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Mapping Sturgeon Foraging Areas in the North-Western Black Sea: Scientific Support for the Sustainable Management of Marine Resources

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Abstract: The study of fish diet composition can provide valuable information on the ecology and ethology of wild populations, even more so in the case of endangered species such as Black Sea sturgeons. The area off the Danube mouths (Western Black Sea shelf, Romania) represents a traditional feeding ground of the family Acipenseridae. At the same time, in recent years, the marine zone of the Danube Delta has become targeted by beam-trawl fisheries of the invasive gastropod *Rapana venosa*, with a potential destructive impact on benthic habitats. In this context, the present study aimed at mapping of sturgeon foraging areas in order to propose appropriate management measures. Zoobenthos samples and stomach contents were analysed in order to identify the feeding preferences of the three sturgeon species investigated (*Huso huso, Acipenser gueldenstaedtii* and *Acipenser stellatus*). Stomach contents samples were collected from 15 individuals using the non-invasive technique of gastric lavage. Zoobenthos samples were taken from the same sampling points, as well as from the established zoobenthos sampling area covering the 20–40 m isobath of the Danube Delta – marine zone (ROSCI0066). The study revealed that *A. gueldenstaedtii* prefers food items belonging to the group Bivalvia, *H. huso* mostly feeds on fish and molluscs while, in *A. stellatus*, the highest dominance was achieved by polychaetes. Overall, a high dominance of polychaetes was recorded in both zoobenthos samples and sturgeon stomach contents, with the highest Index of Relative Importance (IRI – 45.60%) in *A. stellatus*. The study indicated that food availability played an important role in fish diet selection. Fish also recorded a high IRI (23.90%) in the food array of the three sturgeon species, while molluscs recorded an IRI of 13.90%. The identified foraging areas were subsequently mapped using a GIS software, ultimately aiming at providing a sound scientific background for an ecosystem–based management of these valuable species, taking into account the potential impact of invasive fishing methods (beam-trawling) on the feeding habitats of sturgeons.

Key words: foraging grounds; sturgeons; beam-trawling; conservation; Black Sea

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Introduction

Sturgeons belong to the class Actinopterygii, the order Acipenseriformes and the family Acipenseridae (Birstein 1993). According to the worldwide sturgeon reassessment report released by the International Union for the Conservation of Nature (IUCN), all 26 of the world's surviving sturgeon species are now in danger of extinction. In the IUCN Red List, 17 species are now classified as Critically Endangered, three are Endangered and five are Vulnerable (IUCN 2022). All sturgeon species in the Black Sea are of significant biological and economic importance; for centuries, sturgeons have been economically valuable for their meat and eggs (caviar) (Moghadam et al. 2009).

In the past 50 years, sturgeon populations have shown a massive decline due to the exploitation of stocks and irrational, excessive fishing and construction of dams impeding their migration. Moreover, by-catches and poaching contributed to this severe status. In order to improve this situation and to reverse the population trend, the countries of the Black Sea basin issued national regulations and imposed fishing bans (Friedrich et al. 2018). The first country that imposed restrictions was Türkiye in 1997 (Akbulut et al. 2011), followed by Romania in 2006, Serbia and Ukraine in 2009, and Bulgaria in 2011 (Reinartz et al. 2012). Sturgeon populations are also protected at the international level. The Sturgeon Action Plan was adopted in 2005 in the frame of the Bern Convention and was ratified by all Danube countries. Measures were taken at the national and the international level, including sturgeon fishery bans and restocking programs. The current protective international legislation includes the Convention on International Trade with Endangered Species, Bern Convention, Convention on the Conservation of Migratory Species of Wild Animals, Convention on Biological Diversity, Ramsar Convention, Black Sea Commission – Black Sea Convention on the Protection of the Black Sea against pollution and EU Habitats Directive. Nevertheles, the status of sturgeon populations has declined dramatically (Sandu et al. 2013).

Recent studies have indicated a strong sensitivity of sturgeon populations to environmental changes, having a negative impact on reproduction, maturity age and spawning frequency. Changes at the population level have also confirmed that sturgeons are highly vulnerable to commercial fishing, and stock recovery is a very slow process (Jarić et al. 2010). In the Danube Delta marine zone, three sturgeon species have been documented: beluga sturgeon *Huso huso* (Linnaeus, 1758), Russian sturgeon *Acipenser gueldenstaedtii* (Brandt & Ratzeburg, 1833) and starry sturgeon *Acipenser stellatus* (Pallas, 1771); all they are Critically Endangered (Niță et al. 2022).

An important component of ecology is represented by the mapping and identification of foraging habitats for aquatic organisms, mainly for biodiversity conservation. Research on the feeding process of wild fish and the selectivity of food groups is essential for understanding the foodweb within aquatic ecosystems. Knowing the distribution of food sources and mapping the habitats allow in time to identify the components and their interrelationships within the trophic web, but also to protect these essential habitats from anthropogenic impact. Literature sources (Lebreton & Beamish 1998, Bănățean-Dunea et al. 2015) suggest that sturgeons, especially juveniles, are benthic-feeders and prefer soft-bodied benthic organisms. The preference for the food array is different from one species to another but it also depends on the type and availability of food items in the respective habitat.

Huso huso feeds mainly on invertebrates of the groups Harpacticoida, Cumacea, Nematoda, Polychaeta and Mollusca as well as on fishes. In the Danube, juveniles feed mainly on Gammaridae, later on Crustacea and insect larvae. Adults feed on molluscs, crustaceans and fish (anchovy, mullet, turbot, whiting, gobies) (Radu et al. 2008, Niță et al. 2022).

Regarding *A. gueldenstaedtii* in the Danube, the fry feed on Crustacea and Chironomidae; adults feed on larvae of Ephemeroptera as well as on crustaceans and fish. In the sea, adults feed on molluscs, crustaceans, polychaetes and fish (Radu et al. 2008, Niță et al. 2022).

Juveniles of *A. stellatus* feed on larvae of Chironomidae, Trichoptera, Ephemerida as well as on crustaceans while adults feed on invertebrates belonging to the groups Mollusca, Crustacea, Polychaeta, Amphipoda, Cumacea as well as on fish (Radu et al. 2008, Niță et al. 2022).

As sturgeon species are protected, they can no longer be fished commercially or recreationally; this legally excludes most opportunities to examine their stomach contents (Haley 1998). For this reason, less invasive methods are used for the determination of stomach contents, such as gastric lavage. This is a difficult method because sturgeons are physostomic fish – they have swim bladders directly connected to the gastrointestinal tract and the entrance to the pneumatic canal is dangerously close to the end of the oesophagus and at a distinct curve of the digestive tract (Haley 1998). Although gastric lavage methods have been improved recently, they remain limited due to concerns about the excessive handling required and subsequent risk to the organism (Jason & Malcolm 2010). Colon lavage is a promising approach (Hoover et al. 2007, Usvyatsov et al. 2012) but obtaining representative samples without injury remains a challenge. Therefore, it is rather difficult to determine even the general locations and time of the year when sturgeon feed (Usvyatsov et al. 2012), yet a connection with zoobenthos composition in the potential habitats can be made.

