Vienna, 29th November 2020

University of Natural Resources and Life Sciences Vienna: Department of Water Atmosphere-Environment

A comprehensive assessment of potential habitats of sturgeon species in the Danube River

Master Thesis for obtaining

M. Sc. in Environmental Science (EnvEuro)

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Statutory declaration

I hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such. This written work has not yet been submitted in any part.

Acknowledgments

I would like to thank my master thesis supervisors Thomas Hein, Thomas Friedrich, and Paul Meulenbroek at BOKU and my master thesis co-supervisor Klaus Schmieder at Hohenheim University, for their support and revision. I would also like to thank the INTERREG MEASURES project (Managing and restoring aquatic EcologicAl corridors for migratory fiSh species in the danUbe RivEr baSin), for supporting this master thesis.

I would also like to thank my family for the support at the end of the master thesis and especially to my mother, for being the bravest person in my life and for showing me that progress in life will not come easily, or without bumps in the road.

También me gustaría agradecer a mi familia por el apoyo al final del proyecto de fin de máster y especialmente a mi madre, por ser la persona más valiente en mi vida y por mostrarme que el progreso en la vida no será fácil o sin baches en el camino.

Abstract

Six sturgeon species are native in the Danube River Basin (DRB), five are critically endangered (one being regionally extinct and another one considered functionally extinct) and one is considered vulnerable. These species have declined during the last century due to hydropower dams, other hydromorphological alterations, and illegal fishing. The massive sturgeon decline and extinction have become a major environmental concern and recently also of greater public awareness in the Danube countries.

The core task of this study is (1) to review the existing information about sturgeon habitats in the DRB, especially for sterlet, Russian, stellate, and beluga sturgeon; and (2) to study their spatial distribution in the river basin based on existing data and observations. This research seeks to investigate key sturgeon habitats in the DRB: wintering, spawning, and nursery places using available information in the literature; and information provided by Interreg project MEASURES (Managing and restoring aquatic EcologicAl corridors for migratory fiSh species in the danUbe RivEr baSin), in which confirmed and potential sturgeon habitats are being registered in the DRB.

Water depth is especially studied for wintering sturgeon places, which are mainly located in deep pools in the riverbed; likewise, the grain substrate is important for spawning places, in which rocky substrate prevails. From all sturgeon Danube species, only the potamodromous sterlet is present in the whole basin, though in decreasing vulnerable populations. The anadromous species, Russian, stellate, and beluga sturgeon, which are critically endangered, are restricted to the lower part of the Danube until the Iron Gates dams. The hydromorphological status of the habitats according to the EU WFD is also considered, as well as designation as Natura 2000 area, to better define these sturgeon habitats in the Danube. The current bad hydromorphological status of the Danube River has effects on the critical situations of sturgeon populations and sturgeon habitats. However, most of the habitats are located in Natura 2000 sites, particularly in the Upper and Middle Danube, so it makes sense to recuperate the normal hydromorphological status of the river and to further preserve confirmed and potential sturgeon habitats in the Danube River. Finally, it is also important to highlight: the low data availability on sturgeon habitats; and the potential of the Danube river to host sturgeon habitats if future research and conservation measures were suitably implemented.

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1. Introduction

The benefits of water provision to economic productivity are often accompanied by the quality decline in ecosystems and biodiversity, with potentially serious but unquantified costs (Vörösmarty et al., 2010) and ecological consequences. Available evidence suggests that fish abundance and diversity are in decline while the human population and destructive activities, including fishing, are increasing (Angermeier, 2008). Large dams invariably reduce fish diversity but also block movements that connect populations and enable migratory species to complete their life cycles (Winemiller et al., 2016). Only 37% of rivers over 1000 kilometers remain free-flowing over their entire length, due to the fragmentation of dams as a main dominant pressure (Grill et al., 2019). These dams are built for shipping, hydropower generation, flood protection, storage drinking water, and irrigation water (Lehner et al., 2011), but they mostly fragment the aquatic network into isolated river sections, affecting longitudinal and lateral migration of fish species (Fuller et al., 2015; Fullerton et al., 2010).

Sturgeon populations in the Danube River Basin (DRB) have been affected by these impacts and their dramatic decline in the last decades has become an issue of basin-wide importance (Sandu et al., 2013). Six sturgeon species were native in the DRB (Holčík, 1989), five are critically endangered (one being regionally extinct and another one considered functionally extinct) and one is considered vulnerable (Friedrich et al., 2019; IUCN, 2010) (Table 1).

Table 1. IUCN Red List status of Danube sturgeon species

Species	Known as	Status	Trend
Acipenser ruthenus	Sterlet	Vulnerable	Decreasing
Acipenser nudiventris	Ship sturgeon or Fringebarbel sturgeon	Critically endangered	Decreasing
Acipenser gueldenstaedtii	Danube sturgeon or Russian sturgeon	Critically endangered	Decreasing
Acipenser stellatus	Stellate sturgeon	Critically endangered	Decreasing
Acipenser sturio	Common sturgeon, European sturgeon, Atlantic sturgeon	Critically endangered (extinct in DRB)	Decreasing
Huso huso	Beluga sturgeon or great sturgeon	Critically endangered	Decreasing

Source: Friedrich et al., 2019; IUCN, 2010

1.1. Sturgeon species in the DRB

Sturgeons (Acipenseriformes) represent an ancient group of large, bony-plated chondroitin fishes. The family contains 27 species and most are currently classified as extinct, critically endangered, endangered, or vulnerable (Bemis & Kynard, 1997; IUCN, 2010). The sturgeon is a long-lived and large species, and its migratory cycle implies a movement towards the freshwater areas in rivers. All this makes it a perfect umbrella species. In which their protection must have a holistic approach to have a global vision in the conservation of their ecosystems (Friedrich et al., 2018). They are distributed throughout the northern hemisphere and they inhabit rivers, lakes, and coastal marine water in Europe, Asia, and America (Hochleithner & Gessner, 2012; Rochard et al., 1990).

From the six native species in the DRB, two species are potamodromous and four are anadromous (Berg, 1948).

1) Anadromous (Russian-, stellate-, European- and beluga sturgeon): They are born in freshwater but spend most of their lives in saltwater and return to freshwater for spawning. Most feeding and foraging takes place in the sea, followed by reproductive migration of grown individuals (Myers, 1938). An early and a late vernal form enters the river in spring or early summer, to spawn in the river in late summer or fall. The late hiemal form enters the river in fall or winter, migrating far upstream, and overwintering in deep pools while spawning early in the following spring. Smaller runs enter the river throughout the year (Hochleithner & Gessner, 2012; Khodorevskaya et al., 2009).

2) Potamodromous (sterlet and ship sturgeon): Some sturgeon species spend their whole life in freshwater. Generally, migrations are for spawning purposes and cover short distances: from the main stream river to an upstream tributary or between connected lake-river systems. Non-spawning migrations occur for habitat shift to feed or grow between different habitats (Hochleithner & Gessner, 2012; Reinartz & Slavcheva, 2016).

In most sturgeon species different forms can be distinguished regarding their migration and spawning behavior. These differences in their behavioral strategies supposedly increase the ecological niches available for reproduction and juvenile growth. Therefore, it allows the spawning grounds to be used more effectively and for each group to access different food resources (Hochleithner & Gessner, 2012).

1.1.1. Acipenser ruthenus

Sterlet (*Acipenser ruthenus*, Linnaeus 1758) (Table 2 and Figure 1).

Table 2. Sterlet species description

Size	
Maximum length	1.2 m
Maximum weight	16 kg
Average length	0.5 – 1.0 m
Age	
Maximum	>25 years
Maturation (female)	5 – 8 years
Maturation (male)	3 – 5 years
Range: Black, Caspian, Kara, White and Azov Seas, and their tributaries	
Migration pattern: Potamodromous	
River life: Stay in the current in deep depressions in the riverbed, over stony, gravelly, or sandy bottoms.	
IUCN status: Vulnerable	

Source: Hochleithner & Gessner, 2012; Holčík, 1989; IUCN, 2010

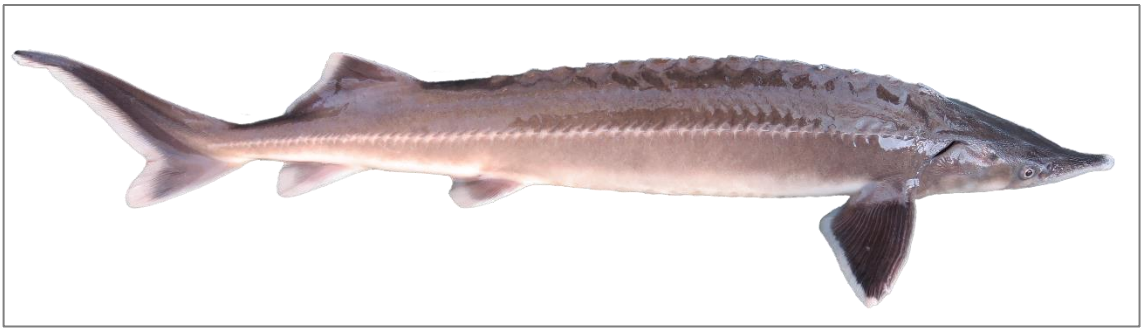


Figure 1. Sterlet.
Source: Thomas Friedrich

1.1.2. Acipenser nudiventris

Ship sturgeon or fringebarbel sturgeon (*Acipenser nudiventris*, Lovetzky 1828) (Table 3 and Figure 2).

Table 3. Ship sturgeon species description

Size	
Maximum length	2.2 m
Maximum weight	120 kg
Average length	1.2 – 1.5 m
Age	
Maximum	>36 years
Maturation (female)	12 – 18 years
Maturation (male)	6 – 12 years
Range: Black, Caspian, Azov and Aral Seas, and their larger tributaries	
Migration pattern: Potamodromous in the Danube, anadromous forms exist in other catchments	
Sealife: Remain in shallow water, above 50, where the **bottom** is muddy, most abundant in river mouths	
River life: Diadromous species, however, a general predilection for freshwater is one of the biological characteristics	
IUCN status: Critically endangered	

Source: Hochleithner & Gessner, 2012; Holčík, 1989; IUCN, 2010

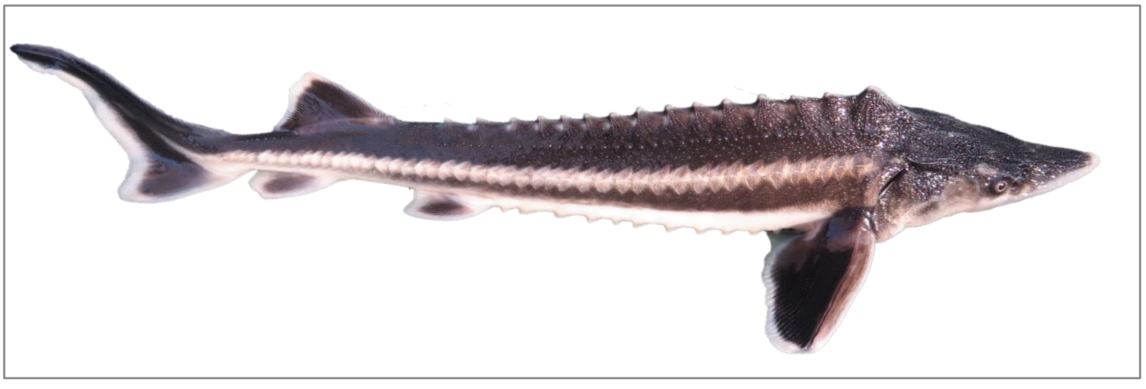


Figure 2. Ship sturgeon

Source: Thomas Friedrich

1.1.3. Acipenser gueldenstaedtii

Russian sturgeon complex, Danube sturgeon (*Acipenser gueldenstaedtii*, Brandt 1833), and Colchic sturgeon (*Acipenser persicus colchicus*, Arthukin & Zarkua, 1986) (Table 4 and Figure 3).

Table 4. Russian sturgeon species description

Size	
Maximum length	2.4 m
Maximum weight	110 kg
Average length	1.3 – 1.6 m
Age	
Maximum	>50 years
Maturation (female)	10 – 16 years
Maturation (male)	8 – 13 years
Range: Black, Caspian and Azov Seas, and their larger tributaries	
Migration pattern: Anadromous, hiemal and vernal forms. Former resident form in the Danube is under discussion	
Sealife: Shallow waters in the continental shelf, staying mainly in brackish waters	
River life: Remain at depths from 2-30 m, in the Danube, the young sturgeons remain in deep water for a long time	
IUCN status: Critically endangered	

Source: Hochleithner & Gessner, 2012; Holčík, 1989; IUCN, 2010

Figure 3. Russian sturgeon

Source: Thomas Friedrich

1.1.4. *Acipenser stellatus*

Stellate or starry sturgeon (*Acipenser stellatus*, Pallas 1771) (Table 5 and Figure 4).

Table 5. Stellate sturgeon species description

Size	
Maximum length	2.9 m
Maximum weight	80 kg
Average length	1.2 – 1.8 m
Age	
Maximum	>35 years
Maturation (female)	8 – 14 years
Maturation (male)	6– 12 years
Range: Black, Caspian, Aegean and Azov Seas, and their tributaries	
Migration pattern: Anadromous, hiemal and vernal forms	
Sealife: Benthic inhabitant of coastal waters in seas	
River life: Lowland sections of rivers	
IUCN status: Critically endangered	

Source: Hochleithner & Gessner, 2012; Holčík, 1989; IUCN, 2010

Figure 4. Stellate sturgeon

Source: Thomas Friedrich

1.1.5. *Acipenser sturio*

European / Atlantic sturgeon / Common sturgeon (*Acipenser sturio*, Linnaeus 1758) (Table 6 and Figure 5).

Table 6. European sturgeon species description

Size	
Maximum length	6 m
Maximum weight	850 kg
Average length	1.5 – 3 m
Age	
Maximum	>60 years
Maturation (female)	13 – 16 years
Maturation (male)	10– 12 years
Range: North, Black Seas, Atlantic Coast, Adriatic Mediterranean Sea, and its rivers	
Migration pattern: Anadromous, hiemal and vernal forms	
Sealife: Compared to other sturgeon species, it wanders more distance through the sea	
River life: Most young-of-the-year sturgeons stay in rivers close to the spawning grounds where they hatched, but some of them move downstream to the estuaries during their first summer	
IUCN status: Critically endangered (extinct in DRB)	

Source: Hochleithner & Gessner, 2012; Holčík, 1989; IUCN, 2010

Figure 5. European sturgeon

Source: Svensson, 2001

1.1.6. Huso huso

Beluga / great sturgeon (*Huso huso*, Linnaeus 1758) (Table 7 and Figure 6).

Table 7. Beluga sturgeon species description

Size	
Maximum length	8 m
Maximum weight	2000 kg
Average length	2.2 – 3.5 m
Age	
Maximum	>100 years
Maturation (female)	14 – 20 years
Maturation (male)	10– 16 years
Range: Black, Caspian, Azov and Adriatic Seas and tributaries	
Migration pattern: Anadromous, hiemal and vernal forms	
Sealife: Inhabits pelagic zones due to its predatory behavior	
River life: Migrate in the deepest parts of the riverbed	
IUCN status: Critically endangered	

Source: Hochleithner & Gessner, 2012; Holčík, 1989; IUCN, 2010

Figure 6. Beluga sturgeon

Source: Thomas Friedrich

1.2. Impacts, and pressures of sturgeon in the DRB

Despite the high abundances of sturgeon populations, a century ago in the DRB, today sturgeon species are under severe pressure, mainly because of caviar demands and its high economic value. In the Middle Ages, the construction of sturgeons' traps caused over-exploitation of sturgeons stocks (Schmall & Friedrich, 2014) and the stock was so much reduced, that at the beginning of the eighteenth century, catching large sturgeons was considered an extraordinary event. Moreover, its life history is characterized by slow maturation, infrequent reproduction, and migratory movements across international borders, and for several species between marine and inland water habitats, it makes them a very vulnerable species. (Birstein et al., 2006; Friedrich, 2013; Friedrich et al., 2019).

Free migration is essential for anadromous species to fulfill their life cycle because a single barrier can make an entire catchment inaccessible. The presence of hydroelectric power stations can play a significant role in limiting sturgeon populations (Haxton & Cano, 2016; van Puijenbroek et al., 2019). An important consequence of the distribution of hydropower plants along the Danube is that the river is now split into many impounded reaches and only five free-flowing river reaches remain. The longest free-flowing reach extends from the mouth of the Danube in Romania to the Iron Gate hydropower plants (approximately 800 km). The second-largest free-flowing reach is situated mainly in the Hungarian Plain. In Austria, two free-flowing reaches remain one of only 48 km between Vienna and Bratislava and the second in the Wachau area (approximately 33 km). In Germany, the last free-flowing reach is found between Straubing and Vilshofen. These free-flowing reaches also happen to be those reaches where navigation bottlenecks exist due to insufficient water depth (Habersack et al., 2013).

This flowing stretch is confirmed by several studies in the DRB, in which it is stated that the remaining anadromous sturgeon species are restricted to 800 km in the Lower Danube stretch, between the Iron Gate dams and the delta. (Friedrich et al., 2019; Reinartz et al., 2012).

As outlined above, Russian, Stellate, and Beluga sturgeon are currently restricted to the Lower Danube, since the commissioning of the dams at the Iron Gate in 1972 and 1984 completely block upstream migration. Sterlet (potamodromous) is currently present in the Upper Danube only in low numbers in few fragmented populations. They are more numerous in the Middle Danube but also experienced a great recession after the loss of spawning habitats due to the Gabčíkovo dam (Guti, 2008). The potamodromous ship sturgeon today is considered functionally extinct (Jarić et al., 2016; Reinartz & Slavcheva, 2016). The European sturgeon is extinct in the DRB (IUCN, 2010).

Sturgeons' diverse habitat utilization and their migratory life cycle jeopardize their populations due to human impacts. Overharvesting, migration barriers, habitat destruction, and pollution by heavy metals have been important factors for their population decline. However, blockage of migratory routes and illegal fishing of sturgeon may, in many cases, be the greatest factor in preventing the recovery of populations for most sturgeon species (Auer, 1996; Friedrich et al., 2018).

