Scientific Papers. Series D. Animal Science. Vol. LXVI, No. 1, 2023
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

UPDATED OVERVIEW OF MARINE FISH BIODIVERSITY: SCIENTIFIC SUPPORT FOR AN ECOSYSTEM-BASED MANAGEMENT OF THE DANUBE DELTA BIOSPHERE RESERVE

Victor NIȚĂ, Mădălina GALAȚCHI, Magda NENCIU

National Institute for Marine Research and Development "Grigore Antipa",
300 Mamaia Blvd, RO-900581, Constanta, Romania

Corresponding author e-mail: mnenciu@alpha.rmri.ro

Abstract

Fish biodiversity is a key indicator of the health of a waterbody and the structure and function of fish communities are considered good indicators of the ecological status of marine ecosystems. Therefore, the long-term assessment and the development of predictions regarding the size and productive capacity of fish populations are necessary, aiming at ensuring an ecosystem-based management of living resources. In the frame of the revision of the Danube Delta Biosphere Reserve Management Plan, an updated evaluation of fish species present in the marine zone (ROSCI0066) was performed. The scientific fishing (by survey trawling and gillnetting) revealed a rich ichthyofauna: 32 taxa, belonging to 21 families were identified. The species array is diverse, including both economically important fish (turbot, shads, anchovy, sprat) and species of high conservative interest (sturgeons), emphasizing the crucial importance of this area as feeding and spawning ground of Black Sea ichthyofauna.

Key words*: assessment, Danube Delta - Marine Zone, ecosystem-based management, fish biodiversity.*

INTRODUCTION

The Danube Delta is the second largest river delta in Europe. The Danube Delta Biosphere Reserve was created to conserve the area's unique diversity, both biological and cultural, comprising a wide variety of habitats, from wetlands, forests to Marine Protected Areas (MPAs). It has a triple international conservation designation: UNESCO World Heritage Site, Biosphere Reserve since 1990 and Ramsar site due to its importance for migratory birds (Gâștescu, 2021).

At European Union level, the Danube Delta is included in the Natura 2000 network, comprising several sites of Community importance: ROSPA0031 Danube Delta and Razelm - Sinoe Lagoon System, ROSPA0076 Black Sea, ROSCI0065 Danube Delta, and ROSCI0066 Danube Delta - Marine Zone (MEWF, 2016). The latter was the focus of this research, in the frame of the POIM Project "Revision of the Danube Delta Biosphere Reserve Management Plan and Regulation".

An updated overview of marine fish biodiversity in the marine zone of the Danube Delta was absolutely necessary in order to have a sound scientific background substantiating an ecosystem-based management of this MPA, all the more so as information in this area have been scarce and focused mainly on commercial species (Nicolae et al., 2014; Țoțoiu et al., 2018).

Marine biodiversity provides a multitude of valuable ecosystem goods and services and is valued for its direct utility to humans. Despite its important role and contribution to human wellbeing, its reduction has been reported worldwide. The main threats to marine biodiversity include habitat loss, overexploitation, pollution by hazardous substances, eutrophication, and invasions by non-indigenous species (Kappel, 2005; Venter et al., 2006). Restoring marine biodiversity through sustainable fisheries management, pollution control, maintenance of essential habitats, and the creation and better management of marine reserves are some of the opportunities for investments that can support the productivity and reliability of goods and services that the ocean provides to humanity (Palumbi et al., 2009).

Biodiversity includes four main components: (I) genetic diversity - which refers to the genetic variation that occurs among members of the same species; (II) species diversity -

which refers to the variety of species or other taxonomic groups in an ecosystem); (III) ecosystem diversity - which refers to the variety of biological communities found on earth; and (IV) functional diversity - which refers to the variety of biological processes, functions or characteristics of a particular ecosystem (Thorne-Miller, 1999). Species diversity is the basis for the diversity of higher taxa and ecological associations such as communities and biomes (Kiester, 2013).

The main objective applied in modern fisheries management is to maintain the diversity of species (II) within the marine ecosystem, since marine organisms contribute to many critical processes that have direct and indirect effects on the health of the oceans and humans (Steele et al., 2001).

