

Mapping sturgeon habitats: High-Resolution riverbed classification on the Danube River

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Abstract: Critically endangered Danube sturgeons rely on specific hydro-geomorphological conditions—such as deep riverbed pools and exposed hard substrates—for spawning, overwintering, and resting. However, continuous high-resolution riverbed maps across the Lower Danube remain scarce. This study provides a high-resolution bathymetric and substrate assessment of three key sturgeon habitats within the Danube Delta Biosphere Reserve: Bălteni, Nufăru, and Isaccea (Noviodunum) in the Danube Delta Biosphere Reserve. Using a 500 kHz interferometric bathymetric sonar coupled with RTK-GNSS positioning and ADCP velocity profiling, we generated 1 m resolution Digital Terrain Models (DTMs) and mapped benthic substrates via side-scan sonar backscatter segmentation. Deep scour pools driven by bedrock steps were mapped at Bălteni (35 m depth) and Nufăru (30 m depth), both hosting exposed hard-bottom substrates that function primarily as overwintering and resting refugia. In contrast, the Isaccea sector features a 17 m deep pool maintained by high flow turbulence over the submerged masonry of the ancient Roman fortress of Noviodunum, exposing a localized gravel-cobble substrate that acts as an active spawning ground. Our findings demonstrate that critical sturgeon habitats in the Lower Danube are highly localized micro-topographic anomalies, emphasizing the necessity of high-definition hydroacoustic surveys for targeted conservation and environmental impact assessments.

1. Introduction

1.1. Background & Ecological Significance

Sturgeons (Acipenseridae) are widely recognized as one of the most critically endangered taxonomic groups of freshwater and anadromous fish worldwide. Serving as quintessential flagship and umbrella species for the Danube River Basin, their presence directly reflects the ecological integrity, longitudinal connectivity, and structural health of the river system (Honț, Ș., 2022). Historically, the Danube supported six native sturgeon species: Beluga (*Huso huso*), Russian sturgeon (*Acipenser gueldenstaedtii*), Stellate sturgeon (*Acipenser stellatus*), Sterlet (*Acipenser ruthenus*), Ship sturgeon (*Acipenser*

nudiventris), and European sea sturgeon (*Acipenser sturio*) (Honț, Ș., 2022). However, severe anthropogenic pressures—most notably habitat fragmentation caused by the construction of the Iron Gates I and II dams, illegal fishing, and river channelization—have driven two species to localized extinction (*A. sturio* and *A. nudiventris*) and pushed the remaining populations to the brink of collapse. The life cycle of sturgeons is intrinsically bound to precise physical riverbed characteristics. For successful reproduction, spawning adults require very specific abiotic conditions, typically consisting of deep scour holes or gravel bars (depths exceeding 8 – 20 m), strong hydraulic current velocities (0.8 - 1.5 m/s), and, crucially, hard, non-silted benthic substrates like gravel, cobble, or bedrock. Hard substrates are essential for the attachment, incubation, and aeration of adhesive sturgeon eggs while protecting early larvae from predators. Conversely, juvenile nursery grounds rely on calmer, shallow backwaters dominated by finer sand and silt that host dense macroinvertebrate communities. Because sturgeons exhibit high site fidelity and stringent habitat selectivity, any disruption to or degradation of these local bathymetric features and sediment distributions severely impairs natural recruitment (Honț, Ș., 2022).

1.2.Limitations of Traditional Monitoring

Despite decades of conservation effort and strict legal protections across lower Danube countries, wild sturgeon recruitment remains critically low. A primary bottleneck in active habitat management and spatial protection is the acute shortage of high-resolution, continuous seabed and riverbed maps. Historically, river bathymetric surveys relied on low-density single-beam acoustic soundings spaced hundreds of meters apart, coupled with sparse physical sediment grabs. While these low-resolution methods provide general channel cross-sections, they fail to capture high-frequency micro-topography, localized scour pockets, and subtle substrate transitions that sturgeons actively seek. Furthermore, traditional sediment grab sampling is inherently point-based, spatially biased, and destructive. Interpolating substrate boundaries from isolated physical samples often misrepresents the highly dynamic morphodynamic heterogeneity of the Danube riverbed, leading to inaccurate environmental impact assessments (EIAs) for dredging activities, navigation works, or river engineering projects.

1.3.Technological Solution: Multi-Acoustic Remote Sensing

To bridge the gap between large-scale river monitoring and micro-habitat identification, advanced hydroacoustic mapping techniques—specifically Multibeam Echosounders (MBES) and Side-Scan Sonar (SSS)—offer unprecedented spatial resolution. Multibeam Echosounders (MBES) yield continuous, full-coverage 3D Digital Elevation Models (DEMs) of the riverbed, accurately pinpointing deep pool refugia, sand waves, and bedrock ledges. Acoustic Backscatter & Side-Scan Sonar (SSS) evaluate the acoustic reflectivity of the benthic boundary layer, allowing non-destructive classification of riverbed composition (e.g., differentiating fine silt from coarse gravel or solid rock outcrops). When coupled with machine learning classification models (e.g., Random Forest) and ground-truthed physical sediment samples, acoustic backscatter analysis enables continuous, high-accuracy mapping of substrate boundaries across expansive river stretches.