The area off the Danube mouths represents the Danube Delta Marine Zone, which is a part of the Danube Delta Biosphere Reserve and the Marine Protected Area under the Habitats Directive ROSCI0066. It is located on the Western Black Sea shelf, Romania, and represents a traditional feeding ground of the family Acipenseridae (Holoştenco et al. 2013). In recent years, however, this area has become targeted by beam-trawl fisheries for the invasive gastropod rapa whelk *Rapana venosa* (Valenciennes, 1846), with a potential destructive impact on benthic habitats. In 2013, the use of the towed fishing gear beam-trawl for the industrial exploitation of *R. venosa* was legalized in Romania. Since then, these fishing gears have been extensively used in the central and northern areas of the Romanian coast, on sandy and muddy substrates (Danilov et al. 2019), typically used by sturgeons for foraging (Holoştenco et al. 2013).

The use of this fishing gear in the feeding habitat of sturgeons can have a negative impact on the zoobenthic populations within these soft-bottom areas and, consequently, on sturgeon population restoration trend. Therefore, the use of beam trawling in this protected area should be clearly regulated. Without additional data, it is difficult to assess the relative impact on sturgeons of actions that disturb the benthic fauna, such as dredging, bottom-trawling, sand or gravel mining, yet the destruction of their foraging habitats is undoubtable, posing a major potential threat on their conservation status.

In this context, our study aimed at mapping sturgeon foraging areas in the Danube Delta – Marine Zone, in order to propose appropriate management measures by analysing both stomach contents and zoobenthos samples from the area.

Materials and Methods

Study area

During 2019–2022, six scientific fishing surveys were performed using *Steaua de Mare 1* research vessel (R/V) of the National Institute for Marine Research and Development "Grigore Antipa" and the "Kingfisher" pneumatic boat. The surveys aimed at assessing the overall fish biodiversity of the area in the frame of the Revision of the Danube Delta Biosphere Reserve Management Plan. The investigated area comprised the extended part of ROSCI0066 Danube Delta Marine Zone, between the 20 and 40 m isobaths (Fig. 1).

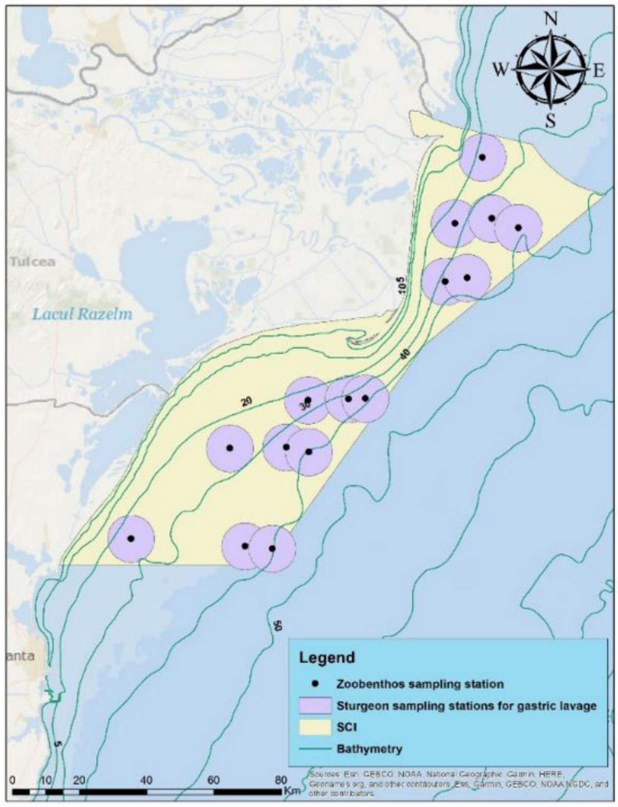

Fig. 1. Scientific fishing and zoobenthos sampling area – Danube Delta Marine Zone (ROSCI0066), Romania. Map by George Harcotă.

Fish collection

The fishing gears used were the demersal trawl (operated from the R/V) and nets deployed from the pneumatic boat, i.e. gillnets (mesh size a = 32 mm, height = 4 m, length = 95 m) and trammel nets (mesh size a = 32 mm, height = 3.20 m, length = 95 m). During these fishing operations in the Danube Delta – Marine Zone (depth 20–40 m) (Fig. 1), 15 sturgeon individuals were by-caught and subjected to the non-invasive method of gastric lavage, being subsequently released back safely into the wild. Additional zoobenthos samples were collected from the same locations where the sturgeons were caught, to complement the established zoobenthos sampling network (between 20 m and 40 m isobaths) of the same area. The examined 15 sturgeon individuals were as follows: two *A. gueldenstaedtii*, four *H. huso* and nine *A.*

Fig. 2. Sturgeon by-catches used for stomach content analysis (NIMRD original photos).

Table 1. Biometric and gravimetric measurements performed on the by-caught sturgeon individuals (total length and weight).

No	Scientific name	Lt (cm)	Weight (g)
1	*A. gueldenstaedtii*	135.00	5,234
2	*A. gueldenstaedtii*	98.00	3,822
3	*H. huso*	78.30	2,423
4	*H. huso*	89.50	4,452
5	*H. huso*	108.00	5,490
6	*H. huso*	109.00	5,975
7	*A. stellatus*	95.20	2,770
8	*A. stellatus*	105.30	3,230
9	*A. stellatus*	93.30	1,830
10	*A. stellatus*	100.50	3,240
11	*A. stellatus*	56.20	347
12	*A. stellatus*	64.20	890
13	*A. stellatus*	89.20	1,900
14	*A. stellatus*	83.40	2,250
15	*A. stellatus*	69.60	978

stellatus (Fig. 2 left). Biometric and gravimetric measurements were performed on all by-caught individuals (Table 1). All fish were placed in seawater tanks provided with aeration and subjected to gastric lavage immediately onboard in order to ensure animal welfare and good survivability after the procedure (Fig. 2, right).

Gastric lavage and stomach contents analysis

To investigate the stomach contents of sturgeons without jeopardizing the integrity of the specimens in any way, gastric lavage was performed, by adapting internationally agreed methods (Haley 1998, Brosse et al. 2002, 2000). A plastic jar was used for collecting stomach contents. A catheter was carefully maneuvered through the oesophagus until it reached the beginning of the first gastric loop. The catheter was securely attached to a wash bottle, which was maneuvered to deliver a flow of seawater into the sturgeon's digestive tract. The flow of seawater forced the stomach contents into the collection jar. The entire procedure, from removing the fish from the fishing gear until the release back to the sea, took between 3 and 7 minutes, depending on the size of the fish as well as the amount of food in the gut (Brosse et al. 2002, 2000). The lavage proper took approximately 30 seconds per specimen. After the procedure, all fish were safely released into the wild (Fig. 3). The stomach content samples were then preserved in 4–10% formaldehyde solution, being later analysed in the laboratory.