The most widely used metric of biodiversity is species richness (Appeltans et al., 2012). Species richness is a fundamental property of any biotic assemblage (Foggo et al., 2003). Accurate estimates of richness, based on the presence or absence of species, can be performed; in turn, reliable correlations of abundance/dominance may be an addition to the potential value of such techniques in biodiversity inventory (Figure 1) (Simberloff & Moore, 1997).

Also, within the EU Marine Strategy Framework Directive (MSFD) the conservation status of vulnerable fish species has been selected as an appropriate measure to report information on the biodiversity of the marine environment, especially regarding the impact of fishing on diversity (Borges et al., 2010). The MSFD puts biodiversity in the center of the assessment of marine environmental status. The descriptor (D1) on biodiversity has the following target to contribute to the achievement of the Good Environmental Status (GES): "Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic, and climatic conditions" (Borja et al., 2010).

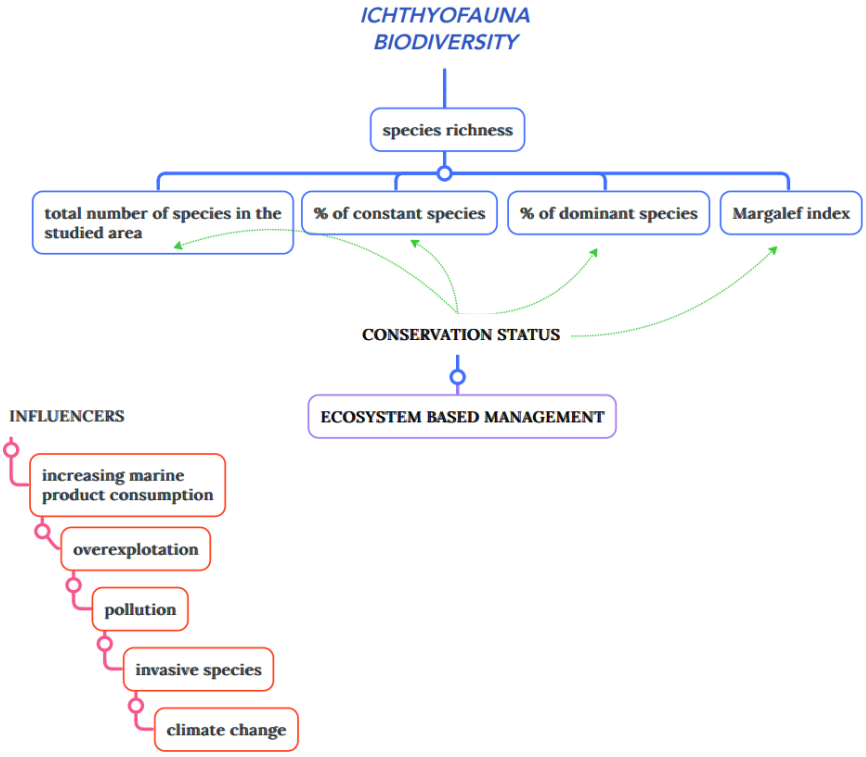

Figure 1. Ichthyofauna biodiversity scheme: components and influencers (*Original figure*)

Thus, the study of the ichthyofauna biodiversity is highly important and in recent years an increase in the number of marine species identified on the Romanian coast has been observed. In the last 10 years, 71 species of fish have been identified, of which 14.28% are rare species, 28.57% are dominant species and 57.15% are common species (Niță et al., 2022).

MATERIALS AND METHODS

In the frame of the revision of the Danube Delta Biosphere Reserve Management Plan, an updated evaluation of fish species present in the marine zone (ROSCI0066) was performed.

Scientific fishing

The inventory activity of marine fish species was carried out by organizing 6 scientific fishing expeditions, between October 2019 and September 2021.

The methodology and techniques that were used both for data collection, verification, processing and analysis, as well as for the assessment of fish biodiversity are those used in the Black Sea basin and in accordance with the most up-to-date international methodology (Carpentieri et al., 2020).

The scientific survey for the inventory of fish species was conducted with:

- the "Steaua de Mare" research vessel, equipped with specialized fishing gears: demersal and pelagic trawls (Figure 2).

