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Ecological Potential of Freshwater Dam Reservoirs Based on Fish Index, First Evaluation in Poland

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Abstract: A pilot ichthyological index was developed for use within the Water Framework Directive in the area of Central and Eastern Europe for dam reservoirs, which are heavily modified water bodies. This is the first approach to assessing this water body type based on ichthyofauna in Poland. Various fishing gear types were used. The tested dam reservoirs were scattered throughout the country, from lowland to mountainous areas, with very diverse hydrological and morphological characteristics and pressure ranges based on the TSI index. In preliminary work, a correlation matrix with the TSI index's pressure indicator was tested based on the abundance or biomass of fish species, fish families present, fishing gear used, and fishing depth range for a total of 588 cases. As a result of the tests carried out, the preliminary indicator was based on the ratio of the number of the two families Cyprinidae and Percidae. The correlation between the developed indicator and the pressure index was strong (r = 0.77; $p < 0.001$). The Percidae family exhibited a strong correlation with the most connections in the matrix. Based on the obtained results, the principle of using already confirmed relationships, such as the ratio between Cyprinidae and Percidae fish families, in the assessment of eutrophication was confirmed to be effective, guaranteeing the effective initial assessment of ecological potential.

Keywords: water quality; eutrophication; artificial lakes

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1. Introduction

According to the main guidelines of the Water Framework Directive (WFD), the main problem for all types of surface waters is the high level of eutrophication [1]. The defined risk caused by this phenomenon is the increasing concentration of nitrogen and phosphorus compounds in water and, as a result, (1) an increase in plant biomass, (2) changes in the species structure of each group of organisms, and (3) changes in the habitats of each group of organisms [1].

According to the WFD guidelines, ichthyofauna is one of the biological elements on the basis of which the level of eutrophication in surface waters is determined. The status of the ichthyofauna corresponds to the defined range of eutrophication. Dam reservoirs are classified as heavily modified water bodies according to the four states of ecological potential: (1) good and higher, (2) moderate, (3) poor, and (4) bad [2,3].

Biotic index indicators, recommended for studying the level of eutrophication in surface water, assess the environment on the basis of the typical taxonomic composition and the sensitivity of individual species in a given group to its elements [4]. The relationship between environmental deterioration in inland waters and changes in the species structure of freshwater ichthyofauna was established as early as the 1970s [5,6]. Moreover, in the 1980s, ichthyofauna became a good biotic indicator for assessing the level and direction of eutrophication [7], and the first index of biotic integrity (IBI), which is still in operation in many forms today, was created during this process.

The ichthyological indicators used to assess the environment are currently in widespread use, but the most developed and evaluated indicators over the years come from inland waters [8,9]. The most popular indicators in inland waters that are currently used in many parts of the world are as follows:

- The IBI (Index of Biotic Integrity) [7]—based on the abundance of different species and groups of fish classified as sensitive to ecosystem conditions;
- The RFAI (Reservoir Fish Assemblage Index) [10]—an extension of the IBI indicator for reservoirs;
- The FBI (fish-based index) [11]—developed for the European Water Framework Directive and based mainly on trophic fish groups for reservoirs;
- The EFI (European Fish Index) [12,13]—developed for the European Water Framework Directive; a fish-based multimetric index for the assessment of the ecological status of running waters;
- The FAII (fish assemblage integrity index) [14]—based on the fish species and classes expected to be present in fish habitat segments for rivers.

Various approaches to assessing the state of the environment based on ichthyofauna return rich data and have been described in at least several hundred peer-reviewed scientific journals; according [9], 450 works on these approaches have been published since 1981, 56% (253) of which involved inland waters. However, for dam reservoirs themselves, compared to those of other inland natural reservoirs, there are currently few developed and tested methods for assessing the environment in terms of ichthyofauna for the purpose of the WFD [15]. Additionally, there is no long-term database of standardized ichthyofauna research data (e.g., 17 reservoirs located in neighboring countries, Czech Republic), such as for natural lakes or rivers [15–17], which makes it difficult to track changes in the structure of ichthyofauna over the years. The results from Poland presented here come from a pilot project and constitute the beginning of a series of data about this type of water body. However, long-term data from inland natural reservoirs are a very strong basis for assessing the ecological potential of dam reservoirs according to the WFD guidelines [15]. For this purpose, it is recommended that the assumptions developed for lakes be applied to the fish-based index (FBI), specified by [18] based on a case study of 445 lakes. Following [18], for dam reservoirs, the main factor/index/pressure parameter causing changes in the structure of ichthyofauna in lakes and causing eutrophication was total phosphorus (TP), meaning the total phosphorus content dissolved in the water (μgL^{-1}). The TP is commonly used for this purpose [9]; however, other available data related not only to the degree of chemicalization of water but also to the level of eutrophication, such as the anthropogenization of the coastal zone and the immediate vicinity or the degree of transformation of the reservoir itself [19], are also used.

The characteristic structure of ichthyofauna in ecological potential classes should be selected based on WFD recommendations and using appropriate statistical tools [20,21]. The result of this work should be the classification of the highest qualitative and quantitative state of ichthyofauna, characterized by reference conditions defining the:

- Undisturbed quality structure of fish;
- Undisturbed quantitative structure of fish;
- Presence of all the fish species sensitive to trophic changes;
- Fish age structure reflecting minor anthropogenic impacts and the ability to maintain all fish populations in good condition [2,7,21].

The tools for this purpose, cited in the main guide to WFD monitoring [2] and based on [21], are as follows:

- The multidimensional classification of formed fish communities using principal component analysis of biomass and abundance data (for example, using principal component analysis (PCA) or multidimensional scaling (MDS));
- The classification of variability in the fish occurrence in different age classes;
- Correlation analysis for CPUE (catch per unit effort) was performed for the total biomass, the total abundance, and the same variants for different species separately between the selected pressure indicators [21].

There is no specific formula for the indicator, and it can take any form. After its selection, in accordance with the WFD requirements [2,3], the occurring values must be scaled with the reference state. Its status must be consistent with the ichthyofaunal typology of the reference reservoir, which has the recognized highest ecological potential. The main purpose of this procedure is to determine the ecological quality ratio (EQR). The ecological quality ratio expresses the degree to which the values of biological parameters observed in a given water body deviate from the values of these parameters expected in the reference state. This value is the basis for determining the classes of ecological potential.

The aim of this study was to develop a pilot ichthyological indicator to assess the ecological potential of dam reservoirs throughout Poland as well as of other strongly modified water bodies. The specific goals are as follows:

- Determination of the typical ichthyofauna composition of dam reservoirs in Poland and a detailed comparison of the studied reservoirs;
- Determination of the state of taxonomic biodiversity of the ichthyofauna of the studied dam reservoirs;
- The testing of various fishing gear for use in dam reservoirs under local conditions;
- The selection of fish species and communities correlated with the pressure indicator;
- Preliminary scaling of the developed indicator to the state of ecological potential.

2. Materials and Methods

2.1. Area of Research

Research was carried out in 11 dam reservoirs located in Poland (Figure 1).

Dam reservoirs on various rivers were selected, with varying hydromorphological parameters such as surface area and depth (Tables 1 and 2). The main factor in the selection of reservoirs was their expertly predicted overall varying ecological status based on the TSI index [22], determined by data from State Environmental Monitoring (Figure 2). The primary indicators used in the TSI index are total phosphorus, secchi disk transparency, and chlorophyll-a.

Table 1. Research site general information.

n.	Dam Reservoir Name	Construction Year	River	River km	Distance from Source [km]	River Basin
1.	Pierzchały	1936	Pasłęka	25.5	150	Bałtyk
2.	Czorsztyn	1997	Dunajec	173.3	50	Wisła
3.	Dobczyce	1986	Raba	60.1	60	Wisła
4.	Żur	1929	Wda	34.3	160	Wisła
5.	Jezioro Kowalskie	1985	Główna	15.4	40	Odra
6.	Koszyce II	1936	Ruda	28.7	10	Odra
7.	Sulejów	1974	Pilica	137.1	182	Wisła
8.	Nielisz	2008	Wieprz	236.2	67	Wisła
9.	Pilchowice	1912	Bóbr	196.7	75	Odra
10.	Niedów	1962	Witka	2.8	49	Odra
11.	Dobromierz	1986	Strzegomka	58.2	21	Odra

