine ecosystems, it is of great importance to study the effects of PAs in freshwater systems. The benefits of freshwater PAs to the fish community have shown positive results [28–31] or neutral effects [32,33].

Although there are a large number of protected areas in many regions of the world, their effectiveness in protecting freshwater systems and their biodiversity has been questioned in recent years [9,34,35]. This is because the designation of protected areas in the past was largely based on the need to protect terrestrial diversity [8,17]. Although freshwater systems are among the most highly threatened ecosystems globally, they have been overlooked in the designation of PAs, and often, their inclusion in existing protected areas has mainly been incidental rather than intentional [35–37]. The lack of inclusion of freshwater systems in the designation and establishment of the protected areas has been identified as a limiting factor in the effectiveness of freshwater fish conservation. Bastin [38] shows in his work that 15% of inland waters worldwide are at PA, but in some continents such as Asia and Africa, only 5% of inland waters are; Azevedo-Santos [17] showed that large migratory fish lack the necessary habitat to complete their life cycles; Chessman [32] reported that PAs in Murray–Darling Basin of Australia, had no effect on protecting native fish populations because they were ineffective in curbing the threat of non-native fish and altering the water regime; Lawrence [39] reported that less than 20% of the highly endangered fish species are protected under the PA territories. Therefore, broad-based research is needed to verify the effectiveness of each PA.

The protected areas in the studied area (Lipno reservoir, the largest water body in the Czech Republic) were created with the aim of increasing the abundance and biomass of target species (especially predatory species) by recreational anglers. Therefore, a better understanding of the effects of lowering anthropogenic activities on these habitats and the dependence of fish on these habitats is essential for guiding management actions aimed at maintaining, enhancing or restoring ecosystem services. In this study, we examine the effectiveness of Lipno PAs and nearby areas of low anthropogenic impact in protecting highly valued wildlife species and associated fish diversity. We sampled and analyzed fish assemblage abundance, biomass, size structure, species richness and composition of four different regions, two with high and direct anthropogenic and angling impact and two with lower and indirect impact.

2. Materials and Methods

2.1. Study Area

Lipno reservoir (Figure 1) is a dam impoundment, near the border with Austria, on the Vltava River in the foothills of the Šumava Mountains (Bohemian Forest); in Southern Bohemia, Czech Republic. The reservoir was built in 1960 as a hydropower reservoir; nowadays, it also serves as flood control, flow augmentation, drinking water supply and recreation. The reservoir has a volume of 306 million m^3, a surface area of 46.5 km^2, a maximum depth of 22 m and a mean depth of 6.6 m [40].

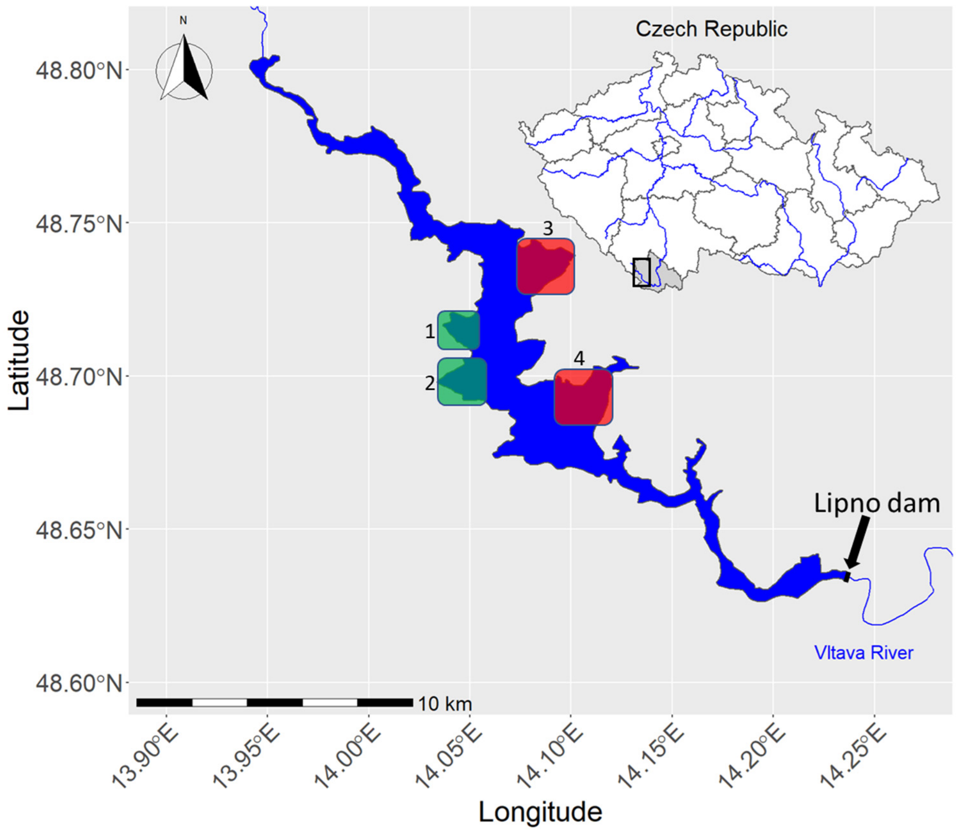

Figure 1. Outline map of Lipno reservoir, with its location in the Czech Republic (black rectangle) and the detailed location of the low anthropogenic impact areas (Green squares, 1. Racinska zatoka; and 2. Kyselovska zatoka) and the control high anthropogenic impact sites (Red squares, 3. Hurka; and 4. Dolni Vltavice).

The sites for this study are located in the middle section of the reservoir. The study areas with low anthropogenic impact (hereafter LAI) are located on the south-west side of the reservoir, the protected area (Kyselovská bay, max. 8 m depth) and in an adjacent bay (Račinská bay, max. 6 m depth). In Kyselovská Bay (2.15 km^2), angling has been prohibited all year round since 2009, while Račinská bay (0.82 km^2) is protected by its remoteness and difficult access for the public. These two bays are located on a forested, wind-protected shore without recreational facilities or cottage districts. During the “iron curtain” period (1948–1989), this area at the border with Austria was strictly closed to the public so that no one could approach the border. The high anthropogenic impact (hereinafter HAI, see

Figure 1) areas are located in two nearby areas, Hůrka area (max. 8 m depth). and Dolni Vltavice basin (max. 10 m depth). HAI areas are located near local settlements with recreational facilities and cottage districts. These areas are among the most visited areas for recreational fishing. Angling is generally allowed throughout all year; predatory fish are protected between 1 January till 16 June.

2.2. Fishing Gear and Field Work Dates

European Standard gillnets (ESG) [41] and Large Mesh Gillnet (LMG) [42] methodologies were used in this experiment. ESG following the European Standard Document (benthic gillnet: 1.5 m height × 30 m length, 2.5 m panels for each 12 mesh sizes; pelagic gillnet: 3 m height × 30 m length, 2.5 m panels for each 12 mesh sizes) were used for sampling from 2016 and 2017 in Lipno reservoir. ESG mesh sizes follow a geometric series with a ratio of about 1.25 (5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43 and 55 mm).

