





## Article

# Status and Perspectives of the Ichthyofauna of the Labudovo okno Ramsar Site: An Analysis of 14 Years of Data

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**Abstract:** Over the last 14 years, ichthyological and ecological parameters have been monitored in the Labudovo okno Ramsar site. This area is important for its biodiversity as it is home to many rare and endangered plants and animal species. A total of 3861 fish specimens were sampled and measured at six sampling sites four times during the sampling period. An analysis of biodiversity indexes, relative biomass (kg/ha), and relative annual production (kg/ha) was carried out to assess the effectiveness of existing conservation measures. The results obtained show a trend decline in biodiversity, relative biomass, and relative annual production. This indicates a biodiversity conservation problem that should be addressed through other mechanisms in addition to the principles of the Ramsar Convention.

**Keywords:** Ramsar site; fish community structure; population parameters; bioindexes; Danube



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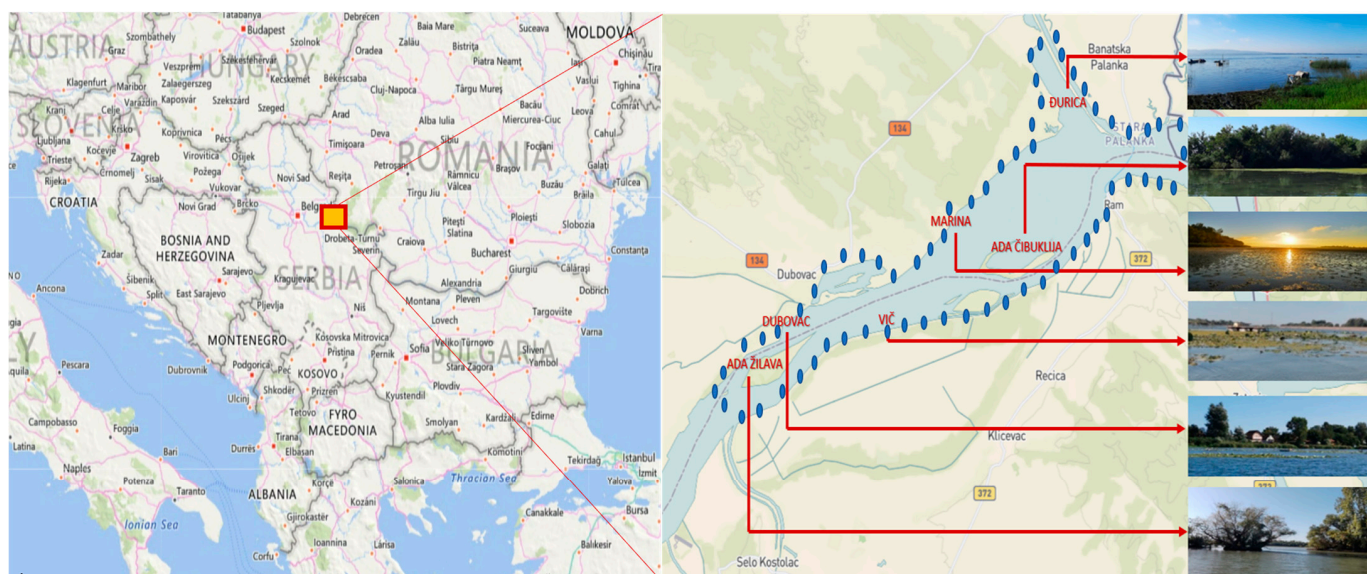


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## 1. Introduction

Freshwater ecosystems undoubtedly offer a high value-added in the green transition process. They play an essential role in ecosystem services, mainly due to their socio-economic value, provided by ichthyofauna as an inevitable component of functional hydroecosystems [1–3]. Freshwater resources are rapidly declining in quantity and quality, putting them under pressure and in many cases becoming scarce for human and ecosystem use [4]. Freshwaters are under threat caused by increasing anthropogenic stress, such as nutrient enrichment, urbanization, industrial waste, deforestation, water abstraction, flood prevention engineering, sedimentation, dam construction, climate change, and the spread of invasive species [5]. Protected areas are the cornerstone of biodiversity conservation with the aim of preserving nature from anthropogenic threats [6]. The protection of important biodiversity areas is intended to be an effective measure to restore, conserve, and fulfill the objectives of the EU Oceans, Seas, and Waters mission [7]. One such area is the Special Nature Reserve (SNR) Deliblatska peščara (Eng. Deliblato Sands), located in north-eastern Serbia (44°53′01″ N 21°05′33″ E/44.88361° N 21.09250° E), covering a total area of 34,829.32 ha in the Danube River Basin (DRB) (Figure 1). Historically, the delta and liman systems include numerous interconnected bodies of water, both fresh and brackish, as well as wetlands. The diversity of biotopes created a wide range of ecological conditions and habitats that allowed for high biological productivity and a great diversity of flora and fauna [6]. The SNR Deliblato Sands represents Europe’s largest resort, consisting of

vast sand layers with distinct forms of dune relief and characteristic sandstone, steppe, forest, and wetlands, and a unique mosaic of biotic communities. Labudovo okno, as an integral part of the SNR “Deliblato Sands”, was declared a Ramsar site in 2006 according to the Ramsar Convention (The Convention on Wetlands), which refers to the protection of wetlands of international importance, especially as habitats for wetland birds. This area is considered one of the most important nesting sites for wetland birds in Serbia. Along with the significant biodiversity of flora in this area, the biodiversity of fauna also stands out.



Legend:

- Geographic position of Labudovo okno in Europe and Serbia
- Ramsar site boundaries

**Figure 1.** Geographic position of Labudovo okno ((source: <https://rsis.ramsar.org/>, accessed on 26 April 2023), modified by authors).