Figure 2. Trawling activity (Original photo)

The trawl is a truncated cone-shaped fishing gear, equipped with its own arming system, towed with the help of a vessel by means of connecting elements (sweeps, wing-lines, bridles, trawl doors etc.). It can be towed either close to the seabed, targeting demersal species, or in the mid-water, targeting pelagic fish schools (Țoțoiu et al., 2017).

- motor-equipped pneumatic boat for gillnet survey fishing (Figure 3).

The gillnet is a net-type fishing gear consisting of a single net wall with a vertical operating position generated by reinforcements provided at the top (floats) and bottom (leads). Gillnetting is a fishing method by entangling and hooking, which consists in blocking the direction of movement of the fish with a vertical wall of netting, in the meshes of which the fish remains hooked and entangled when it tries to pass (Anton, 2016).

Figure 3. Gillnet fishing activity (Original photo)

During the scientific expeditions, observations were made regarding the marine species sampled during 85 trawling operations with the trawl and additional information was obtained from 12 stations where samples were taken with gillnets; nets of different mesh sizes were used, so that all types of habitats and depths were covered, and fish samples were analyzed both on board, but also in the laboratory.

Determination of fish species

For the systematic identification and classification of the collected individuals, the "*Determinator of the Main Fish Species of the Black Sea*" (Radu & Radu, 2008), as well as the updated fish biodiversity atlas (Niță et al., 2022) were used (Figure 4).

Length data

The total length was analyzed with the ichthyometer. Within a sample, the individuals

were assigned to length classes at a range of 50 mm (Figure 4b).

Weight data

The total weight of the individual was measured in grams using an electronic scale (Figure 4a).

Figure 4. Sample sorting onboard: a - fish length classes; b - weight measurement (Original photos)

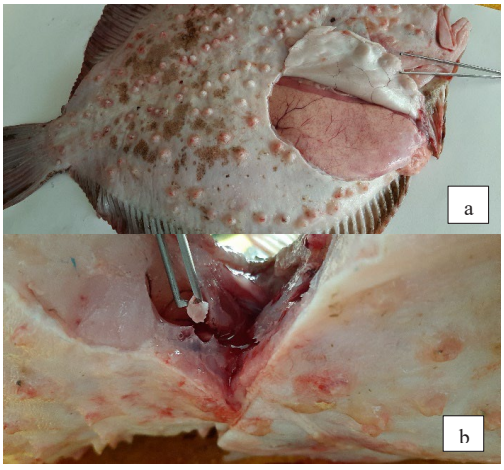

Figure 5. The study of individuals in the laboratory: a - gonad analysis; b - age reading (Original photos)

Gender identification data

To identify the sex, an abdominal incision was made, then the gonads were collected to be subsequently examined according to superficial vascularization, color, transparency, consistency and volume (Figure 5a).

Age reading

Age reading was performed by extracting the otoliths and subsequently analyzing them under a binocular microscope (Figure 5b).

Biodiversity indices

To estimate the species richness within the ichthyofauna, in the studied area, the Margalef Index was calculated (Magurran, 2004):

$$DMg = (S-1)/\ln N$$

where S is the number of species recorded in one sample and N is the total number of individuals (from all species).

It is considered that values <2 represent a low species diversity in the analyzed community and values <5 indicate a high species diversity (Magurran, 2004).

Also, other ecological indicators were analyzed: constancy and dominance (Gomoiu & Skolka, 2001).

Constancy (frequency) is an indicator that expresses the continuity of a species in a certain territory. It is a structural type of indicator, representing the percentage ratio between the number of samples in which a certain species appears and the number of analyzed samples. Depending on the value of constancy in the samples, the species can be divided into the following categories: C1 - accidental species, present in 1-25% of the samples; C2 - accessory species, present in 25.1-50% of the samples; C3 - constant species, present in more than 50.1% of the samples (Gomoiu & Skolka, 2001).

Dominance expresses the so-called relative abundance of a species, representing the ratio between the numbers of a certain species and the sum of the numbers of the other species in the studied area (Gomoiu & Skolka, 2001). Depending on the percentage value, the species are divided according to dominance into: D1 - underrepresented species, when the percentage is below 1.1%; D2 - recessive species, when

the percentage is between 1.2 - 2%; D3 - subdominant species, when the percentage is between 2.1 - 5%; D4 -dominant species, when the percentage is between 5.1 - 10%; D5 - eudominant species, when the percentage is > 10.1% (Gomoiu & Skolka, 2001).