LMG consists of four mesh sizes extending the ESG geometric series (70, 90, 110 and 135 mm; knot to knot; pelagic net size 3 m height × 40 m length, 10 m panels for each of 4 mesh sizes and benthic net size 1.5 m height × 40 m length, 10 m panels for each of 4 mesh sizes) were deployed in the same habitats and localities along with the ESG. Three nets of ESG and three nets of LMG were deployed in every habitat of each area. The large mesh nets (≥70 mm) had four times higher effort (net area) than the CEN standard nets (<70 mm) to catch sufficient numbers of larger fish. Therefore, the catches and net areas of the large mesh gillnets were divided by four to standardize the length of each panel to 2.5 m for all meshes. When all 16 meshes were the same length (2.5 m), catch data were standardized to 1000 m^2 of net area. Gillnets were set at depths of 0–3 m and 3–6 m for benthic habitats; and 0–3 m for pelagic habitats, respectively.

Gillnet deployment occurred on 28–29 August and 1 September 2016, and 27–30 August 2017. To cover both sunset and sunrise peaks of fish activity, gillnets were deployed two hours before sunset and lifted two hours after sunrise. The catch was sorted by species, and standard length and weight were measured for each fish (accuracy of 1 mm and 0.1 g, respectively). Catch per unit of effort (CPUE) was defined as the number of individuals per standardized 1000 m^2 of net area per night; similarly, sampled biomass per unit of effort (BPUE) was defined as kilograms per 1000 m^2. CPUE and BPUE were reported separately for young of the year (YOY) and older year classes (older fish, estimates based on size structure verified by the scale and otolith reading). The CPUE and BPUE were calculated for individual species as well as for the entire fish assemblage.

2.3. Data Analysis

Negative binomial generalized linear models (NBGLM) were applied to describe the differences in fish standard lengths, CPUE and BPUE values with the difference between LAI and HAI areas and the different habitats (benthic and pelagic), as shown in Equation (1).

$$\text{Model} = \text{Value} \sim \text{Impact} + \text{Habitat} \quad (1)$$

The negative binomial generalized linear model was chosen because it can handle large numbers of zeros and over-dispersed data [43]. The MASS package was used for the calculation of all NBGLMs [44].

Shannon–Wiener diversity, Simpson's diversity, Pielou's evenness, and Richness indices were calculated by treatments, time periods, and years of sampling using the Vegan package [45]. The generalized linear negative binomial model was also used to compare the diversity index values using the same structure as the previous models, Equation (1).

Three significance levels were considered, * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$. All data analyzes were performed in R software [46].

3. Results

In total, 102 nets 12 species from 4 orders. The Cypriniformes were represented by common bream (*Abramis brama*), bleak (*Alburnus alburnus*), silver bream (*Blicca bjoerkna*), carp (*Cyprinus carpio*), asp (*Leuciscus aspius*) and roach (*Rutilus rutilus*) and rudd (*Scardinius erythrophthalmus*); the Perciformes were represented by ruffe (*Gymnocephalus cernua*) perch (*Perca fluviatilis*) and pikeperch (*Stizostedion lucioperca*); the Esociformes by pike (*Esox lucius*) and the Siluriformes by wels catfish (*Silurus glanis*). The Cypriniformes (56,39%) were the most abundant group of the older fish community, followed by Perciformes (43,47%), Esociformes and Siluriformes (0.07% each) (Table 1).

Table 1. Species of fish older than young-of-the-year from gillnetting at high-impact sites (HAI) and low-impact (LAI) areas of the Lipno reservoir captured in the study, with their individual catch and proportion of the total catch.

	HAI		**LAI**	
	Individuals	**Proportion**	**Individuals**	**Proportion**
Abramis brama	128	3.41	60	1.72
Alburnus alburnus	1029	27.39	568	16.29
Blicca bjoerkna	274	7.29	317	9.09
Cyprinus carpio	21	0.56	33	0.95
Esox lucius	0	0.00	5	0.14
Gymnocephalus cernua	1436	38.22	1187	34.05
Leuciscus aspius	9	0.24	7	0.20
Perca fluviatilis	124	3.30	441	12.65
Rutilus rutilus	683	18.18	795	22.81
Sander lucioperca	53	1.41	56	1.61
Scardinius erythrophthalmus	0	0.00	13	0.37
Silurus glanis	0	0.00	4	0.11
Total	3757	100.00	3486	100.00

In the YOY fish group, Perciformes (75, 62%) was the most abundant group, followed by Cypriniformes (24, 38%) (Table 2).

Table 2. Species of fish young-of-the-year from gillnetting at high-impact sites (HAI) and low-impact (LAI) areas of the Lipno reservoir captured in the study with their individual catch and proportion of the total catch.

	HAI		**LAI**	
	Individuals	**Proportion**	**Individuals**	**Proportion**
Abramis brama	10	0.51	20	0.29
Alburnus alburnus	1	0.05	54	0.79
Blicca bjoerkna	10	0.51	20	0.29
Gymnocephalus cernua	523	26.45	311	4.54
Perca fluviatilis	1256	63.53	6171	90.04
Rutilus rutilus	29	1.47	155	2.26
Sander lucioperca	148	7.49	123	1.79
Total	1977	100.00	6854	100.00

Average abundance of Cypriniformes older than YOY did not differ significantly between areas HAI and LAI. Common bream showed a preference for the HAI (*p*-value = *), especially in the benthic areas (Table 3). Pike, wels catfish and rudd were caught only in the LAI areas. The mean abundance of Perciformes showed no preference between LAI or HAI, but perch showed a strong preference for benthic habitat in both areas (*p*-value = ***). Ruffe and pikeperch showed a preference for HAI, and this was also true for all species taken together (total catch, *p*-value = **). When comparing habitat preferences, Cypriniformes (*p*-value = *) and Perciformes (*p*-value = ***) showed a preference for benthic areas (Figure 2, Table 3). Most species showed a clear preference for benthic habitats, opposite preference was found for bleak, rudd and asp.

Table 3. Mean and standard error (SE) of the fish older than young-of-the-year CPUE (catch per unit of effort) of gillnets from Lipno reservoir, in individual units per 1000 m^2 of nets. *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$ and ns = $p \geq 0.05$. Families and total catch are given in bold.