A large number of water bird species nest on Labudovo okno, most of which are on the list of natural rarities or endangered species. An important characteristic of this area is the great variability among the ornitofauna; for example, the greater white-fronted goose and greylag goose, common goldeneye, white-tailed eagle and greater spotted eagle, glossy ibis and pygmy cormorant, and many other water bird species inhabit this Ramsar site. The area of Labudovo okno is an ideal spawning ground for fish species such as carp, pike, catfish, perch, and bream. The fauna of Labudovo okno also consists of various freshwater mollusks such as river clams and leeches, insects such as mosquitoes and water spiders, amphibians and reptiles such as the fire-bellied toad and the Balkan wall lizard, and mammals such as the otter and blind mole rat. From all of the above, it can be concluded that Labudovo okno as a Ramsar site has great biological and socio-economic importance, which implies the preservation of ecosystems whose members are closely connected and conditioned by mutual presence, primarily in terms of the food chain. Numerous and diverse flocks of water birds, numbering over several tens of thousands of individuals, gather every year on the waters of Labudovo okno. This is the most important feeding ground for numerous rare and endangered species. It also represents an important wintering place for water birds in Serbia and one of the most important in the Balkans [8].

The SNR “Deliblato Sands” is one of the most important centers of biodiversity in Europe, and its part Labudovo okno (Figure 1) has been designated as a Ramsar wetland (3733 ha) stretching along the left bank of the Danube River in the extreme south-east area of Vojvodina [9,10].

The purpose of this study arises from two facts: (a) there is a deficit of open scientific data dealing with the species diversity of ichthyofauna, its conservation status, and threats in the protected area Labudovo okno, and (b) Labudovo okno is inhabited by 47.98% of the fish species of the Serbian ichthyofauna [11]. The study provides valuable data for the following categories: (i) ichthyology (new valuable data freely available), (ii) social sphere (knowledge transfer, information provision, and awareness raising on the importance of Labudovo okno from the point of view of protection, use, and welfare), and (iii) policy sector (provision of valuable information needed for the future management of the said area).

## 2. Materials and Methods

### 2.1. Sampling Area

The locality Labudovo okno was created by raising the Danube level after the construction of the dam for the hydroelectric power plant “Đerdap I”. The entire Ramsar site was named “Labudovo okno” after this locality [10]. Geographically, this area is located at the south-eastern edge of the Pannonian Plain, in the south-eastern Banat (Figure 1). It stretches along the left bank of the Danube, which is the southern edge of the area known as Deliblatska peščara, between the 1094th and the 1075th rkm (river kilometer). The main types of aquatic biotopes found there are permanent river courses, permanent freshwater wetlands, and occasional flood zones with high groundwater levels under the influence of changes in the water level of the Danube. The area lies in the catchment area of the middle (Pannonian) Danube, which extends from Turn Severin (930 km) to Devinšvrata (1880 km) [10]. From a hydrological point of view, this part of the Danube basin is of great importance as it accounts for more than half of the Danube’s discharge and has the highest concentration of the river’s hydropower [12,13]. In general, the Danube enters the territory of the Republic of Serbia from Hungary at rkm 1433 and leaves it at rkm 845 at the mouth of the Timok River with a total run of 588 km [9].

Sampling localities description:

- (a) Site Marina: elevation 60–70 m, GPS 44°48′49″ N 21°16′51″ E. The Marina Channel is in a permanently flooded area on its left bank (1082.5–1078 R-km). The channel is 4.5 km long and about 100 m wide, most of which is at about 65 m above sea level. It is almost completely covered with submerged and floating macrophytes such as *Potamogeton perfoliatus*, *Ceratophyllum demersum* (the dominant species), *Trapa natans*, etc. The substrate is muddy and exhibits coarse sedimentation. The trophic composition based on macrophytic vegetation can be described as eutrophic [8,14].
- (b) Site Ada Žilava: elevation about 65 m, GPS 44°46′34″ N 21°12′04″ E. The length of the islet is about 2.5 km, and the width is about 1.3 km. The community is mesotrophic to eutrophic and dominated by macrophytes of the genera *Potamogeton*, *Salvinia*, and *Naias*. *Cyperus glomeratus* and *Scirpus lacustris* are abundant in the Ada Žilava itself [8,14].
- (c) Site Vič: elevation about 70 m, GPS 44°47′35″ N 21°14′55″ E. Geological basis is white, yellow, brown, grey, or black carbonate sand of eolian origin, slightly alkaline reaction. The course of the Danube in this area has the characteristics of a typical potamon. Biocoenosis is eutrophic and dominated by floating and submerged plants [8,14].
- (d) Site Đurica: elevation 65 m, GPS 44°50′42″ N 21°18′14″ E. It is characterized by a large area of emergent vegetation (23% of the heath), consisting of typical groups of marsh plants (helophytes). Among the macrophytes, broadleaf cattails (*Typha latifolia*), reeds (*Phragmites australis*), and sweet flags (*Acorus calamus*) dominate on the coast, and *Ceratophyllidae* and *Parvopotamidae* in the water area. The trophic composition based on macrophytic vegetation can be described as eutrophic [8,14].
- (e) Site Ada Čibuklija: elevation ca. 65 m, GPS 44°48′29″ N 21°18′11″ E. It is a floodplain of the Danube near Banatska Palanka. This wetland is elongated, about 4 km long. It is a highly eutrophic community with a high proportion of emergent and submerged macrophytic vegetation consisting of *Potamogeton* spp., *Ceratophyllum demersum*, *C. submersum*, and *Trapa. natans*, *Azolla filicauloides*, and *Lemna* sp. [8,14].

- (f) Site Dubovac: elevation about 70 m, GPS 44°47'23" N 21°12'43" E. The substrate is sandy, fine-grained, and silty, with humus and clay. The macrophyte community structure includes submerged species (*Potamogeton crispus*, *Potamogeton perfoliatus*) and floating plants dominated by *Trapa natans*, *Nymphaea alba*, and *Nuphar luteum*. The trophic composition based on macrophytic vegetation can be described as mesotrophic and eutrophic [8,14].