2. Materials and Methods

2.1. Study Area

The research was conducted in the Danube Delta Biosphere Reserve (DDBR), a highly dynamic fluvio-marine environment globally recognized for its complex morphohydrography and critical role in biodiversity protection (Gâstescu, 2009), focusing on three key river sectors along the main branches of the Danube River: Bălteni, Nufăru, and Isaccea (Fig. 1). These sites represent well-established, critical sturgeon habitats where distinct local geomorphological features generate prominent deep pools within the riverbed (Kynard et al., 2002; Suciu et al., 2008).

At Bălteni and Nufăru, deep bathymetric depressions are driven by local fluvial-geomorphological dynamics, structural bends, and localized flow acceleration (Onăra et al., 2024). At Isaccea, the benthic topography is influenced by historical anthropic interactions—specifically the submerged structural remains of the ancient Roman city of Noviodunum, whose sunken walls introduce artificial hard-bottom relief into the active flow channel (Honț et al., 2022).

Collectively, these three sites display a highly dynamic and heterogeneous riverbed typology ranging from hard substrates (rock outcrops, cobble, gravel, and submerged masonry) to soft alluvial deposits (fine sand, silt, and mud). Endangered sturgeon species (*Huso huso*, *Acipenser gueldenstaedtii*, *Acipenser stellatus*, and *Acipenser ruthenus*) utilize this diverse morpho-sedimentological spectrum across key life-history stages, relying on hard-bottom deep pools for spawning and wintering, and softer acoustic facies for resting and foraging (Reinartz, 2002; Holban et al., 2022; Wolter & Sukhodolov, 2024).

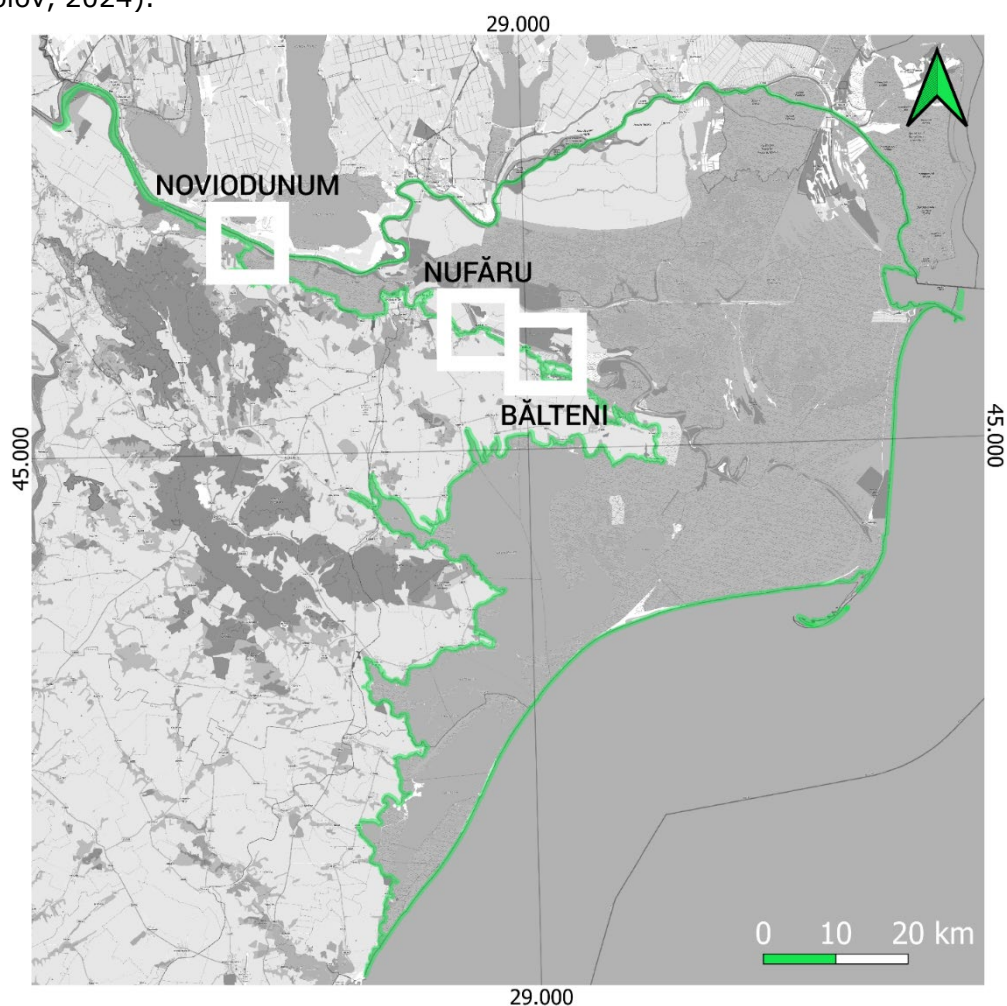


Figure 1. The survey locations for bathymetry studies and riverbed classification within the habitats for sturgeons.

2.2.Data Acquisition

High-resolution bathymetric data were collected using a GeoAcoustics GeoSwath 4R interferometric bathymetric sonar (MBES) operating at a high acoustic frequency of 500 kHz. The transducer head was deployed via a custom over-the-side mount on a small survey vessel optimized for shallow-to-medium riverine navigation. The GeoSwath 4R system provides co-registered, high-density bathymetric soundings alongside synchronized side-scan sonar backscatter imagery across a wide swath width (up to 12× water depth) (GeoAcoustics, 2020; Brown et al., 2011) (Figure 2 & Figure 3).