	Benthic		Pelagic			
Species	**HAI**	**LAI**	**HAI**	**LAI**	**p_Treatment**	**p_Habitat**
Abramis brama	54.7 ± 16.4	21.2 ± 3.3	23.6 ± 8.1	11.1 ± 8.1	*	ns
Alburnus alburnus	37.5 ± 19.8	37.5 ± 13.0	541.7 ± 38.4	450.9 ± 86.1	ns	***
Blicca bjoerkna	159.9 ± 33.1	106.1 ± 10.0	23.9 ± 6.8	80.6 ± 16.8	ns	***
Cyprinus carpio	2.4 ± 0.7	2.8 ± 0.7	0.97 ± 0.5	2.1 ± 0.7	***	*
Leuciscus aspius	0.35 ± 0.2	0.23 ± 0.16	2.2 ± 1.8	1.2 ± 0.5	ns	ns
Rutilus rutilus	354.9 ± 41.1	298.2 ± 25.0	95.6 ± 10.5	139.8 ± 33.2	ns	***
Scardinius erythrophthalmus	0	1.4 ± 0.78	0	9.3 ± 2.9	ns	***
Cypriniformes	**609.7 ± 68.2**	**467.4 ± 27.7**	**687.9 ± 44.5**	**694.9 ± 129.2**	**ns**	*
Esox lucius	0	1.39 ± 0.78	0	1.85 ± 1.22	ns	ns
Esociformes	**0**	**1.39 ± 0.78**	**0**	**1.85 ± 1.22**	**ns**	**ns**
Gymnocephalus cernua	997.2 ± 57.1	549.1 ± 56.0	0	0.93 ± 0.93	**	***
Perca fluviatilis	83.3 ± 19.6	198.7 ± 23.3	2.2 ± 1.3	11.1 ± 4.2	***	***
Sander lucioperca	30.6 ± 6.2	22.1 ± 4.2	5 ± 1.8	4.9 ± 2.8	***	***
Perciformes	**1111.1 ± 50.7**	**769.9 ± 60.3**	**7.2 ± 2.1**	**16.9 ± 4.8**	**ns**	***
Silurus glanis	0	0.58 ± 0.47	0	0.46 ± 0.46	ns	ns
Siluriformes	**0**	**0.58 ± 0.47**	**0**	**0.46 ± 0.46**	**ns**	**ns**
Total catch	1720.8 ± 77.3	1239.2 ± 67.8	695.1 ± 45.3	714.1 ± 129.6	**	***

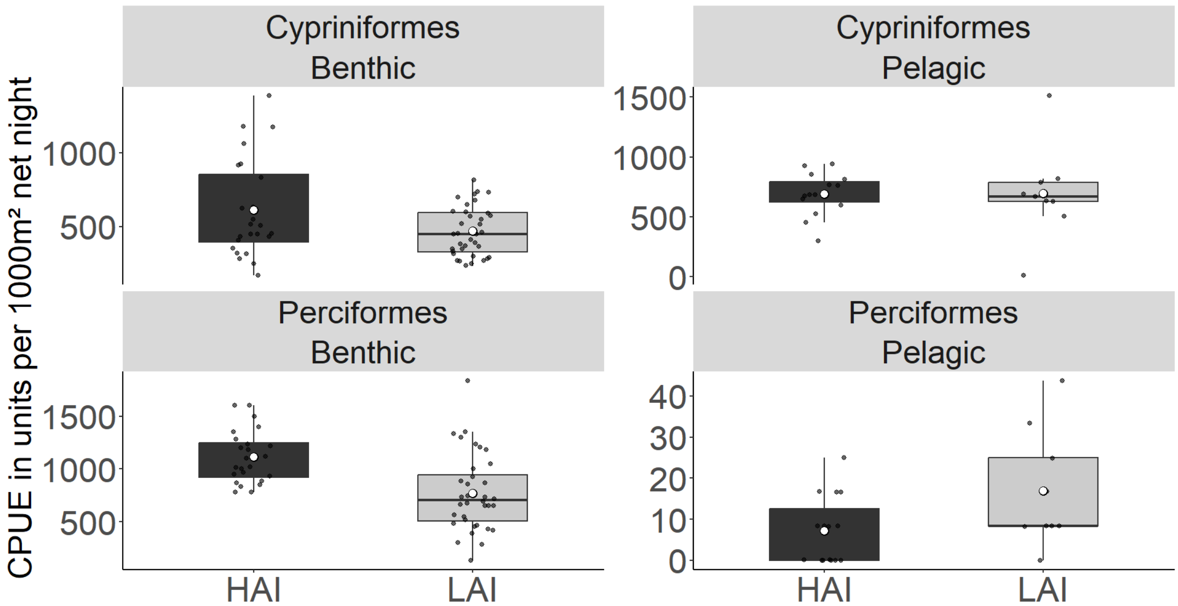

Figure 2. A Total catch-per-unit effort (CPUE; individuals per point) of fish older than young-of-the-year from gillnetting at high-impact sites (HAI) and low-impact (LAI) areas of the Lipno reservoir. The boxplot represents the quartile value of CPUE, the black dots represent the means of individual nets, the thick middle line represents the median, the white dot represents the overall mean of all measurements, and the whiskers represent the lowest and highest actual value of the quartile.

With YOY fish, LAI showed a higher preference for roach, which dominated amongst cyprinids (Table 4). Roach was the most important cyprinid YOY species and thus also caused the overall YOY cyprinid preference for LAI areas (Figure 3). Among percid species, perch was the most abundant, with a strong affinity to LAI areas (p-value = ***). Ruffe (p-value = ***) and pikeperch (not significant) preferred HAI areas. Overall, perch dominated YOY catch, so total percid CPUE (Figure 3) and total catch of YOY (Table 4) was significantly higher in LAI areas (p-value = ***).

Table 4. Mean and standard error (SE) of the young of the year class fish CPUE (catch per unit of effort) of gillnets from Lipno reservoir, in individual units per 1000 m^2 of nets. *** = $p < 0.001$, * = $p < 0.05$ and ns = $p \geq 0.05$.

	Benthic		Pelagic			
Species	**HAI**	**LAI**	**HAI**	**LAI**	**p_Treatment**	**p_Habitat**
Abramis brama	6.94 ± 3.74	2.78 ± 1.94	0	12.96 ± 4.19	ns	ns
Alburnus alburnus	0.69 ± 0.69	0.46 ± 0.46	0	49.07 ± 24.86	ns	ns
Blicca bjoerkna	2.08 ± 1.15	3.24 ± 1.11	3.89 ± 2.68	12.04 ± 5.03	ns	ns
Rutilus rutilus	13.19 ± 6.88	50.46 ± 12.69	5.56 ± 2.25	42.59 ± 16.4	*	ns
Cypriniformes	**22.92 ± 10.17**	**56.94 ± 13.1**	**10 ± 3.47**	**116.67 ± 45.24**	*	**ns**
Gymnocephalus cernua	361.81 ± 42.49	143.52 ± 17.82	1.11 ± 1.11	0.93 ± 0.93	***	***
Perca fluviatilis	862.5 ± 200.61	2829.98 ± 445.8	7.78 ± 3.4	53.7 ± 19.79	***	***
Sander lucioperca	96.53 ± 21.59	56.48 ± 10.14	5 ± 2.27	0.93 ± 0.93	ns	***
Perciformes	**1320.83 ± 222.11**	**3029.98 ± 438.72**	**13.89 ± 4.35**	**55.56 ± 20.65**	***	***
Total catch	**1343.75 ± 228.79**	**3086.92 ± 447.58**	**23.888 ± 6.99**	**172.22 ± 59.56**	***	***