## 2.2. Sampling, Data Collection and Data Analysis

Between August 2008 and October 2022, 3861 fish were collected using multi-mesh nets with a mesh size of 10–60 mm and electrofishing (HONDA 1.2 kW, 6 A) at the six sampling localities of the Labudovo okno Ramsar site shown in Figure 1. The fish were taxonomically identified according to the available literature [15,16], measured and the parameters of relative biomass (kg/ha) and relative annual production (kg/ha) were calculated. Relative biomass and relative annual production (kg/ha) were calculated based on the total fish samples collected during the study period on the one hand and on the effort of Ricker [17] on the other. Relative annual production was assessed according to the methodology of Huet [18]. Other statistical calculations (one-way ANOVA and chi-square test) were performed using Statistica 12 software.

The analysis of the qualitative and quantitative composition of the ichthyofauna was used to calculate Simpson index, Shannon's index  $\alpha$ -diversity, and Menhinik index according to Biological Diversity Frontiers in Measurement and Assessment [19]. The distribution of biodiversity indexes per localities and investigation period was performed using MANOVA test and chi-square test in statistical software Statistica 12.

## 3. Results

In the total fish sample collected from 2008 to 2022, 3861 fish individuals belonging to 35 fish species from 13 families were sampled and taxonomically determined. Moreover, the previous reports on fish biodiversity status in research were consulted to identify the overall biodiversity reported in this area (Table 1) [11,16].

**Table 1.** Community composition and taxa status after international and national legislation (+ sign represents allochthonous species) [20–22].

Taxa	Common Name	IUCN Red List Global	Appendix of the Convention on the Conservation of European Wildlife and Natural Habitats (CETS No.: 104)	Appendix of the Council Directive 92/43/EEC	Appendix of the National Rulebook on the Proclamation and Protection of Strictly Protected and Protected Wild Species
Fam. Anguillidae <i>Anguilla anguilla</i>	European eel	CR			I
Fam. Alosidae <i>Alosa caspia</i> <i>Alosa immaculata</i>	Caspian shad Pontic shad	LC VU		II, V II, V	I
Fam. Acipenseridae <i>Acipenser ruhtenus</i>	Sterlet sturgeon	VU	III	II	II
Fam. Esocidae <i>Esox lucius</i>	Northern pike	LC			II
Fam. Umbridae <i>Umbra krameri</i>	Mudminnow	VU	II		I
Fam. Cyprinidae <i>Cyprinus carpio</i> <i>Carassius gibelio</i> + <i>Carassius carassius</i> <i>Barbus barbus</i>	Common carp Prussian carp Crucian carp Barbel	VU NE LC LC		V	II I II

Table 1. Cont.

Taxa	Common Name	IUCN Red List Global	Appendix of the Convention on the Conservation of European Wildlife and Natural Habitats (CETS No.: 104)	Appendix of the Council Directive 92/43/EEC	Appendix of the National Rulebook on the Proclamation and Protection of Strictly Protected and Protected Wild Species
Fam. Leuciscidae					
<i>Blicca bjoerkna</i>	White bream	LC			
<i>Leuciscus aspius</i>	Asp	LC	III	II, V	II
<i>Rutilus rutilus</i>	Roach	LC			
<i>Scardinius erythrophthalmus</i>	Rudd	LC			
<i>Squalius cephalus</i>	Chub	LC			II
<i>Vimba vimba</i>	Vimba bream	LC	III		II
<i>Chondrostoma nasus</i>	Common nase	LC	III		II
<i>Alburnus chalcoides</i>	Danube bleak	LC	III	II	
<i>Alburnus alburnus</i>	Bleak	LC			
<i>Abramis brama</i>	Bream	LC			II
<i>Ballerus sapa</i>	White eye bream	LC	III		II
<i>Pelecus cultratus</i>	Sichel	LC	III		
Fam. Xenocyprinidae					
<i>Ctenopharyngodon idella</i> <sup>+</sup>	Grass carp	LC			
<i>Hypophthalmichthys nobilis</i> <sup>+</sup>	Bighead carp	DD			
<i>Hypophthalmichthys molitrix</i> <sup>+</sup>	Silver carp	NT			
Fam. Tincidae					
<i>Tinca tinca</i>	Tench	LC			I
Fam. Gobionidae					
<i>Romanogobio albipinnatus</i>	White finned gudgeon	LC	III	II	II
<i>Pseudorasbora parva</i> <sup>+</sup>	Topmouth gudgeon	LC			
Fam. Acheilognathidae					
<i>Rhodeus sericeus</i>	Bitterling	LC	III		
Fam. Cobitidae					
<i>Cobitis taenia</i>	Spined loach	LC	III	II	II
<i>Misgurnus fossilis</i>	Weatherfish	LC	III	II	I
Fam. Gadidae					
<i>Lota lota</i>	Burbot	LC			II
Fam. Syngnathidae					
<i>Syngnathus abaster</i>	Black-striped pipedfish	LC	III		
Fam. Gasterosteidae					
<i>Gasterosteus aculeatus</i> <sup>+</sup>	Three-spined stickleback	LC			
<i>Pungitius platygaster</i> <sup>+</sup>	Southern ninespine stickleback	LC			
Fam. Percidae					
<i>Perca fluviatilis</i>	European perch	LC			II
<i>Gymnocephalus cernuus</i>	Ruffe	LC			
<i>Gymnocephalus baloni</i>	Danube ruffe	LC	III		I
<i>Gymnocephalus schratseri</i>	Schratz	LC			
<i>Zingel zingel</i>	Zingel	LC	III		I
<i>Sander lucioperca</i>	Pike-perch	LC	III		II
<i>Sander volgensis</i>	Volga pikeperch	LC	III		II
Fam. Odontobutidae					
<i>Perccottus glenii</i> <sup>+</sup>	Chinese sleeper	LC			
Fam. Centrarchidae					
<i>Lepomis gibbosus</i> <sup>+</sup>	Pumpkinseed	LC			
Fam. Siluridae					
<i>Silurus glanis</i>	Wels catfish	LC	III		II
Fam. Ictaluridae					
<i>Ameiurus nebulosus</i> <sup>+</sup>	Brown bullhead	LC			
<i>Ameiurus melas</i> <sup>+</sup>	Black bullhead	LC			

Table 1. Cont.