Poaching remains a conservation concern for all sturgeon species, given the exorbitant prices of caviar (Cohen, 1997; Pikitch et al., 2005), this seems to be especially relevant for European stocks (Ivanov et al., 1999; Khodorevskaya et al., 1997; Ludwig, 2006). Overharvesting in the Upper Danube caused the almost disappearance of sturgeon species since the Middle Ages. This also happened over the last centuries in the Middle Danube (Schmall & Friedrich, 2014), but nowadays at the Lower Danube, illegal harvest, and bycatch are the major threats resulting in ongoing diminishing populations (Jahrl & Rosenthal, 2017).

The hydromorphological conditions of the river are highly important to adequately complete the sturgeon reproduction life cycle. For this reason, a lack of morphodynamics and instream structures, the disconnection of side-arms, and riprap are responsible for ecological deficits in key ecosystem functions (Habersack et al. 2016). These hydromorphological conditions are studied in The Joint Danube Survey 3, which created a hydromorphological Danube database in 2015. It indicates that about 60% of the analyzed Danube stretches are moderately modified regarding hydromorphological status. Concerning continuity, 18 dams are located in the Danube, of which only two have the capacity for fish to migrate. and partial sediment management (Schwarz et al., 2014). The loss of sturgeon species in the DRB coincides with strong decrease inaccessibility due to river fragmentation (Friedrich et al., 2019; van Puijenbroek et al., 2019), specifically, anadromous species are restricted to the most downstream 800 km of the Lower Danube between the Iron Gate Gorge dams and the Delta (ICPDR, 2013a; Weiss et al., 2018).

1.3. Cooperation programs in the DRB

The public attention lately gained Danube sturgeons is the output of the close cooperation of several governmental and non-governmental organizations active in the Danube River Basin. The adoption of the EU Strategy for the Danube Region in 2011 created the frame to foster sturgeon conservation and bring this topic high on the political agenda of the Danube countries (Suciu & Ona, 2016). The Danube Sturgeon Task Force was established in 2012 and it aims to coordinate and foster the conservation of native sturgeon species in the Danube River Basin and the adjacent Black Sea by the implementation of the Sturgeon Action Plan adopted under the Bern Convention in 2005. The Danube Sturgeon Task Force also developed a program for the protection and rehabilitation of Danube sturgeons "Sturgeon 2020" which is adopted by the International Commission for the Protection of the Danube River. Furthermore, a European Action Plan for Sturgeons was developed to serve as a guiding framework on the Pan-European level and serve as a guiding framework for sturgeon conservation with an intended lifespan of 2019 to 2029 and subsequent evaluation and adaptation (Friedrich et al., 2018).

Therefore, cooperation programs between the different Danube Member States are needed, and transnational management of these corridors and restoration actions, as well as restocking with indigenous species are essential. The Danube Transnational Programme is a financing instrument of the European Territorial Cooperation, better known as "Interreg". INTERREG MEASURES project (Managing and restoring aquatic EcologicAl corridors for migratory fiSh species in the danUbe RivEr baSin) aims to create ecological corridors by identifying key habitats and initiating protection measures along the Danube and its main tributaries.

The World Sturgeon Conservation Society outlined the guiding principles for urgently needed measures to ensure the future of sturgeons. They also provide key recommendations (Rosenthal et al., 2018) affecting the effectiveness of conservation management, while at the same time emphasizing the requirement to apply best practice when planning or implementing activities.

Natura 2000 network of protected areas proved to be an appropriate source to indicate habitat availability for multiple species (Funk et al., 2019). This database along with other considerations or projects may be useful to describe and identify sturgeon habitats. For instance, the aforementioned "Sturgeon 2020" program is ongoing to protect and rehabilitate Danube sturgeon populations. This program describes the respective measures required to achieve a successful implementation of the conservation and revival of the sturgeon population in the DRB (Sandu et al., 2013). Nevertheless, knowledge of sturgeon species and especially on sturgeon habitat use is rather limited at this moment. Future conservation actions require more specific information on the environmental characteristics of sturgeon key habitats, with the ones investigates in this study:

- wintering,
- spawning,
- and nursery habitats;

besides knowledge on the spatial distribution of these key habitats in the Danube River Basin (Friedrich, 2018; Reinartz et al., 2012). Therefore the present study aims to map and describe key habitats (for wintering, nursery, and spawning) in the DRB and to gather information on sturgeon key habitat preferences in the Danube River.

2. Rationale, objective, and hypothesis

The different research questions will be described below to reach conclusions about the main sturgeon habitats on the Danube. The environmental variables will be taken into account, as well as the different sturgeon species from the Danube.

Research Question 1

Which are the different criteria for suitable sturgeon habitats in the Danube River? How are these habitats defined by environmental variables (depth, gravel substrate, and water flow velocity), life stages, and species based on available data and knowledge?

> **Hypothesis 1.1**. Wintering habitats are not species-specific, they are located in deep pools in the river of 5-10 m and slow flow velocity (range: 0.1 to 1.0 m/s mean flow velocity).
>
> **Hypothesis 1.2**. Mean grain sizes of spawning substrates are not species-specific. They are located in areas with gravel substrate size of range: 2.0 to 20.0 mm.
>
> **Hypothesis 1.3**. Larval habitats are not species-specific. They are located in slow water flow areas (range: 0.1 to 1.0 m/s mean flow velocity).

Research Question 2

To what extent is the data collected by the MEASURES project sufficient to accurately map potential sturgeon habitats in the Danube River upstream of the Iron Gates dam?

> **Hypothesis 2.1**. There are potential wintering habitats for long-distance migratory species upstream from the Iron Gates dam.
>
> **Hypothesis 2.2**. There are potential spawning habitats for long-distance migratory species upstream from the Iron Gates dam.
>
> **Hypothesis 2.3**. There are potential larva habitats for long-distance migratory species upstream of the Iron Gates dam.

Research Question 3

Is there a correlation between the potential and confirmed habitats with the hydromorphological status assessed for the Danube River during the Joint Danube Survey 3 (JDS 3) (ICPDR, 2013b)? Is there a correlation between the potential and confirmed habitats with Natura 2000 sites? What are the main characteristics and supporting factors?

Hypothesis 3.1. Most sturgeon habitats in the Danube have a nearly natural or slightly modified status (according to JDS3 results).

Hypothesis 3.2. Most of the sturgeon habitats are located in Nature 2000 sites.

3. Materials and Methods

3.1. Study site description

The Danube River Basin covers more than 800,000 square kilometers (10% of continental Europe) and extends into the territories of 19 countries, the river is the 21st largest river globally, and the second-largest river in Europe. The basin is spatially heterogeneous and it can be based on its gradients, dividing the Danube into three sub-regions (ICPDR, 2009):

1) The upper basin (Upper Danube) flows from the spring in Germany to Devín Gate or Hainburger Gate in Bratislava (Slovakia). The Danube remains a characteristic mountain river until Passau, with an average bottom gradient 0.0012%, from Passau to Devín Gate the gradient lessens to 0.0006%.

2) The middle basin (Middle Danube) flows from Devín Gate to Iron Gate Gorge in the border between Serbia and Romania. The riverbed widens, and the average bottom gradient is only 0.00006%.

3) The lower basin including the Danube Delta (Lower Danube) flows from Iron Gate Gorge to Sulina in Romania, with an average gradient as little as 0.00003%.

3.2. Literature research

The first step in this master thesis is to get a comprehensive overview of the six sturgeon species in the DRB starting with a literature review on sturgeon species and their habitat requirements. This includes studying the six Danube species and their habitats on the Danube (wintering, spawning, and larvae habitats). Two books are mainly used to gain a comprehensive outline of the topic: “The sturgeons and paddlefishes of the world - biology and aquaculture” from Gessner and Hochleithner (2012) and “The Freshwater Fishes of Europe. Vol. I, Part II: General Introduction to Fishes Acipenseriformes” from Holčík (1989). The information is completed with more books, reports, and papers, which are searched in Google Scholar and Mendeley database. The following keywords were used: Acipenser, sturgeon, Danube sturgeon, sturgeon habitat, sturgeon wintering habitat, sturgeon spawning habitat, sturgeon larvae habitat, sturgeon conservation, Sterlet, *Acipenser ruthenus*, Ship sturgeon, *Acipenser nudiventris*, Russian sturgeon, Stellate sturgeon, *Acipenser stellatus*, European sturgeon, *Acipenser sturio*, Beluga sturgeon, *Huso huso*.

The information is classified in the first part of the results according to the species: *Acipenser ruthenus*, *Acipenser nudiventris*, *Acipenser gueldenstaedtii*, *Acipenser stellatus*, *Acipenser sturi*o, and *Huso huso.* According to information available in each section, data is sorted according to the type of habitat: Wintering habitats, spawning habitats, and nursery habitats.

A summary of the obtained data on the sturgeon habitats is included at the end of this first part. Spawning habitats has the most data availability, so it is extended to other sturgeon species to compare them with Danube species and reach a more comprehensive conclusion.

3.3. MEASURES database

The Interreg project MEASURES aims to create ecological corridors by identifying key habitats and initiating protection measures along the Danube and its main tributaries. Sturgeons and other migratory fish species act as flagship species in supporting its goals. In the three years of the project (2018-2021), MEASURES aims:

- to map and identify key habitats by developing and testing a methodology for migratory fish habitat mapping;
- to develop a harmonized strategy for restoring corridors and supporting the implementation in future management plans;
- to restock two native species to conserve their genetic pool in Hungary and Romania, establishing a network for concerted repopulation of the target species and elaborating a manual for the operation of broodstock facilities providing the offspring needed for the re-population;
- to implement the MEASURES Information System, facilitating the access of relevant information available, for experts, decision-makers as well as the public.

Within the project, a database will be developed, including information on geographical locations of sturgeon habitats in the Danube and its tributaries. This database forms the basis for the sturgeon habitat maps created by the ICPDR for the next 'Danube River Basin Management Plan'.

The displayed data on the maps includes six species, *Acipenser baerii* (non-native), *Acipenser nudiventris* (most probably extinct in the Danube), *Acipenser gueldenstaedtii*, *Acipenser ruthenus*, *Acipenser stellatus*, and *Huso huso*. The majority of the data covers the past 10 years, while some dates back to the 15th century (historical data).

Existing data of **confirmed sturgeon habitats** derived from various sources such as publications, project reports, books, field surveys, historical data, grey literature, or fisheries data was gathered by each country/partner. Additionally, **potential habitats** were identified based on the analyses of bathymetric and navigation maps using expert judgment. The following four habitat types were identified:

- Spawning habitat (Either direct capture/observation of spawning individuals or capture of drifting eggs or larvae);
- Nursery habitat (capture/observation of juvenile Sturgeons);
- Wintering habitat (capture/observation during winter);
- Feeding habitat (all other captures and observations)

List of countries and responsible partners:

Austria (University of Natural Resources and Life Sciences, Vienna), Bulgaria (WWF - World Wide Fund for Nature, Danube-Carpathian Program Bulgaria; Institute of Biodiversity and Ecosystem Research - Bulgarian Academy of Sciences), Croatia (Karlovac University of Applied Sciences), Germany (University of Natural Resources and Life Sciences, Vienna), Hungary, Romania (Danube Delta National Institute for Research and Development), Serbia (Institute for Multidisciplinary Research - University of Belgrade), Slovakia (Trnava University in Trnava, Faculty of Education), Slovenia (Institute for Ichthyological and Ecological Research REVIVO), Ukraine (Danube Delta National Institute for Research and Development).

The following criteria from the MEASURES database are being used to describe sturgeon habitats:

- Category of habitat: wintering places, spawning places, and nursery places

- Location: Latitude and longitude coordinates.
- Water depth (m): Vertical distance between riverbed and water level.
- Potential or confirmed habitat: Category in which the habitat use is validated whether individuals use it (confirmed) or they could use it (potential).
- Sturgeon species: Species currently present in DRB: *Acipenser ruthenus*, *Acipenser gueldenstaedtii*, *Acipenser stellatus*, *Huso huso.*
- Year: Time in which the habitat is registered.

In this section, the habitats are divided into the four Danube species, to then explain how many habitats there are in the following categories:

- Wintering confirmed place;
- Wintering potential place;
- Spawning confirmed place;
- Spawning potential place;
- Nursery confirmed place;
- Nursery potential place.

Subsequently, that information is presented in maps using ArcGIS (ESRI – ArcGIS Desktop version 10.7.1), differentiating recent data, and historical data from the 15th to 19th centuries.

Afterward, two tables present the information following the different references used by MEASURES. The first table has confirmed habitats and the second one potential habitats. As mentioned before, the data is subdivided based on the reference and the organization responsible for that information.

Also added in these tables are the information source (maps, report, field observation, MEASURES field observation, information from fisheries, annual order of the Odessa Fish Inspectorate or Paper); the reference year; the river; the number of habitats; the species; the habitat category (wintering, spawning or nursery); and the habitat depth.

In the end, sturgeon habitats are displayed in tables by depth, considering that it is the only environmental variable presented in the habitat's registration, though not all of them have depth information.

3.4. Hydromorphological assessment and Natura 2000

ArcGIS is the software used to develop the mapping of the MEASURES database in the previous section, so this information is compared and intersected with the hydromorphological status (ICPDR, 2013b) of the habitat and also with Natura 2000 sites (EEA, 2019). The excel file created in the MEASURES project with sturgeon habitats is converted into two shapefiles:

- Sturgeon habitats in Middle Danube, which only present Sterlet habitats.
- Sturgeon habitats in Lower Danube, which present Sterlet, Russian, Stellate, and Beluga sturgeon habitats.

These two shapefiles are intersected with:

- "Danube hydromorphological assessment" shapefile layer from the Joint Danube Survey 3 (JDS3) was made in 2013. It is available from the International Commission for the Protection of the Danube River. The assessment is based on a 10 rkm (river km) segmentation of the whole Danube from Kelheim to the delta (about 2,420 rkm) allowing assessment values for the channel, left/right banks, and left/right floodplain. The assessment of the hydromorphology is based on comparing the deviation from near to natural conditions, which were defined by authors for JDS3 purposes based on the given Danube typology developed in 2003 by Sommerhäuser et al. There are three parameters groups, morphology, hydrology, and river continuity. Each morphological parameter gets the assessment classes 1-5: 1 (near-natural), 2 (slightly modified), 3 (moderately modified), 4 (extensively modified) and 5 (severely modified) (Liška et al., 2015). These parameters assessment is used to better define MEASURES sturgeon habitats.
- "Nature 2000 sites" shapefile layer from 2019. This information is available on the European Environmental Agency. Natura 2000 is the key instrument to protect biodiversity in the European Union. It is an ecological network of protected areas, set up to ensure the survival of Europe's most valuable species and habitats. The spatial data (outlining the boundaries of sites) submitted by each Member State are validated by the European Environment Agency (EEAA, 2019). This information is used to check whether these sturgeon habitats belong to protected areas or not.

4. Results

4.1. Literature research

4.1.1. Acipenser ruthenus

Wintering habitats are usually depressions in the riverbed, those places are often located near the spawning grounds (Hochleithner & Gessner, 2012; Holčík, 1989).

Hochleithner & Gessner (2012) state that spawning season is from April to June, at water temperatures of 10-17ºC on gravel and pebbles of 1.0 to 7.0 cm diameter, in the middle of the rivers at depths of 2.0 to 15.0 m, with a current velocity of 1.5 to 5.0 m/s. Sterlet generally behaves as a resident fish and does not undertake long migrations (Holčík, 1989). Cross-correlation analysis indicates that sterlet reproduction is more successful during low water level periods than during floods (Guti, 2008).

Sterlet larvae and juveniles remain at the spawning sites among rocks and stones during their early development, but later, the juveniles disperse to feeding grounds. By tagging sterlets in the Danube, it was found that this species did not usually travel beyond 200 km and the majority migrate 7 to 23 km downstream per day (Holčík, 1989). In the pre-larvae stage (yolk sac) they are photoactive, meaning larvae drift during the day. This is an important factor for the dispersion of larvae in the first seven days (Chebanov & Galich, 2011; Chebanov et al., 2011).

4.1.2. Acipenser nudiventris

Ship sturgeon overwinters in deep pools (Hochleithner & Gessner, 2012).

Ship sturgeon spawning takes place in cycles of 1-2 years in the males and 2-3 years in females. The spawning migration is mainly during spring, although a fall migration is also known. Spawning seasons are from March to May at water temperatures of 10-20ºC and takes place over clay or pebbles in the middle of the rivers, with a current velocity of 1.0 to 2.0 m/s (Hochleithner & Gessner, 2012). Holčík (1989) mentions that spawning takes place in the Danube at water temperatures between 10-15ºC.

Juveniles usually stay in freshwaters for 2 to 8 years and then enter brackish and seawater (Hochleithner & Gessner, 2012).

4.1.3. Acipenser gueldenstaedtii

Russian sturgeon starts migrating in autumn and usually overwinter in deep pools and metabolize up to 50% of their body lipids during winter (Hochleithner & Gessner, 2012).

Spawning takes place in cycles of 2-3 years in males and 3-6 years in females. In the Danube, spawning ranges from March to October, concerning temperature regime, and usually in the early morning in the middle of the river, over pebble or stony bottom with sand or gravel deposits, in a depth of 4.0 to 25.0 m, with a current velocity of 1.0 to 1.5 m/s (Hochleithner & Gessner, 2012). Holčík (1989) states that in the Danube, the spawning sites are distributed through very large areas, and the Russian sturgeon run continues for a long time. Spawning begins at a temperature of 8ºC and with a current velocity is 1.0 to 1.5 m/s. Most of the reproduction takes place on the riverbed of the main channel. A small number of the spawning shoal reproduces near the mouth, but the great majority migrate upstream before spawning (Holčík, 1989).

Russian sturgeon larvae are found at considerably depths and in rapid currents, which contribute to their rapid downstream movement (Holčík, 1989). At higher water levels, up to 80% of the larvae drift to the lower reaches of the river or may go into the brackish waters of the sea, during low water level the fish tend to stay in freshwater until the fall (Hochleithner & Gessner, 2012).