RESULTS AND DISCUSSIONS

Ichthyofauna represents a basic component of marine biodiversity, and, according to bibliographic sources, the fish fauna of the Black Sea includes over 140 species and subspecies (Radu et al., 2008). Out of the 140 species of fish reported in the Black Sea, in the catches from the Romanian coast, as well as in the research expeditions carried out by the experts of NIMRD "Grigore Antipa" Constanța in the last decade 68 species of fish were identified (Niță et al., 2022).

Following the scientific fishing expeditions carried out in the marine zone of the Danube Delta (ROSCI0066) in the frame of the Management Plan revision project, 32 fish species were identified, belonging to 21 families, of which the three species of sturgeons (*Acipenseridae*) are of particular conservation importance (Figure 6).

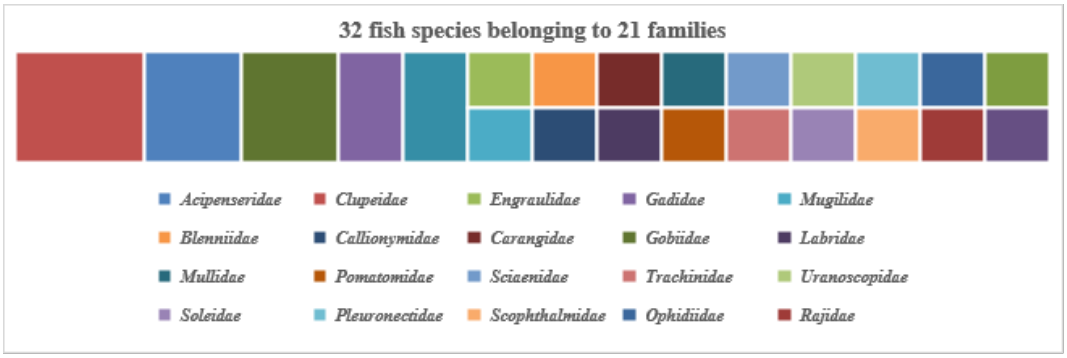

Figure 6. Treemap of fish species identified in the Danube Delta - Marine Zone during the study (2019-2021)

The state of conservation of plants and animals is one of the most used indicators for evaluating the state of ecosystems and their biodiversity. On a global scale, the primary source of information on the conservation status of plants and animals is the International Union for Conservation of Nature (IUCN) Red List of Species. This list is a powerful tool to inform and catalyze action to conserve biodiversity and change the policies essential to protecting the natural resources we need to survive. It also provides information on range, population size, habitat and ecology, use, trade, threats and conservation actions that will assist in making the necessary sustainable management decisions (IUCN, 2023).

Regarding the conservation status of the identified species, the 3 species of *Acipenseridae* are classified as Critically Endangered (CR). Another 5 species fall into the Vulnerable (VU) category and another 3 in the Data Deficient (DD) category (Table 1). All other fish species identified in the marine area of the DDBR are Least Concern (LC). Two other species of Community interest were also identified in the study area, one being included in the list of vulnerable species: *Alosa immaculata* (Table 2).

Table 1. Conservation status of the fish species identified in the marine zone of the Danube Delta

CR				
Huso huso	*Acipenser gueldenstaedtii*		*Acipenser stellatus*	
VU				
Alosa immaculata	*Pomatomus saltatrix*	*Umbrina cirrosa*	*Squalus acanthias*	*Dasyatis pastinaca*
DD				
Ophidion rochei	*Hippocampus guttulatus*		*Nerophis ophidion*	

Table 2. Species of Community interest identified in the study area

Specification	*Huso huso* (Linnaeus, 1758), Genus *Huso*, Beluga
N2000 Code	2489
	Acipenser gueldenstaedtii (Brandt & Ratzeburg, 1833), Genus *Acipenser,* Russian sturgeon
N2000 Code	5040
	Acipenser stellatus (Pallas, 1771), Genus *Acipenser*, starry sturgeon
N2000 Code	2488
	Alosa immaculata (Bennett, 1835), Genus *Alosa*, Pontic shad
N2000 Code	4125
	Alosa tanaica (Grimm, 1901), Genus *Alosa,* Azov shad
N2000 Code	4127

Regarding the application and analysis of biodiversity indicators for the study period, we used all the information collected during the scientific expeditions.