Two methods were used for stomach content determination in the laboratory: qualitative and quantitative. The qualitative analysis consisted in the complete identification of the food components present in the fish's stomach. The quantitative method consisted of numerical analysis and the calculated parameters were: Frequency of Occurrence (FO%), Dominance and Index of Relative Importance (IRI).

The Dominance (D_i%) was calculated as the share of fish stomachs dominated by a certain prey type and expressed as a percentage of the total number of stomachs analysed.

$D_i\% = D_i/D_t \times 100$

where D_i is the total number of taxa of a group and D_t is the total number of taxa identified in the stomach contents.

The Frequencies of Occurrence (FO%), as numerical percentages of prey items, were calculated to characterize the stomach contents (Hyslop 1980, Hansson 1998). The Frequency of Occurrence calculates the percentage of the total number of stomachs, in which the specific prey species occurs, using the formula below:

$FO\% = FO_i/ FO_t \times 100$

Fig. 3. Gastric lavage performed for stomach content analysis and safe release of sturgeon individuals (NIMRD original photos).

where FO_i is the number of stomachs in which the species “i” occurs, and FO_t is the total number of stomachs analysed.

The Index of Relative Importance (IRI) is an integration of measurements of number, weight, and frequency of occurrence to assist in evaluating the relationship of the various food items found in the stomach. It is calculated by summing the numerical and gravimetric percentage values and multiplying with the frequency of occurrence percentage value (Ahlbeck et al. 2012):

$$IRI_i = (\%N_i + \%W_i) * \%FO_i$$

where N_i, W_i and FO_i represent percentages of number, weight and frequency of occurrence of prey “i“, respectively.

To estimate the importance of diet comparisons among species, IRI was standardized to % IRI (Cortés 1997).

Collection and identification of zoobenthos

The zoobenthos samples were taken with a Van Veen grab with an area of 0.1 m^2, according to the methodology agreed at the regional level (Fig. 4 left) (Todorova & Konsulova 2005). On board the vessel, each sample was washed through a 0.5 mm granulometric sieve, stored in a 5-l plastic bucket and preserved with formaldehyde solution between 4–10%. In the laboratory, each sample was washed through granulometric sieves with mesh sizes of 1.0 mm and 0.5 mm. The sorting was done using the OLYMPUS SZX10 stereomicroscope – zoom 0.63x – 6.3x, the organisms being identified at the species or at the group level and then counted (Fig. 4, right). For abundance (density) calculation, the quantitative data from samples were extrapolated to square meter (ind./sqm).

Fig. 4. Zoobenthos sample collection and laboratory analysis (NIMRD original photos).

Statistical analysis, georeferencing and data visualization

The data obtained were statistically processed using Microsoft Excel and PRIMER®v.7. Shade plots**,** which represent multivariate analysis that sometimes can fashion clear community structures, characterizing responses of individual (or groups of) species across the sample, were also obtained by using the PRIMER software (Clarke & Gorley 2015). For data visualization, the densities of the most important groups of benthic invertebrates were transposed into GIS, resulting in maps of potential foraging areas for sturgeon species. For geographical positioning, a GIS class Leica model Zeno 20 Professional equipment was used, having sub-centimetre measurement accuracy and the Leica Zeno Field – OEM ArcPad 10 field-data collection application, compatible with the GIS system offered by ESRI. The ArcGIS Desktop Advance 10.7 system was used to process the data in shapefile format, create the geodatabase and generating the maps. The distribution maps of the feeding habitats of the sturgeon species were made by interpolating the point values using own ArcGIS tools ("Spline with barrier") resulting in a raster with a resolution of 500 m.

Results

The qualitative and quantitative analysis of the stomach contents of the 15 sturgeon specimens revealed that the food array for *A. gueldenstaedtii* was dominated by the Bivalvia. The food elements identified from the stomach contents of *H. huso* were mostly fish and individuals of the Bivalvia. The diet of *A. stellatus* was dominated by individuals of the groups Polychaeta and Crustacea (Table 2, Figs. 5 and 6).

As a result of the analysis of the Frequency of Occurrence (FO%) of food items in the 15 gastric lavage samples, the most consumed food element was represented by Crustacea (Decapoda), followed by fish. Individuals from the groups Polychaeta and Bivalvia were identified in 40% of all analysed samples (Table 3). The Frequency of Occurrence% (FO), Index of Relative Importance (IRI) and %IRI of the main groups identified in sturgeon stomach contents are presented in Table 3.

From the analysis of the dominant food items from the 15 gastric lavage samples and zoobenthos samples, the following aspects were noted:

In the two gastric lavage samples obtained from the species *A. gueldenstaedtii*, the presence of bivalve molluscs in a share of 76.81% was noted, followed by crustaceans (13.04%) and fish (10.14%) (Fig. 7).

The food array of *H. huso* showed a higher consumption of molluscs (54.67%), followed by fish (anchovies and gobies), in a share of 33.33%. Crustaceans were also identified in the beluga diet in a percentage of 12.00% (Fig. 8).

Of the 15 gastric lavage samples obtained from the three sturgeon species, nine belong to *A. stellatus,* in which polychaetes predominated (77.47%), followed by crustaceans (22.22%) and fish (0.31%) (Fig. 9).

Zoobenthos sampling analysis revealed a total number of 47 taxa, the highest diversity being held by representatives of the class Polychaeta (17 taxa), followed by Crustacea (13 taxa) and Bivalvia (11 taxa). Other groups included representatives of the orders Heteronemertea (*L. aurantiaca* and *M. fasciolata*), Polycladida (*Leptoplana* sp.), Actiniaria (*S. undatus* and *D. lineata*) and Pantopoda (*C. phantoma*) (Table 4) (Fig. 10).

Following the processing of the zoobenthos samples collected from the marine zone of the Danube Delta, maps with the distribution of the potential

Table 2. Food items identified in the food array of the three sturgeon species in the Danube Delta – marine zone (ROSCI0066).

Ref. No.	Sturgeon Species	Polychaeta	Bivalvia	Crustacea	Fish	Semi-digested food
1	*A. gueldenstaedtii*	-	12	3	2	x
2	*A. gueldenstaedtii*	-	41	9	5	-
3	*H. huso*	-	12	3	6	-
4	*H. huso*	-	8	6	8	-
5	*H. huso*	-	11	-	4	x
6	*H. huso*	-	10	-	7	-
7	*A. stellatus*	-	-	-	-	x
8	*A. stellatus*	221	-	20	-	-
9	*A. stellatus*	223	-	52	-	-
10	*A. stellatus*	-	-	-	3	x
11	*A. stellatus*	147	-	28	-	-
12	*A. stellatus*	188	-	-	1	-
13	*A. stellatus*	57	-	41	-	x
14	*A. stellatus*	-	-	65	-	-
15	*A. stellatus*	161	-	80	-	-

Table 3. Frequency of occurrence (FO, %), Index of Relative Importance (IRI) and %IRI of the main groups identified in sturgeon stomach contents.