Taxa	Common Name	IUCN Red List Global	Appendix of the Convention on the Conservation of European Wildlife and Natural Habitats (CETS No.: 104)	Appendix of the Council Directive 92/43/EEC	Appendix of the National Rulebook on the Proclamation and Protection of Strictly Protected and Protected Wild Species
Fam. Gobiidae					
<i>Proterorhinus marmoratus</i> <sup>+</sup>	Tubenose goby	LC			
<i>Babka gymnotrachelus</i> <sup>+</sup>	Racer goby	LC			
<i>Ponticola kessleri</i> <sup>+</sup>	Bighead goby	LC			
<i>Neogobius fluviatilis</i> <sup>+</sup>	Monkey goby	LC			
<i>Neogobius melanostomus</i> <sup>+</sup>	Round goby	LC			
<i>Ponticola syrman</i>	Syrman goby	LC			
<i>Proterorhinus semilunaris</i>	Western tubenose goby	LC			

Most of the sampled species (35) are classified into the family Leuciscidae (10) followed by the family Gobiidae (7), Percidae (4), Cyprinidae (4), Xenocyprinidae (2), Acipenseridae (1), Tincidae (1), Gobionidae (1), Acheilognathidae (1), Centrarchidae (1), Siluridae (1), Ictaluridae (1), and Esocidae (1) (Table 2, Figure 2).

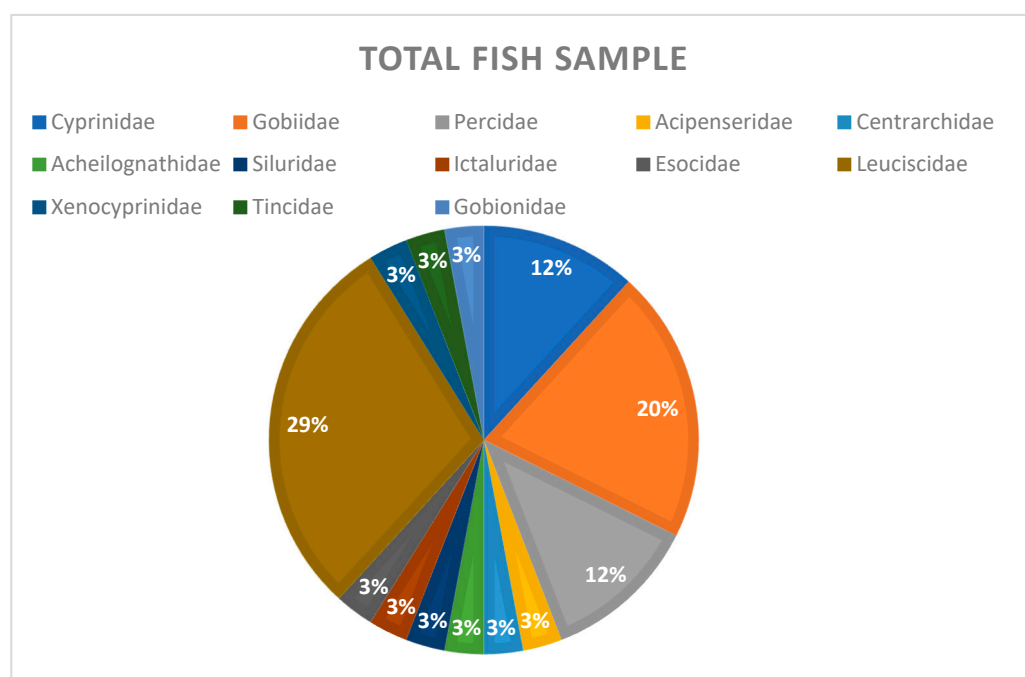


Figure 2. The percentual share of fish families in the total fish sample.