In the autumn expedition of 2019, observations were made in 20 stations and the values of Margalef Index (DMg) varied between 0.47 to 3.47 (Figure 7).

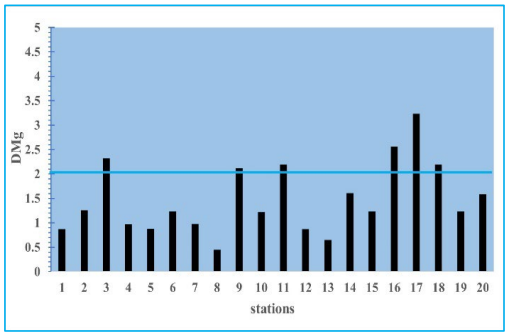

Figure 7. Margalef Index values in the 2019 survey

It is also observed that in several stations the values have exceeded the threshold value of 2, considered to indicate a moderate diversity of species in the study area.

Regarding the other indicators, the following results were obtained:

- whiting, sprat, Azov shad and piked dogfish = constant species (C3);
- gobies, horse mackerel and starry sturgeon = accessory species (C2);
- the other 11 species = accidental species (C1) (Figure 8).

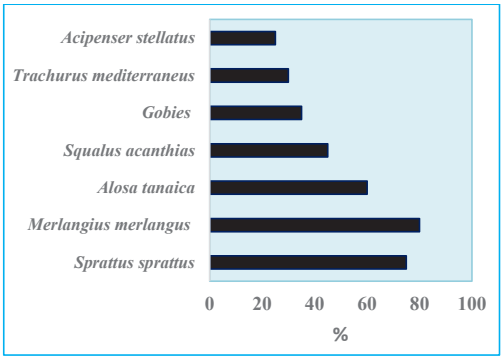

Figure 8. The representation of species (%) consistently identified in the samples during the 2019 survey

During the summer expedition of 2020, we analyzed samples from 13 stations. Thus, it was observed that the value of the Margalef index exceeded the threshold value in several stations, which indicates an increased diversity of species (Figure 9).

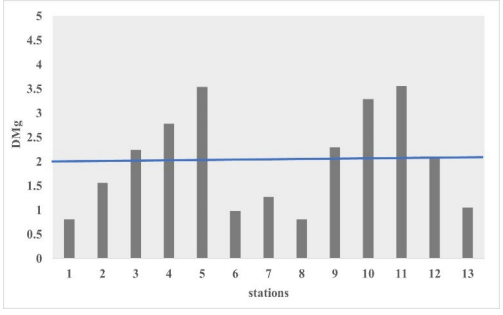

Figure 9. Margalef Index values in the summer 2020 survey

Regarding the constant presence of the species identified in the samples, it can be observed that whiting (*Merlangius merlangus)* had the highest value (Figure 10).

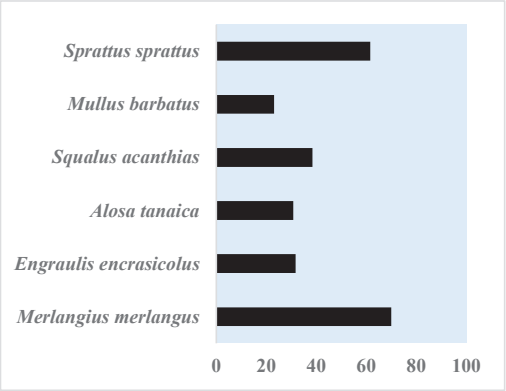

Figure 10. Representation of the constant species in the analyzed samples (summer 2020)

Two of the identified species had a high percentage of constant presence in the samples, the others registering lower values (namely sprat and whiting).
During the autumn expedition in 2020, samples from 18 stations were analyzed. The Margalef indicator had the highest value of 3.58 in one of the sampling stations (Figure 11).