ITEM	% of organisms (N)	% of weight (W)	Frequency of Occurrence % (FO)	Index of Relative Importance (IRI)	%IRI
Bivalvia	6.56	25.23	40.00	1271.60	**13.89**
Crustacea	21.40	1.34	66.66	1514.84	**16.55**
Polychaeta	69.53	34.81	40.00	4173.60	**45.60**
Fish	2.51	38.62	53.33	2193.46	23.96

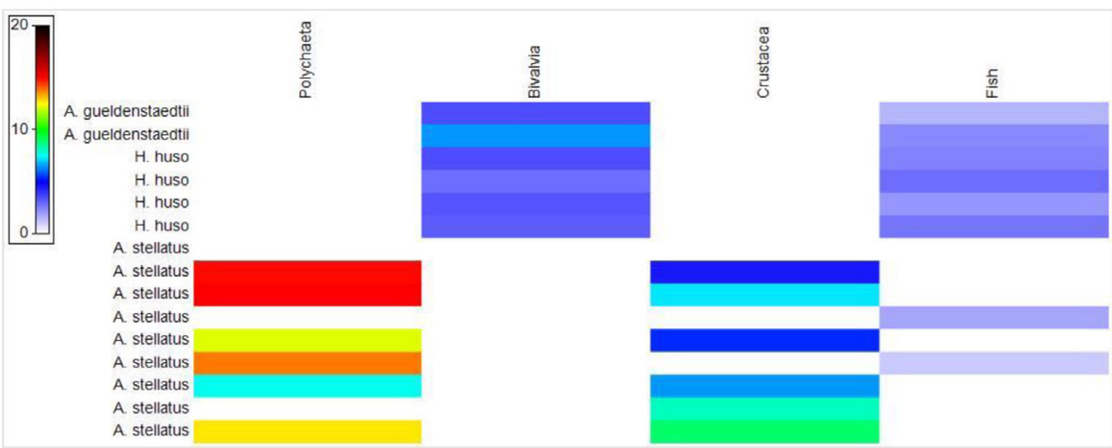

Fig. 5. Shade plot of the food groups identified in the stomach contents of the three sturgeon species (*A. gueldenstaedtii, H. huso, A. stellatus).*

foraging habitats of the three sturgeon species were prepared. The distribution of the main food organisms (i.e., Polychaeta, Mollusca and Crustacea) was also mapped. A higher concentration of polychaetes and crustaceans was noted in the northern part of the analysed perimeter, while molluscs had a rather uniform distribution throughout the entire area (Figs. 11–13).

Discussions

Studies regarding the knowledge of food items in the stomach contents of fish populations have always been a priority in fishery science. In the marine environment, there is a strong correlation between fish and benthic food elements, fish populations rep-

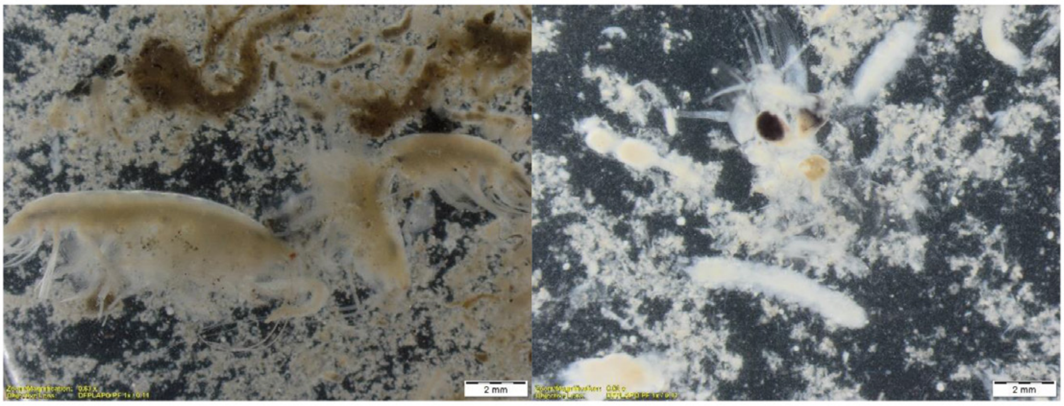

Fig. 6. Food items sampled from sturgeon stomach contents (NIMRD original photos).

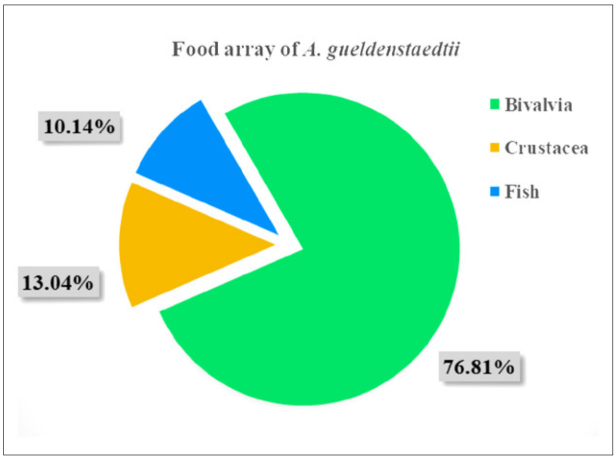

Fig. 7. Dominance of food groups in the stomach contents of *A. gueldenstaedtii.*

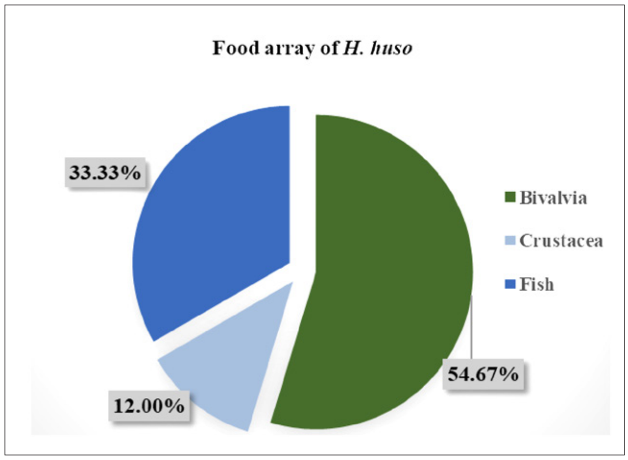

Fig. 8. Dominance of food groups in the stomach contents of *H. huso*.