4.1.4. Acipenser stellatus

Stellate sturgeon spawning takes place in cycles of 2-3 years in males and 3-4 years in females. The spawning season is from April to September, at water temperatures of 15-25ºC, over gravel to pebble substrates of 3.0 to 10 cm diameter, at depths of 1.0 to 15.0 m, with a current velocity of 1.2 to1.5 m/s (Hochleithner & Gessner, 2012). Stellate sturgeon prefers warmer habitats, its spawning runs in the river occur at water temperatures higher than those prevailing during the migrations of beluga sturgeon or other sturgeons. Stellate migration in the Danube takes place from May to June at water temperatures of 17-23ºC. The eggs are laid on beds of scattered stones, pebbles, and gravel mixed with shell fragments and coarse sand (Holčík, 1989).

The larvae of stellate sturgeon undergo initial development close to the spawning grounds and begin to move downstream five to11 days after hatching. Most migrate at a size of 1-7 g into the brackish water of the estuary (Hochleithner & Gessner, 2012). Holčík states that the juveniles under 9.0 cm remain near the mouths and congregate at depths from 6.0 to 18.0 m above a sandy bottom. The larger juveniles usually stay above clayey sediments at depths from 7.0 to 19.0 m, but they occasionally descend as deep as 17.0 m.

4.1.5. *Acipenser sturio*

European sturgeon spawning cycle is 1-3 years in both sexes. The spawning season is from April to July at water temperatures of 13-22ºC, southern stocks spawn earlier than northern ones. Spawning takes place, in groups consisting of one female and several males, over grabble or pebble substrates (3-250 mm), in the deeper parts of the rivers (min. 5 m depth), or near tributaries, with the current velocity of 0.5 to 2.0 m/s (Hochleithner & Gessner, 2012). On the contrary, Holčík (1989) reports that the spawning period continues from March to August, it is later for the northern populations and those spawning at sites farther from estuaries. It also states that spawning takes place in deep pools with swift currents over rocky or pebble bottom, either in the main channel or in lotic branches (Holčík, 1989).

4.1.6. *Huso huso*

Beluga sturgeon in the Ural river is suggested to enter the river at the end of spring and beginning of summer, forming winter aggregations in depressions in the river and migrating up the Ural following spring (Berg, 1948). Spawning occurs at water temperatures of 9-11ºC (Levin, 1997).

Hochleithner & Gessner (2012) report that both sexes spawn in cycles of 3-5 years. Beluga ascends rivers close to the bottom of the deep channels. Historically, migrations of up to 2000 km have been reported. Some fish migrate from February to April while most fish ascends the river from September to November and overwinter close to the spawning grounds. The spawning season is from April to June, at water temperatures of 9-17ºC. It takes place over pebble to rocky substrates at depths of 3.0 to 20.0 m, with a current velocity of 1.0 to 2.0 m/s.

In the Danube, spawning migrations can be observed almost the whole year-round. Nevertheless, two favorite periods have been noted, one for the winter and another for the spring race. The spring run is observed from January through April at a temperature of 4-5ºC. The second is the autumn run, which begins in August and reaches its peak in October and November. In the Danube, the spawning period is in April and May, the great sturgeon spawns at lower temperatures and within a narrower temperature range than other migratory sturgeon species, particularly the Russian and the Stellate sturgeons. The spawning time coincides with a flood peak, Holčík (1989) states that spawning begins at a water temperature of 6-7ºC, and it ceases when the temperature reaches 21ºC. The optimal temperature lies within the range of 9-17ºC. In general, they spawn farther upstream in all rivers than any other migratory sturgeon, and therefore regulation of the water flow and construction of damns have the greatest impact on the natural reproduction of this species. The spawning usually takes place over the hard, stony, or gravelly bottom at a depth of 4.0 to 15.0 m, but it also occurs as deep as 40.0 m. The current velocity is about 1.5 to 2.0 m/s and the oxygen saturation of the water in no less than 80%. The main spawning sites are in the river bed, but temporary sites in flooded places along the rivers may also be utilized for reproduction (Holčík, 1989). The hatchlings of beluga sturgeon do not remain very long in the river, and at an early age, while still larvae, they travel to the sea (Holčík, 1989).

4.1.7. Habitat summary from literature research

The information collected on wintering habitats is coincident with the places used, in other words, literature states that they are in deep pools in the riverbed, however, it does not provide any specific number range of depth. Data on nursery habitats is much less specific compared to wintering or spawning habitats and there is no explicit information on nursery sturgeon habitats because there is not enough data availability. Finally, for spawning habitats, the information is more numerous, and it is different both, depending on the species, and the river stretch or the river. Below in Table 8, a summary of the habitat attributes is shown. Besides, in Table 9 other non-native Danube species have been also added to compare habitat attributes. They are the following ones: Depth (D.) min (m), depth max (m), flow velocity (V.) min (m/s), flow velocity max (m/s), temperature min (ºC), temperature (Tª) max (ºC), type of substrate and name of the river.

Table 8. Danube Sturgeon Spawning habitat attributes.

D (depth); V (flow velocity); Tª (temperature); A (*Acipenser*)

Species	Common name	D. min (m)	D. max (m)	V. min (m/s)	V. max (m/s)	Tª min (ºC)	Tº max (ºC)	Type of substrate	River	Source
A. gueldenstaedtii	Russian sturgeon	4.0	25.0	1.0	1.5	N/A	N/A	Pebble or stony bottom with sand or gravel deposits	N/A	(Hochleithner & Gessner, 2012)
A. gueldenstaedtii	Russian sturgeon	4.0	25.0	1.0	1.5	8.0	N/A	Gravel or stony beds	Danube	(Holčík, 1989)
A. gueldenstaedtii	Russian sturgeon	7.5	20.7	N/A	N/A	N/A	N/A	Mainly bedrock	Danube	(MEASURES, 2019)
A. nudiventris	Ship sturgeon	N/A	N/A	1.0	2.0	10.0	20.0	Clay or pebbles in the middle of the rivers	N/A	(Hochleithner & Gessner, 2012)
A. nudiventris	Ship sturgeon	N/A	N/A	1.0	2.0	N/A	N/A	N/A	N/A	(Holčík, 1989)
A. nudiventris	Ship sturgeon	N/A	N/A	N/A	N/A	10.0	15.0	N/A	Danube	(Holčík, 1989)
A. ruthenus	Sterlet	2.0	15.0	1.5	5.0	10.0	17.0	Gravel and pebbles of 1-7 cm diameter	N/A	(Hochleithner & Gessner, 2012)
A. ruthenus	Sterlet	7.0	15.0	1.5	5.0	8.0	19.0	Pebbles 1 to 7 cm in diameter	Danube	(Holčík, 1989)

Species	Common name	D. min (m)	D. max (m)	V. min (m/s)	V. max (m/s)	Tª min (ºC)	Tº max (ºC)	Type of substrate	River	Source
A. ruthenus	Sterlet	7.4	20.6	N/A	N/A	N/A	N/A	N/A	Danube	(MEASURES, 2019)
A. ruthenus	Sterlet	0.7	1.7	N/A	N/A	N/A	N/A	N/A	Drava, Mura, Siret	(MEASURES, 2019)
A. stellatus	Stellate sturgeon	1.0	15.0	1.2	1.5	15.0	25.0	Gravel to pebble substrates of 3-10 cm diameter	N/A	(Hochleithner & Gessner, 2012)
A. stellatus	Stellate sturgeon	2.0	3.0	0.3	1.2	9.0	16.0	N/A	Lower Volga (rkm 105-347)	(Veschev, 2009)
A. stellatus	Stellate sturgeon	N/A	N/A	0.7	1.9	17.0	23.0	Beds of scattered stones, pebbles and gravel mixed with shell fragments and coarse sand	Danube	(Holčík, 1989)
A. stellatus	Stellate sturgeon	7.5	20.7	N/A	N/A	N/A	N/A	Mainly bedrock	Danube	(MEASURES, 2019)
A. stellatus	Stellate sturgeon	2	2	N/A	N/A	N/A	N/A	Mainly bedrock	Siret	(MEASURES, 2019)
A. sturio	European sturgeon	5.0	N/A	0.5	2.0	13.0	22.0	Grabble or pebble substrates (3-250 mm)	N/A	(Hochleithner & Gessner, 2012)

Species	Common name	D. min (m)	D. max (m)	V. min (m/s)	V. max (m/s)	Tª min (ºC)	Tº max (ºC)	Type of substrate	River	Source
A. sturio	European sturgeon	N/A	N/A	N/A	N/A	7.7	22.0	Rocky or pebble bottom	N/A	(Holčík, 1989)
A. sturio	European sturgeon	5.0	N/A	0.5	N/A	18.0	N/A	N/A	Rhône (rkm 50-60)	(Brosse et al., 2009)
A. sturio	European sturgeon	5.0	N/A	0.5	1.5	14.0	22.0	N/A	Garonne-Dordogne (rkm 170-270 (rkm 100-210)	(Jego et al, 2002)
Huso huso	Beluga sturgeon	3.0	20.0	1.0	2.0	9.0	17.0	Pebble to rocky substrates	N/A	(Hochleithner & Gessner, 2012)
Huso huso	Beluga sturgeon	4.0	15.0	1.5	2.0	9.0	17.0	Hard, stony or gravelly bottom	Danube	(Holčík, 1989)
Huso huso	Beluga sturgeon	N/A	N/A	0.5	0.7	N/A	N/A	N/A	Danube	(Kynard et al., 2002)
Huso huso	Beluga sturgeon	8.5	21.2	N/A	N/A	N/A	N/A	Mainly bedrock	Danube	(MEASURES, 2019)

Table 9. Non-native Danube Sturgeon Spawning habitat attributes.

D (depth); V (flow velocity); T[a] (temperature); A (*Acipenser*)

Species	Common name	D. min (m)	D. max (m)	V. min (m/s)	V. max (m/s)	T[a] min (ºC)	T[o] max (ºC)	Type of substrate	River	Source
A. brevirostrum	Shortnose sturgeon	1.2	10.4	0.4	1.0	9.0	18.0	Cobble, rubble	Conneticut	(Buckley & Kynard, 1985)
A. brevirostrum	Shortnose sturgeon	1.0	5.0	0.4	1.3	6.5	15.9	Gravel, pebble	Conneticut	(Kieffer & Kynard, 2012)
A. brevirostrum	Shortnose sturgeon	6.0	9.0	0.8	0.8	9.0	12.0	Gravel, rubble, cobble	Savannah (rkm 179-190) (rkm 275278)	(Hall et al., 1991)
A. brevirostrum	Shortnose sturgeon	1.8	5.0	0.3	0.7	10.0	14.0	Boulder, rubble	Merrimack (rkm 30-32)	(Kieffer & Kynard, 1996)
A. brevirostrum	Shortnose sturgeon	3.0	4.0	N/A	N/A	9.0	15.0	N/A	Conneticut	(Taubert, 1980)
A. fulvescens	Lake sturgeon	N/A	N/A	0.1	1.9	N/A	N/A	N/A	Des Prairies and L'Assompt	(LaHaye et al., 2008)
A. fulvescens	Lake sturgeon	N/A	N/A	0.9	N/A	N/A	N/A	N/A	N/A	(Threader et al., 1998)
A. fulvescens	Lake sturgeon	9.0	12.0	0.4	1.0	13.0	15.0	Cobble, coarse gravel, coal cinders	Channels Laurentian Great Lakes	(Manny & Kennedy, 2002)
A. fulvescens	Lake sturgeon	0.8	5.5	0.5	1.4	13.0	15.0	Coarse gravel, boulder	Des Prairies	(Dumont et al., 2011)

Species	Common name	D. min (m)	D. max (m)	V. min (m/s)	V. max (m/s)	Tª min (ºC)	Tº max (ºC)	Type of substrate	River	Source
A. fulvescens	Lake sturgeon	6.0	10.0	0.5	0.7	12.0	20.0	Limestone shot rock, sorted limestone, rounded igneous rock	Detroit	(Bouckaert et al., 2014)
A. oxyrinchus	Baltic sturgeon	11.0	13.0	N/A	N/A	13.0	18.0	N/A	N/A	(Scott & Crossman, 1973)
A. oxyrinchus	Baltic sturgeon	0.5	6.0	0.2	2.2	13.0	26.0	N/A	Drawa, Warta, Prosna	(Arndt et al., 2006)
A. sinensis	Chinese sturgeon	7.8	15.0	0.2	1.0	17.0	20.0	N/A	Yangtze (rkm 2206-2817)	(Du et al, 2011; Gao et al., 2013; Yang et al., 2006)
A. transmontanus	White sturgeon	4.0	13.0	0.1	0.8	7.5	14.0	Gravel, cobble	Kootenay (rkm 229-240)	(Paragamian & Wakkinen, 2001)
A. transmontanus	White sturgeon	4.0	13.0	0.1	1.0	8.5	12.0	Gravel, cobble	Kootenay (rkm 229-240)	(Paragamian & Wakkinen, 2002)
A. transmontanus	White sturgeon	N/A	N/A	0.8	2.8	10.0	20.0	Cobble, boulder, bedrock	Columbia: rkm 223-234	(Parsley el al., 1993)
A. transmontanus	White sturgeon	3.0	23.0	0.6	2.4	10.0	18.5	Cobble, boulder, bedrock	Lower Columbia	(McCabe & Tracy, 1994)

The minimum and maximum depths, flow velocity and water temperature described for spawning habitats of the native Danube sturgeon species are quite variable (Table 10) and not comparable to other sturgeon species. The most unanimous habitat attribute is the type of substrate, in which rocky substrate prevails: Pebble (1-7 cm diameter), stony bottom, gravel deposits (3-10 cm diameter), etc.

Table 10. Summary Danube Sturgeon Spawning habitat attributes: D (depth); V (flow velocity); Tª (temperature); A (*Acipenser*)

Species	Common name	D. min (m)	D. max (m)	V. min (m/s)	V. max (m/s)	Tª min (ºC)	Tº max (ºC)	Type of substrate	Source
A. gueldenstaedtii	Russian sturgeon	4.0 - 7.5	20.7 – 25.0	1.0	1.5	8.0	N/A	rocky substrate	(Hochleithner & Gessner, 2012) (Holčík, 1989) (MEASURES, 2019)
A. nudiventris	Ship sturgeon	N/A	N/A	1.0	2.0	10.0	15.0 – 20.0	rocky substrate	(Hochleithner & Gessner, 2012) (Holčík, 1989)
A. ruthenus	Sterlet	0.7 – 7.4	1.7 – 20.6	1.5	5.0	8.0 – 10.0	17.0 – 19.0	rocky substrate	(Hochleithner & Gessner, 2012) (Holčík, 1989) (MEASURES, 2019)
A. stellatus	Stellate sturgeon	1.0 - 7.5	2 – 20.7	0.3 – 1.2	1.2 – 1.9	9.0 – 17.0	16.0 – 25.0	rocky substrate	(Hochleithner & Gessner, 2012) (Holčík, 1989) (Veschev, 2009) (MEASURES, 2019)
A. sturio	Common sturgeon	5	N/A	0.5	1.5 – 2.0	7.7. – 18.0	22.0	rocky substrate	(Hochleithner & Gessner, 2012) (Holčík, 1989) (Brosse et al., 2009) (Jego et al, 2002)
Huso huso	Beluga sturgeon	3.0 - 8.5	15.0 – 21.2	0.5 – 1.5	0.7 – 2.0	9.0	17.0	rocky substrate	(Hochleithner & Gessner, 2012) (Holčík, 1989) (Veschev, 2009) (MEASURES, 2019)

4.2. Results from the MEASURES database

The following sturgeon habitats are found, regarding wintering, spawning, and nursery habitats (Figure 7, 8, and 9):

- Sterlet: 79 confirmed habitats and 303 potential habitats.
- Russian sturgeon: 4 confirmed habitats and 16 potential habitats.
- Stellate sturgeon: 4 confirmed habitats and 19 potential habitats.
- Beluga sturgeon: 7 confirmed habitats and 31 potential habitats.

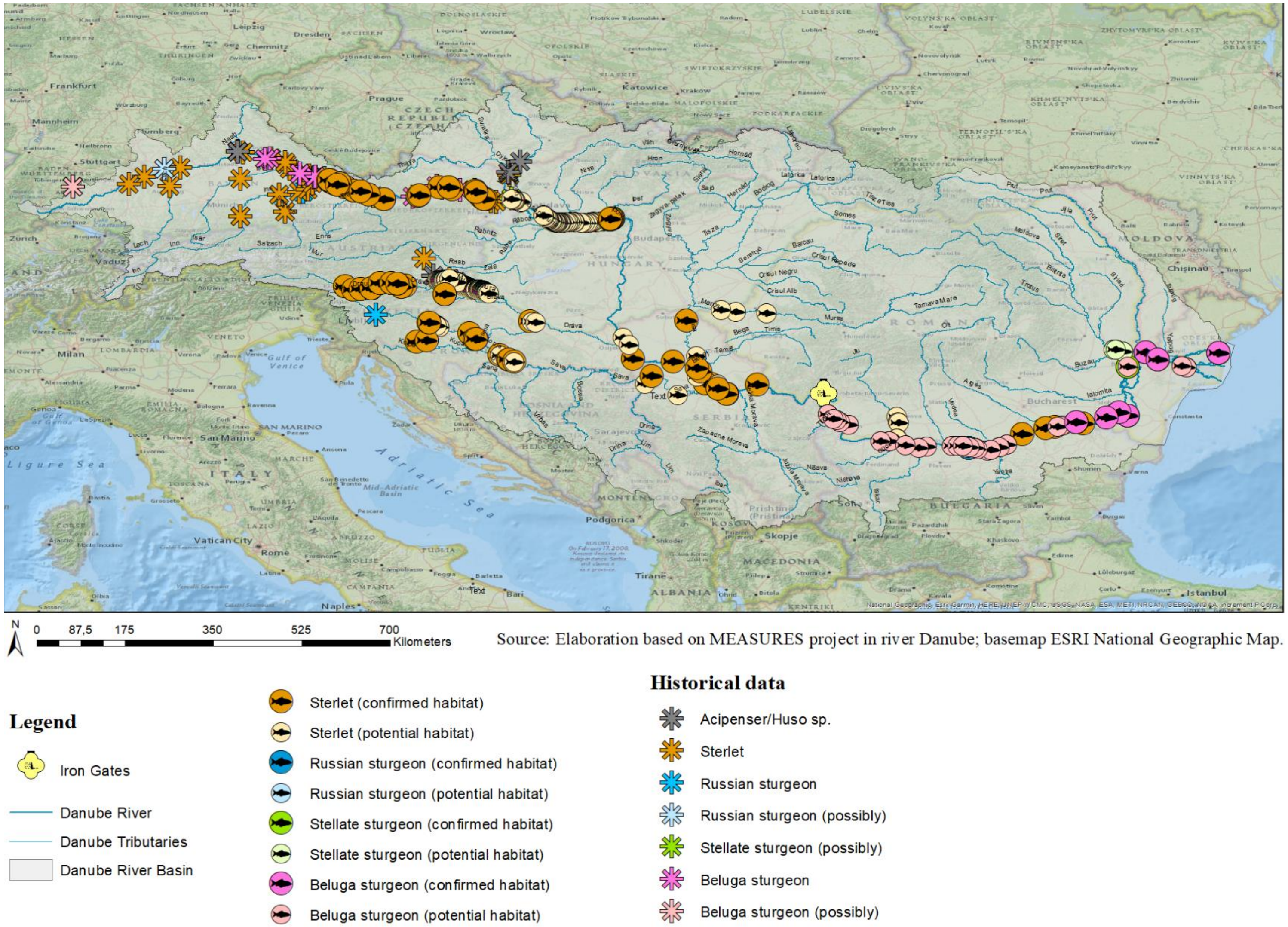
382 Sterlet habitats were found (Figure 10), from which 10 are confirmed wintering habitats, 163 are potential wintering habitats, 6 are confirmed spawning habitats, 42 are potential spawning habitats, 63 are confirmed nursery habitats and 98 are potential nursey habitats.