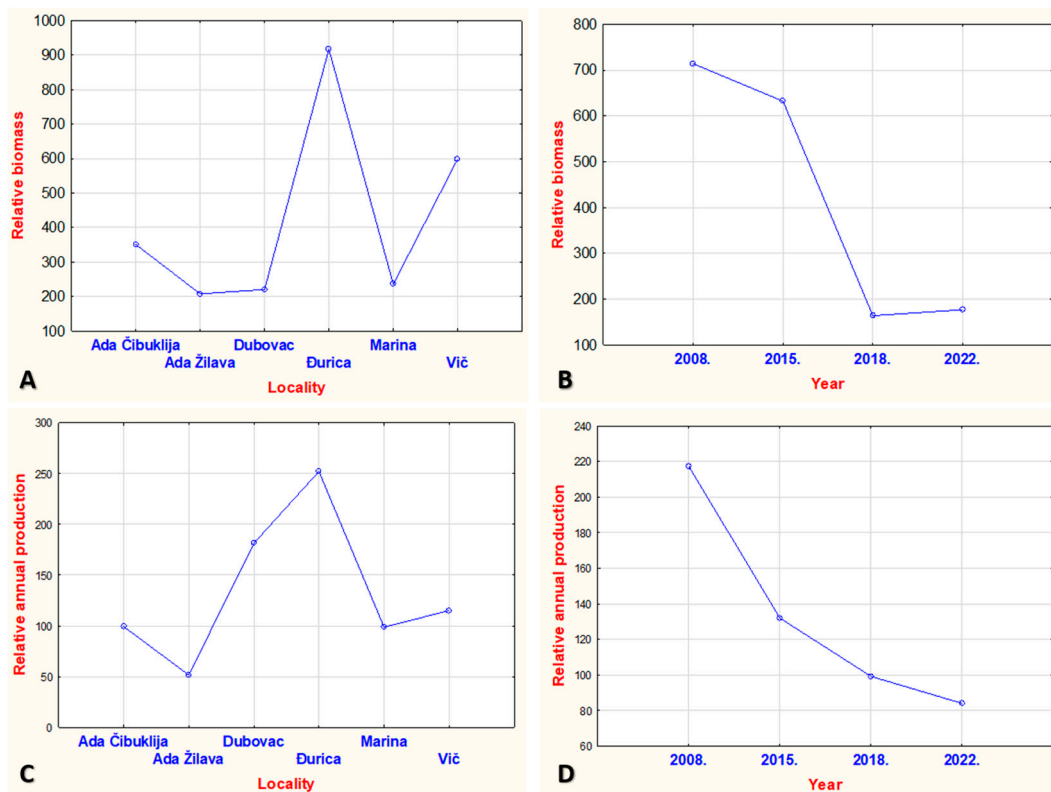
The percentage of the identified fish families in the total sample is shown in Figure 2. Besides taxonomic determination, the relative biomass and relative annual production were calculated as presented in Table 2.

When comparing relative biomass and relative annual production between the localities studied, no statistical significance was found using the ANOVA one way test (Figure 3, Wilkins lambda = 0.6157, F = 1.5696,  $p > 0.05$ ). The test shows no significance in differences between the studied localities, but it is obvious that the highest values of relative biomass were measured at the Đurica and Vič localities. The relative annual production was evenly distributed among the localities. Moreover, relative biomass and relative annual production were evenly distributed over the entire study period (Wilkins lambda = 0.6157, F = 1.7378,  $p > 0.05$ ), unfortunately with decreasing tendencies (Figure 3D).

Table 2. Results of variables analyses.

Family	Variables Species/Year	Relative Biomass (kg/h)				Relative Annual Production (kg/h)			
		2008	2015	2018	2022	2008	2015	2018	2022
Acipenseridae	<i>Acipenser ruthenus</i>		51.21	1.187			14.268		
Esocidae	<i>Esox lucius</i> ◇	46.35	71.524	15.119	1.667	23.600	49.488	31.725	
Cyprinidae	<i>Cyprinus carpio</i>	1.815	127.755	56.899	30.162	121.012	14.984	7.665	67.446
	<i>Carassius gibelio</i>	299.326	163.755	49.897	44.604		21.548	76.032	17.701
	<i>Carassius carassius</i>		2.669						
	<i>Barbus barbus</i>	3.956		2.51	1.43			0.152	0.937
Leuciscidae	<i>Leuciscus aspius</i> ◇	172.66	22.111	6.613	77.605	55.35		6.749	133.183
	<i>Rutilus rutilus</i>	43.149	10.927	16.61	0.059	6.624	1.204	9.227	
	<i>Scardinius erythrophthalmus</i>		9.42	3.928	10.34			0.935	5.675
	<i>Squalius cephalus</i>			4.827				7.413	
	<i>Vimba vimba</i>			0.778	0.83				0.198
	<i>Chondrostoma nasus</i>		16.815						
	<i>Alburnus alburnus</i>	48.916	3.022	31.052	0.81	19.804	0.767	8.653	0.013
	<i>Ballerus ballerus</i>								
	<i>Abramis brama</i>	3.085	166.57	1.646	1.325	2.995	62.179	0.304	0.167
	<i>Ballerus sapa</i>	2.44		1.884	0.406			0.298	0.394
Xenocyprinidae	<i>Ctenopharyngodon idella</i>		78.5		316.8				5.96
	<i>Hypophthalmichthys molitrix</i>		690.8				164.85		
Tincidae	<i>Tinca tinca</i>		5.495	3.267				2.773	
Gobionidae	<i>Pseudorasbora parva</i>	2.771	0.2	0.08	0.3	1.41		1.333	
Acheilognathidae	<i>Rhodeus sericeus</i>		0.222	0.33					
Percidae	<i>Gymnocephalus schraetser</i>	3.12	4.28						
	<i>Perca fluviatilis</i> ◇	5.352	13.253	5.461	0.142	0.452	5.244	1.655	
	<i>Sander lucioperca</i> ◇	90.398	128.156	11.886	5.175	23.436	33.485	12.854	0.975
	<i>Sander volgensis</i> ◇	5.707	2.42	5.425	2.23	3.561	2.972	2.241	0.431
Centrarchidae	<i>Lepomis gibbosus</i>	1.2		7.456		0.067	0.022	2.123	
Siluridae	<i>Silurus glanis</i> ◇	3.539		12.678	0.213		70.494		
Ictaluridae	<i>Ameiurus melas</i> ◇	46.885	49.993	11.03	0.659	15.992	0.204	3.65	
	<i>Proterorhinus marmoratus</i>			0.008					
	<i>Proterorhinus semilunaris</i>	0.533							
	<i>Babka gymnotrachelus</i>	3.848		6		4.079			
	<i>Ponticola kessleri</i>	1.002		3.998				5.07	
	<i>Neogobius fluviatilis</i>	7.192		2.23		4.407		1.281	
	<i>Neogobius melanostomus</i>	0.875		9.068			0.022	4.509	
	<i>Ponticola syrman</i>	3.1							
Total		799.025	1.704.13	271.968	496.847	282.789	451.246	186.602	233.336

Legend: ◇ sign represents piscivorous species.