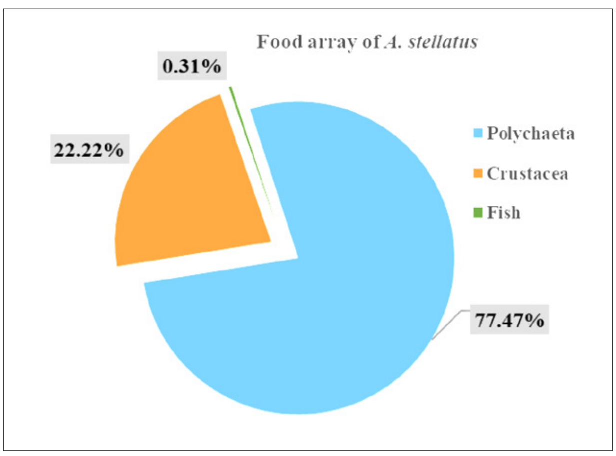

Fig. 9. Dominance of food groups in the stomach contents of *A. stellatus*.

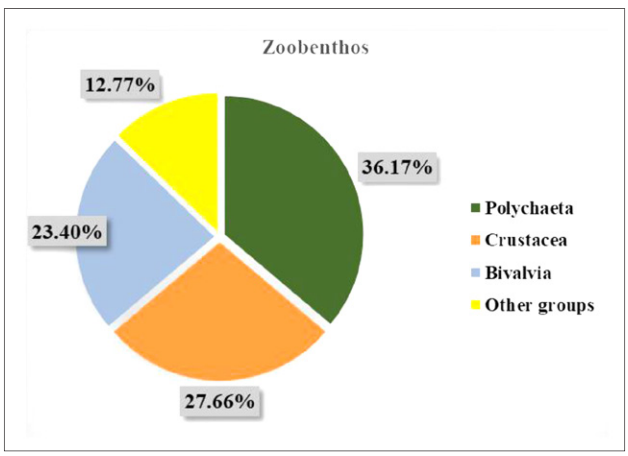

Fig. 10. Dominance of benthic organisms in zoobenthos samples.

resenting a significant link in the food web. Fish are the main consumers, and the analysis of food components in the stomach can help assess the state of the ecosystem from an ecological point of view.

The analysis of the stomach contents of the two *A. gueldenstaedtii* specimens revealed that bivalve molluscs were by far dominant, which is consistent with relevant literature data. Russian sturgeon is a benthic fish and, according to Zolotarev et al. (1996), mussels are the most important food for *A. gueldenstaedtii*. They are also documented to eat crustaceans (shrimps and crabs) and fish, which

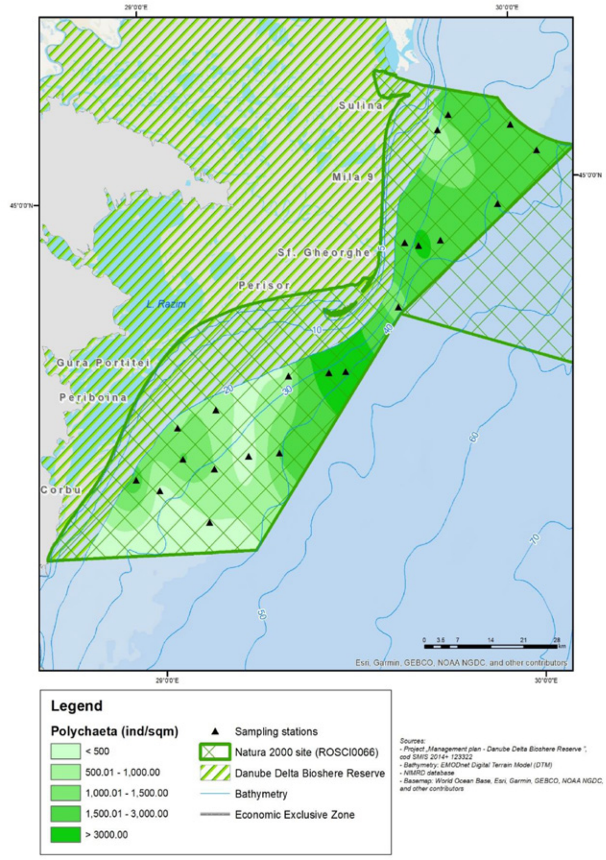

Fig. 11. Distribution of sturgeon foraging habitats in the Danube Delta – marine zone (ROSCI0066) – polychaetes.

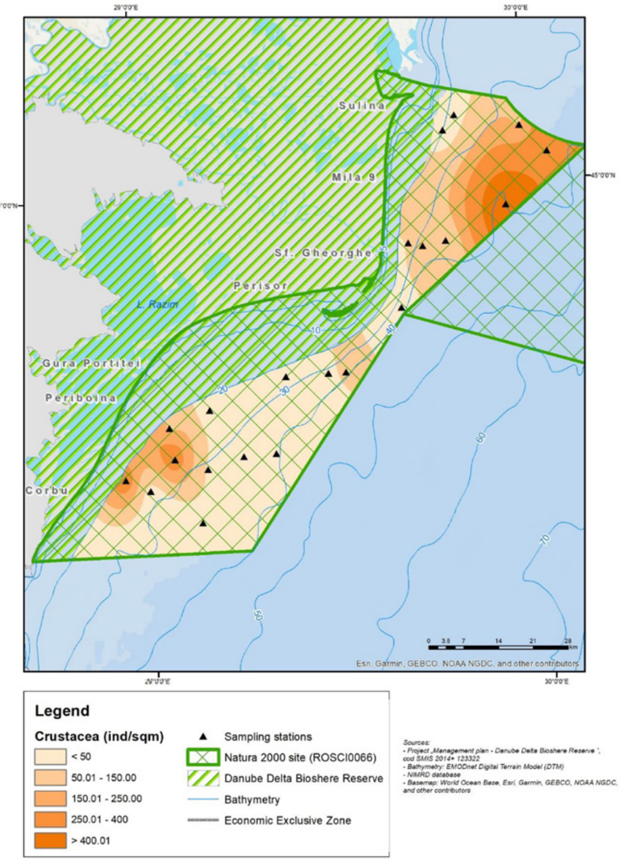

Fig. 12. Distribution of sturgeon foraging habitats in the Danube Delta – marine zone (ROSCI0066) – crustaceans.

was confirmed by our investigations. The main food items of Russian sturgeon fry are crustaceans and polychaetes (Berg 1962). The analysis of the zoobenthos samples from the point of view of dominance showed that the group Bivalvia is well represented in the study area, which indicates that the Russian sturgeon specimens in this area have sufficient food for development and recovery.