20 Russian sturgeon habitats were found (Figure 11), from which 10 are potential wintering habitats, 1 is a confirmed spawning habitat, 5 are potential spawning habitats, 3 are confirmed nursery habitats and 1 is a potential nursery habitat.

24 Stellate sturgeon habitats were found (Figure 12), from which 11 are potential wintering habitats, 7 are potential spawning habitats, 4 are confirmed nursery habitats, 1 is a potential nursery habitat and 1 is a confirmed feeding habitat.

38 Beluga sturgeon habitats were found (Figure 13), from which 2 are confirmed wintering habitats, 11 are potential wintering habitats, 2 are confirmed spawning habitats, 19 are potential spawning habitats, 3 are confirmed nursery habitats, and 1 is a potential nursery habitat.

Historical data is also added to the following maps (Figure 7 to 13). These sturgeon habitats correspond to the 15th-19th century data.



Source: Elaboration based on MEASURES project in river Danube; basemap ESRI National Geographic Map.

Figure 7. Map: General overview of sturgeon species habitat in DRB

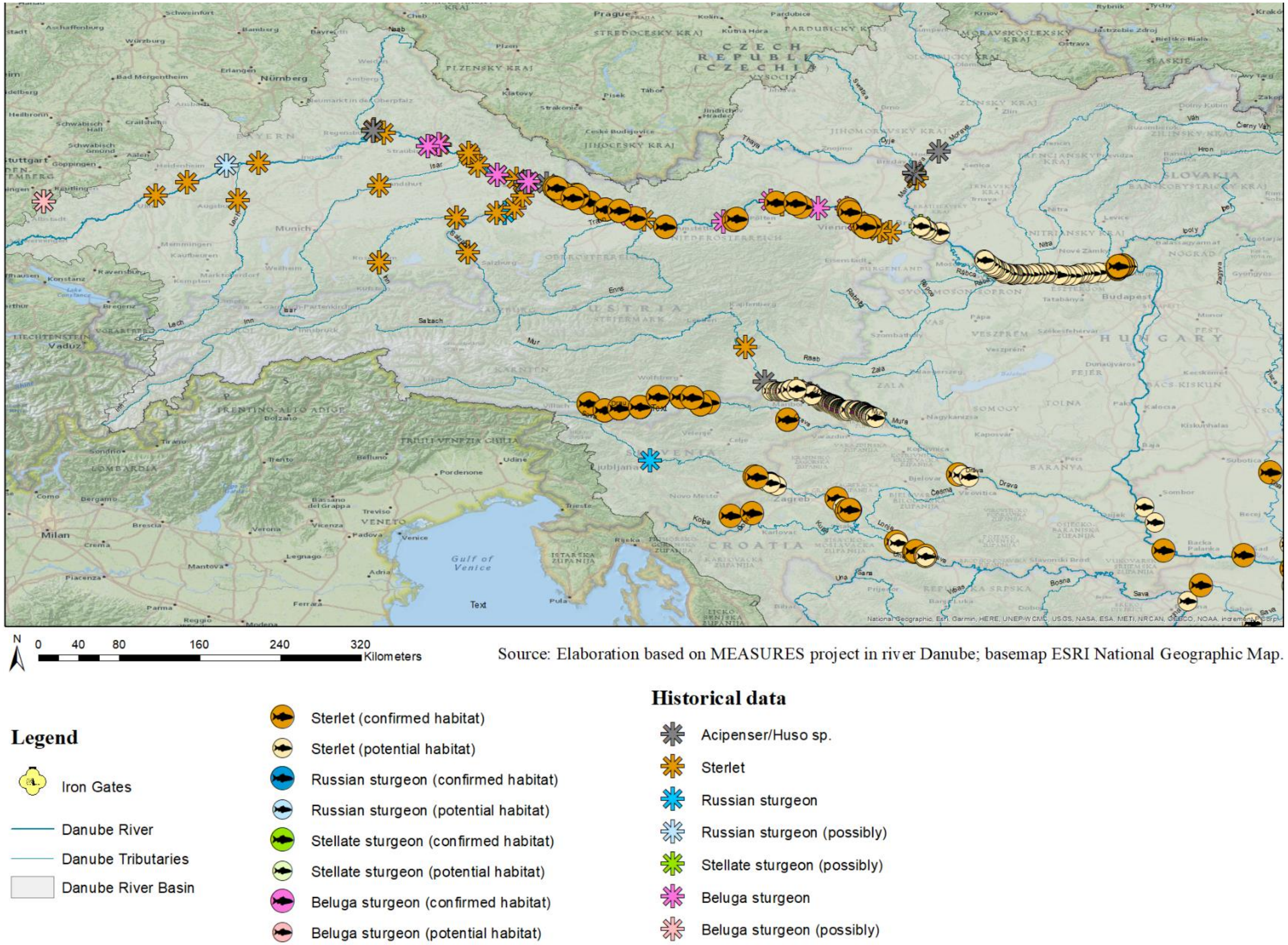


Figure 8. Map: General overview of sturgeon species habitat in Upper and Middle Danube

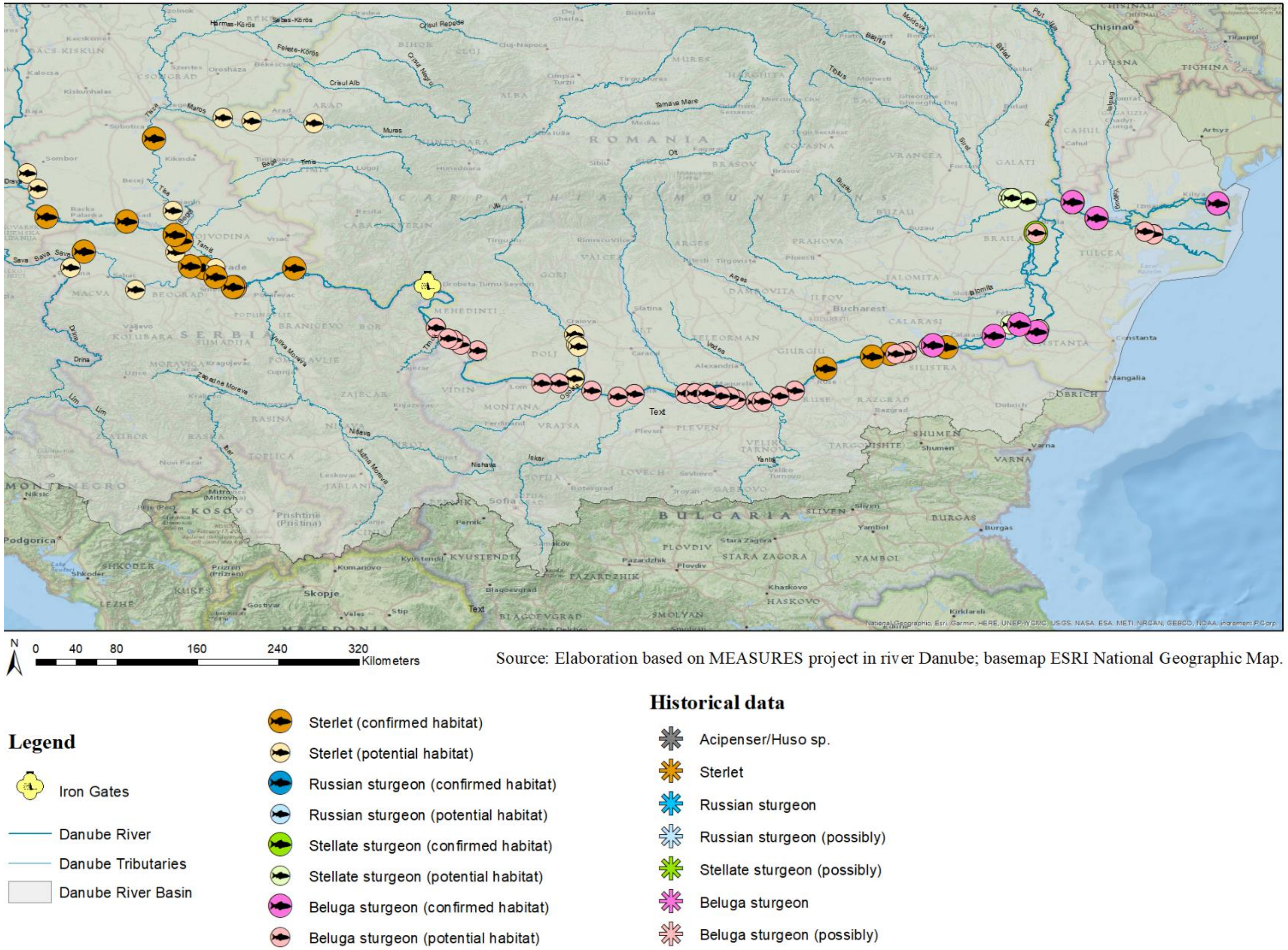


Figure 9. Map: General overview of sturgeon species habitat in Lower Danube

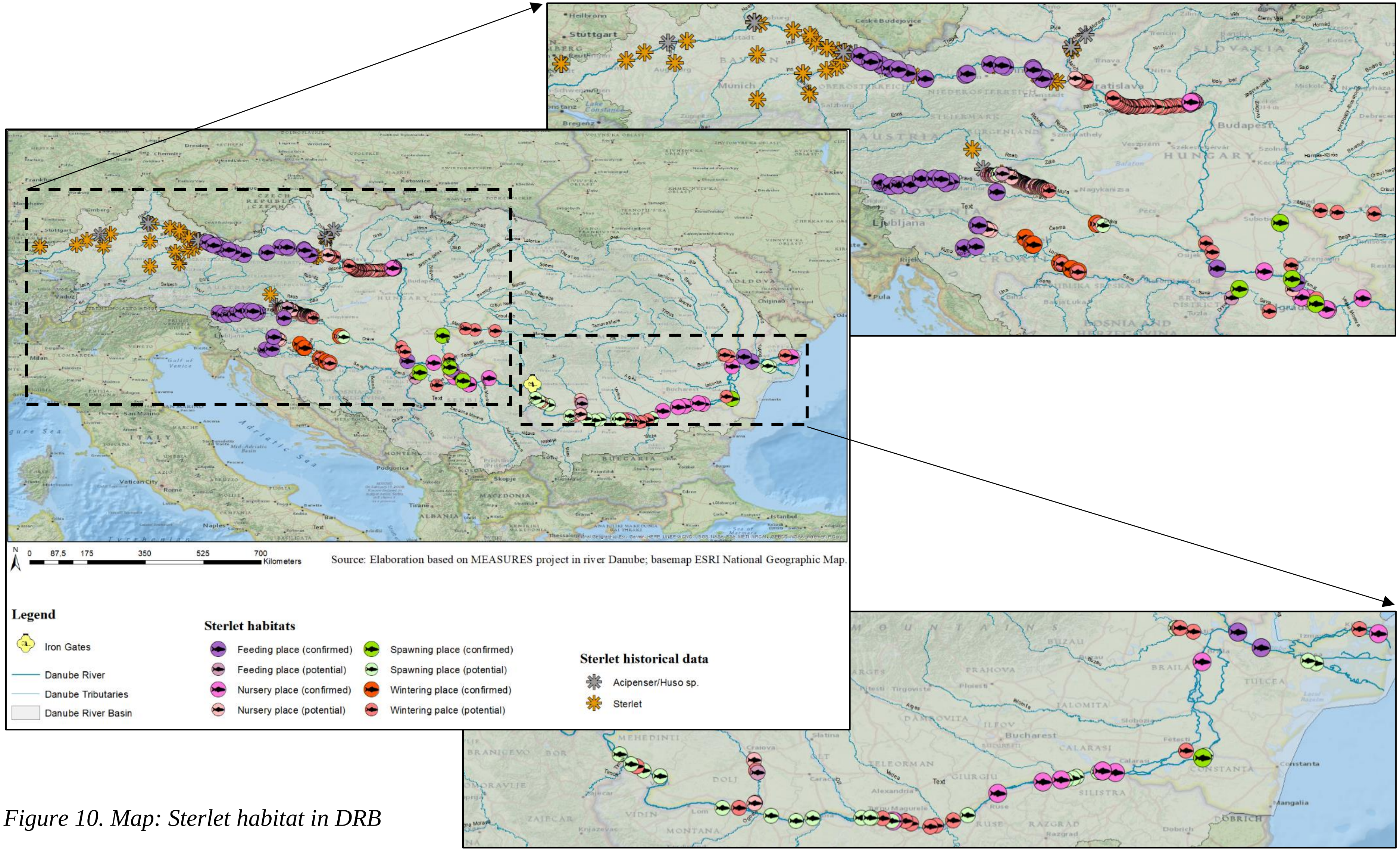


Figure 10. Map: Sterlet habitat in DRB

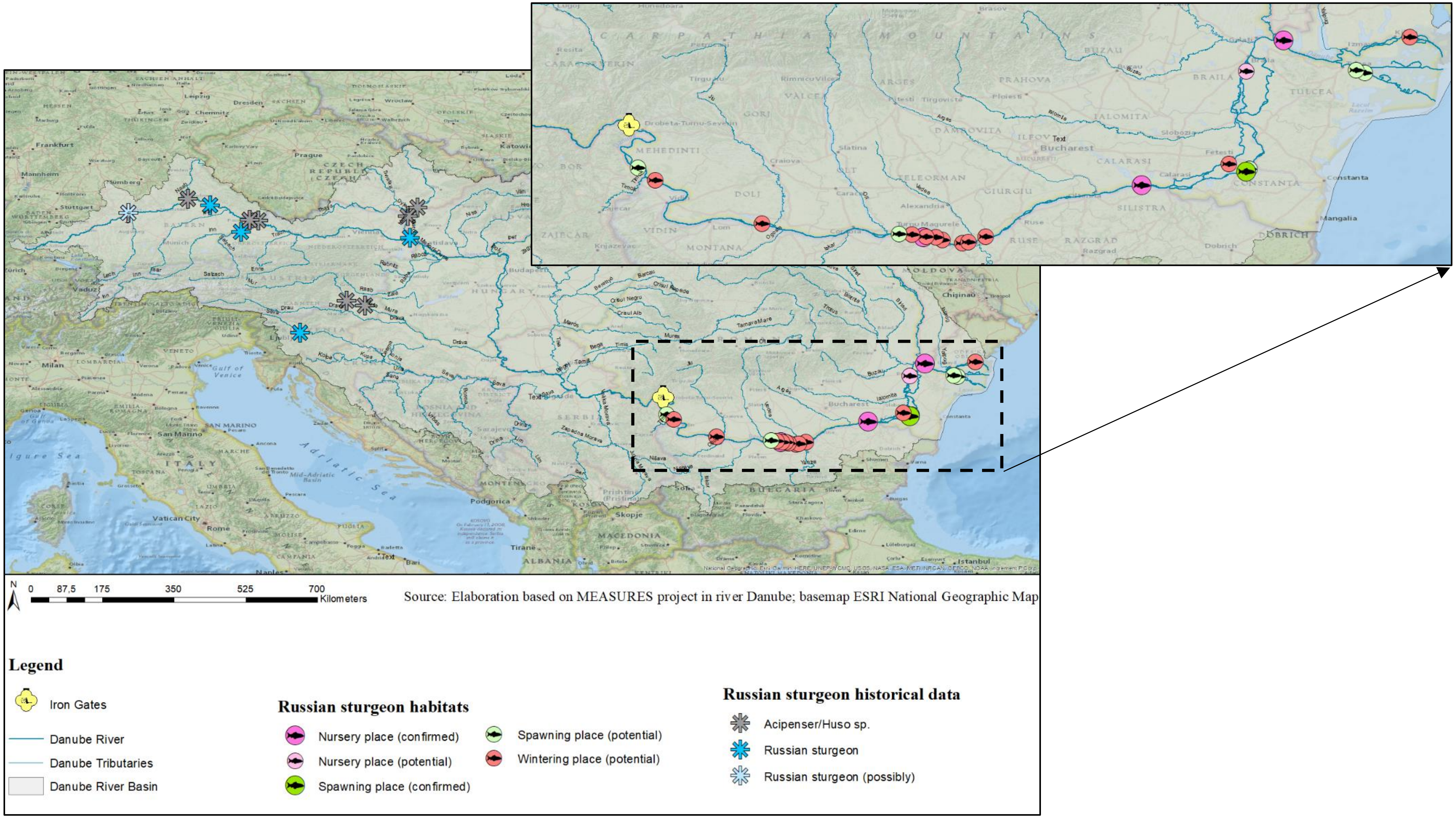
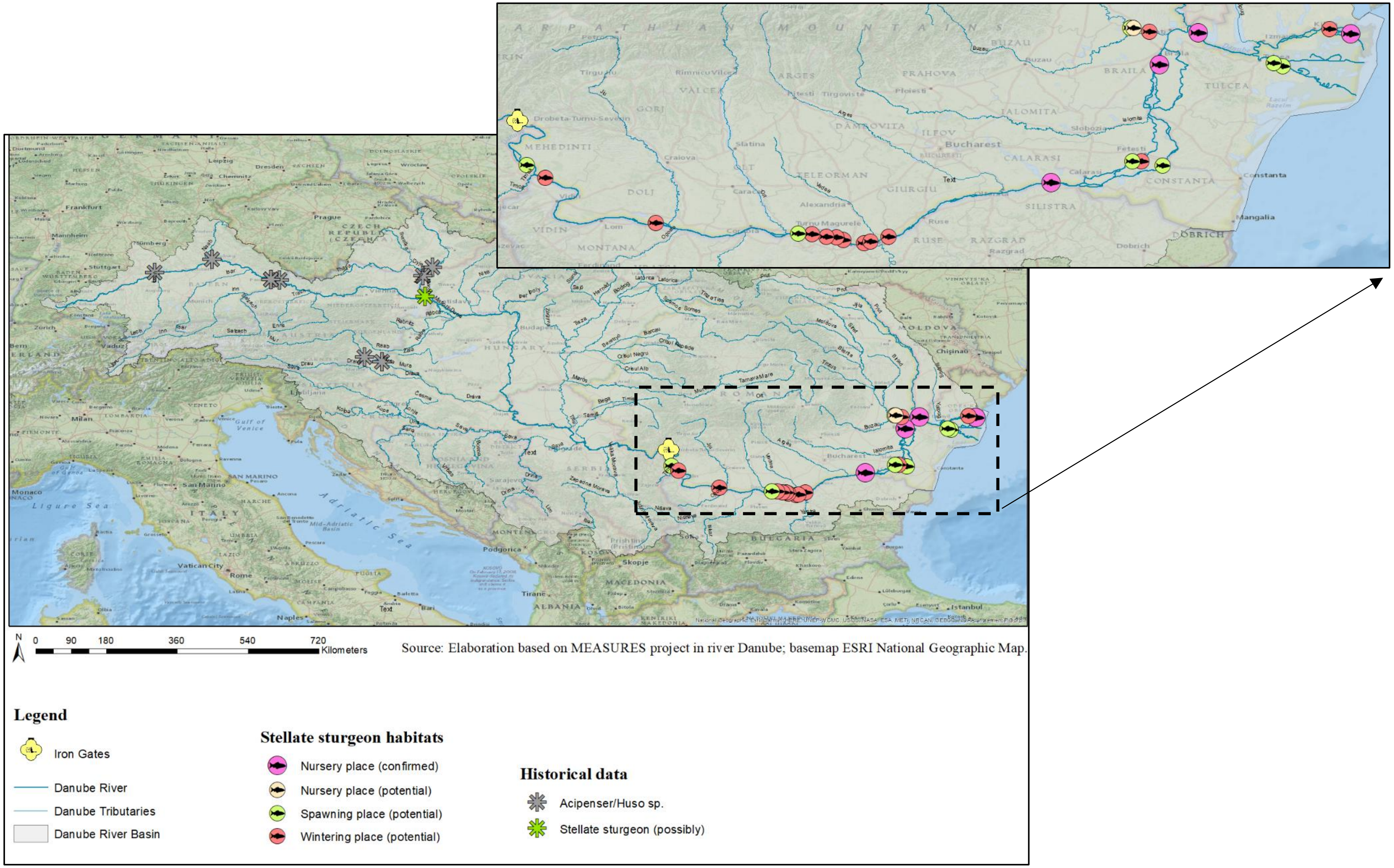