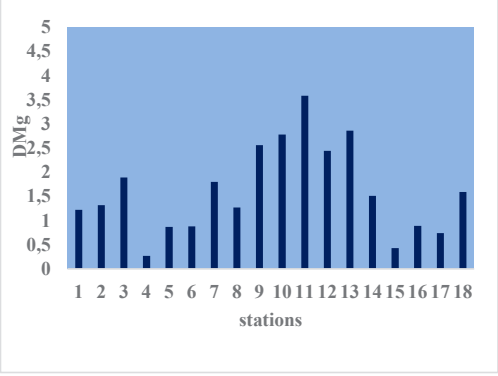

Figure 11. Margalef Index values in the autumn 2020 fishing survey

Analyzing the presence of species, it was observed that the species with the most constant presence was the horse mackerel (*Trachurus mediterraneus)* in more than 30% of stations (Figure 12).

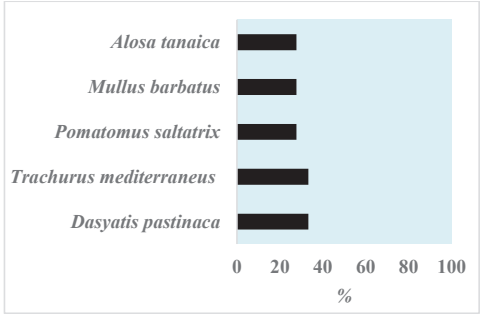

Figure 12. The graphic distribution of the constant species in the analyzed samples (autumn 2020)

Regarding the spring expedition in 2021, we analyzed samples from 10 stations. The Margalef indicator had values above the threshold value in approximately half of the analyzed stations (Figure 13).

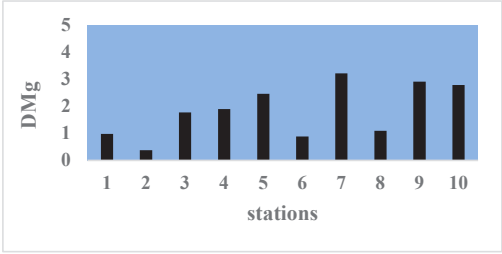

Figure 13. Margalef Index values in the spring 2021 survey

Regarding the species presence in samples, whiting was present in all the stations (Figure 14).

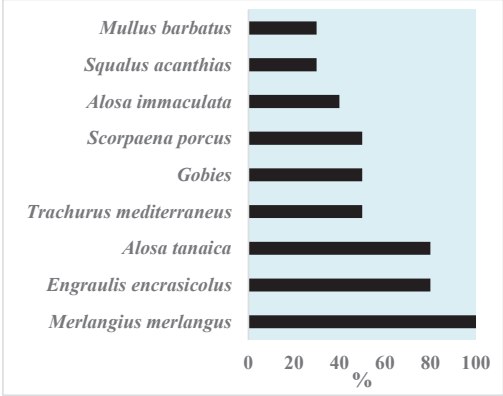

Figure 14. Representation of the constant species in the analyzed samples (spring 2021)

Also, other two species registered a very good presence in the samples (80%): anchovy (*Engraulis encrasicolus*) and Azov shad (*Alosa tanaica*) (Figure 14).
During the summer survey of 2021, observations were made from 16 stations (Figure 15).

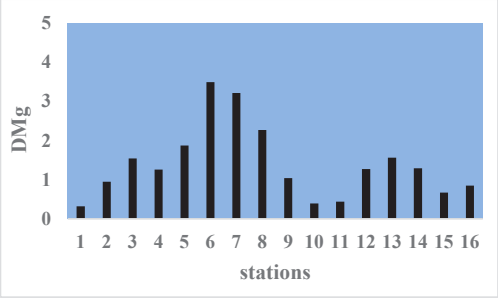

Figure 15. Margalef Index values in the summer 2021 survey

In this expedition the diversity indicator registered values which show a high diversity of fish species in the analyzed area. 22 species of fish were identified during the survey.
Regarding the presence in the analyzed samples, the sprat (*Sprattus sprattus*) was the most constant species (Figure 16).