Figure 2. Sidescan image generated by interpreting the backscatter data collected by the GeoSwath 4R sonar.

To ensure sub-decimeter spatial accuracy, positioning was synchronized with a land-based Real-Time Kinematic (RTK) GNSS base station communicating via UHF radio link to the rover unit aboard the survey boat (figure 4). Heading, pitch, roll, and heave motion corrections were logged continuously using an integrated Motion Reference Unit (MRU). Speed-of-sound variations through the water column were calibrated at the start and end of each survey day using a Sound Velocity Profiler (SVP) to eliminate refractive artifacts in the outer acoustic beams (Lurton, 2010; Blondel, 2009).



Figure 3. The Geoswath 4r mounted on a small survey boat



Figure 4. RTK base station

Benthic substrate mapping was conducted by leveraging the co-registered side-scan sonar (SSS) imagery acquired during the multibeam acquisition. Following raw signal processing, image segmentation was performed on the geo-referenced side-scan mosaics to convert continuous acoustic reflectivity variations into discrete vector polygons (Blondel & Gomez Sichi, 2009).

The segmentation process divides the grayscale side-scan image into contiguous, homogeneous regions based on local acoustic intensity, statistical texture (e.g., grey-level co-occurrence matrices—GLCM), and spatial contiguity. High acoustic returns (dark greyscale response) indicate hard, coarse materials (gravel, cobble, rock), whereas low acoustic returns (bright greyscale response) indicate soft, sound-absorbing substrates (silt, clay, fine sand) (Lucieer et al., 2013; McGonigle et al., 2009). This semi-automated segmentation groups adjacent pixels with similar backscatter signatures into unified vector boundaries, generating discrete vector polygons that represent homogenous riverbed facies.

2.3.Data Processing & Terrain Modeling

Raw hydroacoustic measurements were processed in a multi-stage workflow combining proprietary acquisition software, open-source GIS platforms, and advanced graphic enhancement tools (table 1).

Table 1. Data processing flow

GeoSwath GS4	QGIS (Spatial Analysis)	Photoshop / CorelDraw
Raw Ping Filter & Sounding Clean	Kriging Interpolation & DEM 3D Surface Generation	Cartographic Polish & Final Layout Export

Initial post-processing was executed using GeoAcoustics' proprietary software (GS4). Sounding data were subjected to amplitude and phase-error filtering, speed-of-sound corrections, tide/water-level normalization relative to the local gauge datum, and spatial ping filtering to remove water-column noise (e.g., fish schools, suspended debris) (GeoAcoustics, 2020).

Cleaned Point Cloud soundings (X, Y, Z) and backscatter intensity maps were exported into Quantum GIS (QGIS). Bathymetric surfaces were generated by applying spatial interpolation algorithms (Ordinary Kriging and Inverse Distance Weighting - IDW) to create continuous, high-resolution Digital Elevation Models (DEMs) at a 1 m grid cell resolution (Mitasova et al., 2005). QGIS built-in spatial tools were used to extract cross-sectional profiles, calculate riverbed roughness indices, and compute slope vectors.

Final exported thematic maps were refined in Adobe Photoshop and CorelDRAW. These design tools were utilized to enhance visual contrast, polish hillshade rendering, harmonize color palettes for publication, and finalize cartographic layouts (legend formatting, scale bars, orientation indicators).

2.4.Riverbed Type Classification

The classification of riverbed substrates relied on an established acoustic intensity thresholding method executed within QGIS. Side-scan sonar backscatter images were normalized to an 8-bit radiometric resolution, yielding a dynamic grayscale spectrum ranging from 0 (total acoustic absorption / soft substrate) to 255 (maximum acoustic reflection / hard substrate) (Blondel, 2009; Lucieer et al., 2013).

Vector polygons derived during the segmentation step (Section 3.2.2) were assigned classification attributes by evaluating their internal mean backscatter values against quantitative thresholds defined in published benthic mapping literature (e.g., Collier & Brown, 2005; Brown et al., 2011; Onăra et al., 2024):

$$\text{Substrate Class} = \begin{cases} \text{Mud / Silt} & 0 \leq \text{Value} \leq 65 \\ \text{Fine / Medium Sand} & 66 \leq \text{Value} \leq 130 \\ \text{Coarse Sand / Small Gravel} & 131 \leq \text{Value} \leq 185 \\ \text{Gravel / Cobble / Hard Bottom} & 186 \leq \text{Value} \leq 255 \end{cases}$$

This classification scheme yielded vector-based riverbed maps categorized into distinct substrate zones. The final maps were intersected with bathymetric DEMs to pinpoint locations where deep pools coincide with hard substrate classes (gravel/cobble)—delineating high-priority target zones for sturgeon spawning and overwintering assessment.