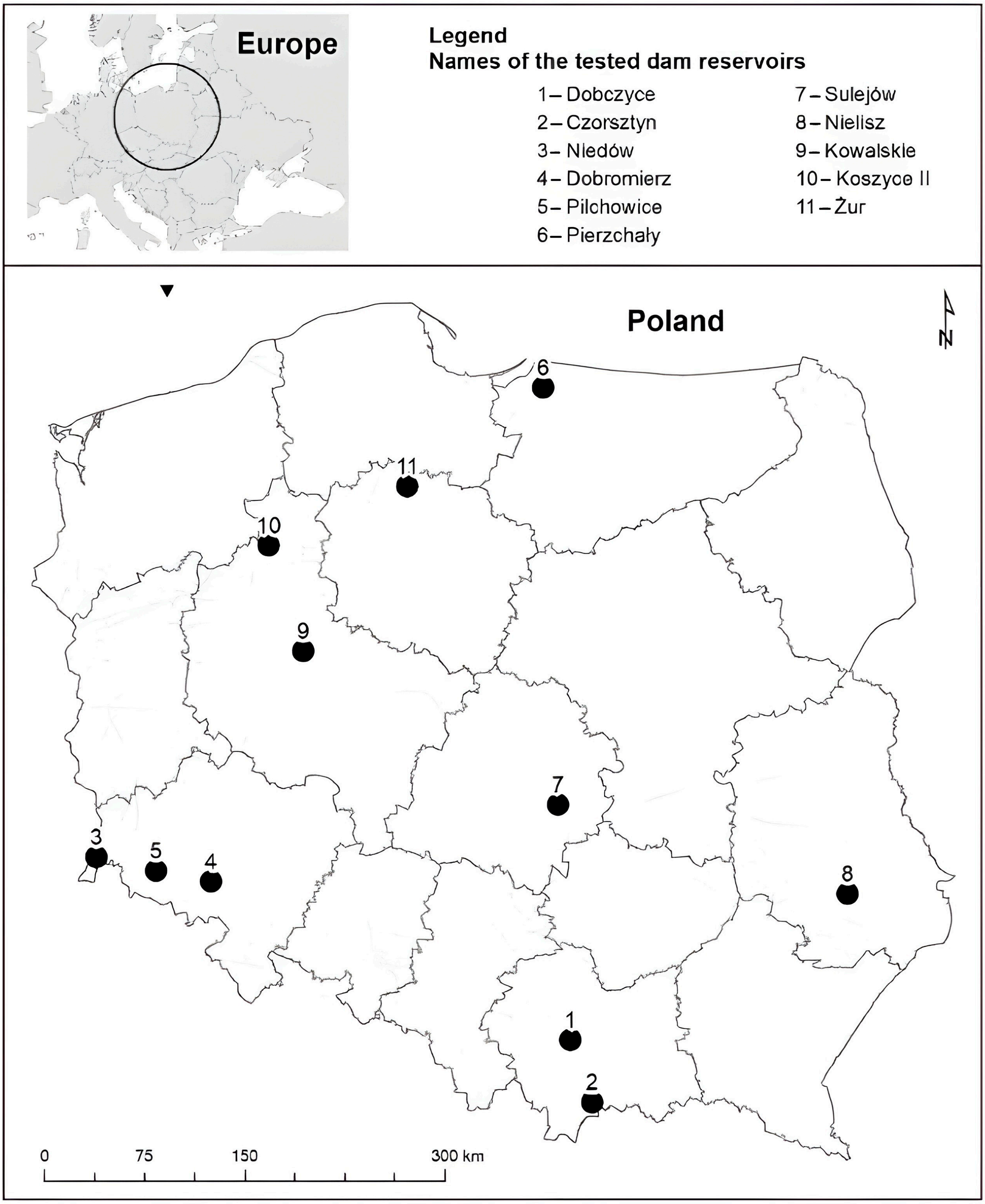


Figure 1. Research site locations on 11 specific dam reservoirs in Central and Eastern Europe.

Table 2. Morphometric and hydrological data for the research sites.

N.	Dam Reservoir Name	Water Table Height [m above Sea Level]	Reservoir Area [ha]	Catchment Area [km^2]	Capacity [Thousands m^3]	Maximum Depth [m]	TSI Index
1.	Pierzchały	20	194	2100	7500	10.0	65.76
2.	Czorsztyn	532.3	1159	1147	231,900	49.1	50.08
3.	Dobczyce	268.5	1090	768	137,720	30.0	46.79
4.	Żur	67.9	222	1825.2	14,900	13.9	77.56
5.	Jezioro Kowalskie	87	192	200	5967	5.5	69.99
6.	Koszyce II	60.6	46	n.a.	650	3.3	73.20
7.	Sulejów	166	1980	4900	84,220	10.8	65.87
8.	Nielisz	197.5	992	1236.2	28,471	5.5	66.98
9.	Pilchowice	288.7	240	1209	50,000	30.8	63.84
10.	Niedów	210	145	303	5178	11.0	61.03
11.	Dobromierz	298.5	113	80	11,350	19.2	61.96

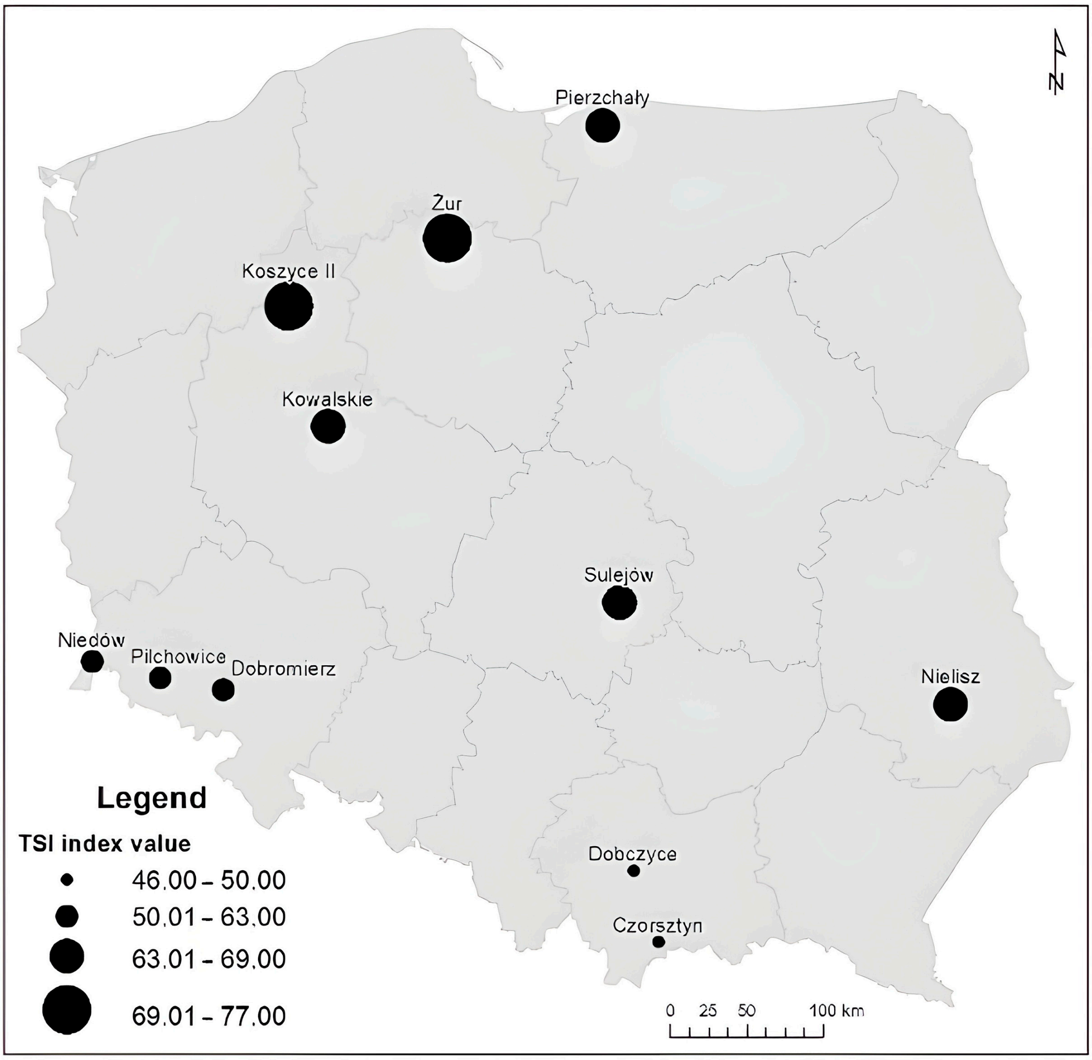


Figure 2. Pressure indicator values based on the TSI index [22] for 11 specific dam reservoirs.

In the dam reservoir selection, the focus was also on including a potential reference reservoir (Dobczyce) in the research to calculate the ecological quality ratio (EQR). This reservoir was chosen because it has the lowest TSI index among the dam reservoirs studied in Poland. This reservoir also provides drinking water for a large urban agglomeration.

2.2. Fishing Effort and Technique

Research fishing was conducted from 2019–2021, and research campaigns were conducted during the summer season from August to September. The fishing effort was conducted in accordance with the matrix in Table 3, based on a modified matrix for lakes from norm EN 14757 [23]. The modification consisted solely of reducing the amount of fishing gear deployed due to agreements with the Chief Inspectorate of Environmental Protection in Poland and to increasing protests from the public and the fishery sector based on observed fish mortality in the scientific research process.

Table 3. The matrix of fishing effort, which depends on the area and depth of the dam reservoir, indicates the effort of the individual site.

Catchment Area [km^2]	**Depth Range [m]**	**Maximum Depth [m]**					
		<6	**6–12**	**12–19.9**	**20–34.9**	**35–49.5**	**>50**
		Number of Multipanel Bottom Gillnet Sets/NORDIC (EN 14757)					
<250	<3	4	4	4	3	3	3
	3–5.9	4	4	4	3	3	3
	6–11.9		3	3	4	4	3
	12–19.9			3	3	2	3
	20–34.9				3	2	2
	35–49.5					2	2
	>50						2
	total	8	11	14	16	16	18
	Studied reservoir	Koszyce Kowalskie	Pierzchały Niedów	Żur Dobromierz	-	Pilchowice	-
251–1000	<3	6	6	5	5	5	5
	3–5.9	6	6	5	5	5	5
	6–11.9		4	4	4	5	5
	12–19.9			4	4	4	4
	20–34.9				3	3	3
	35–49.5					2	2
	>50						3
	total	12	16	18	21	24	27
	Studied reservoir	Nielisz	-	-	-	-	-
>1000	<3	6	6	6	5	5	5
	3–5.9	6	6	6	5	5	5
	6–11.9		6	5	6	6	5
	12–19.9			5	6	4	5
	20–34.9				6	5	4
	35–49.5					3	4
	>50						2
	total	12	18	22	28	28	30
	Studied reservoir	-	Sulejów	-	Dobczyce	Czorsztyn	-

Table 3. *Cont.*

Catchment Area [km^2]	**Depth Range [m]**	**Maximum Depth [m]**					
		<6	**6–12**	**12–19.9**	**20–34.9**	**35–49.5**	**>50**
		Number of Multipanel Bottom Gillnet Sets/NORDIC (EN 14757)					
		Number of pelagic multipanel gillnets sets (EN 14757)					
All reservoirs	<6	0	1	1	1	1	1
	6–11.9			1	1	1	1
	12–19.9				1	1	1
	20–34.9					1	1
	35–49.5						1
	>50						0
	total	0	1	2	3	4	5
	Studied reservoir	Koszyce Kowalskie Nielisz	Pierzchały Niedów Sulejów	Żur Dobromierz	Dobczyce	Czorsztyn Pilchowice	-

Fishing was carried out using 3 types of gear: a bottom gillnet (1); a pelagic gillnet (2) from the EN 14757 standard; and a gillnet with larger mesh dimensions (3) with mesh sizes of 70, 90, 110, and 135 mm (knot to knot, 10 m panels). This gear selection was based on research by [24], who to verified the validity of its use in the local conditions of Polish dam reservoirs. The fishing gear was placed randomly at selected depth ranges according to the matrix; however, for each part of the reservoir, upper, middle, and dam locations were selected.