The main food items identified in the stomach contents samples collected from the four beluga specimens were fish (anchovies, gobies) and bivalve molluscs. Previous research (Khodorevskaya et al. (1995) demonstrated that, in the digestive track of *H. huso*, there is diversity in the food composition, of which 73.61% is fish (various species); the same study also demonstrated that the food items varied according to the stage of migration (Khodorevskaya et al. 1995). Schmutz (2006) reported that *H. huso* migrated to the Black Sea near the shore for feeding and the main food is fish (gobies, anchovies)

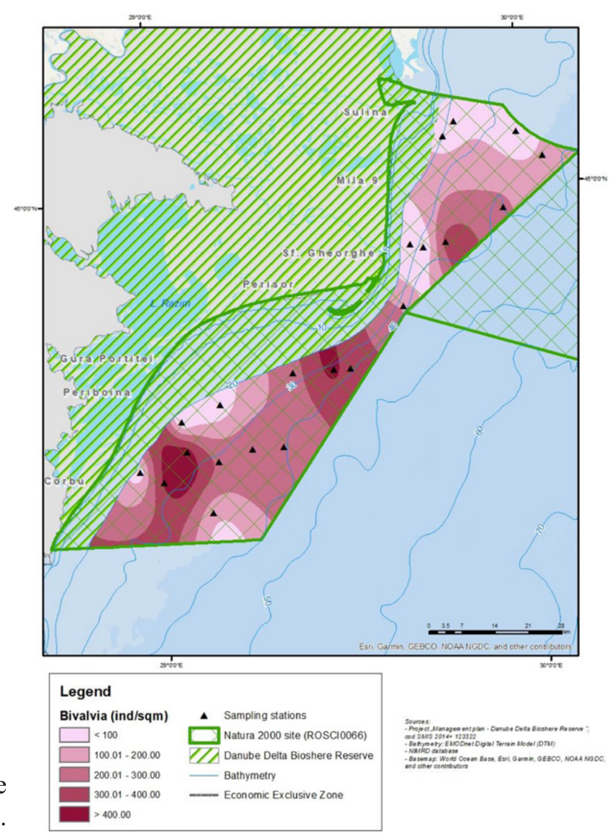

Fig. 13. Distribution of sturgeon foraging habitats in the Danube Delta – marine zone (ROSCI0066) – bivalves.

Table 4. Macrozoobenthos taxa identified in samples collected from the Danube Delta - Marine Zone (20–40 m isobath).

No.	Species	Aphia ID	Authority accepted
POLYCHAETA			
1.	*Capitella capitata*	129876	(Fabricius, 1780)
2.	*Heteromastus filiformis*	129884	(Claparède, 1864)
3.	*Phyllodoce mucosa*	334512	Örsted, 1843
4.	*Nereiphylla rubiginosa*	130659	(de Saint-Joseph, 1888)
5.	*Terebellides stroemii*	131573	Sars, 1835
6.	*Alitta succinea*	234850	(Leuckart, 1847)
7.	*Nephtys cirrosa*	130357	Ehlers, 1868
8.	*Nephtys hombergii*	130359	Savigny in Lamarck, 1818
9.	*Micronephtys longicornis*	1322948	(Perejaslavtseva, 1891)
10.	*Scolelepis squamata*	131177	(O.F. Muller, 1806)
11.	*Melinna palmata*	129808	Grube, 1870
12.	*Prionospio chilensis*	1379353	Hartmann-Schröder, 1962
13.	*Streblospio shrubsolii*	131193	(Buchanan, 1890)
14.	*Dipolydora quadrilobata*	131121	(Jacobi, 1883)
15.	*Polydora cornuta*	131143	Bosc, 1802
16.	*Harmothoe reticulata*	130780	(Claparède, 1870)
17.	*Lagis koreni*	152367	Malmgren, 1866
BIVALVIA			
1.	*Anadara kagoshimensis*	504360	(Tokunaga, 1906)
2.	*Mytilus galloprovincialis*	140481	Lamarck, 1819
3.	*Spisula subtruncata*	140302	(da Costa, 1778)
4.	*Mya arenaria*	140430	Linnaeus, 1758
5.	*Parvicardium exiguum*	139008	(Gmelin, 1791)
6.	*Acanthocardia paucicostata*	138993	(G. B. Sowerby II, 1834)
7.	*Cerastoderma glaucum*	138999	(Bruguière, 1789)
8.	*Abra alba*	141433	(W. Wood, 1802)
9.	*Abra prismatica*	141436	(Montagu, 1808)
10.	*Polititapes aureus*	246150	(Gmelin, 1791)
11.	*Pitar rudis*	141926	(Poli, 1795)
CRUSTACEA			
1.	*Amphibalanus improvisus*	421139	(Darwin, 1854)
2.	*Ampelisca diadema*	101896	(A. Costa, 1853)
3.	*Microdeutopus damnoniensis*	102047	(Spence Bate, 1857)
4.	*Deflexilodes gibbosus*	236539	(Chevreux, 1888)
5.	*Perioculodes longimanus*	102915	(Spence Bate & Westwood, 1868)
6.	*Phtisica marina*	101864	Slabber, 1769
7.	*Iphinoe elisae*	110455	Băcescu, 1950
8.	*Iphinoe tenella*	110461	Sars, 1878
9.	*Crangon crangon*	107552	(Linnaeus, 1758)
10.	*Carcinus aestuarii*	107380	Nardo, 1847
11.	*Upogebia pusilla*	107741	(Petagna, 1792)
12.	*Correanemertes bioculatus*	156315	(Corrêa, 1958)
13.	*Carinina heterosoma*	122619	Müller, 1965
OTHER GROUPS			
1.	*Leucocephalonemerthes aurantiaca*	122492	(Grube, 1855)
2.	*Micrura fasciolata*	122555	Ehrenberg, 1828
3.	*Leptoplana* sp.	142229	Ehrenberg, 1831
4.	*Sagartiogeton undatus*	101002	(Müller, 1778)
5.	*Diadumene lineata*	395099	(Verrill, 1869)
6.	*Callipallene phantoma*	134645	(Dohrn, 1881)

as well as shrimps, crabs and molluscs. Likewise, Zengin et al. (2013) observed that *H. huso* feeds on anchovies, especially in winter, in addition to horse mackerel, whiting and gobies.

In the stomach samples collected from *A. stellatus*, a prominent dominance of polychaetes was observed, with crustaceans being the second favourite food item. Polyaninova & Molodtseva (1995) showed that the food identified in the digestive track of the starry sturgeon is composed of worms and crustaceans, which is confirmed by the present study. Diets for adult sturgeons vary among species but generally include small fish, molluscs, worms and crustaceans (Billard & Lecointre 2001).

Among all the food items identified in the 15 gastric lavage samples collected from the three sturgeon species, the polychaetes predominated with the highest percentage (%N) and %IRI (45.6%). The highest Frequency of Occurrence (66.6%) was noted for the Crustacea. Another food item preferred by the three sturgeon species and with a high %IRI value (23.9%) was represented by fish. The Bivalvia reached the %IRI value of 13.9% and the Frequency of Occurrence was 40%.