Figure 11. Map: Russian sturgeon habitat in DRB



Fgure 12. Map: Stellate sturgeon habitat in DRB

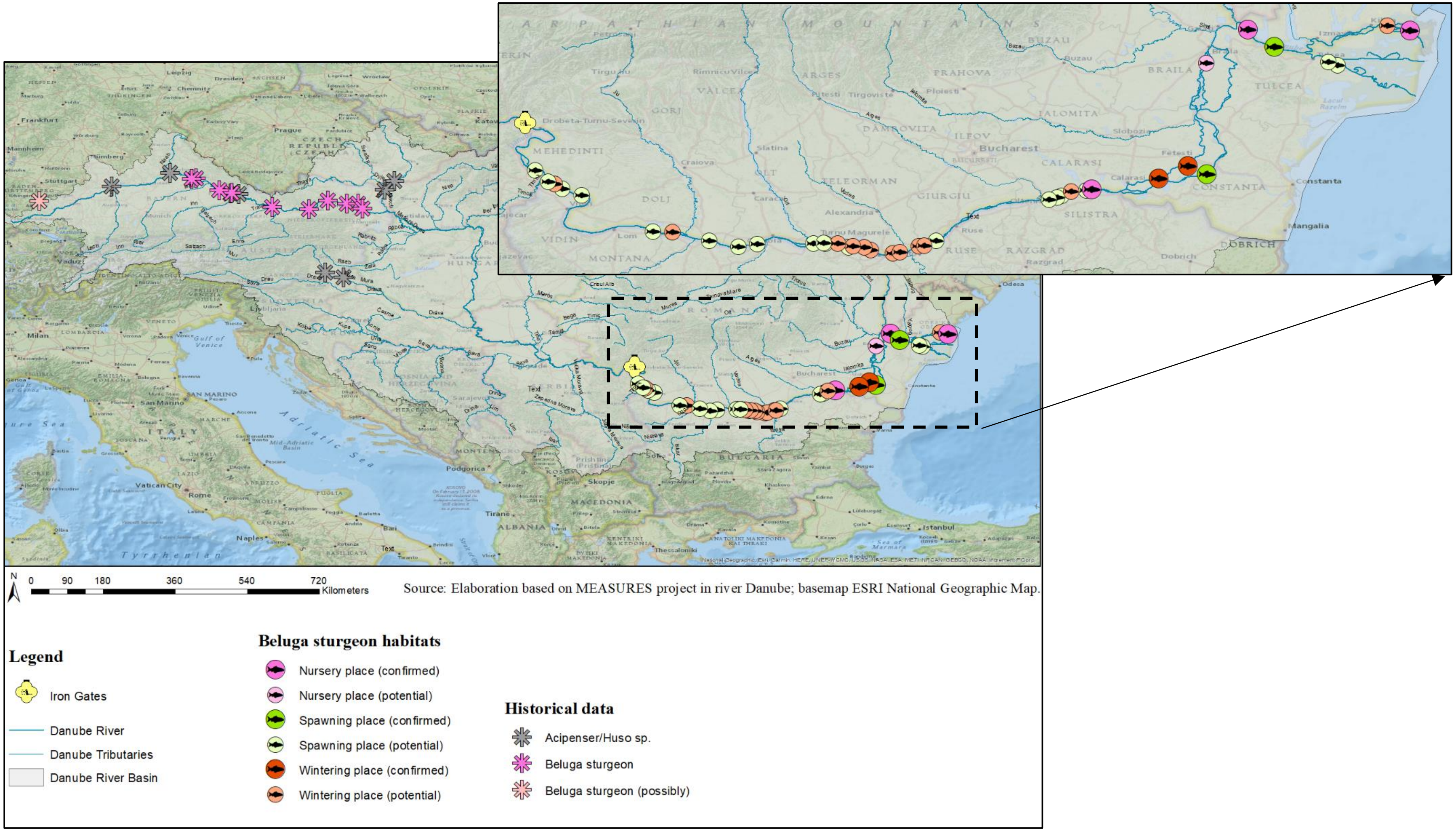


Figure 13. Map: Beluga sturgeon habitat in DRB

Following in Table 11 (confirmed habitats) and 12 (potential habitats) are the different references used by MEASURES. The number of habitats collected is shown with their corresponding attributes:

- Species: *A. ruthenus* (Sterlet), *A. gueldenstaedtii* (Russian sturgeon), *A. stellatus* (Stellate sturgeon), or *Huso huso* (Beluga sturgeon).
- Habitat category: Wintering (W), spawning (SP), or nursery (N).
- Depth (m)

Table 11: Confirmed sturgeon habitats from MEASURES project in the DRB (wintering - W, spawning - SP, or nursery - N)

Reference	Responsibility	Source	Year	River	Quantity of Habitats	Species	Category of habitat	Depth (m)
Croatian Ichthyology Society, 2018	VUKA (Croatia)	Field observation	2018	Drava	1	Sterlet	W	18
				Sava	8	Sterlet	W	14 to 23
Hanganu, 2018	DDNI (Romania)	Report	2018	Danube	1	Sterlet	SP	15
					2	Beluga sturgeon		
Paraschiv, 2011	DDNI (Romania)	Report	2011	Danube	1	Russian sturgeon	N	13
					1	Sterlet		
					1	Stellate sturgeon		
					1	Beluga sturgeon		
Mihov, 2007-2019	WWF-BG (Bulgaria)	Field observation	2013 to 2019	Danube	2	Russian sturgeon	N	N/A
					7	Sterlet		
					1	Stellate sturgeon		
					1	Beluga sturgeon		
Ristic, 1969	IMSI (Serbia)	Paper	1969	Danube	2	Sterlet	SP	13 to 18
				Sava	1			N/A
				Tisa	1			N/A
Suciu, 2007		Report	2007	Danube	1	Russian sturgeon	SP	10

Reference	Responsibility	Source	Year	River	Quantity of Habitats	Species	Category of habitat	Depth (m)
	DDNI (Romania)				1	Sterlet		
					1	Beluga sturgeon		
Suciu et al., 2011	DDNI (Romania)	Report	2011	LDR	1	Sterlet	N	8
					1	Stellate sturgeon	N	8
					2	Beluga sturgeon	W	20
Unpublished	Fish inspection	Preliminary report IMB NASU	2019	LDR	1	Sterlet	N	4 to 6
					1	Stellate sturgeon		
					1	Beluga sturgeon		
N/A	IMSI (Serbia)	Fisheries	2002 to 20018	Danube	53	Sterlet	N	4 to 7
	TRUNI (Slovakia)	Field observation	2015					

Table 12: Potential sturgeon habitats from MEASURES project in the DRB (wintering - W, spawning - SP, or nursery - N)

Reference	Responsibility	Source	Year	River	Quantity of Habitats	Species	Category of habitat	Depth (m)
Mihov, 2007-2019	WWF-BG (Bulgaria)	Maps and report	2007 to 2019	LDR	8	Russian sturgeon	W	N/A
					8	Sterlet		
					8	Stellate sturgeon		
					8	Beluga sturgeon		
		Field observation	2013 to 2018	LDR	1	Russian sturgeon	W	N/A
					1	Sterlet	W	
					15	Sterlet	SP	
					1	Stellate sturgeon	W	
					15	Beluga sturgeon	SP	
					1	Beluga sturgeon	W	
Suciu, 2007	DDNI (Romania)	Report	2007	LDR	1	Russian sturgeon	SP	10
					1	Sterlet		
					1	Stellate sturgeon		
Suciu et al., 2011	DDNI (Romania)	Report	2011	LDR	1	Russian sturgeon	W	20
					1	Russian sturgeon	N	8
					1	Sterlet	W	20
					1	Stellate sturgeon	W	20
					1	Stellate sturgeon	SP	10
					1	Beluga sturgeon	N	8
N/A	DDNI (Romania)	MEASURES field observation	2019	LDR	2	Russian sturgeon	SP	20 to 25
					2	Sterlet	SP	20 to 25
					2	Stellate sturgeon	SP	20 to 25
					2	Beluga sturgeon	SP	20 to 25

Reference	Responsibility	Source	Year	River	Quantity of Habitats	Species	Category of habitat	Depth (m)
				Siret	2	Sterlet	W	2 to 18
					1	Sterlet	N	2
					1	Sterlet	SP	2
					1	Stellate sturgeon	W	2
					1	Stellate sturgeon	SP	2
					1	Stellate sturgeon	N	2
				Mures	3	Sterlet	W	4
		Maps	N/A	LDR	1	Russian sturgeon	SP	12
					1	Sterlet	SP	12
					1	Stellate sturgeon	SP	12
					2	Beluga sturgeon	W	9
					1	Beluga sturgeon	SP	12
				Jiu	2	Sterlet	W	3
					2	Sterlet	N	3
	IMSI (Serbia)	Field observation	2001	Danube	1	Russian sturgeon	SP	N/A
					1	Sterlet	SP	N/A
					1	Stellate sturgeon	SP	N/A
					1	Beluga sturgeon	SP	N/A
		Fisheries	2005 and 2018	Danube	1	Sterlet	N	N/A
					1	Sterlet	W	12
		Map	N/A	Danube	2	Sterlet	W	N/A
				Sava	1	Sterlet	W	
				Tisa	1	Sterlet	W	
	TRUNI (Slovakia)	Map	N/A	Danube	51	Sterlet	W	5.5 to 17.5

Reference	Responsibility	Source	Year	River	Quantity of Habitats	Species	Category of habitat	Depth (m)
					1	Sterlet	SP	6
					4	Sterlet	N	6 to 8
	REVIVO (Slovenia)	MEASURES field observation	2019	Mura	75	Sterlet	N	1 to 4.6
					61	Sterlet	W	1 to 8.5
					16	Sterlet	SP	1 to 1.7
			2019 to 2020	Sava	15	Sterlet	N	1 to 3.2
					17	Sterlet	W	1 to 4.5
	VUKA (Croatia)	MEASURES field observation	2019	Drava	1	Sterlet	W	10
					1	Sterlet	SP	0.5
				Mura	5	Sterlet	W	5 to 10
					2	Sterlet	SP	5
				Sava	6	Sterlet	W	9 to 21
					1	Sterlet	SP	16
Order N. 337, 2019	Fish inspection	Annual order of the Odessa Fish Inspectorate	2019	LDR	1	Sturgeon (*Acipenser* / *Huso* sp.)	W	20 to 34

4.2.1. *Environmental characteristics of Sturgeon habitats*

From the 464 recorded habitats in the MEASURES database for wintering, spawning, and nursery places, 319 have water depth data (Table 13 and 14).

- Sterlet – 288 habitats from 382 contain water depth data.
- Russian sturgeon – 8 habitats from 20 contain water depth data.
- Stellate sturgeon – 11 habitats from 24 contain water depth data.
- Beluga sturgeon – 11 habitats from 38 contain water depth data.
- Sturgeon (*Acipenser/Huso* sp.) – 1 habitat contains water depth data.

Other environmental variables studied in the first part of the results, literature research, are flow velocity, water temperature, and grain size, though they are not available from the MEASURES database.

Table 13. Water depth data summary from MEASURES – confirmed habitats

<table>
<tr><th>Species</th><th colspan="3">Confirmed habitats</th></tr>
<tr><td>Category of habitat</td><td>Spawning</td><td>Wintering</td><td>Nursery</td></tr>
<tr><td rowspan="4">Sterlet
(in the Danube, Drava or Sava)</td><td>10 m
(Suciu, 2007) in the Danube</td><td rowspan="4">14 – 23 m
(Croatian Ichthyology Society field observation, 2018) in Drava and Sava</td><td>1,5 – 8,5 m
(TRUNI field observation in the Danube)</td></tr>
<tr><td>15 m (Hanganu, 2018) in the Danube</td><td>4 – 7 m
(Serbia fisheries in Danube, 2002, 2016, 2018)</td></tr>
<tr><td rowspan="2">13-18 m (Ristic, 1969) in the Danube</td><td>8 m
(Suciu, 2011) in the Danube</td></tr>
<tr><td>13 m (Paraschiv, 2011) in Danube</td></tr>
</table>

Species	**Confirmed habitats**		
Category of habitat	Spawning	Wintering	Nursery
Russian sturgeon (in the Danube)	**10 m** (Suciu, 2007)	**13 m** (Paraschiv, 2011)	N/A
Stellate sturgeon (in the Danube)	N/A	N/A	**8 m** (Suciu, 2011)
			13 m (Paraschiv, 2011)
Beluga sturgeon (in the Danube)	**10 m** (Suciu, 2007)	**20 m** (Suciu, 2011)	**13 m** (Paraschiv, 2011)
	15 m (Hanganu, 2018)		

Table 14. Water depth data summary from MEASURES – potential habitats

Species	**Potential habitats**		
Category of habitat	Spawning	Wintering	Nursery
Sterlet (in the Danube, Drava, Mura, Siret,	**0,5 m** (MEASURES field observation in Drava, 2019)	**1 - 9 m** (MEASURES field observation in Mura, 2019)	**1 – 3,2 m** (MEASURES field observation in Sava, 2019)
	1 - 5 m (MEASURES field observation in Mura, 2019)	**1 - 19 m** (MEASURES field observation in Sava, 2019)	

Species	**Potential habitats**		
Category of habitat	Spawning	Wintering	Nursery
Mures or Sava)	**2 m** (MEASURES field observation in Siret, 2019)	**2 m and 18 m** (MEASURES field observation in Siret, 2019)	**1 – 4,6 m** (MEASURES field observation in Mura, 2019)
	6 – 12 m (maps)	**3 m** (maps in Jiu)	
Sterlet (in the Danube, Drava, Mura, Siret, Mures, Sava or Jiu)	**10 m** (Suciu, 2007)	**4 m** (MEASURES field observation in Mures, 2019)	**2 m** (MEASURES field observation in Siret, 2019)
	16 m (MEASURES field observation in Sava, 2019)	**5,5 – 17,5 m** (maps in Danube)	**3 m** (maps in Jiu)
	20-25 m (MEASURES field observation in Danube, 2019)	**10 m** (MEASURES field observation in Drava, 2019)	**6 - 8 m** (maps in the Danube)
		12 m (fisheries in Serbia, 2005)	
Russian sturgeon (in the Danube)	**10 m** (Suciu, 2007)	N/A	N/A
	12 m (maps in the Danube)		
	20-25 m (MEASURES field observation, 2019)		

<table>
<tr><th>Species</th><th colspan="3">Potential habitats</th></tr>
<tr><td>Category of habitat</td><td>Spawning</td><td>Wintering</td><td>Nursery</td></tr>
<tr><td rowspan="3">Stellate sturgeon
(in the Danube or Siret)

Stellate sturgeon
(in the Danube or Siret)</td><td>2 m
(MEASURES field observation in the Siret)</td><td>2 m
(MEASURES field observation in Siret, 2019)</td><td rowspan="3">2 m
(MEASURES field observation in Siret, 2019)</td></tr>
<tr><td>12 m
(maps in the Danube)</td><td rowspan="2">20 m
(Suciu, 2011) in the Danube</td></tr>
<tr><td>20-25 m
(MEASURES field observation in Danube, 2019)</td></tr>
<tr><td rowspan="4">Beluga sturgeon
(in the Danube)</td><td>10 m
(Suciu, 2007)</td><td rowspan="2">9 m
(maps in Danube)</td><td rowspan="4">8 m
(Suciu, 2011)</td></tr>
<tr><td>12 m
(maps in the Danube)</td></tr>
<tr><td>15 m
(Hanganu, 2018)</td><td rowspan="2">20 m
(Suciu, 2011)</td></tr>
<tr><td>20-25 m
(MEASURES field observation, 2019)</td></tr>
<tr><td>Sturgeon
(Acipenser/ Huso sp.)
(in the Danube)</td><td>N/A</td><td>20-34 m
(Order N 337, 2019)</td><td>N/A</td></tr>
</table>

4.3. Hydromorphological assessment and Natura 2000

The hydromorphological assessment along the whole 2,400 rkm long Danube river made by the Joint Danube Survey 3 (JDS3) describes the following categories depending on how anthropologic affect river alteration (for example, sediment conditions, sand bars, gravel banks, etc.):

- Nearly natural,
- Slightly modified,
- Moderately modified,
- Extensively modified, and
- Severely modified.