3. Results

3.1. Bathymetric Characteristics

The hydroacoustic processing yielded high-resolution Digital Terrain Models (DTMs) provided as GeoTIFF outputs at a spatial grid cell resolution of 1 m across all three study stretches (GeoAcoustics, 2020). To construct an integrated representation of the channel topography and adjacent floodplain morphology, the bathymetric datasets were merged with a high-accuracy terrestrial LiDAR DTM (dating from 2011). All spatial datasets and maps are projected within the official national Romanian reference coordinate system Stereo 70 (EPSG: 3844). The bathymetric datasets reflect conditions captured during the April 2025 hydrographic field campaign conducted by the authors under the framework of the EU NatureFirst Project (NatureFirst Consortium, 2025).

To evaluate channel geometry relative to localized benthic pool structures, cross-sectional (transversal) and longitudinal bathymetric profiles were positioned based on specific channel configurations and thalweg geometry across each site (table 2):

Table 2. Bathymetric comparison of study sites

BATHYMETRIC COMPARISON OF STUDY SITES			
Metric / Feature	Nufăru Sector	Bălteni Sector	Isaccea Sector
Max Pool Depth	30 m	35 m	17 m
Spatial Orientation	West-to-East	West-to-East	West-to-East
Deep Pool Location	Right Bank	Right Bank	Right Bank
Bank Geometry	Steep Right Bank	Both Banks Steep	Steep Right Bank
Hydrodynamics	High Turbulence (ADCP Verified)	Pool Volume	Shear Zones
Primary Function	Wintering/Resting	Wintering/Resting	Spawning Site

A comparison between the Nufăru (Figure 5) and Bălteni (Figure 6) river sectors reveals structural geomorphological similarities (Suciu et al., 2008). Both sectors exhibit a general West-to-East spatial alignment and feature deep scour pools driven by local bank geometry along the right bank (Onăra et al., 2024).

The deep pool reaches a maximum depth of 30 m along the right bank. Transversal profiles show a asymmetric channel cross-section with a steep bank slope along the right margin and a gentle rise toward the left bank. Acoustic Doppler Current Profiler (ADCP) velocity profiling conducted at the downstream boundary of the Nufăru sector reveals dynamic hydraulic zoning: high current velocities and turbulent shear stress are concentrated directly within the deep pool zone, transitioning into a laminar, low-velocity flow regime along the shallower left bank (Wolter & Sukhodolov, 2024).

Bălteni displays a deeper scour structure, reaching a maximum depth of 35 m. Unlike Nufăru, where the pool is confined closer to the right margin, the Bălteni pool expands across a broader portion of the channel width, bounded by steep banks along both sides and offering a higher volume of deep-water refuge (Kynard et al., 2002).

At the Isaccea (Noviodunum) site (Figure 7), bathymetric mapping reveals a maximum pool depth of 17 m. The pool extends longitudinally along the right riverbank, where structural relief is influenced by the submerged masonry remains of the ancient Roman fortress of Noviodunum (Honț et al., 2022). Two transversal and two longitudinal profiles across this reach document a steep right bank where submerged structures interrupt the stream bed, creating localized micro-topographic variations. Moving northward toward the left bank, the riverbed easily slopes upward to a depth of roughly 5 m.

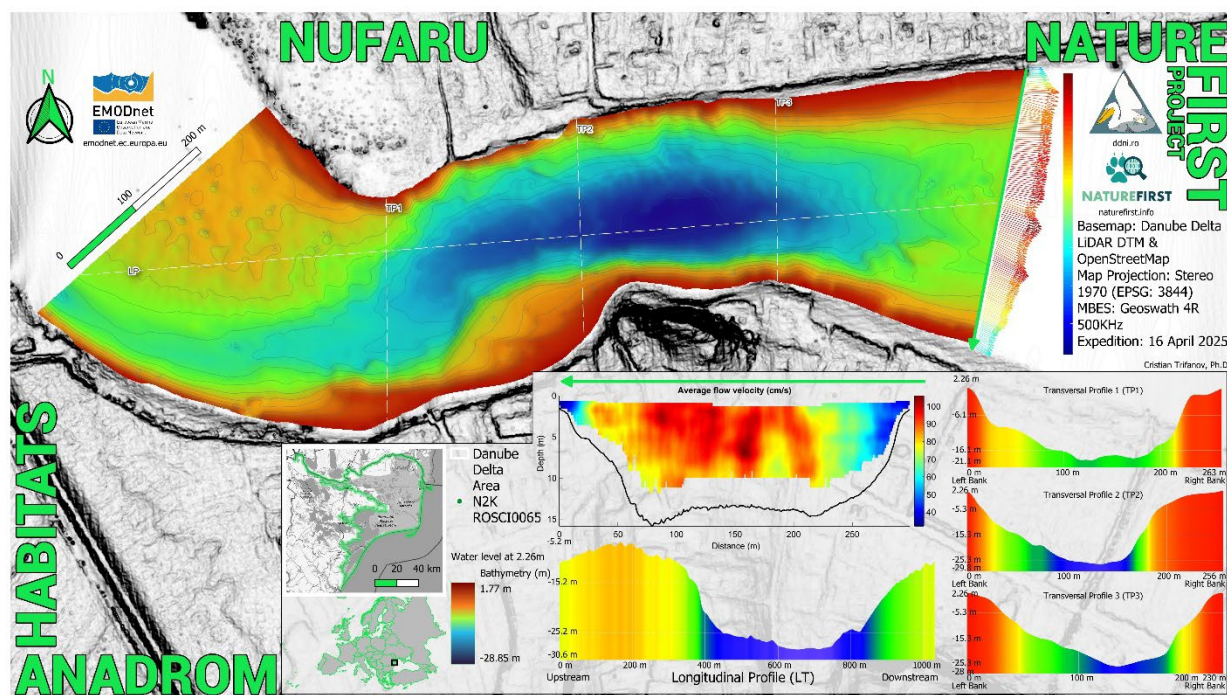


Figure 5. Nufăru river segment bathymetry for mapping and riverbed classification.