The mapping of the feeding area for sturgeons was made based on the results obtained from the zoobenthos samples, which were correlated with the diet array obtained from the gastric lavage samples. Polychaetes also dominated in the zoobenthos samples, while being the preferred food of *A. stellatus*. Bivalve molluscs and crustaceans were found both in the zoobenthos samples and in the digestive tracks of the sturgeons investigated.

Mapping the foraging areas of sturgeons and stomach content analysis by gastric lavage bring a novel scientific input to the overall availability of the food supply in the Danube Delta – Marine Zone as well as the feeding preference of the species studied. The analysis of the two data sets (stomach contents and zoobenthos samples) indicates that sturgeons can find in the studied area sufficient food for population recovery and suggests that food availability plays an important role in fish diet selection. Acquiring a sound knowledge of the food items and their spatiality in the studied area is important for raising an alarm signal that invasive fishing techniques (such as beam trawling) should be strongly regulated, if not completely banned in certain areas by creating Fisheries Restricted Areas (FRAs) where vulnerable and (or) essential habitats are found. This type of management measures could support the conservation of the three sturgeon species (*H. huso, A. gueldenstaedtii* and *A. stellatus*).

Towed demersal fishing gears have been demonstrated to affect the benthic environment by modifying habitats, community structure and even geochemical processes. Beam trawling and dredging cause physical disruption of the seabed through contact of the gear components with the sediment and the resuspension of sediment into the water column in the turbulent wake of the gear (Depestele et al. 2016). At the Romanian coast, however, there is no research dedicated to the effects of beam-trawling on benthic habitats but only a study on gear selectivity and by-catches. The findings indicate that this type of gear does not retain juvenile individuals of the target species *Rapana venosa*; however, as by-catches, the most sensitive benthic species is turbot *Scophthalmus maeoticus* (Pallas, 1814) (Danilov et al. 2019), suggesting that sturgeons can also be strongly affected by such gear.

Most importantly, an ecosystem-based approach to fisheries management (EAFM) requires that the sustainability of beam-trawling effects in regards to the benthic species have to be evaluated. They are also habitat builders and provide a significant amount of food for demersal fish (Hiddink et al. 2006), as the present sturgeon stomach content analyses revealed.

The conservation status of all sturgeon species in Europe has become extremely critical and the monitoring after the first attempts for recovery indicates that previous actions have not been efficient. Several experts have argued four main reasons for the insufficient success of the existing action plans: lack of simplicity, lack of coordination and accountability, lack of resources, lack of public awareness and politics (Friedrich et al. 2018, Strat & Gheorghe 2023). Therefore, it is of utmost importance to substantiate any management and conservation measure on accurate, reliable and clear information. The present study is a step in creating a pool of knowledge on the relationship between essential foraging habitats, invasive fisheries, food availably, habitat destruction and the conservation concerns.

Conclusions

The analysis of the results obtained in the study indicates that the main component that dominate the zoobenthos samples in the Danube Delta – Marine zone was the group Polychaeta. The dominant food items identified in sturgeon stomach contents varied across the sturgeon species: *A. gueldenstaedtii* preferred bivalve molluscs while the food array of *H. huso* was based mainly on small fish and the diet of *A. stellatus* was dominated by polychaetes.

Mapping the foraging habitats, along with raising an alarm regarding beam-trawling in these sensitive areas, can have a positive impact on the recovery of sturgeon populations. This type of action must be carried out in the long term in order to obtain the desirable results.

Summarising, the present study allowed the delimitation and mapping of habitat areas in Marine Zone ROSCI0066 where the food items characteristic for sturgeon diet are present in a sufficient diversity and abundance, ensuring the recovery of the populations. However, it also demonstrated the need of applying and maintaining certain protection and conservation measures in light of the newly revised Management Plan of the Danube Delta Biosphere Reserve – Marine Zone.

Sturgeon populations are impacted not only by the destruction of their feeding habitats (by reduction and or/alteration of the biota they prey on), but also by Illegal, Unreported and Unregulated (IUU) fishing, which is a major issue affecting all Black Sea stocks. As such, in order to achieve the reconciling of conservation targets with the sustainable use of marine resources, a stronger control enforcement should be encouraged, reducing the existing pressures on these flagship species of the entire Danube basin, by protecting both the foraging areas and the fish.

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References

Ahlbeck I., Hansson S. & Hjerne O. 2012. Evaluating fish diet analysis methods by individual-based modelling. Canadian Journal of Fisheries and Aquatic Sciences 69(7): 1184–1201. https://doi.org/10.1139/f2012-051.

Akbulut B., Zengin M., Çiftçi Y., Ustaoğlutiril S., Memiş D., Alkan A., Çakmak E., Kurtoğlu İ.Z., Aydin İ., Üstündağ E., Eroğlu O. & Serdar S. 2011. Stimulating sturgeon conservation and rehabilitation measures in Turkey: an overview on major projects (2006-2009). Journal of Applied Ichthyology 27: 415–419. https://doi.org/10.1111/j.1439-0426.2011.01736.x.

Bănățean-Dunea I., Corpade A-M., Grozea A., Nicolin A., Corpade C., Osman A., Bostan C., Crista N-G. 2015. Ghid sintetic de monitorizare a speciilor comunitare de pești din România. Cluj-Napoca, România: Casa Cărții de Știință Publishing House. ISBN 978-606-17-0779-9, 134 p. (in Romanian).

Berg L.S. 1962. Freshwater fishes of the U.S.S.R. and adjacent countries. Jerusalem: Israel Program for Scientific Translations Ltd., 4th edition, Vol. 1, 493 p.

Billard R. & Lecointre G. 2000. Biology and conservation of sturgeon and paddlefish. Reviews in Fish Biology and Fisheries 10: 355–392.

Birstein V.J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. Conservation Biology 7: 773–787. https://doi.org/10.1046/j.1523-1739.1993.740773.x.

Brosse L., Dumont P., Lepage M. & Rochard E. 2002. Evaluation of a gastric lavage method for sturgeons. North American Journal of Fisheries Management 22: 955–960.

Brosse L., Lepage M. & Dumont P. 2000. First results on the diet of the young Atlantic sturgeon *Acipenser sturio* L., 1758 in the Gironde Estuary. Boletin Instituto Espanol de Oceanografia 16(1/4): 75–80.

Clarke K.R. & Gorley R.N. 2015. PRIMER v7: User Manual/Tutorial. PRIMER - Plymouth, 296 p.

Cortés E. 1997. A critical review of methods of studying fish feeding based on analysis of stomach contents: Application to elasmobranch fishes. Canadian Journal of Fisheries and Aquatic Sciences 54 (3): 726–738. https://doi.org/10.1139/f96-316.