2.3. Physical and Chemical Parameters

Before carrying out the fishing research, measurements of oxygenation, temperature, and water transparency parameters were taken in the water column, at the dam, and at various depth ranges at which the research gillnets were placed in accordance with the matrix, taking into account the deepest, intermediate, and shallowest zones of the reservoir. Measurements at each station where the gillnets were placed were made with a calibrated CTD SAIV probe (Model SD204) and a Sechcci disk. The depth of visibility of the Sechcci disc was averaged over all measurements, while oxygenation and temperature were presented for all of the results without averaging the values. In addition, a gradient was used for significantly unfavorable values for freshwater fish for oxygen content below the range of 2–3 mg/l [25,26] using the package 'ggplot2' version 3.4.2 from R version 4.3.1—"Beagle Scouts".

2.4. Characterizing and Comparing Fish Communities

Dam reservoirs throughout the country have very different morphological and hydrological parameters, which is one of the most significant problems in unifying their assessment. Therefore, a detailed comparison of their fish communities was performed.

The catch unit (CPUE) was assumed to be the relative number of individual fish taxa in a given fishing effort for each researched reservoir, and can be written as:

$$\mathrm{CPUE}_{\mathrm{N}\ or\ \mathrm{B}} = \mathrm{n}_{\mathrm{taxa}} \text{ or } \mathrm{b}_{\mathrm{taxa}} \cdot 12\mathrm{h}^{-1} \cdot \mathrm{S}^{-1} \quad (1)$$

where:

- n_{taxa} or b_{taxa}—the number or mass of individuals within a species, YOY (young of the year) fish are excluded based on [27,28];
- 12—~12 h of fishing gear exposure;
- S—one gill net.

To compare and characterize fish assemblages occurring in dams, three methods were used for cross-validation of the results: (1) nonmetric multidimensional scaling (NMDS) [29] and (2) Bray-Curtis dissimilarity cluster analysis based on a community table using a heatmap where abundances were coded by color [30], and (3) differences between groups and dispersion within groups were determined using ANOSIM [31,32]. All cases were analyzed for two variants, both for abundance and biomass. The Rényi diversity index was used to determine biodiversity [33,34]. All the comparative analyses were performed using the Community Ecology Package 'vegan' version 2.6-4 with R version 4.3.1—"Beagle Scouts".

2.5. Determination of the Correlation between the Composition of Ichthyofauna and the Selected Pressure TSI Index

To determine the correlation between the composition of the ichthyofauna and the selected pressure indicator, the r-Pearson correlation coefficient [35] was used for the selected correlations—the occurrence of all the fish species and the two families Cyprinidae and Percidae—along with the pressure indicator TSI index [22]. The Cyprinidae and Percidae families of fish have been tested successfully in many studies over the years for demonstrations of water eutrophication [5–8,18]. Correlation analyses were performed for each catch result obtained without using aggregation or averaging, treating a single net as a sample for each concatenated number and weight of species. Catch data were log10-transformed as described in the study by [27]. For statistical significance of the results, one-way analysis of variance was performed using the package 'vegan' version 2.6-4, and visualization was performed using the package 'ggplot2' version 3.4.2 and 'ggpubr' version 0.6.0, with R version 4.3.1—"Beagle Scouts".

Tests were performed for variants of the factor combination matrix (FCM):

- Species-abundance~TSI-index (all-net type (1), type (2), type (3));
- Species-biomass~TSI-index (all-net type (1), type (2), type (3));
- Species-abundance~TSI-index (bottom nets—type (1));
- Species-biomass~TSI-index (bottom nets—type (1));
- Species-abundance~depth range~TSI-index (bottom nets—type (1));
- Species-biomass~depth range~TSI-index (bottom nets—type (1));
- Family (Cyprinidae and Percidae)—abundance~TSI index (all-net type (1), type (2), type (3));
- Family (Cyprinidae and Percidae)—biomass~TSI index (all-net type (1), type (2), type (3));
- Family (Cyprinidae and Percidae)—abundance~TSI index (bottom nets—type (1));
- Family (Cyprinidae and Percidae)—abundance~depth range~TSI index (bottom nets—type (1));
- Family (Cyprinidae and Percidae)—biomass~depth range~TSI index (bottom nets—type (1));

The method assumes that, after carrying out the basic layout with FCM, possible connections of selected factors will be made. The threshold value of test probability taken into account for further analyses was $p > 0.1$.

The r-Pearson correlation scale was used: <0.19, very weak; 0.20–0.39, weak; 0.40–0.59, moderate; 0.60–0.79, strong; 0.80–0.99, very strong; and 1, perfect. For the development of the index, the two strongest correlations were selected as factors, one in the negative direction and the other in the positive direction. Therefore, the principle was adopted that the indicator should not be based on only one direction of impact. Such an application is based on the first observed and, for years, confirmed correlations between eutrophication increase and changes in the structure of ichthyofauna, where some species respond by increasing their abundance and biomass with an increase in eutrophication, while others reduce it to provide, together, a fuller state condition of the environment [8,18,36]. A standard scale of statistical significance was used: $p > 0.1$, no evidence against the null hypothesis;

$0.5 < p < 0.1$, weak; $0.01 < p < 0.05$, moderate; $0.05 < p < 0.001$, good; $0.001 < p < 0.01$, strong; and $p < 0.001$, very strong.

The construction and selection of indicator elements is included in the results section of the article due to the application of results from correlation analyses.

3. Results

3.1. Characterization of the Physical and Chemical Parameters of the Studied Reservoirs

The average Secchi disc depth, in accordance with the predicted phenomena, increased with a decreasing Carlson's TSI pressure index, which is a subparameter. The reference Dobczyce Reservoir, together with the Czorsztyn Reservoir, differed significantly from the other dam reservoirs, for which the disc visibility was 2.7 m (Table 4). Oxygen concentrations ranging from 12 to 6 mg/L were observed in most of the tested reservoirs up to a depth of 6 m (Figure 3). All the shallow reservoirs, Koszyce, Kowalskie, Niedów, Nielisz, Pierzchały, and Sulejów, had very good oxygen conditions across their entire surface and in their depth profile. Extremely anaerobic conditions were not observed; however, there were low dissolved oxygen levels in the water of some reservoirs, with values below the range of 2 to 3 mg/L, especially in reservoirs with greater depth, but only in some of their parts, such as bays away from the dam at depths above 10 m. However, at the dam, these values were always above this range.

Table 4. Average Secchi disc depth based on all measuring points where the nets were deployed.

Number	Reservoir	Secchi Disc Depth [m]
1.	Dobczyce	2.7
2.	Czorsztyn	2.7
3.	Niedów	0.71
4.	Dobromierz	0.84
5.	Pilchowice	0.7
6.	Pierzchały	0.9
7.	Sulejów	0.9
8.	Nielisz	0.68
9.	Kowalskie	0.5
10.	Koszyce II	0.4
11.	Żur	0.4

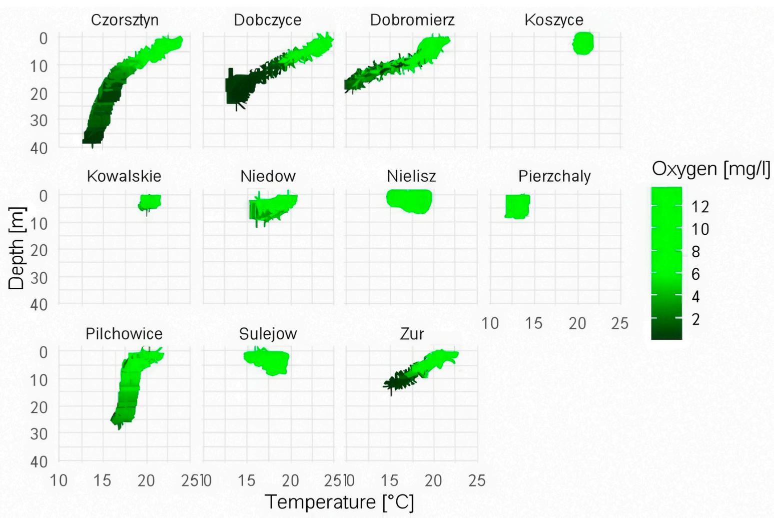
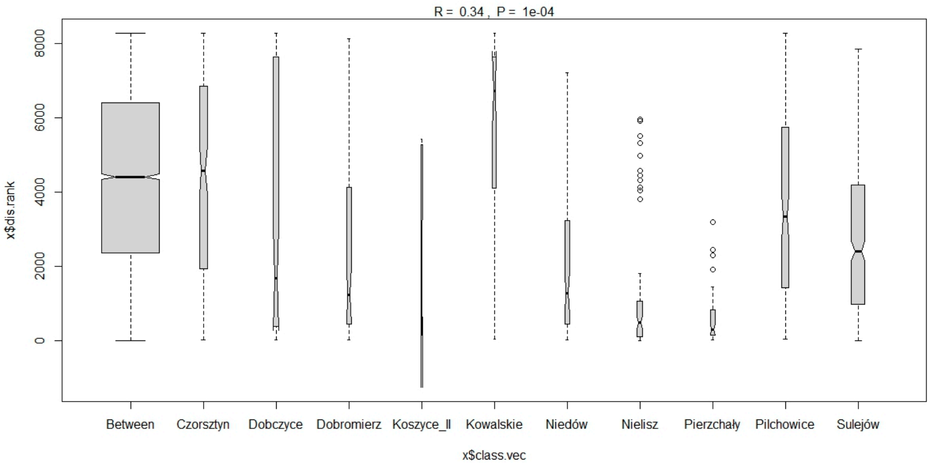


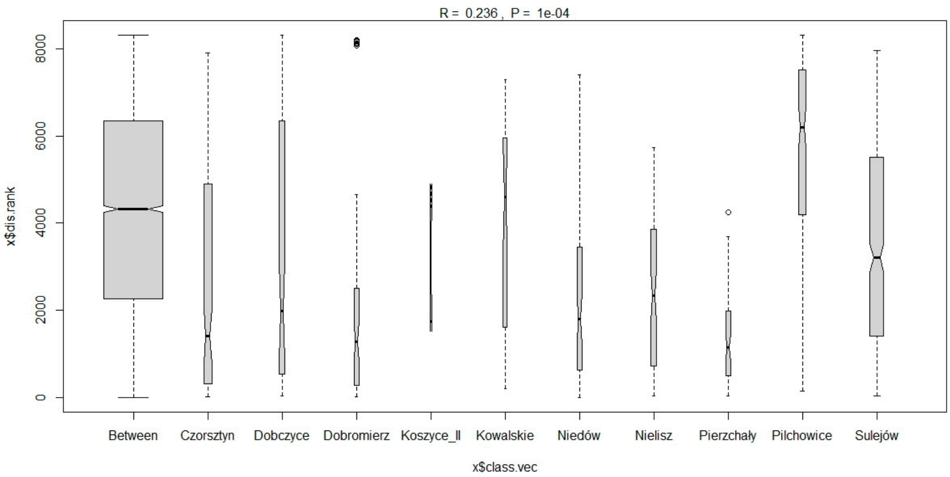
Figure 3. Variability patterns of temperature (°C) and dissolved oxygen in the water column [mg/L] at a given depth for the 11 reservoirs with a limit value gradient of 2 mg/L are shown, where the green color is above this value and the dark color is below it.