**Figure 3.** (A) One-way ANOVA on investigated localities (statistical significance was not detected in distribution of relative biomass in investigated localities:  $F(5, 18) = 1.6447$ ,  $p = 0.19907$ , but it is evident that localities Đurica and Vič have higher values of the relative biomass compared to others. Using chi-square test, the inequality in relative biomass distribution per investigated localities was confirmed:  $\chi^2 = 3816.512$ ,  $df = 5$ ,  $p < 0.05$ ). (B) One-way ANOVA on relative biomass in the period of investigation (statistical significance was not detected, taking into account period of investigation:  $F(3, 20) = 2.8401$ ,  $p = 0.06388$ , but it is evident that in the year 2008 and 2015 higher values of relative biomass were detected. Using chi-square test, the inequality of the relative biomass distribution in investigation period was confirmed:  $\chi^2 = 3635.791$ ,  $df = 3$ ,  $p < 0.05$ , so it is evident that the relative biomass had a tendency to decrease in the last 14 years). (C) One-way ANOVA on relative annual production per investigated localities (statistical significance was not detected in distribution of relative annual production in investigated localities:  $F(5, 18) = 1.1067$ ,  $p = 0.39127$ , but it is evident that localities Dubovac and Đurica have higher values of relative annual production compared to others. Using chi-square, the inequality in distribution of relative annual production per localities was confirmed:  $\chi^2 = 775.2887$ ,  $df = 5$ ,  $p < 0.05$ ). (D) One-way ANOVA on relative annual production in period of investigation (statistical significance was not detected, taking into account period of investigation:  $F(3, 20) = 1.1360$ ,  $p = 0.35852$ , but it is evident that in the year 2008 and 2015, higher values of relative annual production were detected. Using chi-square, the inequality in relative annual production distribution was confirmed:  $\chi^2 = 485.8249$ ,  $df = 3$ ,  $p < 0.05$ , so it is possible to state that the relative biomass had a tendency to decrease in the last 14 years).

Statistical significance in the distribution of the biodiversity indexes was tested by the repeated ANOVA/MANOVA test and the  $\chi^2$  test. Both tests revealed no statistical significance in the above distribution (Wilkins Lambda = 0.33731,  $F = 1$ , 3446,  $p > 0.05$ ; Figure 4A). The highest values of the Simpson, Shannon, and Menhinik indexes were obtained (see Table 3).

The fish community studied was also analyzed using selected biotic indices, and the values obtained are shown in Table 3.

During the study period, no statistical significance in differences was found in the biodiversity indexes of each sampling site (Wilkins Lambda = 0.42723,  $F = 1.9298$ ,  $p > 0.05$ ;



Simpson:  $X^2 = 0.1830718$ ,  $df = 3$ ,  $p > 0.05$ ; Shannon:  $X^2 = 0.1501606$ ,  $df = 3$ ,  $p > 0.05$ ; Menhinik:  $X^2 = 0.0117812$ ,  $df = 3$ ,  $p > 0.05$ ; Figure 4B).

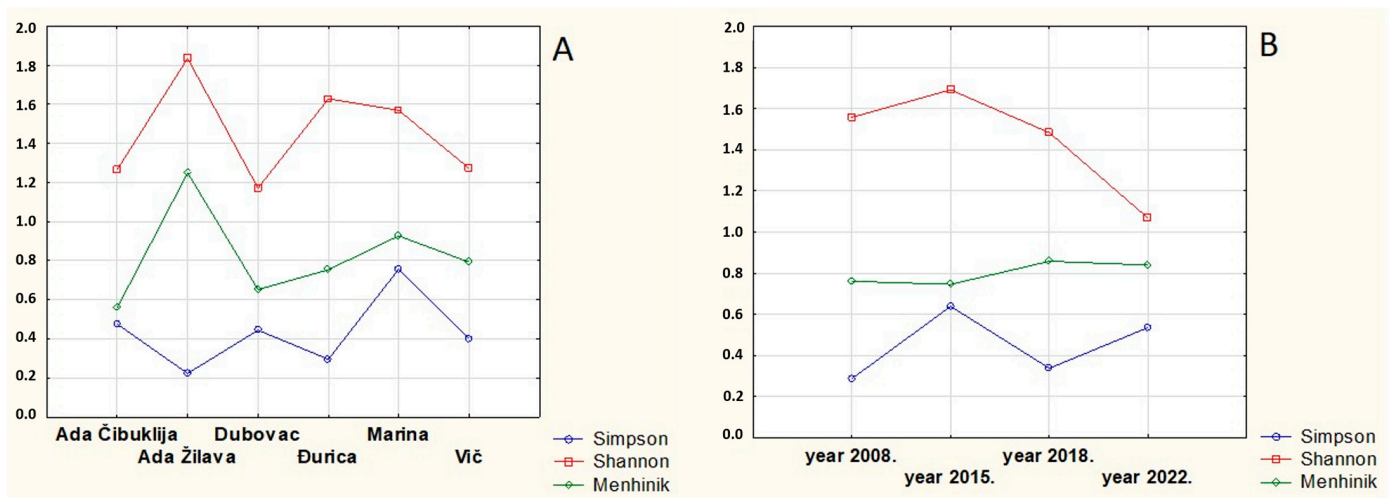


Figure 4. ANOVA/MANOVA test on the biodiversity indexes per investigated localities (A) and ANOVA/MANOVA test on the biodiversity indexes during the investigation period (B).

Table 3. Maximum, minimum, and average values of the biodiversity indices.

Biodiversity Index	Maximum	Minimum	Locality (Year)	Average
Simpson	0.7737	0.0905	Dubovac (2022), Ada Žilava (2015)	0.4420
Shannon	2.5770	0.5091	Ada Čibuklija (2015), Vič (2022)	1.4399
Menhinik	1.5950	0.4082	Ada Žilava (2022), Ada Čibuklija (2018)	0.8035

The contribution of predatory fish species (indicated in Table 2) in the total biomass was also calculated and presented in Figure 5.