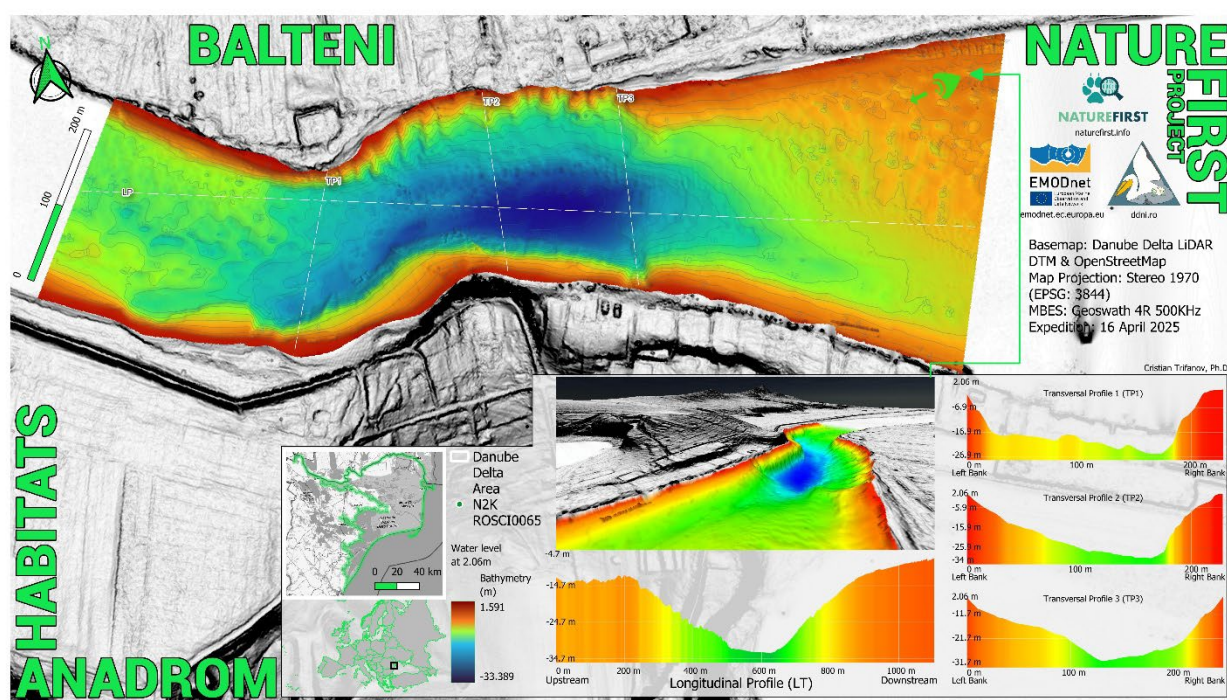


Figure 6. Bălteni river segment bathymetry for mapping and riverbed classification.