3.2. Characteristics of Ichthyofaunal Communities in the Studied Reservoirs

The ANOSIM plot revealed slight dissimilarities between ichthyofaunal communities in the reservoirs (Figure 4). There was a greater difference based on abundance (r = 0.34) than on biomass (r = 0.24); however, the difference was influenced only by nonsignificant set elements. Nonmetric multidimensional scaling (NMDS) was also performed for both A, abundance, and B, biomass (Figure 5) and it was found that the fish communities are similar despite the different physical parameters of the reservoirs. It is worth noting that the Nielisz Reservoir sets itself apart (Figure 6A,B), mainly on the basis of the following species: ide (*Leuciscus idus*), crucian carp (*Carassius carassius*), prussian carp (*Carassius gibelio*), and catfish (*Silurus glanis*). The common species that were responsible for the greatest similarities between the reservoirs were the following: roach (*Rutilus rutilus*), rudd (*Scardinius erythrophthalmus*), ruffe (*Gymnocephalus cernua*), bleak (*Alburnus alburnus*), and european perch (*Perca fluviatilis*) (Figure 6A). In terms of biomass, the species responsible for the greatest similarities were: ruffe (*G. cernua*), pike-perch (*Sander lucioperca*), roach (*R. rutilus*), bream (*Abramis brama*), white bream (*Blicca bjoerkna*), and bleak (*A. alburnus*) (Figure 6B). The Rényi diversity index showed that Sulejów was the most diverse in terms of fish numbers, and that the Dobczyce reference reservoir was the least diverse (Figure 7).

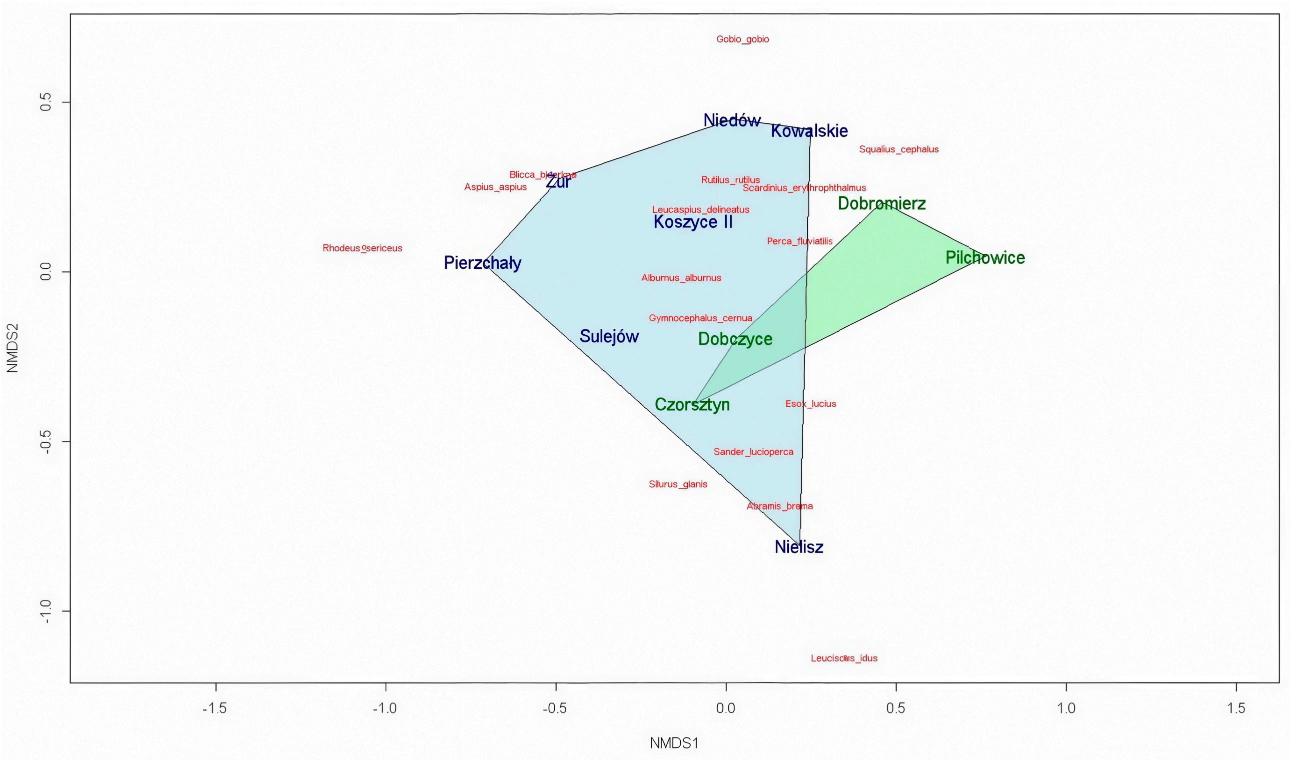


(**A**)

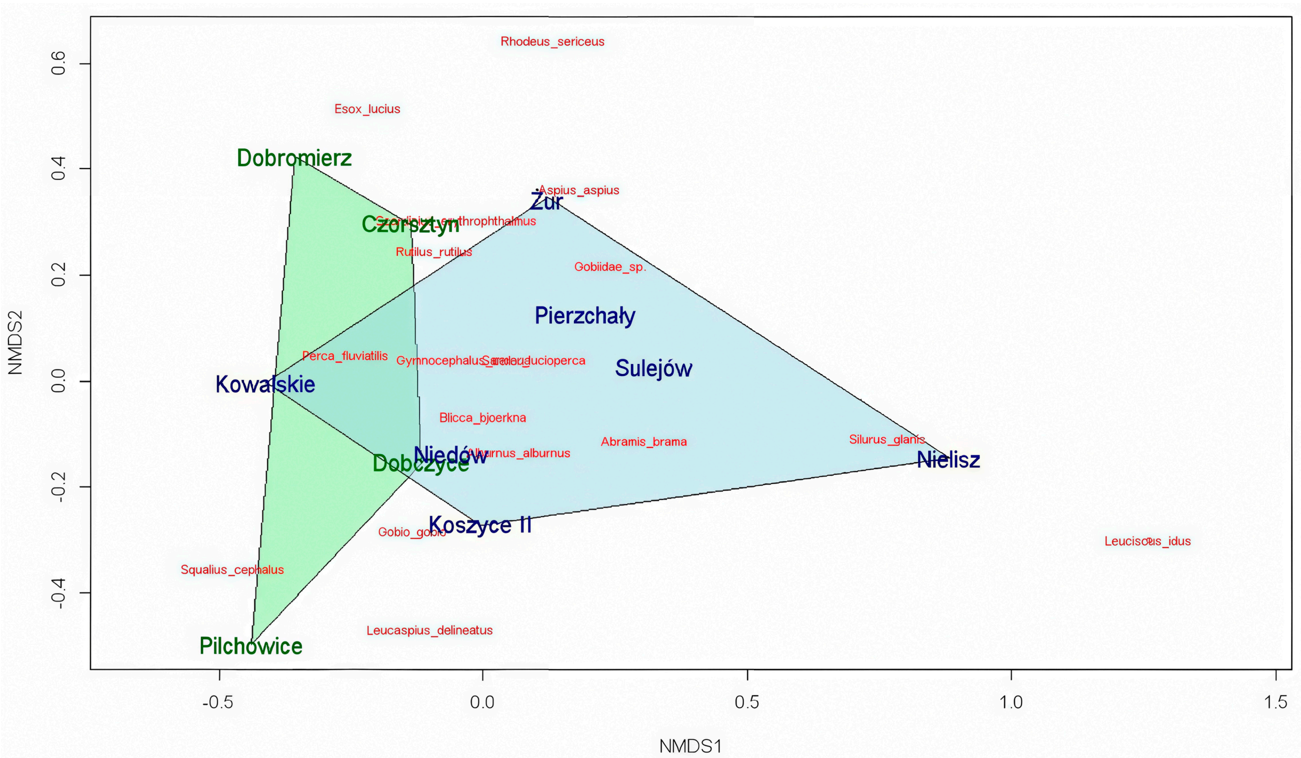


(**B**)

Figure 4. ANOSIM plot showing dissimilarity between and within the 11 sites included in this study, with R and p values for abundance (**A**) and biomass (**B**) based on CPUE from bottom nets—type (1) (standard: EN 14757). The bold horizontal bar in the box indicates the median, the bottom of the box indicates the 25th percentile, and the top of the box indicates the 75th percentile. Whiskers extend to the most extreme data points.