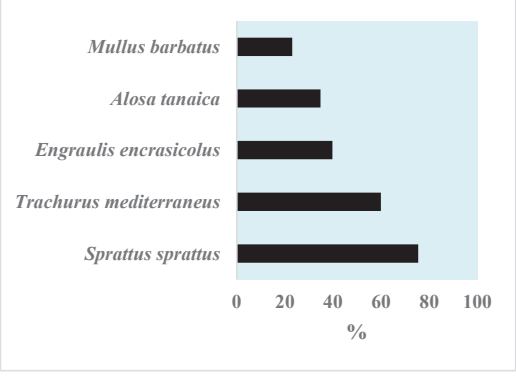

Figure 16. Representation of the constant species in the analyzed samples (summer 2021)

Regarding the autumn expedition in 2021, observations concerning the fish species diversity, were made from 8 stations (Figure 17).

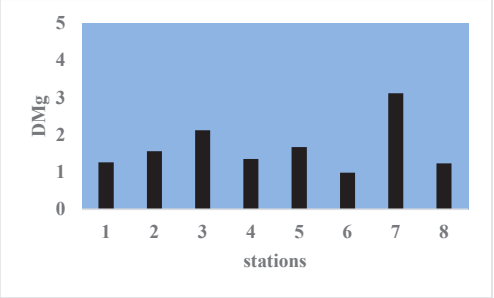

Figure 17. Margalef Index values in autumn 2021 expedition

During this expedition, lower values of the diversity indicator were observed.
Referring to species presence in the analyzed samples, it was observed that sprat and horse mackerel consistently prevailed (Figure 18).

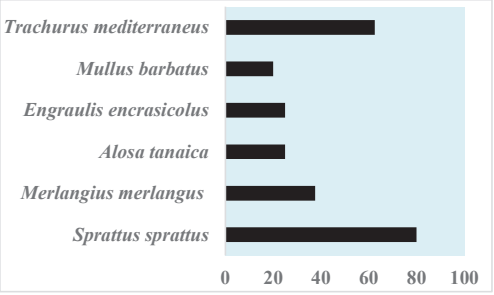

Figure 18. The graphic distribution of the constant species in the analyzed samples (autumn 2021)

As regards the dominance indicator, for the entire study period, the presence of 5 species in the eudominant category and 3 species in the dominant category was highlighted, the rest of the species belonging to the other categories (Table 3).
Among the eudominant species the prevalence of small commercial interest species is to be remarked.
Moreover, the dominance of the species in the samples varied depending on the season in which the scientific expedition was carried out.
In the spring fishing season, sprat and Azov shad predominated in higher percentages, while in the summer season the percentage of anchovies increased, and in the winter season, horse mackerel was dominant.

Table 3. List of species according to the category of dominance indicator

D1 - underrepresented (<1.1%)	D2 - recessive (1.2-2%)	D3 - subdominant (2.1-5%)	D4 - dominant (5.1-10%)	D5 - eudominant (> 10.1%)
Huso huso	*Clupeonella cultriventris*	*Neogobius melanostomus*	*Alosa immaculata*	*Sprattus sprattus*
Acipenser gueldenstaedtii	*Gobius niger*	*Pegusa lascaris*	*Squalus acanthias*	*Merlangius merlangus*
Gaidropsarus mediterraneus	*Symphodus rostratus*	*Platichthys flesus*	*Pomatomus saltatrix*	*Engraulis encrasicolus*
Chelon auratus	*Trachinus draco*	*Scophthalmus maeoticus*	*Mullus barbatus*	*Alosa tanaica*
Parablennius tentacularis		*Dasyatis pastinaca*		*Trachurus mediterraneus*
Callionymus pusillus		*Scorpaena porcus*		
Aphia minuta		*Acipenser stellatus*		
Umbrina cirrosa				
Uranoscopus scaber				
Ophidion rochei				
Hippocampus guttulatus				
Nerophis ophidion				

Two of the sturgeon species (beluga and Russian sturgeon) were underrepresented, while starry sturgeon was subdominant. Other subdominant species include turbot, stingray and gobies, which are also important for commercial fisheries. The rare species (E.g. *Symphodus rostratus, Trachinus draco, Umbrina cirrosa, Uranoscopus scaber, Ophidion rochei, Hippocampus guttulatus* etc.) were either recessive or underrepresented, yet their presence in the catches accounts for a rich biodiversity of the investigated area.