There is a considerable difference between the Upper and Middle Danube and the Lower Danube, while in the Upper and Middle Danube the more predominant hydromorphological status category are "moderately modified" and "extensively modified", in the Lower Danube the more predominant are "slightly modified" and "moderately modified" categories (Figure 14).

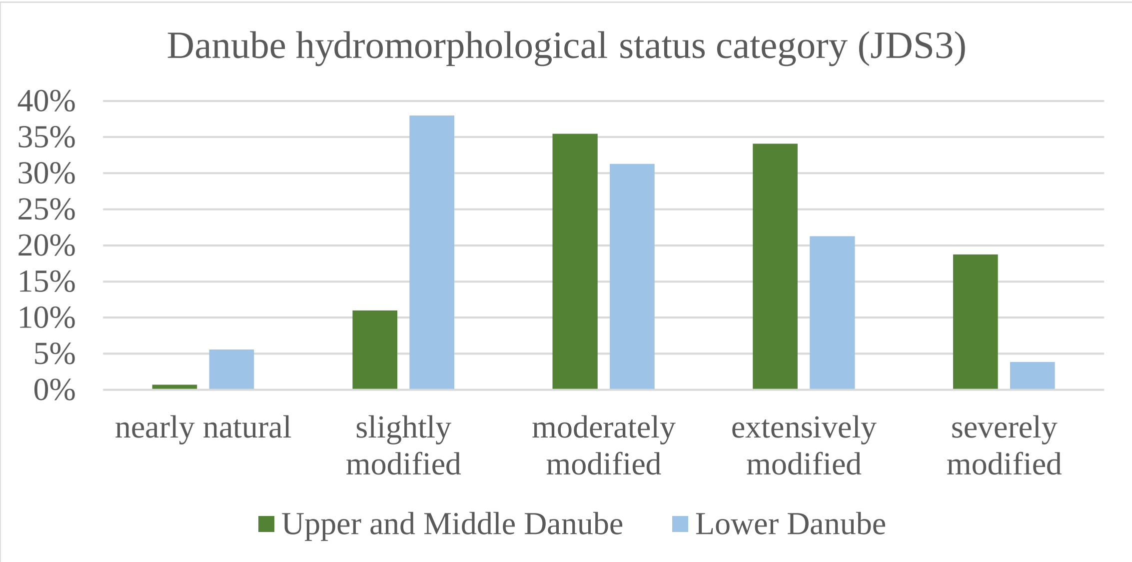


Figure 14. Danube hydromorphological status categories in Upper, Middle Danube and, Lower Danube (JDS3)

4.3.1. Upper and Middle Danube – Sterlet habitats

Sterlet habitats ("quantity oh habitats = h" in Figure 15) from the MEASURES database are the only ones found in Upper and Middle Danube. In total, two hundred and twenty-two sterlet habitats correspond to the area analyzed in the Upper and Middle Danube by the JDS3 hydromorphological assessment. Fifty-one habitats belong to slightly modified areas, forty-three to moderately modified, fifty-nine to extensively modified, and sixty-eight to severely modified areas.

Feeding sterlet habitats are in severely or extensively modified places, while most confirmed nursery places are in slightly modified stretches of the river. Most of the wintering places are in moderately modified places, but they are also present in other areas with worse hydromorphological status.

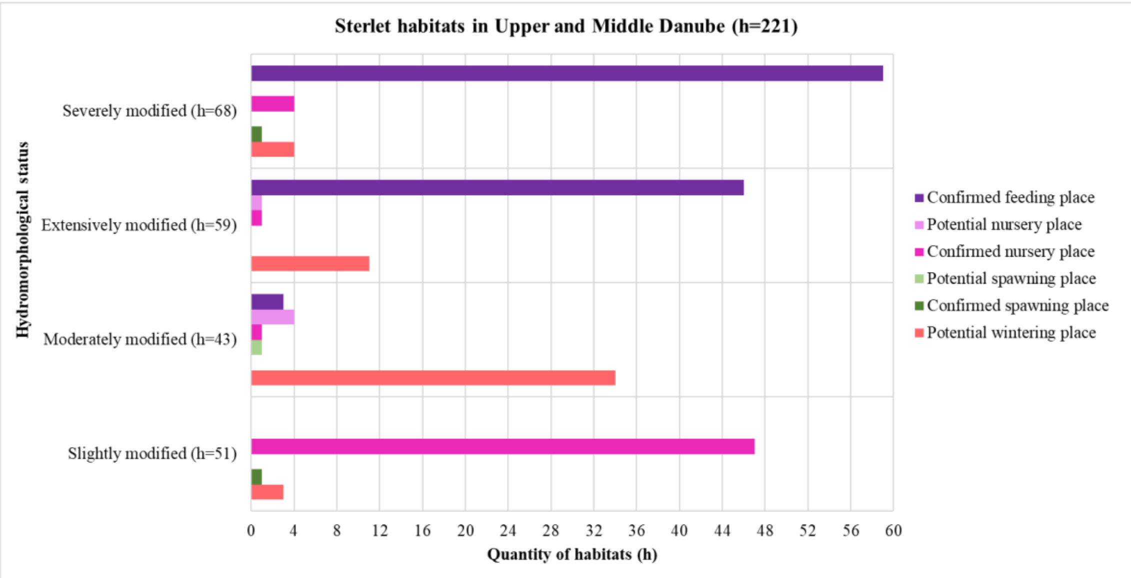


Figure 15. Hydromorphological status of Sterlet habitats in Upper and Middle Danube

One hundred and seventy-nine habitats from these two hundred and twenty-two sterlet habitats (86%) in the Upper and Middle Danube belong to Natura 2000 sites and thus are protected areas (most of Natura 2000 are shown in Figure 16). These areas are in Germany (de), Austria (at), Slovakia (sk) and Hungary (hu): "Donau zwischen Straubing und Vilshofen" (de), "Donau zwischen Regensburg und Straubing" (de), "Donau von Kachlet bis Jochenstein mit Inn- und Ilz Mündung" (de) "Donau-Auen östlich von Wien" (at), "Machland Nord" (at), "Niederösterreichische Alpenvorlandflüsse" (at), "Eferdinger Becken" (at), "Tullnerfelder Donau-Auen" (at), "Oberes Donau- und Aschachtal" (at), “Donau von Kachlet bis Jochenstein mit Inn- und Ilz Mündung” (at), “Dunaj” (sk), “Dunajske luhy” (sk), “Dunajske luhy” (sk), “Bratislavske luhy” (sk), “Duna és ártere” (hu) and “Szigetköz” (hu).

- Forty-six habitats are in slightly modified areas in Duna és ártere (hu), Dunajske luhy (sk), and Dunaj (sk).
- Forty-one habitats are in moderately modified areas in Donau zwischen Straubing und Vilshofen (de), Donau-Auen östlich von Wien (at), Niederösterreichische Alpenvorlandflüsse (at), Duna és ártere (hu), Dunajske luhy (sk), Dunaj (sk), Szigetköz (hu), Dunajske luhy (sk) and Bratislavske luhy (sk).
- Sixty-three habitats are in extensively modified areas in Donau von Kachlet bis Jochenstein mit Inn- und Ilz Mündung (de), Donau zwischen Straubing und Vilshofen (de), Eferdinger Becken (at), Tullnerfelder Donau-Auen (at), Oberes Donau- und Aschachtal (at), Duna és ártere (hu) and Dunajske luhy (sk).
- Therty-seven habitats are in severely modified areas in Machland Nord (at), Tullnerfelder Donau-Auen (at), Oberes Donau- und Aschachtal (at), Dunajske luhy (sk), Szigetköz (hu) and Dunajske luhy (sk).

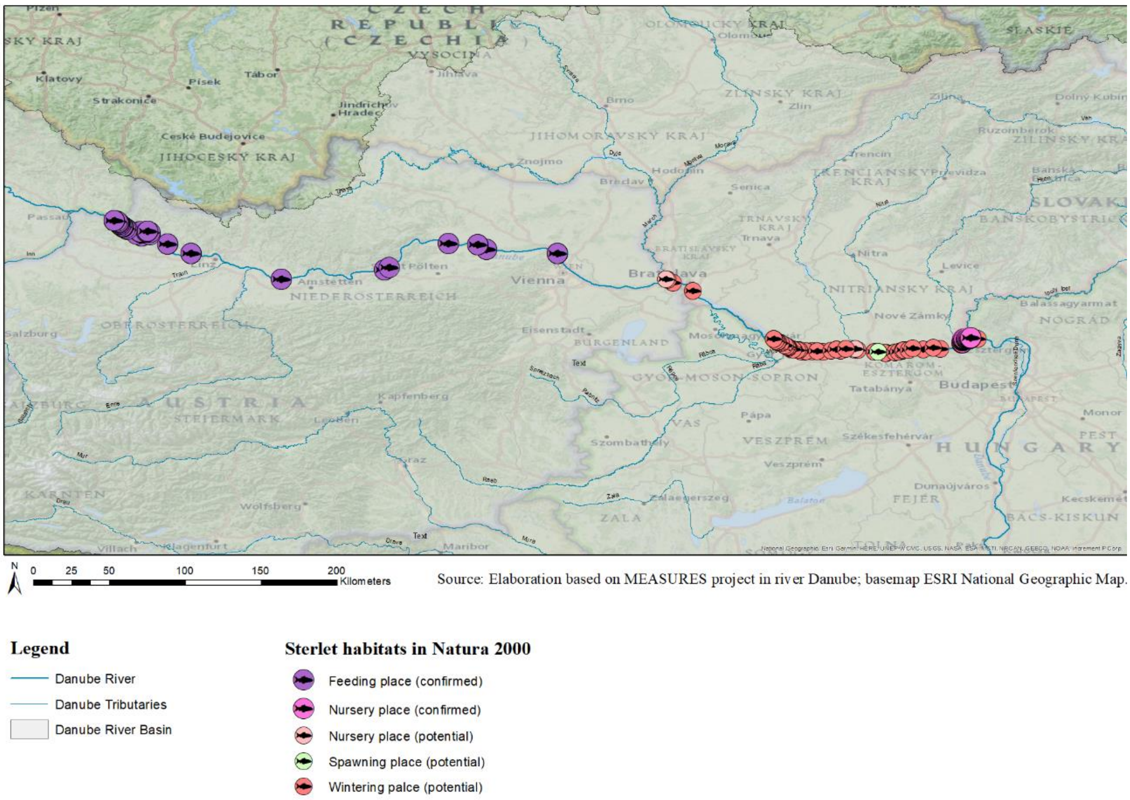


Figure 16. Sterlet habitats in Upper and Middle Danube in Natura 2000 sites

4.3.2. Lower Danube

4.3.2.1. Sterlet habitats

Thirty-seven sterlet habitats ("h" in Figure 17) from MEASURES are in the area analyzed by the JDS3 hydromorphological assessment. Three habitats belong to nearly natural areas, twenty-six to slightly modified areas, seven to moderately modified, and one to extensively modified areas.

Most of the potential spawning sterlet habitats in the Lower Danube are in slightly modified areas. Potential wintering places seem also to be slightly modified, while confirmed nursery places are both in moderately modified areas and slightly modified ones.

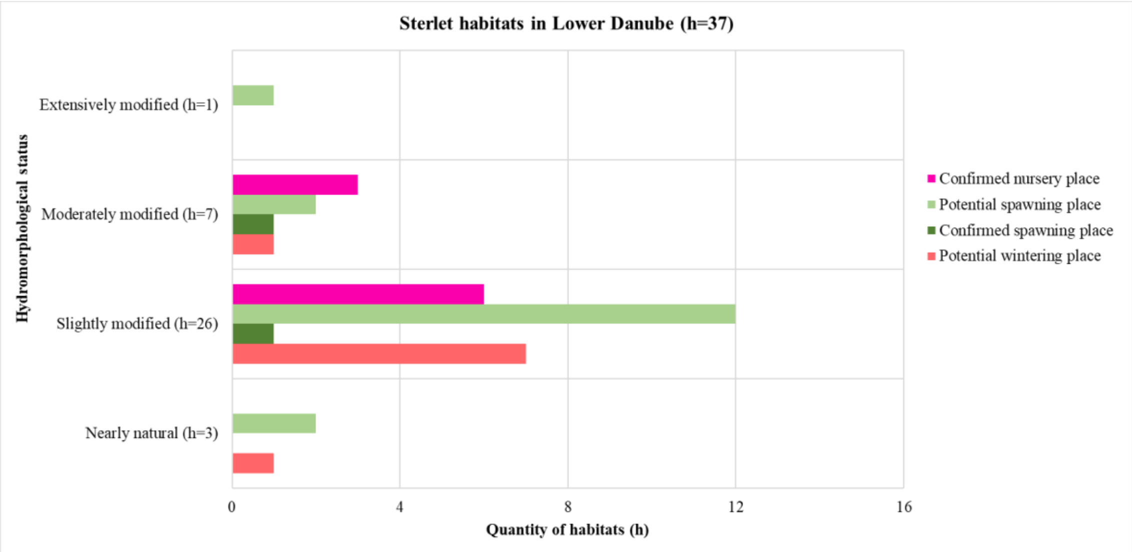
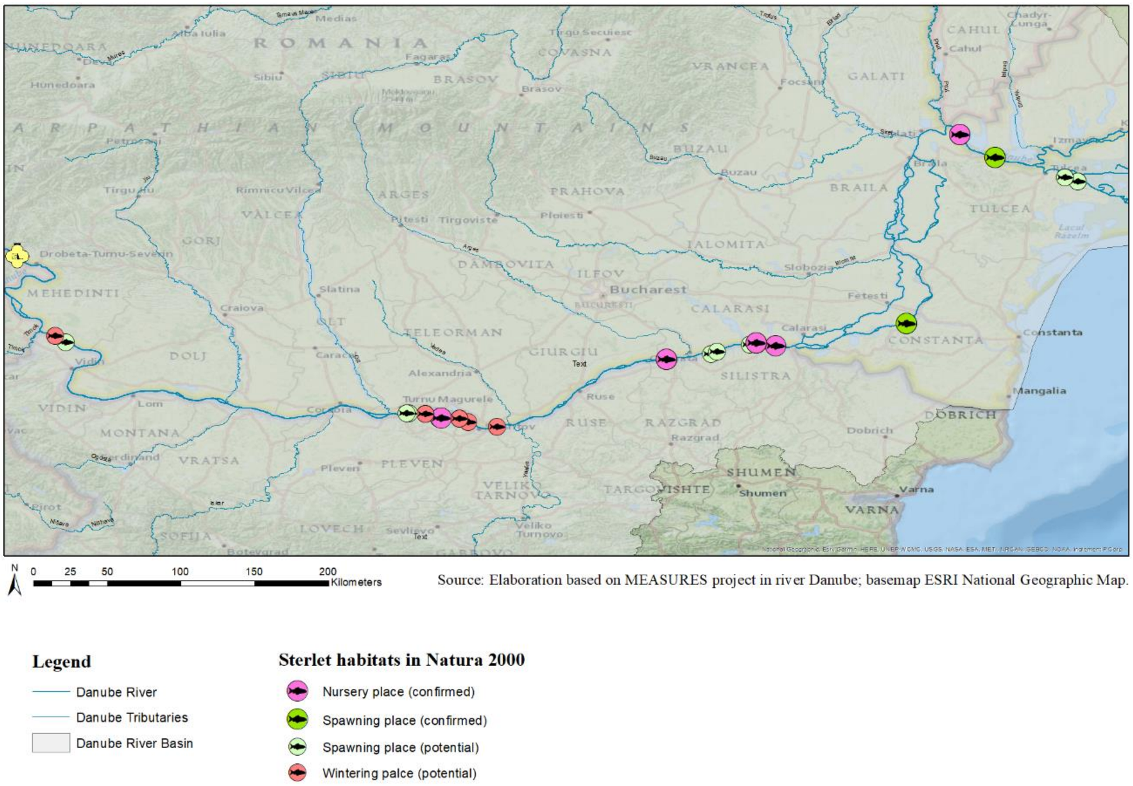


Figure 17. Hydromorphological status of Sterlet habitats in Lower Danube

Eighteen habitats from these thirty-seven sterlet habitats (50%) in the Lower Danube belong to Natura 2000 sites (Figure 18), and thus are protected areas. These areas are in Romania (ro) and Bulgaria (bg): "Ostrov Vardim" (bg), "Suhaia" (ro), "Persina" (bg), "Kompleks Belenski ostrovi" (bu), "Ostrov Lakat" (bg), "Corabia - Turnu Măgurele" (ro), "Kompleks Kalimok" (bg), "Kalimok – Brashlen" (bg), "Pozharevo – Garvan" (bu), "Ostrov Chayka" (bg), "Novo selo" (bg), "Dunărea la Gârla Mare – Maglavit" (ro), "Dunăre – Ostroave" (ro), "Delta Dunării și Complexul Razim – Sinoie" (ro) and "Delta Dunării" (ro).