Danilov C.S., Nicolaev S., Anton E., Țiganov G., Nicolaev A.D., Păun C.V. & Maximov V. 2019. Dynamics of the fishing capacities used for the mechanized exploitation of the gastropod *Rapana venosa* at the Romanian coast during 2013–2017. Cercetări Marine – Marine Research Journal 49: 133–140.

Depestele J., Ivanović A., Degrendele K., Esmaeili M., Polet H., Roche M., Summerbell K., Teal L.R., Vanelslander B. & O'Neill F.G. 2016. Measuring and assessing the physical impact of beam-trawling. ICES Journal of Marine Science 73(1): 115–126. https://doi.org/10.1093/icesjms/fsv056.

Friedrich T., Gessner J., Reinartz R. & Striebel-Greiter B. 2018. Pan-European action plan for sturgeons. In: Convention on the Conservation of European Wildlife and Natural Habitats. T-PVS/Inf, 6. The World Sturgeon Conservation Society and WWF. Available online: https://rm.coe.int/pan-european-action-plan-for-sturgeons/16808e84f3 (Accessed on 27 January 2023.

Hansson S. 1998. Methods of studying fish feeding: a comment. Canadian Journal of Fisheries and Aquatic Sciences 55(12): 2706–2707.

Hiddink J.G., Hutton T., Jennings S & Kaiser M.J. 2006. Predicting the effects of area closures and fishing effort restrictions on the production, biomass and species richness of benthic invertebrate communities. ICES Journal of Marine Science 63: 822–830.

Holoștenco D., Onără D., Suciu R., Honț Ș. & Paraschiv M. 2013. Distribution and genetic diversity of sturgeons feeding in the marine area of the Danube Delta Biosphere Reserve. Scientific Annals of the Danube Delta Institute 19: 25–34. https://doi.org/10.7427/DDI.19.04.

Hoover J.J., George S.G. & Killgore K.J. 2007. Diet of shovelnose sturgeon and pallid sturgeon in the free-flowing Mississippi River. Journal of Applied Ichthyology 23(4): 494–499. https://doi.org/10.1111/j.1439-0426.2007.00893.x.

Hyslop E.J. 1980. Stomach content analysis – a review of methods and their application. Journal of Fisheries Biology 17(4): 411–429.

IUCN 2022. International Union for the Conservation of Nature Red List. Available online: https://www.iucn.org/press-release/202207/migratory-monarch-butterfly-now-endangered-iucn-red-list (Accessed on 5 July 2023).

Jarić I., Ebenhard T. & Lenhardt M. 2010. Population viability analysis of the Danube Sturgeon Populations in a Vortex Simulation Model. Reviews in Fish Biology and Fisheries 20: 219–237. https://doi.org/10.1007/s11160-009-9151-0.

Jason K. & Malcolm M. 2010. A Protocol for use of shortnose, Atlantic, gulf, and green sturgeons. United States, National Marine Fisheries Service. NOAA Technical Memorandum NMFS-OPR 45. Available online: https://repository.library.noaa.gov/view/noaa/3801 (Accessed on 15 February 2023).

Khodorevskaya R.P., Polyaninova A.A., Geraskin P.P. & Romanov A.A. 1995. A study on physiological and biochemical status of beluga sturgeon, *Huso huso* (L.), and its feeding habits. Proceedings of the International Sturgeon Symposium. Moscow, VNIRO: 164–172.

Lebreton G.T. & Beamish F.W.H. 1998. The influence of salinity on ionic concentrations and osmolarity of blood serum in lake sturgeon, *Acipenser fulvescens*. Environmental Biology of Fishes 52: 477–482. https://doi.org/10.1023/A:1007421410090.

Moghadam K.H., Pajand Z., Parandavar H., Chubian F. & Pahlavan Y.M. 2009. Diet composition of the Persian sturgeon *Acipenser persicus* at the coast of the Guilan Province, Caspian Sea. Russian Journal of Marine Biology 35: 331–334. https://doi.org/10.1134/S1063074009040087.

Niță V., Nenciu M. & Galațchi M. 2022. Fish species of the Romanian coast. Updated atlas. Constanța, Romania. ISBN 978-973-0-36642-6, 152 p.

Polyaninova A.A. & Molodtseva A.I. 1995. The benthos sturgeon feeding relationship for the Caspian Sea. Proceedings of the International Sturgeon Symposium Moscow, VNIRO: 151–157.

Radu G., Radu E., Nicolaev S. & Anton E. 2008. Atlas of the main fish species in the Black Sea. Romanian Marine Fisheries. Constanța, Romania: Virom Publishing House, ISBN 978–973-7895-32-5, 293 p.

Reinartz R., Bloesch J., Sandu C., Suciu R., Lenhardt M., Guti G. & Jarl J. 2012. Sturgeon conservation in the Danube River Basin: How to implement the Sturgeon Action Plan 2005. Proceedings of 39th IAD Conference Living Danube, Szentendre, Hungary, pp. 21–24.

Sandu C., Reinartz R. & Bloesch J. (Eds.) 2013. Sturgeon 2020: A program for the protection and rehabilitation of Danube sturgeons. Danube Sturgeon Task Force (DSTF) & EU Strategy for the Danube River (EUSDR) Priority Area (PA) 6 – Biodiversity, 24 p.

Schmutz S. 2006. Assessment of the potential transboundary effects of the construction of the Bystre Deep-Water Navigation Channel on fish and fisheries. Report to the ESPOO Inquiry Commission, Vienna, 56 p.

Strat D. & Gheorghe I.F. 2023. Conservation status and effectiveness of the national and international policies for the protection and conservation of sturgeons in the Danube River and Black Sea Basin. Diversity 15: 568. https://doi.org/10.3390/d15040568.

Todorova V. & Konsulova T. 2005. Manual for collection and treatment of soft-bottom macrozoobenthos samples. Available online: http://www.blacksea-commission.org/_publ-Manual_zoobenthos.asp (Accessed on 17 January 2023).

Usvyatsov S., Watmough J. & Litvak M.K. 2012. Modeling the effect of environmental parameters on feeding ecology of the shortnose sturgeon in the Saint John River, New Brunswick. Transactions of the American Fisheries Society 141: 238–256. https://doi.org/10.1080/00028487.2012.654890

Zengin M., Gümüş A., Dağtekin M. & Firidin Ș. 2013. Biological data derived from sturgeon (*Acipenser stellatus*, *Acipenser gueldenstaedtii* and *Huso huso*) by-catch along the coasts of the southern Black Sea (Turkey). Turkish Journal of Fisheries and Aquatic Sciences 13: 745–752. https://doi.org.10.4194/1303-2712-v13_4_20.

Zolotarev P.N., Shlyakhov V.A. & Akselev O.I. 1996. The food supply and feeding of the Russian sturgeon *Acipenser gueldenstadtii* and the starred sturgeon *Acipenser stellatus* of the north-western part of the Black Sea under modern ecological conditions. Journal of Ichthyology 36: 317–322.

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