Scientific support for an ecosystem-based management of the Danube Delta - Marine Zone

The information collected during the study regarding the species richness, indicators of diversity, the constant presence of some species in certain areas and periods, are the basis for the initialization of an ecosystem-based management of the Danube Delta Biosphere Reserve, in the frame of the revised Management Plant, which is currently under official approval.

Ecosystem-based management (EBM) is place-based, considers connections within and among ecosystems (including a balanced and integrated view of social and natural components), and focuses on maintaining the long-term ability of ecosystems to deliver a range of services (Grumbine, 1994). A shift to EBM requires management actions across a range of spatial scales and attention to connections among spatial as well as governance units. The revision of the Danube Delta Management Plan is an optimal occasion to include specific conservation measures aiming at fostering the fish biodiversity of the area.

Given the high richness of ichthyofauna in the analyzed area (32 species), as well as the presence here of vulnerable and critically endangered species, it is aboslutely necessary to apply specific measures aiming to maintain the balance within the Danube Delta - Marine Zone (ROSCI0066).

Whereas the major themes covered by the **revised Management Plan** are biodiversity conservation and management (species and habitats of conservative interest) and detailed biodiversity inventorying and monitoring, the measures proposed focus in two directions: conservation activities and prohibitive measures.

Fish conservation activities include: enforcement of stricter fishing regulatory measures in ROSCI0066 (mesh size, number of gears, thread fineness etc.); ensuring compliance with the turbot fishing prohobition period and the provisions regarding permitted gear and the minimum size of retained specimens; permanent monitoring and control of the commercial fishing activity in ROSCI0066 in order to ensure the accuracy of data from the fishery for the correct estimation and management of stocks; facilitation and implementation of "ghost net" fishing practices; promotion and stimulation (including financial) of mollusk fishing and harvesting using low-impact gears; inventory and monitoring of conservative interest fish species.

Restrictive measures, on the other hand, include: total ban on fishing for the three species of sturgeons throughout the year (except for fishing for scientific purposes and, in this case, with their immediate release in a viable state); prohibition of commercial fishing for Pontic shad (*A. immaculata*) throughout the year in front of the mouths of the Danube (in accordance with the annual prohibition orders); prohibition of the use of the beam trawl and the classic hydraulic dredge in the territory of ROSCI0066 below the 20 m isobath; between the 20 - 40 m isobaths, their use will be allowed only by alternating in time and space the perimeters subject to the impact with perimeters of biological recovery, following the completion of specialized studies; only small low-impact hydraulic or hand-operated dredges are proposed to be allowed (Niță et al., 2021); ban on the use of the pelagic trawl in ROSCI0066 below the 20 m isobath; ban of the deliberate introduction into ROSCI0066 of invasive species.

All proposed measures are in line with the applicable fisheries legislation in Romania and were openly debated with stakeholders within a participatory approach process.

CONCLUSIONS

During the analyzed period, 32 fish species were identified as a follow-up of scientific fishing. Regarding the conservation status of the identified species, the three species of *Acipenseridae* are classified as Critically Endangered (CR), another five species fall into the Vulnerable (VU) category and another three in the Data Deficient (DD) category.

Biodiversity indices were calculated and, as respects of Margalef Index values, these ranged from 0.32 - 3.58, indicating a high fish diversity in certain stations. Regarding the information obtained in the study concerning the presence of some species in the samples, the constant presence of some species of commercial interest was highlighted (sprat, horse mackerel, anchovy). However, a constant presence in the samples of some vulnerable (dogfish) or threatened species (starry sturgeon) was also observed.

Referring to the dominance indicator, only five species were eudominant (sprat, whiting, anchovy, Azov shad, horse mackerel and red mullet) and three species were dominant (Pontic shad, dogfish and bluefish). Other species were identified in lower percentages, yet the fish fauna array of the Danube Delta - Marine Zone indicates a high diversity.

All the information acquired regarding fish species richness, indicators of constant presence and dominance are the scientific background for the newly revised Management Plan of the Danube Delta Biosphere Reserve, which contains the proposed targeted measures (both conservative and restrictive) aiming at ensuring an ecosystem-based management of marine fish resources in the area.

ACKNOWLEDGEMENTS

This study was carried out in the frame of the POIM Project "Revision of the Danube Delta Biosphere Reserve Management Plan and Regulation", SMIS Code 123322, Contract Number 253/18.06.2019.

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