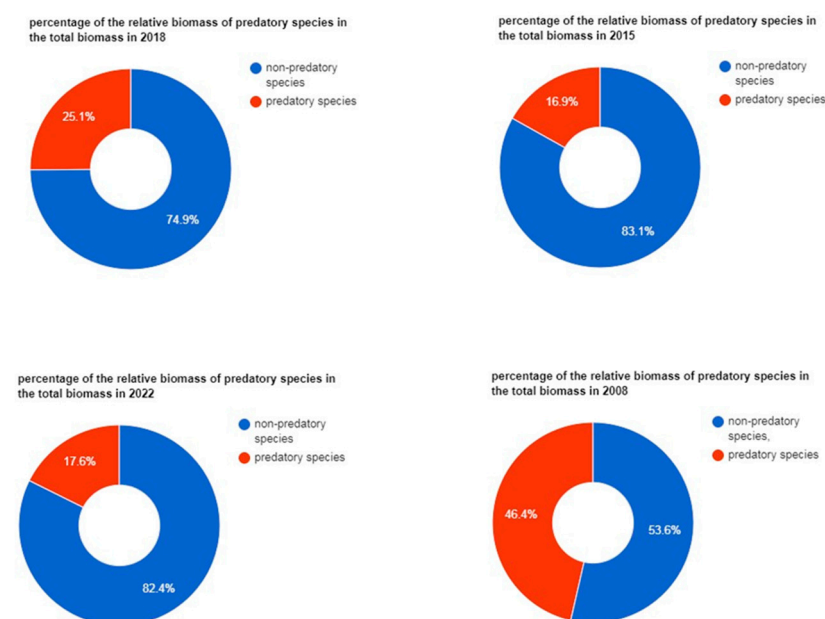
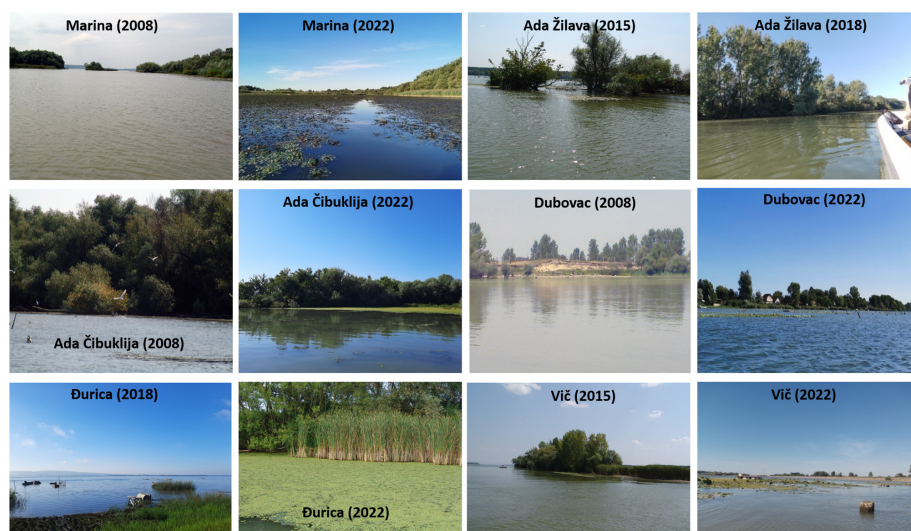


Figure 5. Changes in contribution of predatory species in fish community over 14 years.

#### 4. Discussion

Our results clearly show the declining trend of the two parameters of fisheries biology—relative biomass and relative annual production. Despite being an area declared a Ramsar site and protected since 2006, it has been evident over the last 14 years that biodiversity and natural production have shown a declining trend (Table 2; Figures 3 and 4). In addition, habitat destruction became evident (Figure 6), which affected the decline in biomass and natural fish production and is a similar prediction for the future. Comparing the state of fish biodiversity in terms of relative biomass and relative annual production with other similar studies, we can see that many other protected areas and Ramsar sites have the same problem [23]. As Figure 1 shows, the locality Đurica is a specific, almost isolated water area that is not subject to direct anthropogenic influence. Sudden changes in the water regime are of low intensity in this locality, which could be the reason for higher values of relative biomass and relative annual production compared to the other five localities [24]. In addition, the terrain at this site is favorable for controlling illegal fishing, which is one of the factors contributing to the decline in biomass in the entire Ramsar site [25].



**Figure 6.** The image of habitat destruction.

A comparison of the relative biomass and relative annual production of the studied sites (2008–2022) undoubtedly shows the trend of a decline in both ecological parameters. Encouraging factors are the fact that the relative biomass and relative annual production of alien and invasive species (Prussian carp *Carassius gibelio*, black bullhead *Ictalurus melas*) are significantly lower than before (Table 2). Even though the values of relative biomass and relative annual production of these species varied from site to site and still vary now (depending on the habitat types the sites represent), it can be seen that the values for biomass and production of Prussian carp in the 2018 samples are between three times (Marina) and ten times (Đurica) lower than in those of 2008 (Table 2). A similar ratio can be observed for the brown bullhead [26].

On the other hand, a significant increase in the proportion of autochthonous species, especially common carp (*Cyprinus carpio*), Wels catfish (*Silurus glanis*), and both pike-perch species (*Sander lucioperca* and *Sander volgensis*), as well as other cyprinids, leuciscids, and perch-like species in the fish communities, can be observed (Table 2). We strongly believe that such a trend is due to the increased influence of competitors within the fish community, especially the Prussian carp, without any direct targeted influence on its population size. This could be the reason for the stimulation of Prussian carp production. In another case, the targeted capture of Prussian carp aimed at reducing its abundance and biomass would stimulate its production and the occurrence of its invasiveness [27]. This effect is known

for pioneer and invasive species, especially if the habitats are suitable and do not change over time. Targeted capture of the Prussian carp would only favor clonal reproduction (gynogenesis), increase its production, and affect the existence of autochthonous species. Due to this effect, it is necessary to act in the same direction for at least a while longer by stocking common carp, whose increased production has a significant fishery effect in addition to the ecosystem effect, especially in commercial fisheries, which both commercial and recreational fishermen consider very positive [28].