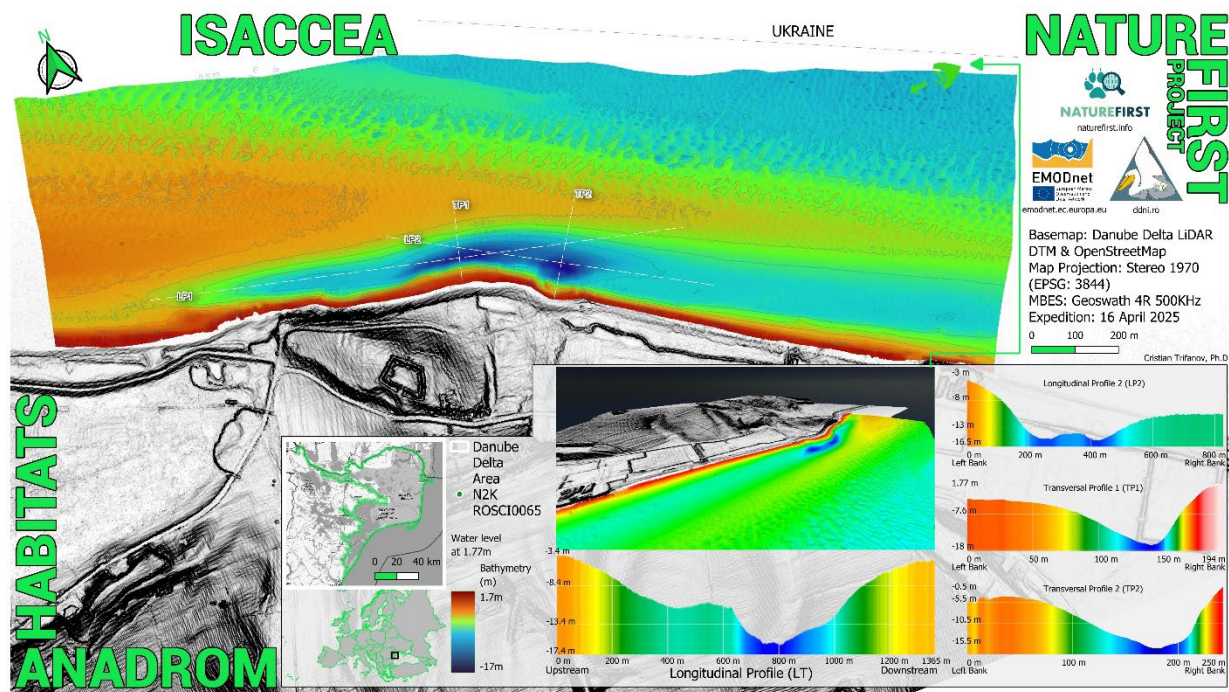


Figure 7. Isaccea (Noviodunum) river segment bathymetry for mapping and riverbed classification.

3.2.Riverbed Substrate Distribution

Benthic substrate maps were generated via side-scan sonar backscatter segmentation and radiometric thresholding (8-bit grayscale values: 0–255) (Blondel, 2009; Lucieer et al., 2013). The same classification parameters were applied across all three reaches to ensure regional comparability (Collier & Brown, 2005) (table 3).

Table 3. Riverbed substrate comparability

NUFĂRU	BĂLTENI	ISACCEA (NOVIODUNUM)
Deep Pool: 30 m; Right Bank: Rock/Bedrock Step; Substrate: Coarse Rocky/Hard Bottom.	Deep Pool: 35 m; Wide Pool Geometry Narrowing Bedrock; Lower Hard-Bottom % Hard-to-Soft Drift.	Deep Pool: 17 m; Right Bank: Gravel/Sunken Masonry; Outer Bed: Dunes/Sandy-Mud Alluvium.
Wintering/Rest	Wintering/Rest	Active Spawning

The Nufăru river segment (Figure 8) is characterized by high bank erosion along the steep right margin. The pool is structurally maintained by an underlying bedrock step (Onăra et al., 2024). The elevated shear stress from flow acceleration over this bedrock step creates an "auto-dredging" effect, sweeping away fine alluvial silts and maintaining a exposed rocky hard-bottom substrate. This rocky unit extends along the right side of the channel, gradually narrowing toward the downstream end of the survey reach as flow velocities decrease.

Similar to Nufăru, the Bălteni sector (Figure 9) features a bedrock step along its right bank that preserves deep scour conditions (Kynard et al., 2002). However, while the pool in Bălteni is spatially wider and deeper (35 m), the relative percentage of exposed hard-bottom substrate is lower than at Nufăru. The hard substrate band remains aligned

along the right bank but contracts rapidly in spatial area downstream, giving way to finer, soft alluvial deposits across the wider pool floor.

The substrate distribution at Isaccea (Figure 10) exhibits distinct spatial partitioning. High-velocity, turbulent flow along the steep right bank maintains a continuous belt of coarse gravel, cobble, and rocky debris associated with the submerged Noviodunum archaeological structures (Honț et al., 2022). Outside of this high-energy pool zone, the riverbed transitions into soft alluvial deposits (fine sand and mud), displaying bedform features such as sand dunes and ripples.