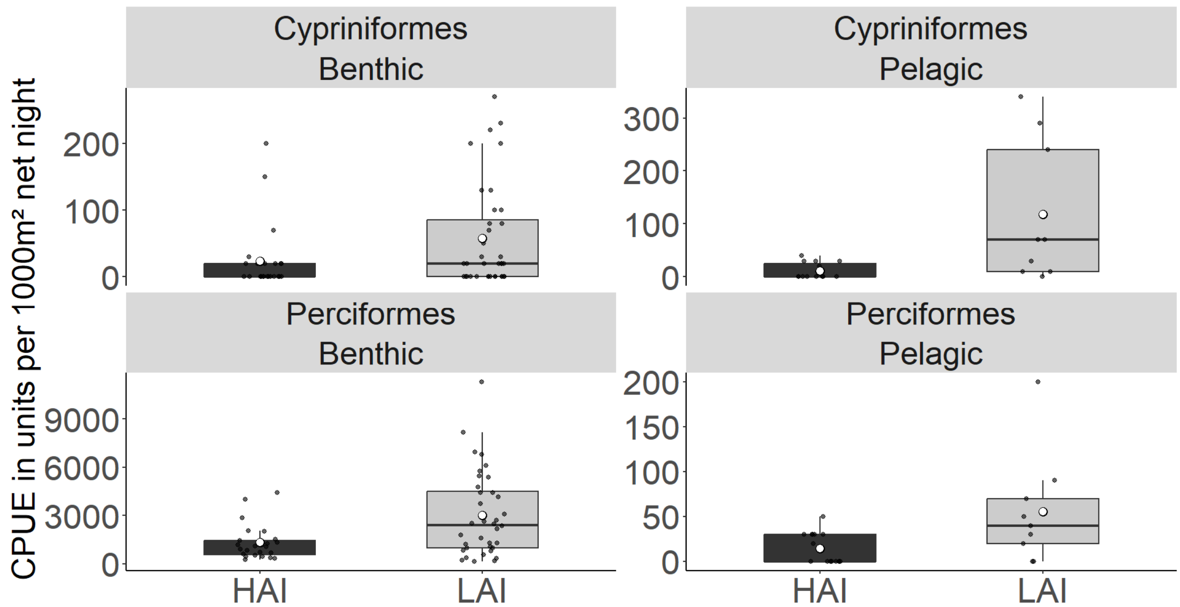

Figure 3. A Total catch-per-unit effort (CPUE; individuals per point) of young-of-the-year fish from gillnetting at high-impact (HAI) sites and low-impact (LAI) areas of the Lipno reservoir. The boxplot represents the quartile value of CPUE, the black dots represent the means of individual nets, the thick middle line represents the median, the white dot represents the overall mean of all measurements, and the whiskers represent the lowest and highest actual value of the quartile.

Biomass of older cyprinids showed no significant differences between LAI and HAI areas. (Table 5). Perciformes (*p*-value = ***) showed a significant preference for the LAI (Figure 4, Table 5), especially due to the strong dominance of perch in benthic habitats (*p*-value = ***). Ruffe showed a trend toward HAI (*p*-value = *), and perch showed a trend towards LAI (*p*-value = ***), both for the benthic area. Esociformes and Siluriformes were represented only in the LAI areas. Total fish biomass was not significantly different between LAI and HAI areas. Habitat preferences of different species are generally similar to CPUE, mainly toward benthic habitats (Figures 2 and 4, Tables 3 and 5).

Table 5. Mean and standard error (SE) of the fish older than YOY BPUE (biomass per unit of effort) of gillnets from Lipno reservoir, in kilograms per 1000 m^2 of nets. *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$ and ns = $p \geq 0.05$.

	Benthic		Pelagic			
Species	**HAI**	**LAI**	**HAI**	**LAI**	**p_Treatment**	**p_Habitat**
Abramis brama	8.51 ± 2.15	6.28 ± 1.07	8.3 ± 3.08	3.86 ± 2.98	ns	ns
Alburnus alburnus	1.02 ± 0.45	0.91 ± 0.3	13.49 ± 1.57	10.47 ± 2.25	ns	***
Blicca bjoerkna	26.28 ± 4.07	20.35 ± 2.06	6.22 ± 1.9	17.75 ± 3.94	ns	***
Cyprinus carpio	4.79 ± 1.31	5.7 ± 1.73	1.86 ± 0.9	4.67 ± 1.37	ns	ns
Leuciscus aspius	0.98 ± 0.69	0.58 ± 0.4	3.28 ± 2.15	2.61 ± 1.09	ns	ns
Rutilus rutilus	37.14 ± 4.4	26.43 ± 2.68	24.02 ± 2.28	36.27 ± 9.31	ns	ns
Scardinius erythrophthalmus	0	0.48 ± 0.3	0	3.7 ± 1.28	ns	ns
Cypriniformes	**78.72 ± 6.88**	**60.13 ± 4.2**	**57.17 ± 7.25**	**79.33 ± 14.36**	**ns**	**ns**
Esox lucius	0	1.24 ± 0.71	0	3.6 ± 2.39	ns	ns
Esociformes	**0**	**1.24 ± 0.71**	**0**	**3.6 ± 2.39**	**ns**	**ns**
Gymnocephalus cernua	8.3 ± 0.51	4.91 ± 0.54	0	0.01 ± 0.01	*	*
Perca fluviatilis	9.27 ± 2.12	29.09 ± 3.4	0.39 ± 0.22	1.82 ± 0.62	***	***
Sander lucioperca	9.12 ± 2.32	11.52 ± 1.93	2.53 ± 0.88	3.44 ± 2.37	ns	**
Perciformes	**26.69 ± 2.88**	**45.51 ± 4.25**	**2.92 ± 0.88**	**5.27 ± 2.4**	***	***
Silurus glanis	0	0.45 ± 0.33	0	1.16 ± 1.16	ns	ns
Siluriformes	**0**	**0.45 ± 0.33**	**0**	**1.16 ± 1.16**	**ns**	**ns**
Total catch	**105.41 ± 6.619**	**107.94 ± 7.05**	**60.087 ± 7.726**	**89.367 ± 14.96**	**ns**	**