Wetlands such as the Đurica pond, part of Marina, and Dubovac are ideal habitats for strictly protected species, the crucian carp *Carassius carassius* and the tench *Tinca tinca*, which are among the rarest fish species of the Danube ecosystem, not only because of the current limitation of their habitat distribution, but also because of the high abundances of allochthonous and, according to the characteristics of population biology, invasive species such as Prussian carp (*Carassius gibelio*) and bullhead, both brownhead and bullhead (*Ameiurus nebulosus* and *Ameiurus melas*) [29].

The changes in the ecosystem caused by the transformation of the river habitat (Figure 5) into water accumulations affect the relative biomass and relative annual production of carp as well as bream, but certainly also other fish species, especially native benthivores, in addition to crucian carp and tench. The introduction of non-native species such as Prussian carp, bullhead, Amur sleeper, gobies, etc. into a novel habitat undoubtedly leads to a change in fish community structure within the different trophic levels (planktivorous and benthivorous). This must have had an impact on natural production, as new, previously non-existent links in the food chains were created and this natural production was redistributed to new members of these communities [30].

In addition to the consequences for natural production resulting from trophic relationships, the advantages of the biological characteristics of individual non-native species in terms of reproduction should not be forgotten (gynogenesis in the Prussian carp, maintenance of the eggs and offspring of crucian carp, sunfish, and flounder, the absence of a free embryo and larval stage in the individual development of Pontus, variable morphology, the territoriality of the Amur sleeper, etc.) [30]. This leads to the community of these species having a highly invasive character, and it must affect the decrease in abundance or disappearance of steno-valent species, both Potamon and Rhytron, leading to dynamic instability of the population. In such disturbed communities within ecosystems that are themselves disturbed in their abiotic component, a decline in natural production is to be expected, especially for species that are less competitive in the new habitat type [31].

The second part of the study presents the calculation of biodiversity indexes comparing six studied sites during the monitoring period (Figures 4 and 5). The figure shows a decreasing trend of the diversity index, which is a clear indicator of habitat degradation, mainly due to the increase of vegetation cover, silt deposition, and the change of oxygen regime in such sensitive habitats. In addition, overfishing of attractive species can lead to a decline in biodiversity and an increase in the proportion of non-native species in certain locations and generally throughout the area [32]. Climate change and land development are having a major impact on freshwater habitats by altering flow patterns and increasing overall water temperature, which may lead to a decline in fish species that require cold or cool and/or flowing water for part or all of their life cycle [33].

After long-term and thorough research, the conclusion is that Labudovo okno must be preserved as a Ramsar site for numerous reasons, especially for its great biological and socio-economic importance.

For example, fishing was and remains one of the main types of use of the area. In addition to commercial fishing, today within the limits of the protected natural resource of limited capacity, sport fishing is also present, with much greater possibilities than currently used. In the interest of development aligned with the needs of nature protection and the enhancement of ecological tourism, it is necessary to stimulate traditional fishing methods.

The basis of hunting, which is also present in the area of Labudovo okno, is the abundance of water ornitofauna, the use of which is limited by the protection measures of the SNR “Deliblato Sands”.

Agriculture in the area is based on cattle and sheep grazing, for which there are natural conditions and a need in terms of preserving specific natural values. In the future, the focus on the breeding of old, autochthonous breeds may represent the basis of healthy food production, as well as a tourist attraction. Forestry takes place mainly on river islands, limited by protection measures, and agricultural production is present only on small plots and mainly based on extensive cultivation of cereals.

Favorable opportunities for the development of tourism are offered by the Danube with the edge of Deliblato Sands (hunting and fishing, watching and photographing birds, observing the spring and autumn migration of water birds, nautical tourism). Investing in tourist equipment, along with adequate promotion, should contribute to classifying tourism as one of the basic ones in future development aligned with the protection of natural values.

Labudovo okno is also used for scientific research (flora and vegetation, ornithology and herpetofauna, water quality), as well as education for biology students.

Based on the attached results of long-term research, and the established high biodiversity, it is necessary to take all measures for the preservation and sustainable development of Swan’s shaft as one of the most important Ramsar sites, not only in Serbia, but also in the region.

There is a noticeable decrease in the percentage of the biomass of predatory species in relation to the total biomass (Figure 5), and decline of the diversity indexes is also noticeable (Figure 4). Managing eutrophication by restoring wetlands could be much more cost efficient if the wetlands were designed to both reduce nutrients and function as recruitment areas for predatory fish [34]

The reduction of fish biomass of predator species to low levels may compromise the sustainability of fishing and support only relatively low economic yields [35].

## 5. Conclusions

Protected areas are the cornerstone of biodiversity conservation with the aim of preserving nature from anthropogenic threats. Despite being an area declared a Ramsar site and protected since 2006, it has been evident over the last 14 years that the biodiversity and natural production in the area of Labudovo okno have shown a declining trend. However, other factors are of course also influencing the impoverishment of biodiversity, and these are certainly global warming, habitat destruction due to climate change, and human influence, especially in the form of overfishing. After long-term and thorough research, the conclusion is that Labudovo okno must be preserved as a Ramsar site for numerous reasons, especially for its great biological and socio-economic importance. In addition to the concept of protecting these areas, other mechanisms should also be applied to preserve biodiversity.

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