- three habitats are in nearly natural areas in Persina (bg), Kompleks Belenski ostrovi (bg), and Pozharevo – Garvan (bg).
- therteen habitats are in slightly modified areas in Ostrov Vardim (bg), Suhaia (ro), Persina (bg), Ostrov Lakat (bg), Corabia - Turnu Măgurele (ro), Kompleks Kalimok (bg), Kalimok – Brashlen (bu), Oltenița - Mostiștea – Chiciu (ro), Oltenița – Ulmeni (ro), Dunăre – Ostroave (ro) and Delta Dunării (ro).
- five habitats are in moderately modified areas in Oltenița - Mostiștea – Chiciu (ro), Ostrov Chayka (bg), Novo selo (bg), Dunărea la Gârla Mare – Maglavit (ro) and Delta Dunării (ro).



Source: Elaboration based on MEASURES project in river Danube; basemap ESRI National Geographic Map.

Figure 18. Sterlet habitats in Lower Danube in Natura 2000 sites

4.3.2.2. Russian sturgeon habitats

Fifteen Russian sturgeon habitats ("h" in Figure 19) from MEASURES (Figure 15) are in the area analyzed by the JDS3 hydromorphological assessment. One habitat belongs to nearly natural areas, thirteen to slightly modified areas, two to moderately modified, and one to extensively modified areas.

Most of the potential wintering Russian sturgeon habitats are in slightly modified areas, as well as, confirmed spawning places. Potential spawning places are also there, but also one is in extensively modified areas in the river.

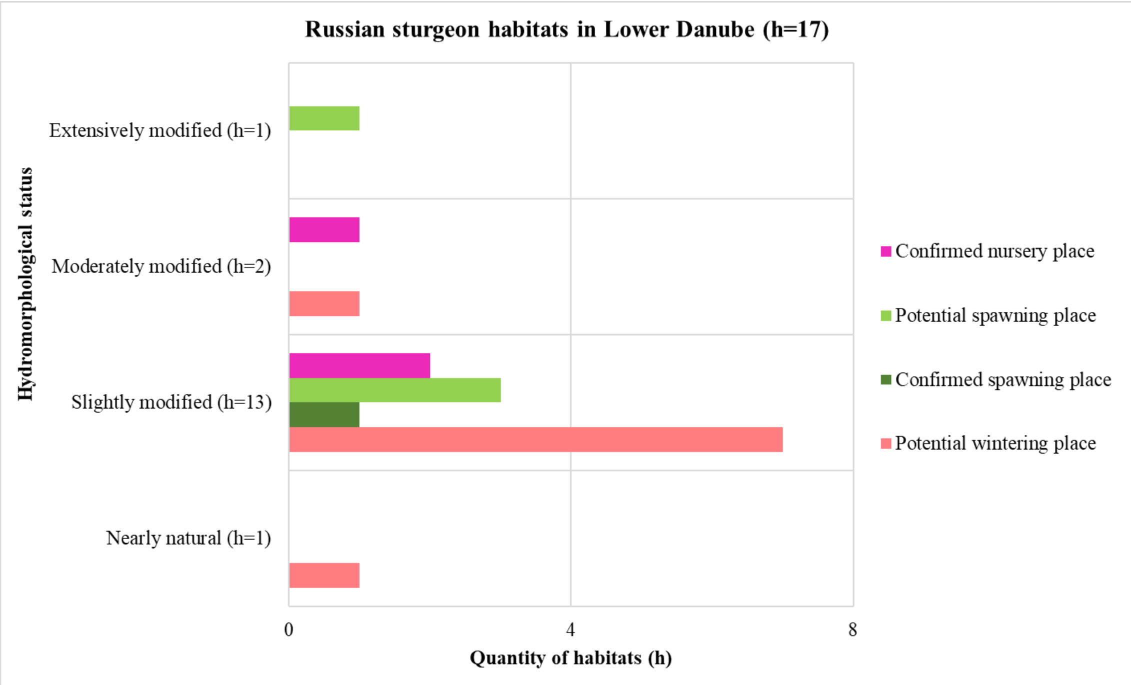


Figure 19. Hydromorphological status of Russian sturgeon habitats in Lower Danube

Twelve habitats from these seventeen Russian sturgeon habitats (71%) in the Lower Danube belong to Natura 2000 sites (Figure 20), and thus are protected areas. These areas are in Romania (ro) and Bulgaria (bg): "Ostrov Vardim" (bg), "Suhaia" (ro), "Persina" (bg), "Kompleks Belenski ostrovi" (bu), "Ostrov Lakat" (bg), "Corabia - Turnu Măgurele" (ro), "Pozharevo – Garvan" (bu), "Novo selo" (bg), "Dunărea la Gârla Mare – Maglavit" (ro), "Canaralele Dunării" (ro), "Dunăre – Ostroave" (ro), "Delta Dunării și Complexul Razim – Sinoie" (ro) and "Delta Dunării" (ro).

- one habitat is in nearly natural areas in Persina (bg) and Kompleks Belenski ostrovi (bg).
- ten habitats are in slightly modified areas in Ostrov Vardim (bg), Suhaia (ro), Persina (bg), Ostrov Lakat (bg), Corabia - Turnu Măgurele (ro), Pozharevo – Garvan (bu), Canaralele Dunării (ro), Dunăre – Ostroave (ro), Delta Dunării și Complexul Razim – Sinoie (ro) and Delta Dunării (ro).
- two habitats are in moderately modified areas in Dunărea la Gârla Mare – Maglavit (ro), Delta Dunării și Complexul Razim – Sinoie (ro) and Delta Dunării (ro).

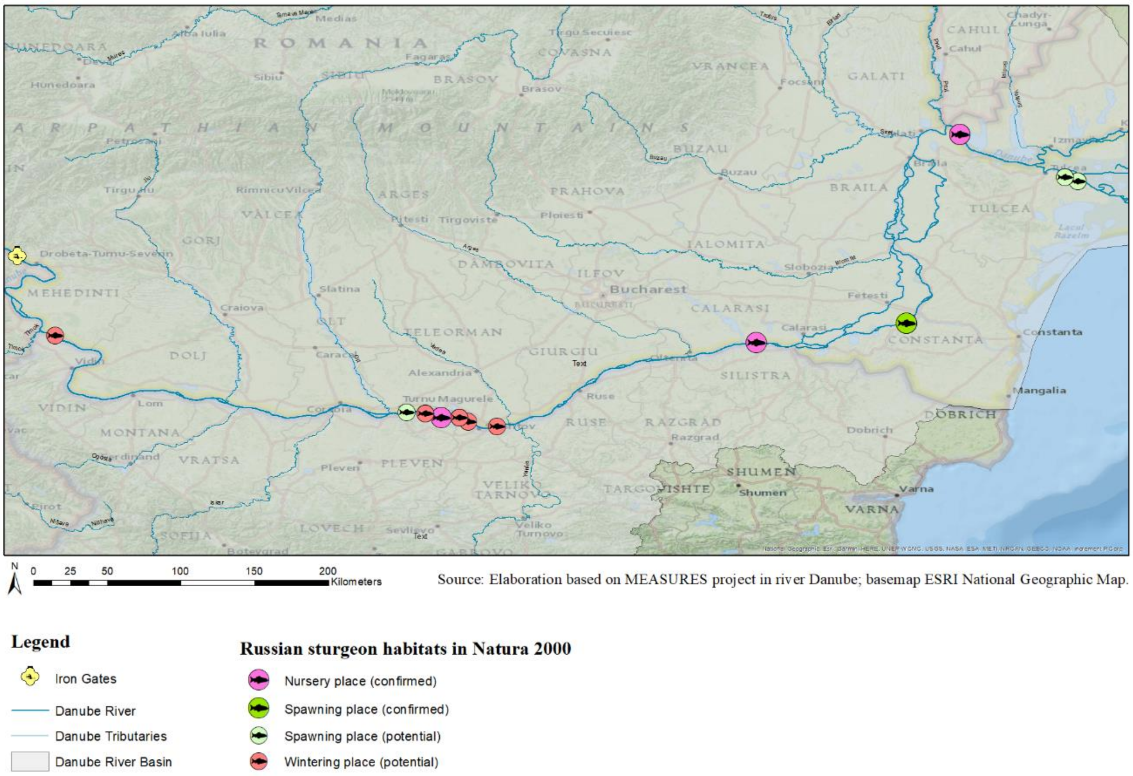


Figure 20. Russian sturgeon habitats in Lower Danube in Natura 2000 sites

4.3.2.3. Stellate sturgeon habitats

Sixteen stellate sturgeon habitats ("h" in Figure 21) from MEASURES are in the area analyzed by the JDS3 hydromorphological assessment. One habitat belongs to nearly natural areas, twelve to slightly modified areas, two to moderately modified, and one to extensively modified areas.

Most of the potential wintering stellate sturgeon habitats are in slightly modified areas. Confirmed nursery places are there too, but also in moderately modified areas. Potential spawning places are also present in slightly modified areas, but one is also present in extensively modified areas.

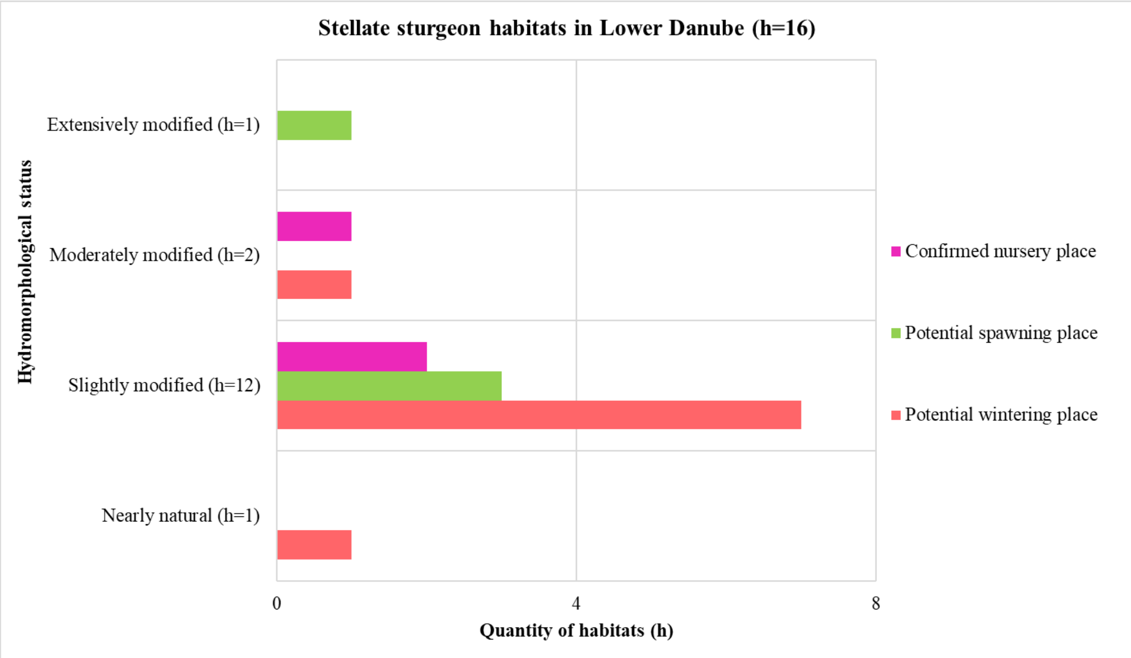


Figure 21. Hydromorphological status of Stellate sturgeon habitats in Lower Danube

Nine habitats from these sixteen stellate sturgeon habitats (56%) in Lower Danube belong to Natura 2000 sites (Figure 22), and thus are protected areas. These areas are in Romania (ro) and Bulgaria (bg): "Ostrov Vardim" (bg), "Suhaia" (ro), "Persina" (bg), "Kompleks Belenski ostrovi" (bu), "Ostrov Lakat" (bg), "Corabia - Turnu Măgurele" (ro), "Pozharevo – Garvan" (bu), "Novo selo" (bg), "Dunărea la Gârla Mare – Maglavit" (ro), "Delta Dunării și Complexul Razim – Sinoie" (ro) and "Delta Dunării" (ro).

- one habitat is in nearly natural areas in Persina (bg) and Kompleks Belenski ostrovi (bg).

- seven habitats are in slightly modified areas in Ostrov Vardim (bg), Suhaia (ro), Persina (bg), Ostrov Lakat (bg), Corabia - Turnu Măgurele (ro), Pozharevo – Garvan (bu), Delta Dunării și Complexul Razim – Sinoie (ro) and Delta Dunării (ro).
- two habitats are in moderately modified areas in Novo selo (bg), Dunărea la Gârla Mare – Maglavit (ro) and Delta Dunării și Complexul Razim – Sinoie (ro).

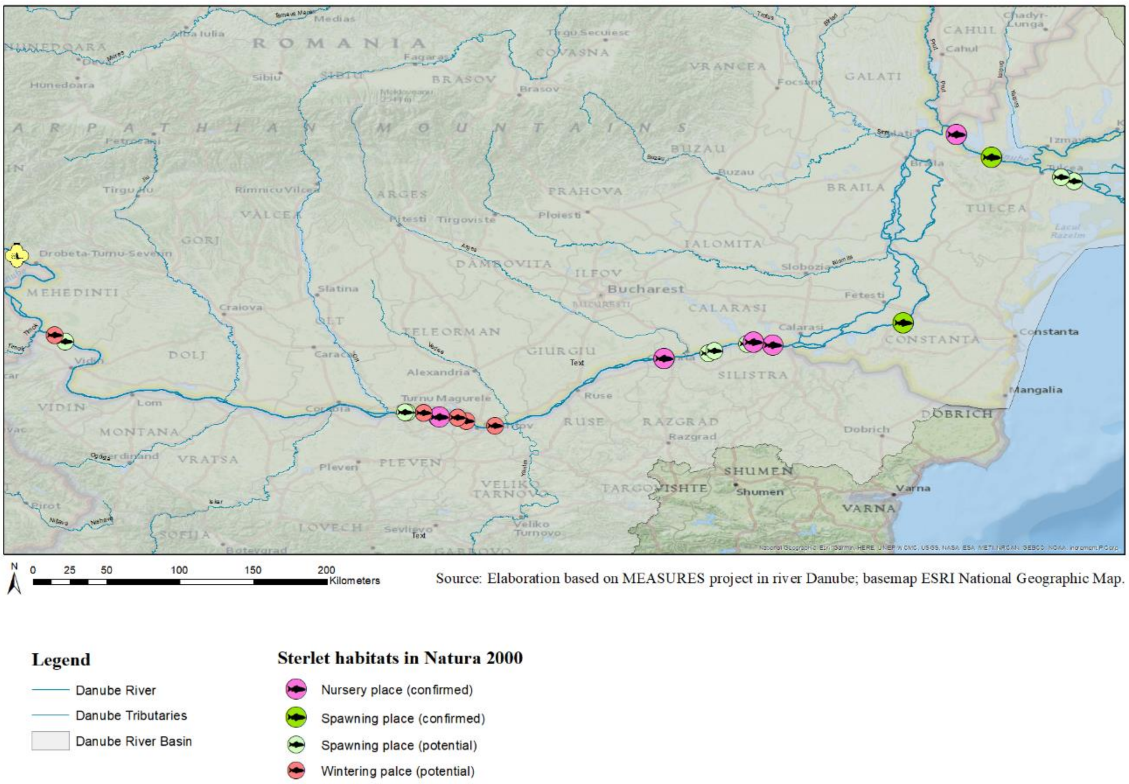


Figure 22. Stellate sturgeon habitats in Lower Danube in Natura 2000 sites

4.3.2.4. Beluga sturgeon habitats

Thirty-three Beluga sturgeon habitats ("h" in Figure 23) from MEASURES are in the area analyzed by the JDS3 hydromorphological assessment. Four habitats belong to nearly natural areas, twenty-three to slightly modified areas, five to moderately modified, and one to extensively modified areas.

Most of the potential spawning places and potential wintering places are in slightly modified areas. Confirmed nursery places and confirmed spawning places are both in moderately modified areas and slightly modified areas.

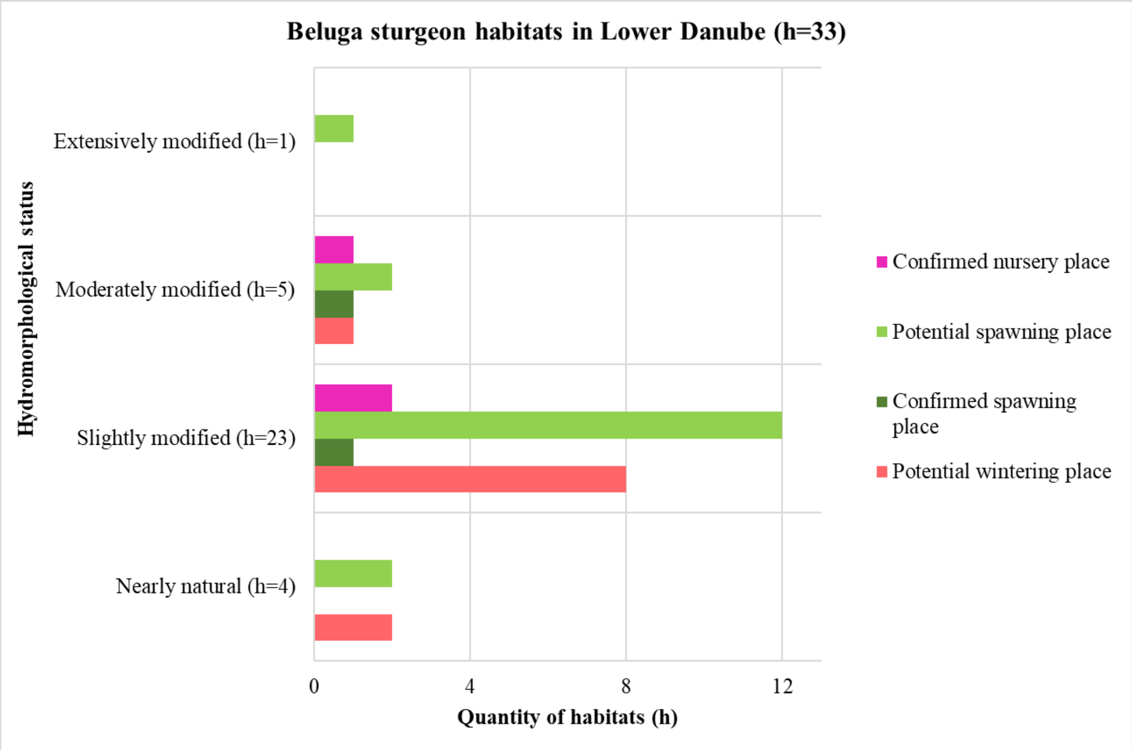


Figure 23. Hydromorphological status of Beluga sturgeon habitats in Lower Danube

Eighteen habitats from these thirty-three beluga sturgeon habitats (56%) in Lower Danube belong to Natura 2000 (Figure 24). These areas are in Romania (ro) and Bulgaria (bg): "Ostrov Vardim" (bg), "Suhaia" (ro), "Persina" (bg), "Kompleks Belenski ostrovi" (bg), "Vedea – Dunăre" (ro), "Gura Vedei - Șaica – Slobozia" (ro), "Ostrov Lakat" (bg), "Corabia - Turnu Măgurele" (ro), "Pozharevo – Garvan" (bg), "Oltenița - Mostiștea – Chiciu" (ro), "Oltenița – Ulmeni" (ro), "Novo selo" (bg), "Dunărea la Gârla Mare – Maglavit" (ro), "Canaralele Dunării" (ro), "Dunăre – Ostroave" (ro), "Delta Dunării și Complexul Razim – Sinoie" (ro), "Delta Dunării" (ro).