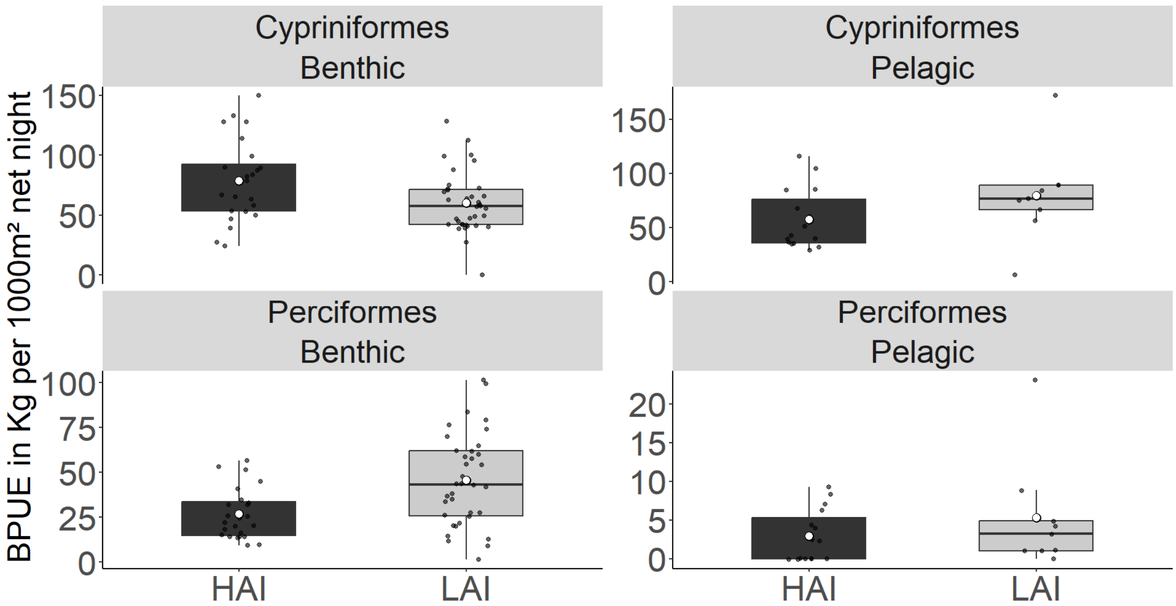

Figure 4. A Total biomass-per-unit effort (BPUE; kg per point) of fish older than YOY from gillnetting at high-impact (HAI) sites and low-impact (LAI) areas of the Lipno reservoir. The boxplot represents the quartile value of BPUE, the black dots represent the means of individual nets, the thick middle line represents the median, the white dot represents the overall mean of all measurements, and the whiskers represent the lowest and highest actual value of the quartile.

YOY BPUE of cyprinid fish was very low and without significant differences between LAI and HAI areas. The same is true for YOY percids with the exception of ruffe with the preference for benthic HAI areas (p-value = **). Habitat preferences of cyprinids YOY were not significant, while percids YOY showed a clear preference for benthic habitats (Table 6, Figure 5).

Table 6. Mean and standard error (SE) of the young of the year class fish BPUE (biomass per unit of effort) of gillnets from Lipno reservoir, in kilograms per 1000 m^2 of nets. *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$ and ns = $p \geq 0.05$.

	Benthic		Pelagic			
Species	**HAI**	**LAI**	**HAI**	**LAI**	**p_Treatment**	**p_Habitat**
Abramis brama	0.03 ± 0.02	0.01 ± 0.01	0	0.04 ± 0.02	ns	ns
Alburnus alburnus	0	0	0	0.11 ± 0.06	ns	ns
Blicca bjoerkna	0.01 ± 0.001	0.01 ± 0.001	0.01 ± 0.01	0.04 ± 0.02	ns	ns
Rutilus rutilus	0.05 ± 0.02	0.18 ± 0.05	0.02 ± 0.01	0.15 ± 0.06	ns	ns
Cypriniformes	**0.08 ± 0.04**	**0.21 ± 0.05**	**0.04 ± 0.01**	**0.35 ± 0.13**	**ns**	**ns**
Gymnocephalus cernua	0.85 ± 0.12	0.3 ± 0.04	0	0	**	ns
Perca fluviatilis	1.17 ± 0.48	1.75 ± 0.3	0.02 ± 0.01	0.11 ± 0.04	ns	***
Sander lucioperca	1.39 ± 0.34	0.96 ± 0.23	0.02 ± 0.01	0	ns	*
Perciformes	**3.4 ± 0.77**	**3.01 ± 0.39**	**0.04 ± 0.01**	**0.11 ± 0.05**	**ns**	***
Total catch	**3.48 ± 0.786**	**3.219 ± 0.4**	**0.077 ± 0.02**	**0.46 ± 0.16**	**ns**	**ns**

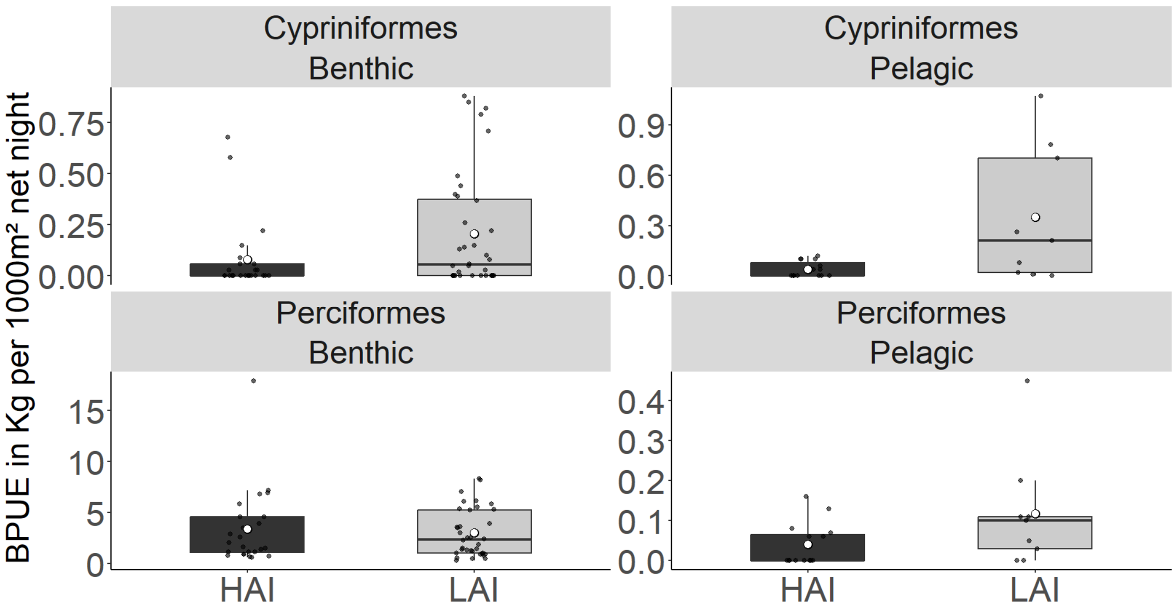

Figure 5. A Total biomass-per-unit effort (BPUE; kg per point) of YOY fish from gillnetting at high-impact (HAI) sites and low-impact (LAI) areas of the Lipno reservoir. The boxplot represents the quartile value of BPUE, the black dots represent the means of individual nets, the thick middle line represents the median, the white dot represents the overall mean of all measurements, and the whiskers represent the lowest and highest actual value of the quartile.