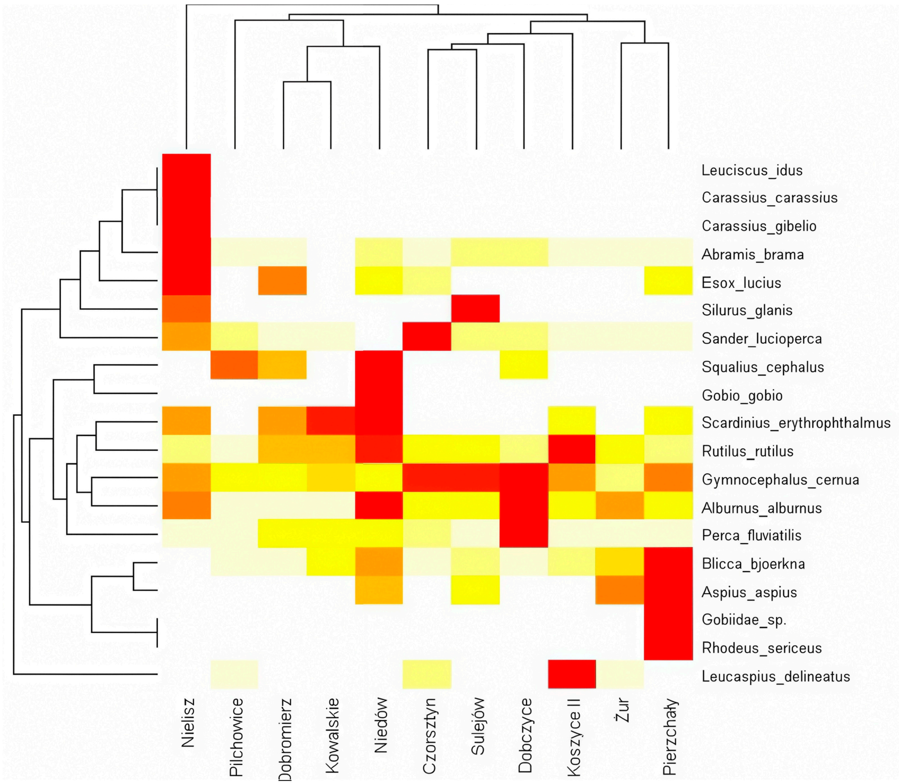


(A)

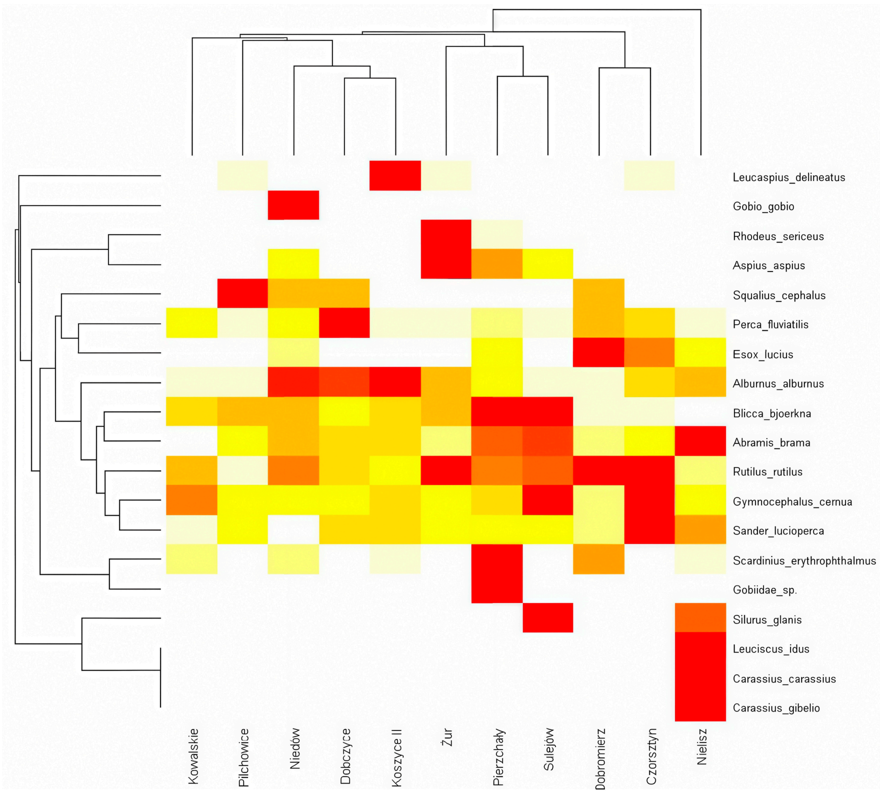


(B)

Figure 5. Nonmetric multidimensional scaling (NMDS) for (**A**) abundance and (**B**) biomass based on the CPUE from bottom nets—type (1) (standard: EN 14757). Reservoirs are divided into two groups: deep reservoirs more than 19 m deep (green) and shallow water reservoirs less than 14 m deep (blue).



(**A**)



(**B**)

Figure 6. The heatmap community table was constructed using Bray-Curtis dissimilarity distances, where abundance (**A**) and biomass (**B**) based on CPUE from bottom nets—type (1) (standard: EN 14757)—were coded by gradient color. Lighter colors (yellow) indicate similarity, and darker colors (red) indicate increasing dissimilarity.

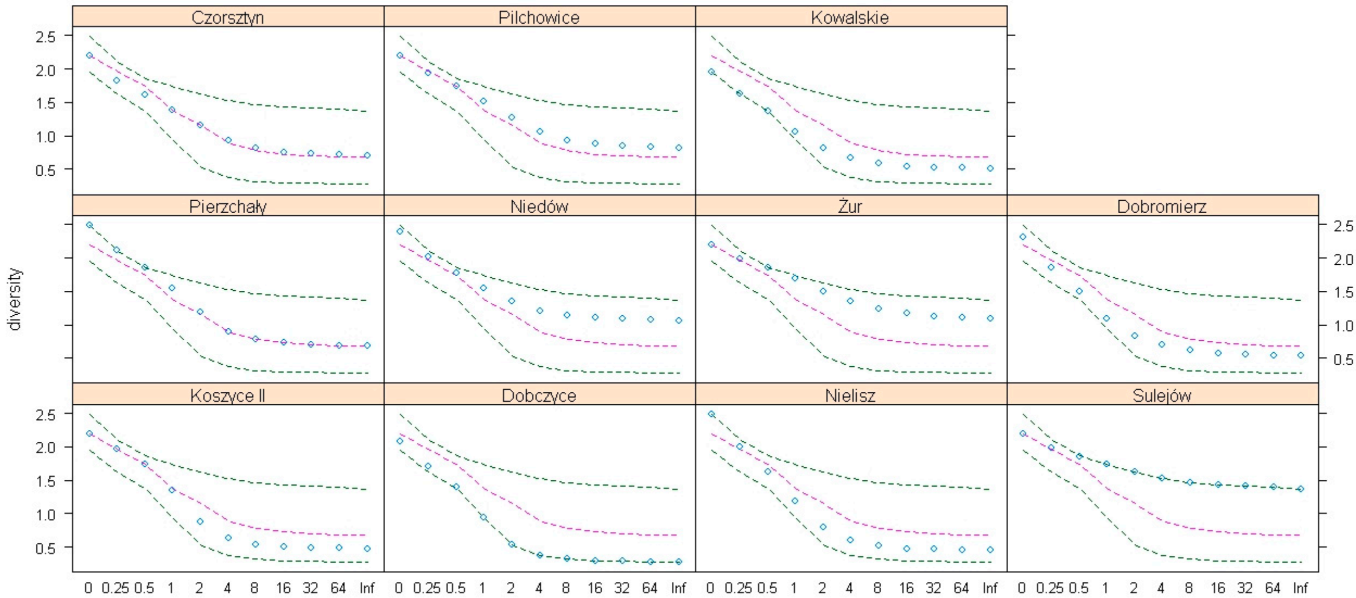


Figure 7. Rényi diversity index of the 11 sites included in this study. The dots denote the diversity value for the fish abundance based on the CPUE from bottom nets (type (1) (standard: EN 14757)); the outer two dashed lines, the extremes; and the inner pink line, the median.

3.3. Fish Index Development

3.3.1. Factor Correlation with the Pressure Indicator

A total of 588 correlations between the selected factors and the TSI index pressure index were analyzed, 30 of which yielded at least a weak correlation ($r > 2$) (Table 5). Most of the FCM results showed at least a strong correlation ($R > 0.6$) with the pressure indicator for the type (1) gillnet (7/10). Moreover, most of such cases were observed for the perch family (4/10). For the impact on individual fish species, a very strong correlation was observed only for the species European carp (*Cyprinus carpio*) for the gillnet type (3) ($R = 0.82$, $p < 0.1$). The species that had a positive correlation with the pressure indicator value were the cyprinid fish species European carp (*C. carpio*), white bream (*B. bjoerkna*), roach (*R. rutilus*), and bream (*A. brama*). A negative result was observed for bleak (*A. alburnus*) (Cyprynidae) and fish from the Percidae family, which included pike-perch (*S. lucioperca*), European perch (*P. fluviatilis*), and ruffe (*G. cernua*).

Table 5. A summary of the statistically significant values ($p < 0.1$) and the Pearson correlation coefficient ($R > 0.2$) between the TSI index and FCM factor combination matrix for the fish community were generated, where the data were divided into A—abundance and B—biomass; depth range: all depths are specified; fishing gear: all-net type (1) and type (2), type (3), or bottom net type (1). The data are shown in the direction of the strongest correlation [R].

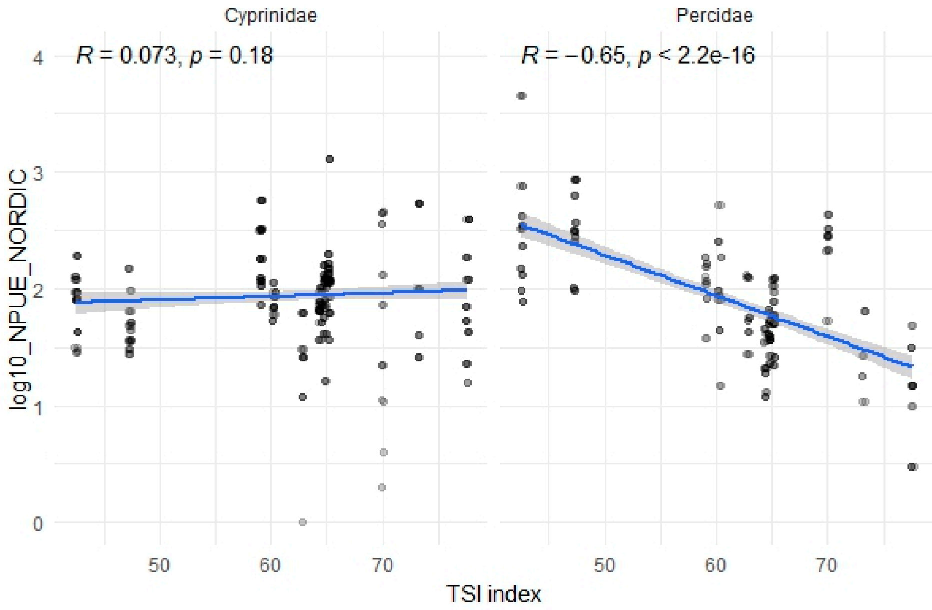
N.	Factor/Species Name	Data Type A—Abundance; B—Biomass	Depth Range [m], Gear Type: (1), (2), (3)	Pearson Correlation [R]	*p* Value [*p*]
1	*Cyprinus carpio*	B	0–3, (3)	0.82	<0.1
2	Percidae	B	3–6, (1)	−0.75	<0.001
3	*Alburnus alburnus*	A	3–6, (1)	−0.68	<0.001
4	Percidae	A	0–3, (1)	−0.68	<0.001
5	Abramis brama	B	0–3 (3)	0.66	<0.1
6	Percidae	B	0–3, (1)	−0.65	<0.001