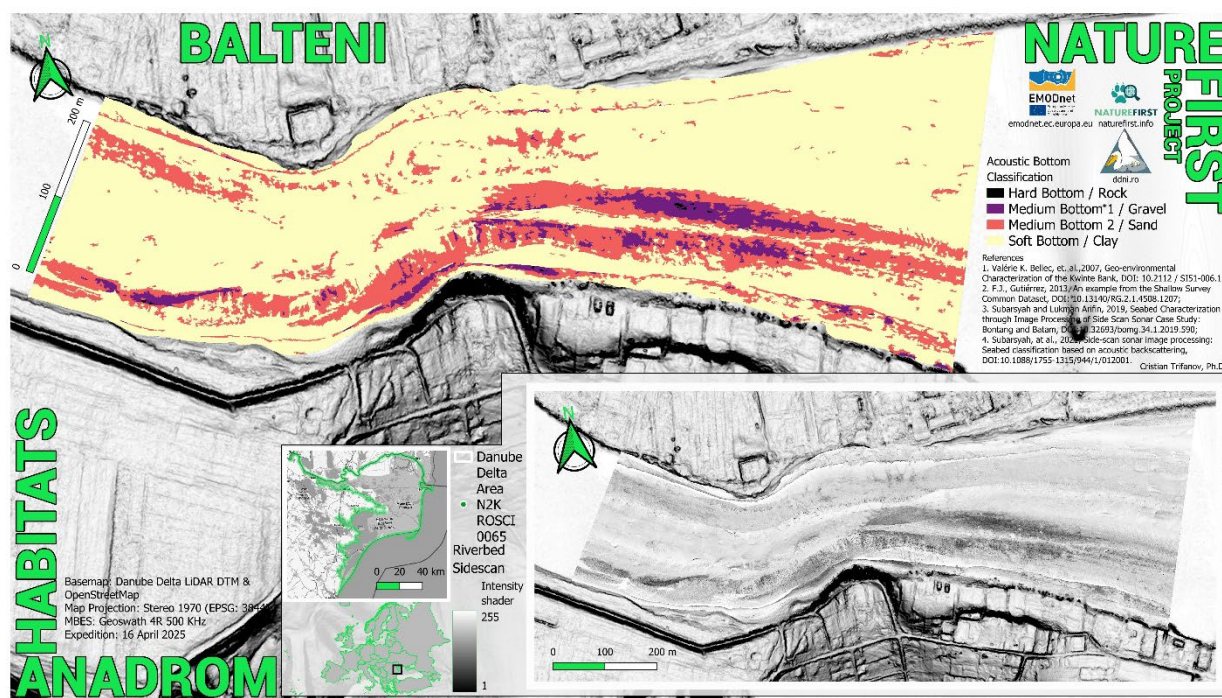


Figure 8. Bălteni river segment riverbed classification.

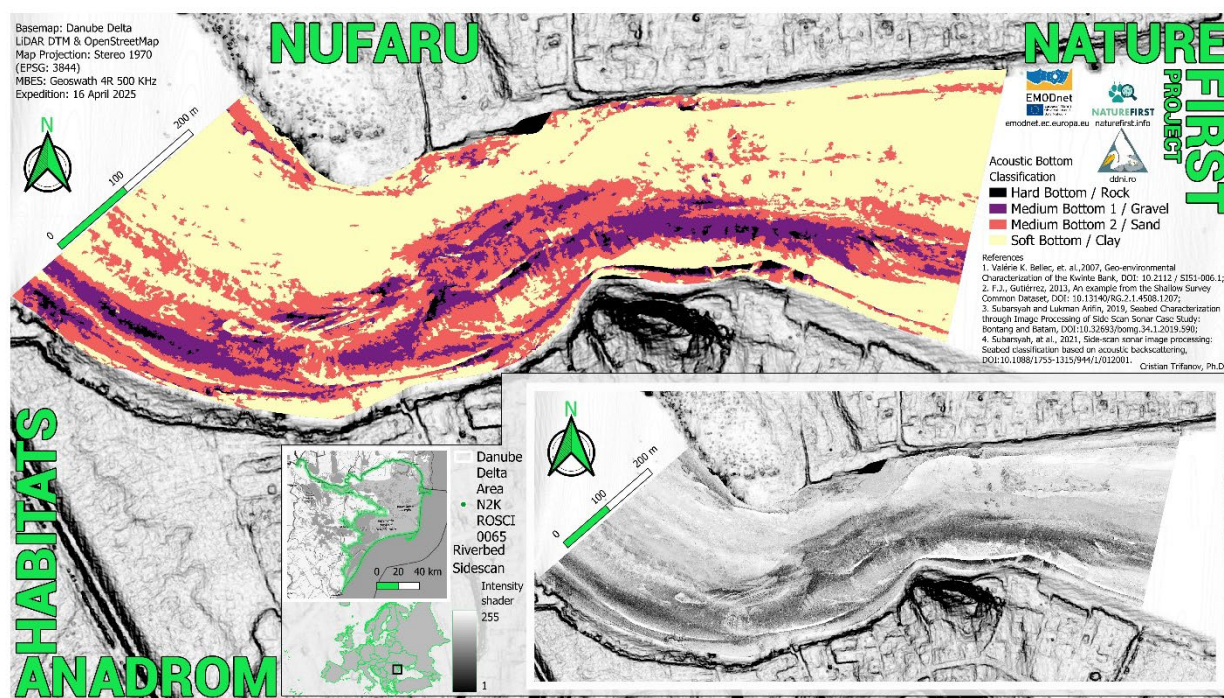


Figure 9. Nufăru river segment riverbed classification.