The size spectrum of fishes showed that the peak abundance of larger fishes for most species was found in LAI rather than HAI, mainly in the pelagic habitat (Table 7).

This trend was confirmed for common bream (p-value = **), carp (p-value = ***), ruffe (p-value = **), pikeperch (p-value = ***) and perch (p-value = ***). Pikeperch is probably the most important species highly valued by anglers, and Figure 6 shows how the protection at LAI areas is reflected in the length frequency distribution. The legal size of the pikeperch was 450 mm in total length, which is approximately 395 mm in standard length. It can be seen that individuals of this size and larger are much more common in the areas of LAI. Asp (p-value = ***) and roach (p-value = **) had larger sizes in HAI areas. Of the YOY fish, larger individuals were found in HAI areas for common bream (p-value = ***) and roach (p-value = ***), while larger white bream (p-value = ***) and pikeperch (p-value = ***) were found in LAI areas (Table 8).

Table 7. Mean, standard error (SE), maximum (Max) and minimum (Min) standard length of fish older than YOY, in millimeters, from gillnets of Lipno reservoir. *** = $p < 0.001$, ** = $p < 0.01$, and ns = $p \geq 0.05$. For complete species names, check Table 1 or Table 3.

	Benthic				Pelagic					
	HAI		LAI		HAI		LAI			
Species	**Mean ± SE**	**Max-Min**	**Mean ± SE**	**Max-Min**	**Mean ± SE**	**Max-Min**	**Mean ± SE**	**Max-Min**	**p_Treatment**	**p_Habitat**
A. brama	172.48 ± 8.09	320-69	222.46 ± 11.14	320-85	255.11 ± 6.24	400-170	240.83 ± 16.37	310-105	**	ns
A. alburnus	121.94 ± 2.36	150-75	116.35 ± 2.01	145-75	124.13 ± 0.6	180-70	125.47 ± 0.84	155-70	***	***
B. bjoerkna	160.61 ± 4.37	305-66	173.93 ± 4.31	295-66	204.98 ± 6.83	275-85	194.26 ± 5	320-86	ns	***
C. carpio	399.29 ± 13.3	455-280	413.96 ± 9.39	490-310	403.57 ± 13.39	445-350	423.33 ± 20.16	580-390	***	***
E. lucius	-	-	466.67 ± 24.55	510-425	-	-	585 ± 15	600-570	ns	***
G. cernua	73.62 ± 0.24	113-55	75.17 ± 0.32	130-55	-	-	85	85	**	***
L. aspius	525 ± 30	555-495	505 ± 5	510-500	457.86 ± 38.51	560-315	512 ± 4.06	520-500	***	***
P. fluviatilis	157.82 ± 4.96	310-83	172.53 ± 3.02	320-70	202.5 ± 13.15	240-180	193.33 ± 9.5	255-150	***	***
R. rutilus	155.06 ± 2.08	290-75	145.09 ± 1.91	280-75	221.87 ± 2.45	310-75	221.79 ± 2.78	285-80	**	***
S. lucioperca	241.84 ± 15.53	520-156	305.54 ± 18.52	580-158	326.11 ± 20.98	395-230	380 ± 46.94	525-235	***	***
S. erythrophthalmus	-	-	228.33 ± 18.78	260-195	-	-	243 ± 4.84	275-220	ns	***
S. glanis	-	-	502.5 ± 162.5	665-340	-	-	672.5 ± 47.5	720-625	ns	***

Table 8. Mean, standard error (SE), maximum (Max) and minimum (Min) standard length of the young of the year class fish, in millimeters, from gillnets of Lipno reservoir. *** = $p < 0.001$, * = $p < 0.05$ and ns = $p \geq 0.05$. For complete species names, check Table 2 or Table 4.

	Benthic				Pelagic					
	HAI		LAI		HAI		LAI			
Species	**Mean ± SE**	**Max-Min**	**Mean ± SE**	**Max-Min**	**Mean ± SE**	**Max-Min**	**Mean ± SE**	**Max-Min**	**p_Treatment**	**p_Habitat**
A. brama	55.8 ± 2.32	62-40	54.17 ± 2.34	65 ± 49	-	-	54.07 ± 1.61	63-40	***	***
A. alburnus	56	56	65	65	-	-	56.74 ± 0.56	65-49	ns	ns
B. bjoerkna	55.67 ± 5.9	63-44	58.14 ± 2.01	65-53	53.86 ± 1.39	59-51	54.46 ± 1.57	65-46	***	***
G. cernua	47.64 ± 0.18	55-33	45.88 ± 0.26	55-30	48 ± 2	50-46	43	43	ns	***
P. fluviatilis	52.55 ± 0.22	72-37	48.23 ± 0.12	73-33	52 ± 1.57	60-42	48.52 ± 0.52	56-39	ns	*
R. rutilus	55.53 ± 1.02	65-43	56.38 ± 0.42	66-42	58.4 ± 1.16	64-51	55.76 ± 0.56	65-49	***	***
S. lucioperca	90.88 ± 2.96	155-41	100.58 ± 2.8	155-42	55.78 ± 7.28	95-29	43	43	***	***