Table 5. *Cont.*

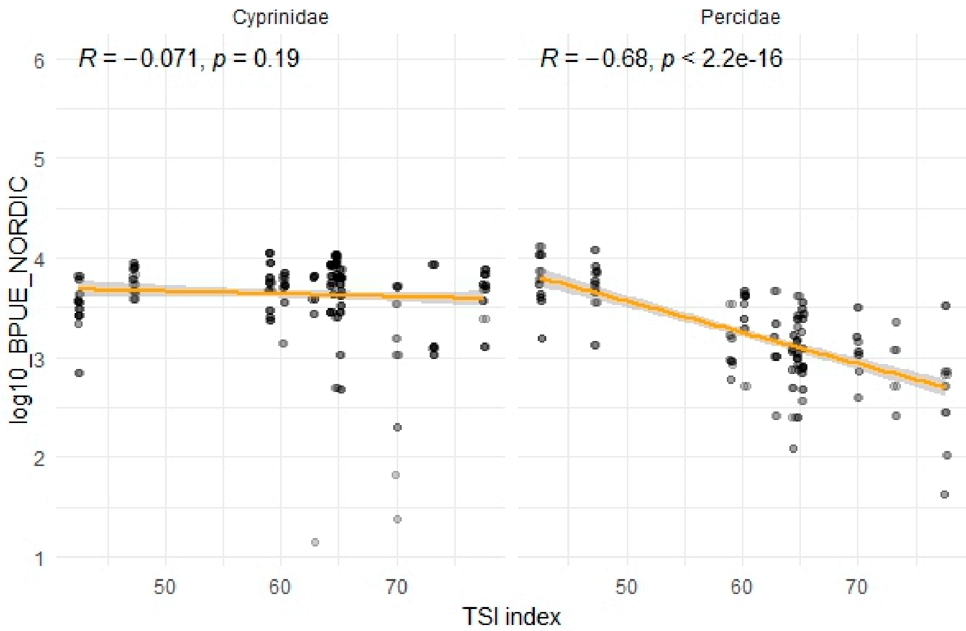
N.	Factor/Species Name	Data Type A—Abundance; B—Biomass	Depth Range [m], Gear Type: (1), (2), (3)	Pearson Correlation [R]	*p* Value [*p*]
7	*Blicca bjoerkna*	A	6–12, (1)	0.64	<0.01
8	*Sander lucioperca*	A	3–6, (1)	−0.63	<0.001
9	*Rutilus rutilus*	A	0–6 (2)	0.63	<0.1
10	Percidae	A	3–6, (1)	−0.62	<0.001
11	*Perca fluviatilis*	A	3–6, (1)	−0.57	<0.001
12	Percidae	A	12–20, (1)	−0.56	<0.05
13	Percidae	A	all depths: (1)	−0.52	<0.001
14	*Perca fluviatilis*	A	0–3, (1)	−0.51	<0.001
15	Percidae	A	6–12, (1)	−0.48	<0.001
16	Abramis brama	B	all depths: (3)	0.47	<0.001
17	Percidae	B	all depths: (1)	−0.38	<0.001
18	*Sander lucioperca*	A	all depths: (1), (2), (3)	−0.38	<0.001
19	*Gymnocephalus cernua*	A	6–12, (1)	−0.35	<0.1
20	*Perca fluviatilis*	B	all depths: (1)	−0.34	<0.001
21	*Perca fluviatilis*	A	all depths: (1), (2), (3)	−0.33	<0.001
22	*Gymnocephalus cernua*	A	all depths: (1), (2), (3)	−0.32	<0.001
23	*Rutilus rutilus*	A	all depths: (1), (2), (3)	−0.31	<0.05
24	*Perca fluviatilis*	B	all depths: (1), (2), (3)	−0.3	<0.001
25	*Sander lucioperca*	B	all depths: (1)	−0.3	<0.05
26	*Gymnocephalus cernua*	A	3–6, (1)	−0.28	<0.1
27	Cyprinidae	A	0–3, (1)	0.25	<0.001
28	*Sander lucioperca*	A	0–3, (1)	−0.25	<0.1
29	*Alburnus alburnus*	B	all depths: (1)	−0.22	<0.1
30	*Rutilus rutilus*	B	all depths: (1)	−0.22	<0.05

Note(s): (component factor average TSI) correlation scale: <0.19: very weak, 0.2–0.39: weak, 0.4–0.59: moderate, 0.6–0.79: strong, 0.8–1.0: very strong.

Two depth ranges of 0–3 and 3–6 m were selected from the FCM table (Table 5) for fish from the Percidae family, which were strongly correlated with the pressure index regardless of the type of data—abundance (R = −65, $p < 0.001$) or biomass (R = −68, $p < 0.001$) (Figure 8A,B). Fish from the Cyprinidae family, however, occurred at this depth range in every tested reservoir without significant correlations (Figure 8A,B).



(**A**)



(**B**)

Figure 8. A scatter plot with the r-Pearson correlation coefficient (R) and *p* value (*p*) between the TSI index and (1) Cyprynidae and (2) Percidae for depth ranges of 0–3 m and 3–6 m. The abundance is presented in chart (**A**) (NPUE—blue) and the biomass in chart (**B**) (BPUE—orange), and the data were normalized by the decimal logarithm based on the CPUE from bottom nets—type (1) (standard: EN 14757).

3.3.2. Stages to Development of Fish-Based Indicator Components

Stage 1

In the first stage, the following were selected: tool type, depth range, factor specification, and data type. The index was based on data from only the gillnet type (1) because the combination of several tools did not significantly strengthen the correlation of the results with the pressure indicator (Table 5). The depth ranges considered were 0–3 and 3–6 m. In this range, the best correlation fit was obtained, and combining fishing results from the entire tested depth range weakened the correlation. Ultimately, all the tested reservoirs had results within this data range.

With the adoption of the principle of selecting two components of the index, the Percidae fish family was taken as the negative factor. This factor showed by far the strongest correlation with the pressure indicator in the adopted depth range as well as with the type (1) tool, while correlating well with many other combinations. Selection of the second component, where a positive correlation was planned to be used, was difficult. Only the results for gillnet type (1) showed a weak correlation with the Cyprynidae fish family (R = 0.25, $p < 0.001$) (Table 5).

The type of data, abundance or biomass, used for the Percidae family did not significantly differ from the pressure indicator, so the data analysis began for the composed indices in both cases.

Stage 2

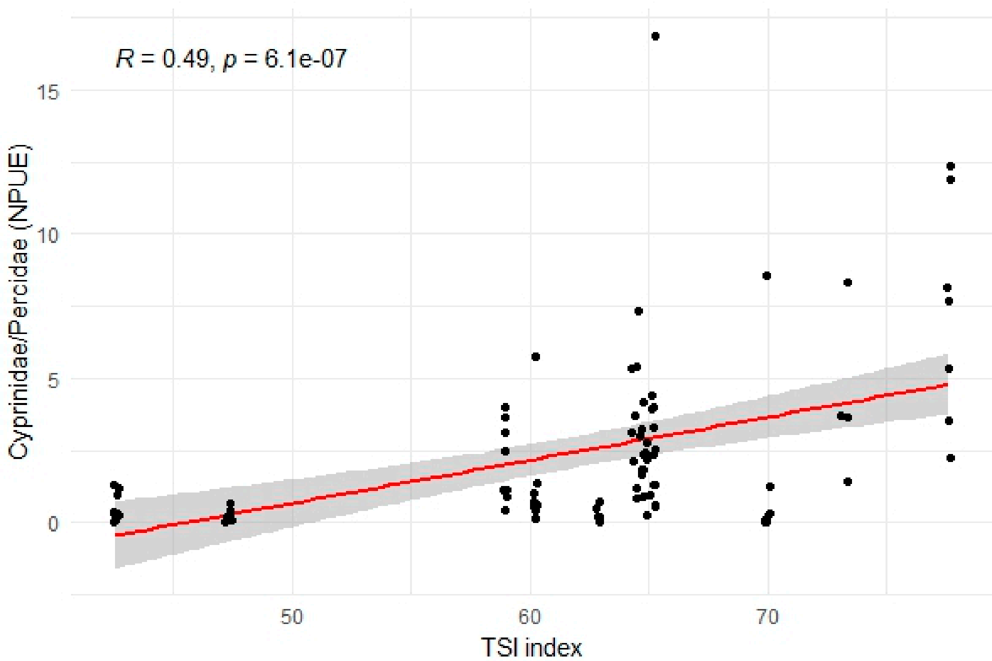
In the second stage, two selected factors were combined. Because both components have the same nature and properties, a method based on proportion was used so that the positive factor appeared in the numerator and the negative factor in the denominator, so that the value of the indicator increased in the direction of the interaction:

$$C/P_{index} = \frac{\text{Cyprynidae}}{\text{Percidae}}\text{index} = \frac{CPUE_{N \text{ or } B}}{CPUE_{N \text{ or } B}} \quad (2)$$

where $CPUE_{N \text{ or } B}$ is the number or mass of individuals within families.