- six habitats are in nearly natural areas in Persina (bg) Kompleks Belenski ostrovi (bg), Pozharevo – Garvan (bg), Oltenița - Mostiștea – Chiciu (ro) and Oltenița – Ulmeni (ro).
- fifteen habitats are in slightly modified areas in Ostrov Vardim (bg), Suhaia (ro), Persina (bg), Vedea – Dunăre (ro), Gura Vedei - Șaica – Slobozia (ro), Ostrov Lakat (bg), Corabia - Turnu Măgurele (ro), Pozharevo – Garvan (bu), Canaralele Dunării (ro), Dunăre – Ostroave (ro), Delta Dunării și Complexul Razim – Sinoie (ro) and Delta Dunării (ro).
- four habitats are in moderately modified areas in Novo selo (bg), Dunărea la Gârla Mare – Maglavit (ro), Delta Dunării și Complexul Razim – Sinoie (ro) and Delta Dunării (ro).

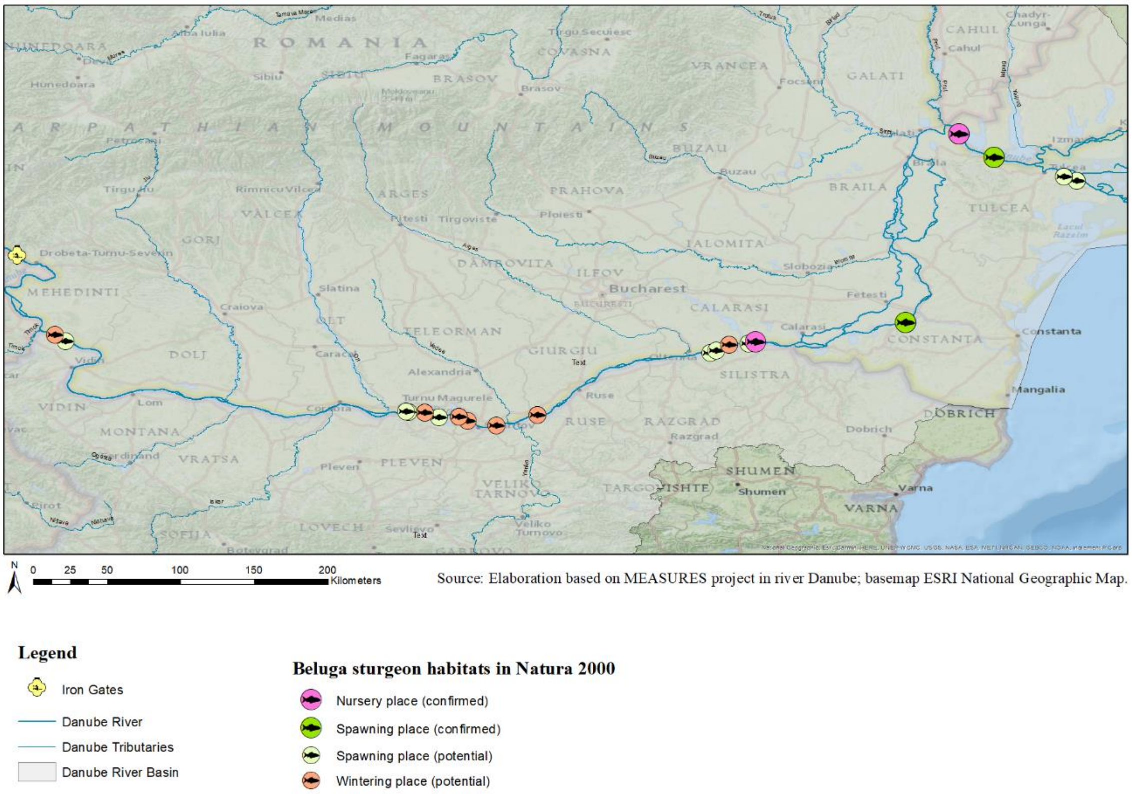


Figure 24. Beluga sturgeon habitats in Lower Danube in Natura 2000 sites

5. Discussion

The damming and illegal catching of sturgeon individuals in the Danube River Basin seriously influenced the natural reproduction of sturgeon species, especially for anadromous species (Russian sturgeon, stellate sturgeon, and beluga sturgeon), which are confined to the lower part of the Danube until the Iron Gates dams. Damming has also radically changed the river dynamics and the natural sturgeon habitats in the Volga-Caspian basin in the late 20^{th} and early 21^{st} centuries. The construction of dams on the Volga River also resulted in a dramatic reduction in the size of sturgeon spawning grounds, confined only to the lower segment of the Volga river, from the Volgorad Dam down to the delta (Ruban et al., 2019). As previously mentioned, this has also happened on the Danube and it is discussed below with the research questions and hypotheses of this master thesis.

5.1. Research Question 1

Which are the criteria for suitable habitats of the different sturgeon life stages and species located in the Danube River? How are these habitats defined by environmental variables (depth, gravel substrate, and water flow velocity) based on available data and knowledge?

Hypothesis 1.1. Wintering habitats are not species-specific, neither for anadromous species nor for the sterlet.

Sturgeons are thought to form winter aggregations in deep pools in river depressions, regardless of the species. However, the literature does not provide any specific depth range. MEASURES data demonstrate that depth does not depend so much on the species but on the river morphology. For example, for sterlet winter habitats that were observed on Danube tributaries (Drava, Sava, Mura, Siret, Jiu, or Mures), depths ranges appear to be wider and shallower. Instead, Danube winter habitats are deeper, even reaching 20 m. It can be concluded that they use the deepest parts of the river that are available, both anadromous species and sterlet. Therefore, the hypothesis is accepted.

Hypothesis 1.2. Mean grain sizes of spawning substrates are not species-specific, and they are in the gravel substrate size (range: 2.0 to 20.0 mm).

Several authors (Hochleithner & Gessner, 2012; Holčík, 1989) stated that sturgeon habitats are located in gravel substrate (range: 2 to 63 mm). In addition to using that substrate range (gravel), literature also demonstrates that they use cobble and boulder in some cases, but never sand or silt-clay substrates. Therefore the hypothesis is accepted since gravel substrate size is a predominant characteristic for spawning sturgeon habitats.

Dam reservoirs and other hydromorphological alterations in the Danube river caused changes in sediment transport, such as interrupted bed load continuum, deposition of suspended sediment in impounded reaches, sediment deficit in free-flowing river sections, dredging (for navigation), leading to increased river bed erosion (Technum et al., 2008). These impacts along the Danube river are likely to reduce the availability of spawning habitats, due to substrate change. Therefore, to gain greater spawning habitats availability, an improvement in the hydromorphological conditions of the river will have to be taken into account in the future.

Hypothesis 1.3. Larvae habitats are not species-specific. They are located in slow water flow areas (range: 0.1 to 1.0 m/s mean flow velocity).

Larvae habitats have not enough data availability and can not be confirmed whether they are species-specific or not. However, Holčík (1989) stated that Russian sturgeon larvae are found in rapid currents, which contribute to their rapid downstream movement.

5.2. Research Question 2

Is the existing data compiled within the MEASURES project enough to map potential sturgeon habitats in the Danube River upstream of the Iron Gates dam accurately?

Hypothesis 2.1. There are potential wintering habitats for long-distance migratory species upstream from the Iron Gates dams.

Upstream of the Iron Gates, no current sturgeon habitats are found for long-distance migratory species, but feeding habitats are recorded in historical information in the Danube and some tributaries like the Inn, the Sava, or the Mura (Fridrich, 2013; Schmall & Friedrich, 2014). Nowadays, one of the main problems is the disrupted of the river within the Middle and Upper part of the Danube, due to the non-existent access to the upper habitat. Facilitation of fish migration bypassing at the two Iron Gate dams would reopen over 1,000 km of the river including tributaries (Friedrich et al., 2019) when fish passes are available. Consequently, the hypothesis can be accepted, since they would use the deepest available parts of the river if the connectivity of the river is ensured.

Standard passing solutions for sturgeons at migration barriers are not available and every particular migration barrier needs a particularly adapted passing solution. Fish-passes have to be considered as only part of the whole passing solution. The type of barrier and characteristic traits of up- and downstream riverine sections and the sturgeon migrating species determine the function of a passing solution (Reinartz, 2002). This issue requires further research to achieve fully-functional fish passes that allow the passage of several species regardless of their size.

Hypothesis 2.2. There are potential spawning habitats for long-distance migratory species upstream from the Iron Gates dams.

As discussed in the previous hypothesis, current habitats for long-distance migratory sturgeon species have not been confirmed upstream from the Iron Gates dams, but historical feeding habitats are documented in the Danube (Fridrich, 2013; Schmall & Friedrich, 2014). Besides, sturgeon spawning habitats are not species-specific, Hochleithner & Gessner (2012) and Holčík (1989) stated that sturgeon spawning habitats are located in gravel substrate and the MEASURES project confirmed sterlet spawning habitats upstream the Iron Gates. Accordingly, long-distance migratory sturgeon species could use those sterlet spawning habitats. thus, this hypothesis can be confirmed.

Hypothesis 2.3. There are potential larvae habitats for long-distance migratory species upstream of the Iron Gates dams.

Although there is not enough data to describe nursery habitats for Russian, stellate, and beluga sturgeon, sterlet nursery habitats were confirmed in the Middle and Upper Danube by the MEASURES project. So, the hypothesis cannot be confirmed or denied, as there is insufficient data. Nevertheless, if long-distance migratory sturgeon species larvae could use sterlet nursery habitats, the hypothesis could be confirmed.

5.3. Research Question 3

Is there a correlation between the potential and confirmed habitats with the hydromorphological status assessed for the Danube River during the Joint Danube Survey 3 (JDS 3) (ICPDR, 2013b)? Is there a correlation between the potential and confirmed habitats with Natura 2000 sites? What are the main characteristics and supporting factors?

Hypothesis 3.1. The majority of sturgeon habitats in the Danube have a nearly natural or slightly modified status (JDS3).

Just 1% of Upper and Middle Danube hydromorphological status falls into the nearly natural status and 11% into slightly modified status (ICPDR, 2013b). In this part of the river, there are just sterlet habitats, none of them are in a nearly natural status and 24% have slightly modified status. So, in appearance, to the low availability of good hydromorphological status parts of the river appear to be one of the reasons why sturgeons are not present there, since sturgeon habitats need good hydromorphological conditions. By specifying in confirmed nursery sterlet habitats, most of them are in a slightly modified status, so nursery habitats seem to need better hydromorphological needs than other types of habitats. While wintering habitats are more distributed in the other statuses, both in slightly modified, moderately modified, extensively modified and severely modified, so apparently, it seems that these types of habitats are not so specific in terms of hydromorphological conditions;

6% of Lower Danube is classified as nearly natural status, 38% into slightly modified status (ICPDR, 2013b), and 80% of sturgeon habitats (sterlet, Russian, stellate, and beluga sturgeon) are in these two mentioned statuses. Most of the sturgeon individuals in Lower Danube use the best hydromorphological possible habitat conditions in the river to settle as a wintering, spawning, or nursery habitat utilization. As mentioned before, 38% are slightly modified areas, and 31% are in moderately modified areas. The difference between these two states is just 7%, while the percentage of sturgeons in slightly modified areas is 73% and 15% in moderately modified areas. The difference is quite big (7% compared to 58%), so it can be said that sturgeon habitats location in slightly modified areas is due as an effect of less availability of near-natural state reaches.

A similar study carried out in the Polish Carpathians has analogous results in terms of fish habitats and good hydromorphological status of the river, where unmanaged, multi-thread cross-sections with varying proportions of flow depth, velocity, and bed material size were necessary for fish habitats. That study determinate that the degradation of hydromorphological river quality, caused by human impacts, is reflected in the remarkable impoverishment of fish communities (Wyżga et al., 2009).

This hypothesis cannot be accepted due to the lack of nearly natural or slightly modified parts of the Danube, which sturgeons could use for wintering, spawning, and nursery habitats. The current bad hydromorphological status of the Danube River has effects on the critical situations of sturgeon populations, so management and mitigations measures are required (Schiemer et al., 2003), since, sturgeons tend to use good hydromorphological parts where there is the availability and that would lead to higher availability of sturgeon habitats.

Hypothesis 3.2. The majority of sturgeon habitats are located at Nature 2000 sites.

86% of sturgeon habitats in Upper and Middle Danube and 58% in the Lower Danube belongs to Natura 2000 protected areas. Some of the habitats are present in the frontier between two countries, for example between Slovakia and Hungary, or between Romania and Bulgaria. That is why some habitats are counted in two types of hydromorphological status because the rkm section can be part of two Natura 2000 sites. Given that, when it comes to protecting or conserving these habitats, there must be good cooperation and communication mechanisms between the different involved actors, as it is also described in “Sturgeon 2020” measures and recommendations (Sandu et al., 2013). This hypothesis can be accepted. However, the Natura 2000 conservation tool does not improve the current sturgeon situation in the Danube directly. Even if new Natura 2000 conservation sites are created, this will be useless if certain benefits are not generated for the area to be conserved. In other words, projects for the restoration of ecosystems and the protection of species are necessary to promote the good conservation and recovery of ecosystems. Otherwise, no matter how much more Natura 2000 spaces are generated, they will continue to be isolated spots in the territory without connectivity and without the potential for improvement for the species that use these areas of the river.

In the Upper and Middle Danube, most of the sterlet habitats are already part of Natura 2000 sites Those habitats, which are not part of Natura 2000, belong to Serbia, which is not part of the European Union, so it does not belong to the Natura 2000 network. In this regard, sturgeon habitat utilization indicates the effectiveness of this conservation network. This is also stated in other studies in which conservation and management planning are investigated (Cortina & Boggia, 2014; Funk et al., 2019).

As for the lower part of the Danube, on the one hand, just 60% of sturgeon habitats belong to Natura 2000 sites, though both Bulgaria and Rumania belong to this conservation network. On the other hand, the habitats found in Danube tributaries (Jiu and Sirtet), all belong to Natura 2000 sites. Considering that the Lower Danube hydromorphological status is in better condition than in the Middle or Upper part, it would make sense for these ecosystems or sturgeon habitats to be protected and conserved before human impacts further affect the Lower Danube Basin.

6. Conclusion

A limited amount of information is available about sturgeon habitats in the Danube, while the endangered populations are decreasing. Along with this, sturgeon decline in the DRB is mainly due to poaching and river fragmentation (Pitkitch et al., 2005; Friedrich et al., 2019). It is well known that the sturgeon situation in the Danube is extremely critical but there is almost no information on their habitat requirements. Most of the literature is not even recent and it is difficult to find precise information about sturgeons in the Danube, especially for nursery sturgeon habitats and for long-distance migrating species like the Russian sturgeon, the stellate sturgeon, and the beluga sturgeon.

In this sense, the MEASURES project is collecting available data about sturgeon habitats in the DRB through accessible information from the Danube countries which participate in the project. Thanks to this project, important information for the recovery and conservation of these species is coming to light. The development of MEASURES is serving as a solution to this lack of sturgeon species information in the Danube. Precise and faithful coordination with the adequate involvement of stakeholders of the Danube countries is necessary to obtain more information and to recover its bad ecological situation of the Danube.

It is also important to mention the lack of confirmed habitats information for long-distance migratory sturgeon habitats. Additionally, these results show a fairly clear distribution along the Danube depending on the species, where sterlet can be observed both in the Upper, Middle, and Lower Danube due to its potamodromous characteristic, and where Russian, stellate, and beluga sturgeon (long-distance migratory species) can only migrate until the Iron Gate dams, because of river fragmentation. Danube's ability to host these sturgeon species mainly depends on the free access to the spawning grounds up from the Iron Gates. This would allow a sturgeon population recovery on the Danube through the promotion of joint conservation and rehabilitation programs.

The fact that potential sturgeon habitats in the Middle and Upper Danube have been confirmed, encourages correct environment conservation, which would have positive consequences on sturgeon species protection, especially considering the high percentage of potential habitats in protected areas through Natura 2000 sites.

Important management actions to address the ongoing decline include: the recovery of the river natural hydromorphological conditions; the adaptation of fish passes at the dams; and, controlling the illegal sturgeon fishing pressure so that sturgeon populations can recover over time in the future. For these actions to be possible in the future, better knowledge and consciousness about sturgeon habitats requirements are needed. The information available on sturgeons is not very extensive, especially for the Danube basin. It is especially scarce for the available information on sturgeon habitats and their needs. That is why projects such as MEASURES are necessary to continue researching these issues and taking a step forward in terms of the coordination, conservation, and protection of these species.

In conclusion, it is necessary to highlight: (1) the low data availability on sturgeon habitats and (2) the potential of the Danube river to host sturgeon habitats also upstream from the Iron Gates, if the river's connectivity improves soon. However, these issues require further analysis of suitable habitat criteria for the different sturgeon life stages and species.

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