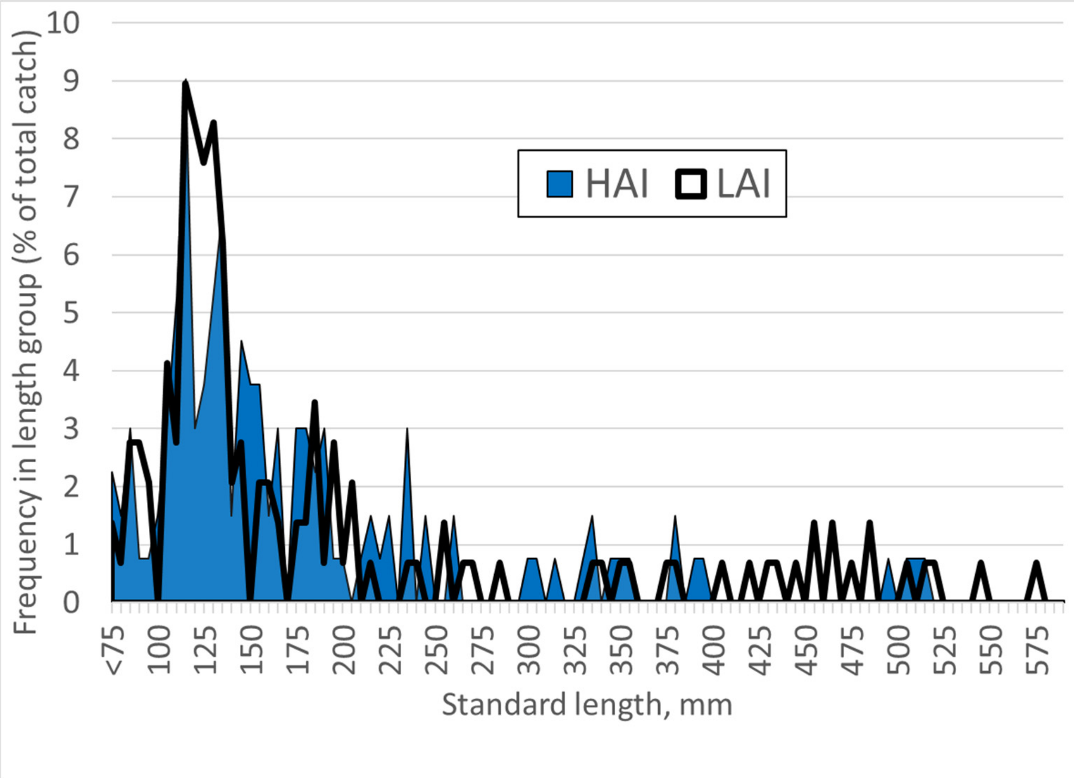

Figure 6. Length frequency distribution of pikeperch at high impact (HAI) and low impact (LAI) areas of the Lipno reservoir.

The values of the Shannon, Simpson, Pielou's and Richness diversity indices showed significantly higher values for the older fish in LAI (p-value = ***) (Figure 7).

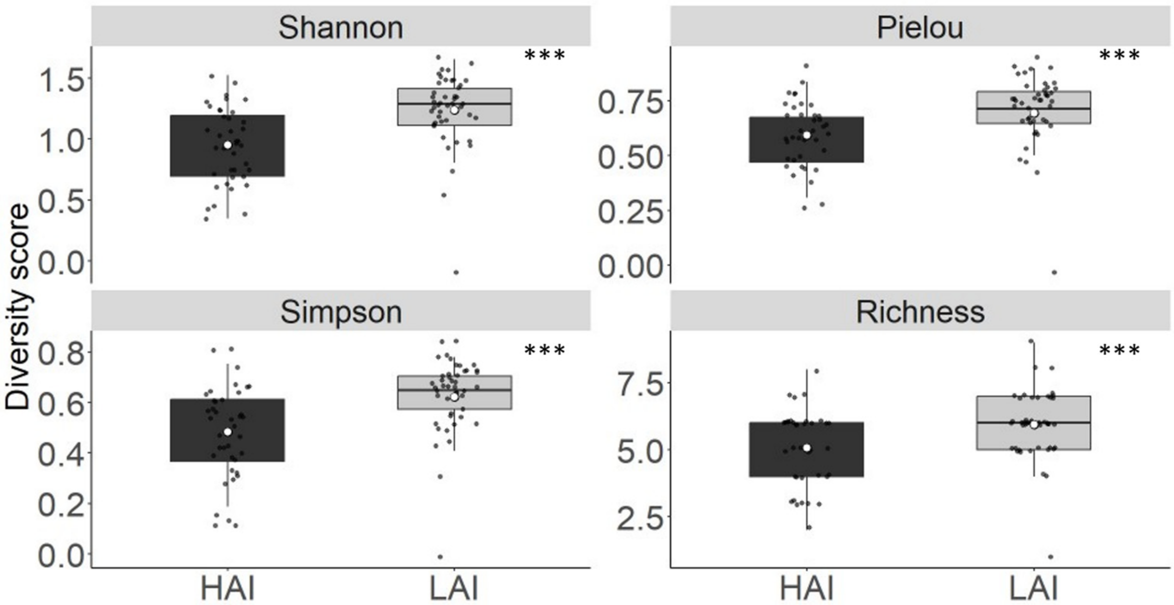

Figure 7. Diversity score of the fish older than YOY in the Lipno experiment from Shannon, Pielou's, Simpson and Richness indices. The boxplot represents the quartile value of the diversity score, the black dots represent the means of individual nets, the thick middle line represents the median, the white dot represents the overall mean of all measurements, and the whiskers represent the lowest and highest actual value of the quartile. *** = $p < 0.001$,.

Differences in the diversity indices of YOY fish were largely nonsignificant, except for species richness, which was higher at LAI (p-value = *) and Simpson for HAI (p-value = ***, Figure 8).

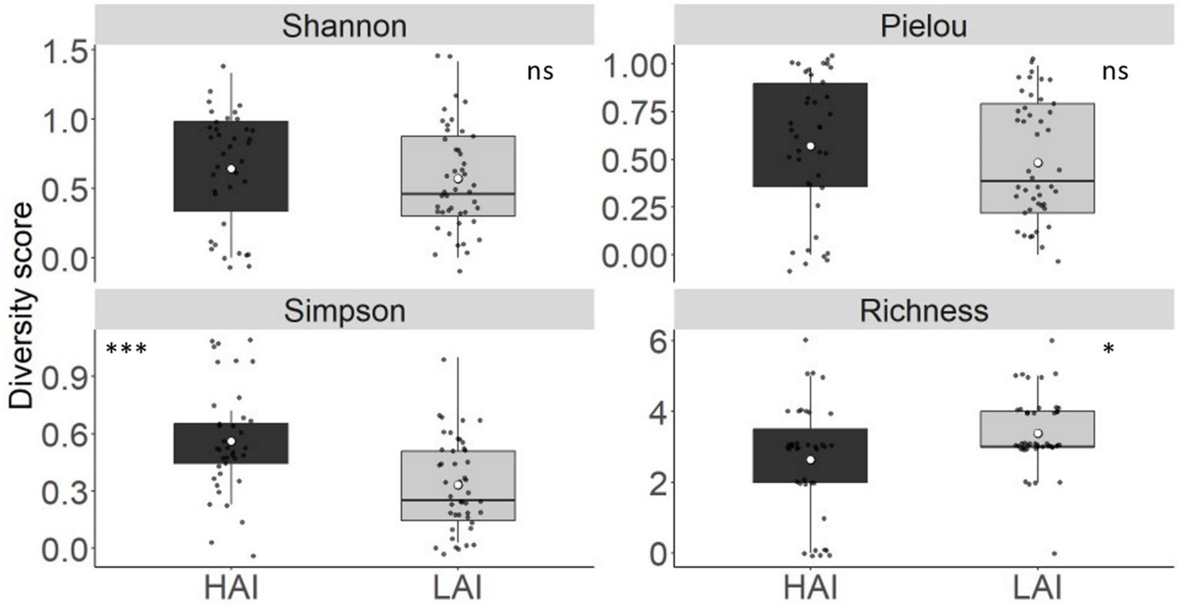

Figure 8. Diversity score of the YOY fish in the Lipno experiment from Shannon, Pielou's, Simpson and Richness indices. The boxplot represents the quartile value of the diversity score, the black dots represent the mean of the individual net, the thick middle line represents the median, the white dot represents the overall mean of all measurements, and the whiskers represent the lowest and highest actual value of the quartile. *** = $p < 0.001$, * = $p < 0.05$ and ns = $p \geq 0.05$.