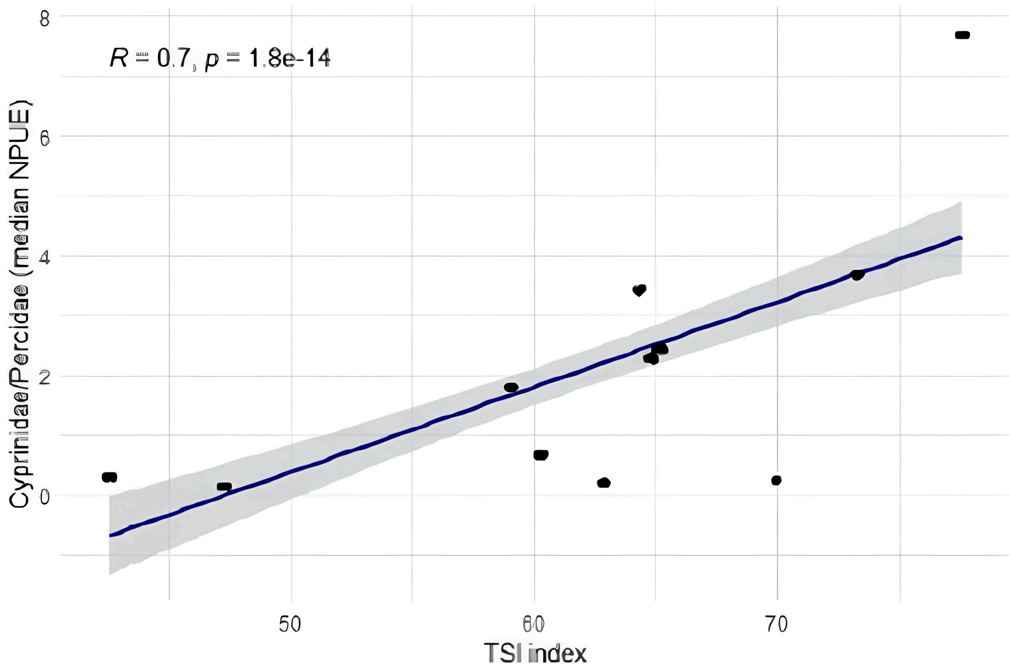
The C/P_{index} was tested for both the abundance and biomass. The biomass exhibited an unsatisfactory correlation (R = 0.31; $p < 0.01$) with the pressure indicator.

In contrast, the abundance indices showed a moderate correlation with the basic data (R = 0.49; $p < 0.001$) (Figure 9A), and for the median R = 0.70 and mean R = 0.77, a strong correlation was observed ($p < 0.001$) (Figure 9B,C).

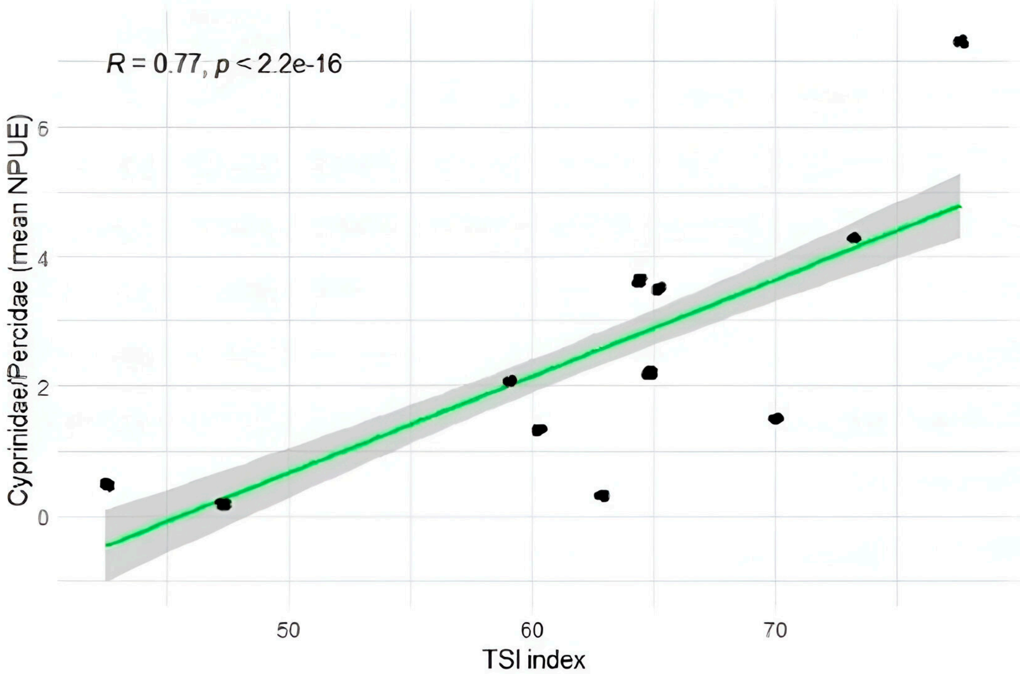


(**A**)

Figure 9. *Cont.*



(**B**)



(**C**)

Figure 9. A scatter plot with the r-Pearson correlation coefficient (R) and *p* value (*p*) for the relationship between the TSI index and the ratio of Cyprinidae to Percidae based on fish abundance (NPUE), in the ranges of 0–3 m and 3–6 m from the bottom net type (1) (standard: EN 14757), and corresponding datasets (**A**), medians (**B**), and means (**C**).

3.3.3. Preliminary Proposal for Indicator Scaling

A preliminary proposal for C/P_{index} scaling was made for the data using the median to exclude extreme values in the set. The results are presented in the form of a box plot to visualize the results in the context of the entire dataset, which facilitates the interpretation of the results (Figures 10 and 11). The Dobczyce reference reservoir obtained a value of C/P_{index} = 0.31; however, the lowest value was obtained for the Czorsztyn Reservoir (C/P_{index} = 0.15). The initial proposal for the assessment according to the C/P_{index} was based on commonly confirmed principles, the dominance of Cyprinidae over Percidae [5,8], in order for good conditions to be maintained in the standards of the reference reservoir:

- Good, 0.00–0.40, predominance of the Percidae fish family;
- Moderate, 0.41–1.00, for the level of equalization of the ratio of fish families;
- Poor, 1.01–2.00, for a level of predominance of fish from the Cyprinidae family;
- Bad, ≥2.01, indicating a double predominance of fish from the Cyprinidae family.

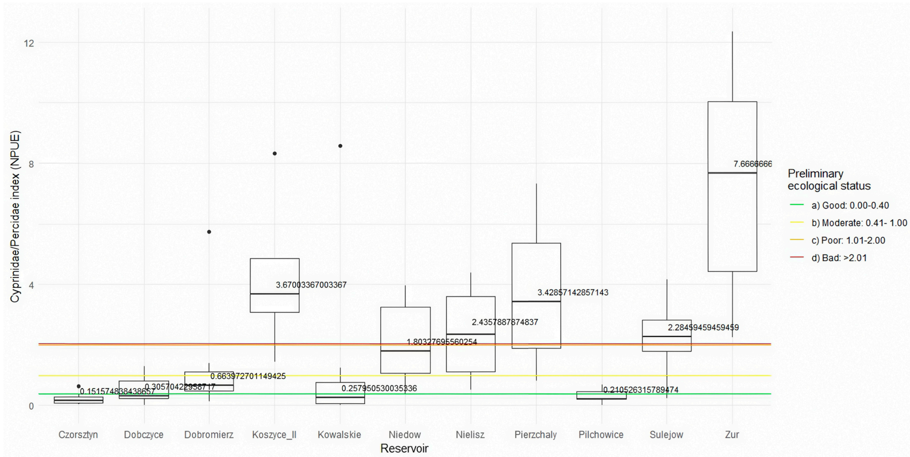


Figure 10. Box plot for the Cyprinidae/Percidae index based on fish abundance (NPUE) in the 0–3 m and 3–6 m ranges of the bottom net type (1) (standard: EN 14757). The bold horizontal bar in the box indicates the median, the bottom of the box indicates the 25th percentile, and the top of the box indicates the 75th percentile. Whiskers extend to the most extreme data points. The number indicates the median of each box plot, which corresponds to the four classes of water ecological potential.

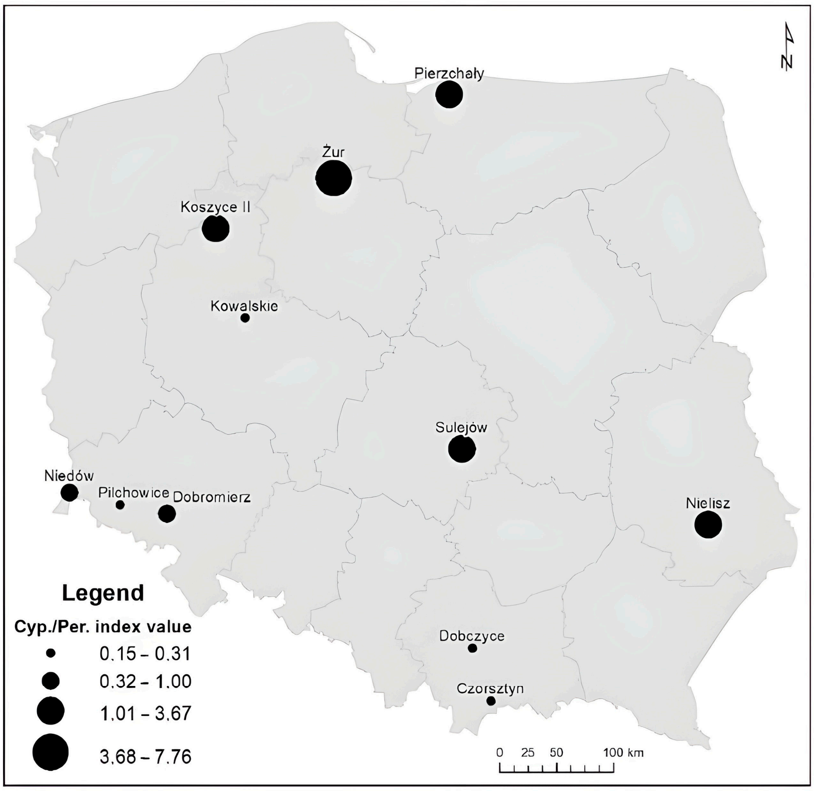


Figure 11. Cyprinidae/Percidae index values for 11 dam reservoirs.

4. Discussion

4.1. Pressure Indicator

The total phosphorus parameter in water is considered the most popular parameter for assessing eutrophication in the context of fish occurrence [9] and was the basis for this study. However, other indicators that are not based on water quality can be used as pressure indicators, although these indicators significantly deviate from the WFD recommendation. The most common factor unrelated to water parameters is the anthropogenization of the water body's shoreline according to the FBI, which was calculated based on the 2006 CORINE Land Cover SOeS database [37]. For the purposes of the WFD, multicomponent pressure indicators, such as the Baltic Sea Impact Index (BSII), were also used [38]. These indicators go a step further by considering georeferenced datasets of human activities (36 datasets), pressures (18 datasets), and ecosystem components (36 datasets) and include sensitivity estimates of ecosystem components that combine pressure and ecosystem component layers.

The BSII was also used to create the current ichthyological indicator for WFD transitional and coastal waters in Poland [39]. The general assumptions of the WFD focus on the issue of water eutrophication. However, these assumptions date back decades. Currently, many studies have focused on new assessment methods using new technologies for mapping areas and human impacts on ecosystems. New correlations were made between new pressure indicators and ichthyofauna through the implementation of new assessments of the state of the studied environment. An important study would be to calibrate the methods for selecting pressure indicators for ichthyofauna and for the final assessment of the environment.