4. Discussion

The most fished species in Czech reservoirs are carp and predatory fish such as pikeperch and pike [47,48]. Our results showed that the main predatory fish species targeted by the angler's pikeperch, perch, wels catfish and pike, have to some extent either more CPUE/BPUE or larger average size inside the LAI than in the control areas. Pike and wels catfish densities in the HAI areas were so low that no individuals were captured during the current survey. The lower exploitation in the LAI areas allows fish to reach larger sizes or densities, as shown in Figure 6. Smaller percid fish may be more abundant in HAI areas, while larger ones are more abundant in LAI areas. With the exception of pike and wels catfish, there is not much difference in densities, possibly due to fish migration from LAI and limited fishing pressure, including illegal poaching. It is also interesting to note that the two bays on the southwest coast of Lipno had very similar fish compositions, even though only one of them is designated as a no-fishing zone. The results suggest that the remote location of Račinská Bay may also serve as a protection, as it is difficult for anglers to reach.

Protection in the Lipno LAI areas consists mainly of the angling ban and isolation from tourism and local anglers. While in other parts of the reservoir, fishing pressure is quite strong, in these areas, there is theoretically little or no fishing. However, the two areas of LAI are not closed off from the lake so that fish can migrate, but they are large enough (several tens to hundreds of hectares) to develop stronger subpopulations of some species [49–51]. The differences between the LAI and HAI areas' fish communities may also be caused by some inherent differences between the west and east side of the lake, which are not related to anthropogenic pressure. In order to limit recreational fishery as little as possible, all the protected areas were declared at the western shore of the reservoir. However, the differences in predatory species abundance and size structure (Figure 6) show that the life expectancy of these highly valued fish species is much higher in the LAI areas. Recreational angling can be as or even more impactful than commercial fishery in different environments and habitats, even though commercial fishery is completely banned in Czech reservoirs [52–54].

Total fish densities were actually lower in LAI. Some fish are highly attracted to feeding anglers at their favorite sites; this tactic is quite effective for cyprinids such as carp and roach [55–57], so anglers attract these cyprinid fishes to HAI areas that are more frequented by anglers. HAI areas also receive more nutrients and are likely to be more productive. It was interesting to observe that rudd were more abundant in LAI areas. This species, which is not common in reservoirs, seems to prefer sheltered bays. In the late stages of its life, it changes to a more herbivorous diet [58]. In Czech reservoirs, it is considered an indicator of the presence of macrophytes and good ecological potential [59], and it is more abundant in bays protected from prevailing westerly winds [40].

Protected areas are essential for biodiversity conservation and are essentially the cornerstones of all national and international conservation strategies [17,60,61] that aim to maintain functioning natural ecosystems, act as refugia for species, and preserve ecological processes in all types of environments [10,62]. Intact freshwater systems are becoming increasingly rare worldwide and require administrative, ecological, and social action before they fall victim to a range of threats to maintain their natural state or unique biodiversity [13,63]. Protected areas are often the most important measure we have to save many threatened or endemic species from extinction [10,15,64].

Due to the global decline in freshwater biodiversity [3], the literature on PA has mainly focused on the diversity benefits of PA [65]. Freshwater fish have received the most attention in the analysis of the effectiveness and success of PA, although there is some evidence that aquatic invertebrates and freshwater-dependent mammals are also underrepresented in existing PA networks [66–68]. For a PA to be truly successful, all elements should be included in the management strategy, such as water flow, water quality, surrounding vegetation, and control of potential invasion by alien species [65]. Considering the ecosystem as a whole brings the next level of PA, as it focuses more on restoring the entire environment as close as possible to its original state and helping the entire species community to recover [8]. LAI areas in Lipno are more exposed to mammalian predators, such as otters (*Lutra lutra*) and avians (heron, *Ardea cinerea*, sea eagle, *Haliaeetus albicilla*, cormorant, *Phalacrocorax carbo*). Increased predation and low nutrient and fish bait input likely negatively affect fish abundance and biomass in LAI areas.

Fish migration is one of the most controversial drawbacks of PA [28,69,70]. Because the PA of Lipno is a bay open to the rest of the reservoir, migration to new habitats or new food sources may cause populations to leave the PA [69,70]. Larval dispersal from the PA may also be included in this equation, with juvenile perch, and YOY pikeperch being more abundant outside of the LAI areas. As our results indicate, perch are one of the most abundant fish in the PA, and their population may exert pressure on the YOY and juveniles to seek habitat and refuge outside the protected area [71–74].

The European standard gillnets have proven effective in the sampling of the study areas. Of course, it should be noted that the CEN gillnets underestimate the YOY fish, especially the cyprinids of some small-bodied fish species [75]. However, this bias should affect the results of LAI and HAI in the same way. The same is true for some other selectivity characteristics of the gillnets. The fish community in Lipno reservoir is monitored by several other methods (fry seining, fry trawling, electrofishing and hydroacoustics [24]). However, none of these methods revealed any important species that were not recorded in the gillnet catches. In other words, the CEN multimers gillnets performed very reasonably in assessing the fish community in the LAI and HAI areas. The loss or destruction of nets and habitat complexity created by submerged trees in some areas was another complication encountered, especially at LAI. The beneficial effects of the LAI areas may be underestimated or overestimated in this study because fish migrate between the LAI areas and the HAI areas. For some fish species, the home range may be larger than the actual LAI areas, and they spend only part of the diurnal cycle in the area [32]. One solution to this type of problem is to use telemetry to monitor movement behavior and obtain a more accurate estimate of home range for the community in the LAI areas.

5. Conclusions

Our study represents an attempt to assess the impact of protected areas in the largest water body in the Czech Republic, the Lipno reservoir, on fish abundance, biomass, and species composition. Three groups of fish were found to prefer protected areas with low anthropogenic pressures:

1. YOY perch, as the superdominant of the young-of-the-year fish community.
2. Pike, wels catfish and rudd, which were not found at high anthropogenic impact areas during this survey.
3. Larger individuals of pikeperch, which apparently survive better in low anthropogenic impact areas.

The latter two groups benefit from protection from angling, which is otherwise a fairly strong mortality factor in the reservoir. The abundance of all fish older than YOY was higher in the high anthropogenic impact areas, likely due to higher nutrient inputs and extensive use of fish bait. The fish community in the protected areas had greater values of estimated diversity indices due to both the promotion and protection of less common species (pike, perch, rudd) and limited attractiveness to superdominant cyprinids. It can be concluded that the areas of LAI serve as protective habitats for heavily fished species and increase the diversity of the fish community in the reservoir. The example of the protected and low impact areas of Lipno should be followed in other water bodies with high fishing pressure and anthropogenic impact.

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