4.2. Fishing Tools and Techniques

The tool type (1) (standard: EN 14757), which is used as a bottom gillnet, has been recommended for years for research on surface waters in the field of ichthyofauna. This tool has also been used for dam reservoirs [15,40,41]. Moreover, the diversification of fishing gear, both the use of gillnets of the type (1) throughout the water column [42] and other types of gear, such as "large fish" gillnets [24], has been shown to increase the pool of useful data for evaluation. Various types of tools were used in the research presented here. The gillnet from [23], showed very promising fishing results for further research based on biomass in the case of European carp (*C. carpio*) and bream (*A. brama*). The fishing results for the pelagic gillnet type (2) used here are strongly correlated with the abundance of roach (*R. rutilus*). However, the combined fishing results from multiple gear types did not exhibit strong correlations in this case; rather, they exhibited only weak correlations. For further research in the future, it is necessary to return to further testing of all the tools used here to look for further correlations and use the data for intercalibration with other European countries, which has not been possible thus far. Moreover, apart from the diversification of gillnets, the shallow-water coastal zone in inland reservoirs offers promising results for electrofishing [43,44]. However, for dam reservoirs, this zone is unstable and characterized by significant fluctuations in the water column, which makes it difficult to perform repeatable tests with this tool. In these studies, electrofishing was also tested, and unsatisfactory results were obtained when comparing electrofishing with or without net fishing.

Differences between fishing distances from the dam to the inlet of the feeding river were not tested in this study.

4.3. Data Type and Scope

Fishing effort can significantly affect fishing performance. Evenly distributed survey stations in at least three areas of the reservoir (upper, middle, and dam) and the coverage of all possible depth ranges provide a sufficient range of data to analyze the impact of pressure on fish [40,45]. In this work, a reduced effort was used from the EN 14757 standard, which, in reference to the study by [6], confirms that the scope used with a single network at the station still leads to a positive correlation between the pressure index and the structure of the reservoir's ichthyofauna. Additionally, the analysis of similarities between ichthyofaunal communities in reservoirs at different depths ranging from 3.3 to 49.9 m and in areas ranging from 44 to 1980 ha did not reveal any significant differences.

Validation of the obtained data in the context of Polish data could not be performed. There is a lack of data on dam reservoirs collected over the years, particularly using gillnets from the EN 14757 standard. This project was a pilot. Moreover, the methods used here, both in terms of fishing gear and fishing technique, are consistent with most of the work carried out for the WFD, which has led to adequate and widely accepted results being obtained for assessing ecological status or potential. Moreover, the obtained species compositions and structures of ichthyofauna are significantly similar, as determined by long-term studies of approximately 500 lakes in Poland [16]. The main similarities between reservoirs and lakes concern the biomass of the dominant ichthyofauna, which in both cases contains the same 10 species. The main differences concern tench (*Tinca tinca*) and bitterling (*Rhodeus sericeus*), which are common in lakes and less common in dam reservoirs; in contrast, pike-perch (*S. lucioperca*) is common in dam reservoirs and less common in lakes.

It is worth noting that the studied Nielisz reservoir stood out, mainly due to the occurrence of *crucian carp* (*C. carassius*), prussian carp (*C. gibelio*), ide (*L. idus*), and catfish (*S. glanis*). This very young reservoir was created in 2008 and is subject to restocking of the abovementioned species, which influenced this distinctiveness and is understandable.

The NPUE and BPUE are used interchangeably or in combination (multi-index) in ichthyological research because of their correlation with pressure. Additionally, in this study, the data from both ranges showed positive, strong correlations depending on the analyzed variant. However, it is worth noting that 19/30 of the analyzed correlations were based on the NPUE. Research by [6], also showed better results for the NPUE than for the BPUE, where, in both cases, the species that were positively correlated with pressure for the NPUE were pike-perch (*S. lucioperca*) and european perch (*P. fluviatilis*), which constitute a very important component of the index presented here.

4.4. Fish-Based Index Components

The dam reservoirs examined throughout the country for the assessment conducted here were significantly diversified in terms of hydrology and morphology, as well as in terms of the level of the tested pressure indicator. Initially, large differences between ichthyofaunal communities and biodiversity levels were expected, which could have led to the use of different assessment methods for different separated fish communities; however, relying on the ecosystem approach was an erroneous assumption due to high similarity between the reservoirs. Through preliminary statistical comparative analyses, it was possible to better interpret the results of the correlation between the pressure and the qualitative and quantitative composition of fish.

Ichthyological indicators used in assessing the state of eutrophication or ecological potential include many components of various origins, such as the quantitative components of abundance and biomass, and the qualitative components of age, belonging to alien species, or exhibiting different levels of sensitivity. A multicomponent indicator based on both qualitative and quantitative components was adopted as an indicator for dam reservoirs in Central Europe following the study by [4]. The total biomass and number of fish for individual species, as well as the age, size, and length of the fish, as well as whether the fish belonged to certain groups such as Salomonidae, phytophiles, or hybrids, were assumed. The second closest indicator to the one analyzed in this study is the Polish indicator for lakes, in which only quantitative values based on the biomass of selected fish species are used. The Introduction briefly discusses other popular ichthyological indicators, so there will be no reference to them here.

The main focus should be drawn to the qualitative part of the indicator, which is the occurrence of selected fish species. Some of them react in a similar way in all cases in inland waters, increasing or decreasing their abundance and biomass in correlation with an increase in eutrophication. These are all species of salmonid fish that have been recognized for several years as extremely responsive to environmental disturbances [5,7,10–12,14,15,18,46]. Unfortunately, under the conditions of Polish dam waters, it is impossible to apply this principle due to their deficiencies. The remainder of the discussion will refer to the species for which high correlations were observed in this study.

An increase in biomass with increasing eutrophication is widely expected, especially for large individuals, such as bream (*A. Brama*), carp (*C. carpio*), white bream (*A. bjoerkna*), and roach (*R. rutilus*), which was also documented in this study. However, eutrophication generally has the opposite effect on European perch (*P. fluviatilis*), which is a frequently repeated case of a very strong correlation in this study. Species less commonly recognized as indicators are very interesting local cases. The direction of pressure on their numbers and biomass often differs. In the case of both [4] and this study, zander (*S. lucioperca*) was included as an indicator but in the opposite direction. Zander *(S. lucioperca*) is a species that copes well in conditions with high levels of eutrophication [47,48]; in particular, it copes very well in conditions of low visibility, where it has an advantage over prey and rivals [49,50]. However, this is not a direct result of increased primary production or tolerance to pollution, which lead to population decline in this species [51]. It is also worth noting that the reservoirs in which zander (*S. lucioerca*) was abundant in the case analyzed here were oligotrophic reservoirs with a Secchi disc depth of 2.7 m and the lowest pressure index values. Such conditions are also favorable for the development of this species, as observed in Finland [52], and it is also able to adapt with great reproductive success to the prevailing conditions in deep and large-scale water bodies [37,47,53], such as the reservoirs with the lowest eutrophication levels studied here. In the analyzed case, the bleak (*A. alburnus*) also correlated well with the pressure indicator, having a high abundance in reservoirs with a low pressure; however, this is indicated by the generally favorable conditions in which this fish was found in large and deep reservoirs compared to the rest of the studied reservoirs. Such conditions favor the development of this species [54,55] and are probably not related to the tested eutrophication level.

The proportions of two groups of species, Precidae and Cyprinidae, used here for the correlations between the studied morphologically diverse and hydrologically diverse reservoirs are safe solutions that have been well researched and documented for various types of inland waters [5]. Despite only a weak correlation between the entire group of fish from the Cyprinidae family, in general terms of abundance or biomass with pressure, the strongest correlations in this study were still the selected classic species from this family, such as European carp (*C. carpio*) ($r = 0.82$), perch (*P. fluviatilis*), and roach (*R. rutilus*). Furthermore, these species also represented both groups in the highest numbers and constituted the main components of ichthyofaunal communities, which also validates the research results to a greater extent because changes in fish communities directly responded to the indicator values. The second factor that influences the high value of such an indicator is its simple mathematical structure without the need for modifications with the weight share for individual components. Dam reservoirs are highly modified inland reservoirs that are often subject to management regimes such as water level regulation, flow regulation, and hydrotechnical construction, which significantly affect frequent changes in the eulittoral zone and the entire reservoir. Therefore, it seems desirable to assess these water bodies under the WFD as simply as possible, which is difficult.

5. Conclusions

A pilot ichthyological indicator was developed for WFD purposes in Central and Eastern Europe for dam reservoirs with heavily modified water bodies. The indicator was based on the ratio of the abundance of two families of fish, Precidae and Cyprinidae, where the predominance of fish from the perch family showed better ecological potential. The correlation of the indicator with the average pressure indicator was strong, at $r = 0.77$ ($p < 0.001$). In preliminary work, a correlation matrix with the TSI index pressure indicator was tested based on the abundance or biomass of fish species, the abundance of fish families, the fishing gear, and the fishing depth range for a total of 588 cases. From the analyzed cases, only 30 correlations with a minimally weak value of r > 2 and $p < 0.1$ were isolated and used for further work in the selection of indicator components. The Percidae family exhibited a strong correlation with the most connections in the matrix used. Moreover, despite individual cases of a certain configuration of very strong or strong correlations for relevant fish species, such as European carp (*C. carpio*), bleak (*A. alburnus*), bream (*A. brama*), and white bream (*B. bjoerkna*), their combination has been proven to not yield satisfactory results. The use of the strongest correlations from only a selected range of data could also lead to the construction of the correct indicator. However, here, the principle was to use already developed and confirmed relationships, such as the ratio of biomass between perch and cyprinid fish, and to select the widest possible range of available data, such as using two combined depth ranges and taking into account most of the fish caught. It has been proven that the use of strictly appropriate fishing gear, fishing methods, and effort is effective for the assessment of morphologically and hydrologically diverse dam reservoirs. It is necessary to continuously obtain data in the following years to evaluate the method of assessing dam reservoirs in Poland and intercalibrate with neighboring countries. Further work on the evaluation of the indicator should include the monitoring of other dam reservoirs in Poland, at least according to the same methodology presented here. The main need in further work on the development of fish-based assessments of dam reservoirs in the region is to increase the scope of data to include different levels of eutrophication of dam reservoirs and time ranges.

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