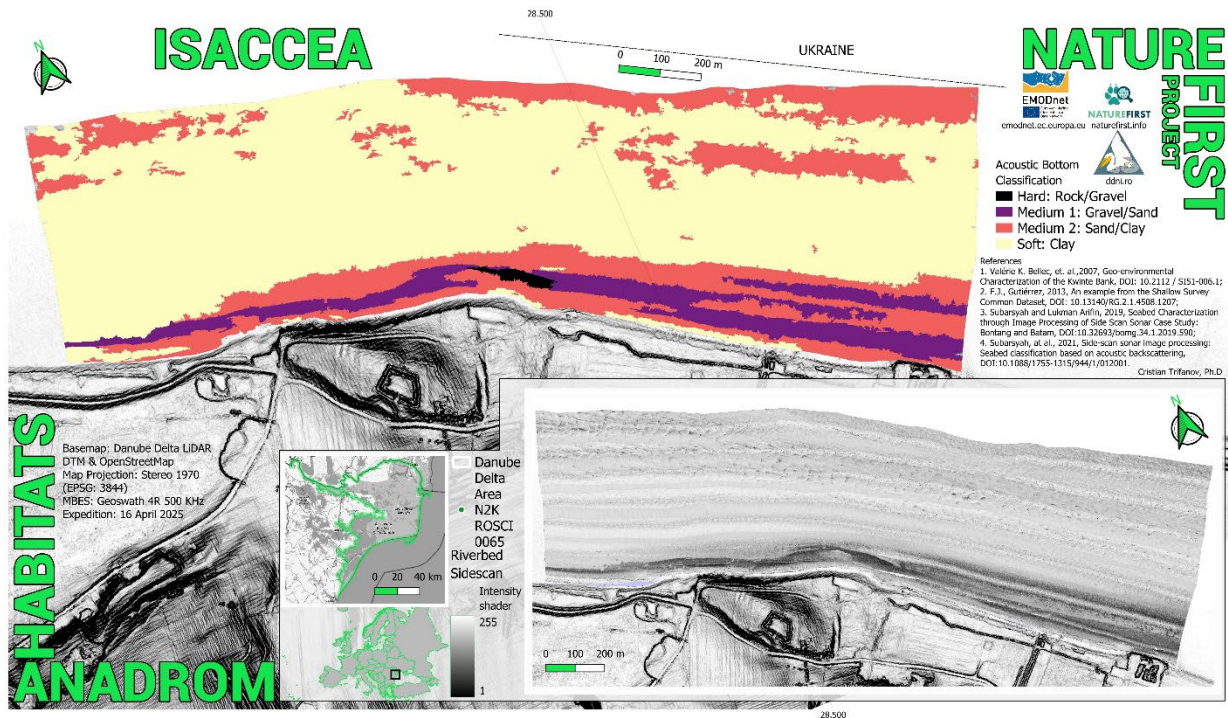


Figure 10. Isaccea (Noviodunum) river segment riverbed classification.

3.3. Functional Ecological Implications for Sturgeon Species

Intersecting the high-resolution bathymetric models, substrate classifications, and ADCP hydraulic profiles highlights an ecological distinction between the three study sites (Holban et al., 2022):

Despite having a shallower maximum pool depth (17 m) and smaller spatial area than Nufăru or Bălteni, Isaccea is the primary active spawning site among the three river segments (habitats) (Honț et al., 2022). The combination of a hard gravel-rock substrate, high-velocity turbulent flow, and its position further upstream from the Black Sea interface fulfills the specific environmental requirements needed for successful sturgeon egg attachment and egg aeration (Wolter & Sukhodolov, 2024).

While both Nufăru and Bălteni offer deeper bathymetric pools (30–35 m) and exposed bedrock features, their proximity to the river mouth and specific hydrodynamic profiles mean they function primarily as critical overwintering and thermal/hydraulic resting refugia for adult sturgeons. The buffering capacity of these deep riverbed structures against seasonal water temperature variability in the Lower Danube (Dunea, Brețcan et al., 2022) provides a vital resting ground (*Huso huso*, *Acipenser gueldenstaedtii*, *Acipenser stellatus*, and *Acipenser ruthenus*) rather than active spawning locations (Suciu et al., 2008; Onăra et al., 2024).

4. Discussion

4.1. Interpretation of Physical and Hydrodynamic Findings

The high-resolution hydroacoustic surveys conducted across the Bălteni, Nufăru, and Isaccea (Noviodunum) sectors underscore the intense morphodynamic heterogeneity of the lower Danube River. The bathymetric profiles demonstrate a consistent pattern of deep pool formation along the right bank, primarily driven by channel curvature and localized geological controls (bedrock steps). As observed at Nufăru and Bălteni, the presence of these bedrock sills accelerates flow velocities, initiating an "auto-dredging" mechanism that sweeps away fine alluvial sediments and maintains exposed hard-bottom facies at depths of 30–35 m (Onăra et al., 2024; Suciu et al., 2008).

A particularly unique geomorphological finding is the anthropogenically influenced bathymetry at the Isaccea sector. Here, the sunken masonry of the ancient Roman city of Noviodunum acts as an artificial geological control. Similar to natural bedrock outcrops, these submerged archaeological structures disrupt the laminar flow, generating high-velocity turbulent shear zones that scour the riverbed to 17 m and expose coarse gravel and cobble (Honț et al., 2022). This highlights how historical human infrastructure can become integrated into modern riverine morphodynamics, inadvertently generating essential physical micro-habitats.

4.2. Ecological Implications for Sturgeon Conservation

The structural differences between the three surveyed sites directly dictate their ecological utility for endangered sturgeon species (*Huso huso*, *Acipenser gueldenstaedtii*, *A. stellatus*, and *A. ruthenus*). Sturgeon spawning requires a precise intersection of depth, hard/soft substrate, temperature, PH, day duration and turbulent hydrodynamics to ensure egg adhesion and prevent hypoxic mortality caused by sedimentation (Wolter & Sukhodolov, 2024; Holban et al., 2022).

Although Bălteni and Nufăru offer substantial depths (up to 35 m) and hard/soft-bottom substrates, they serve primarily as overwintering and resting habitats observed by the experts through long studies and telemetry. Their proximity to the Black Sea makes them critical staging grounds for pre-spawning adults migrating upstream, providing thermal and hydraulic refuges (Kynard et al., 2002). Conversely, Isaccea serves as a confirmed active spawning ground. Despite being shallower (17 m), Isaccea is situated further upstream and features the specific gravel-cobble substrate mosaic and highly turbulent flow regime required by spawning adults. The spatial mapping of Isaccea confirms that high-quality spawning habitat in the Lower Danube is often highly localized and dependent on micro-scale topographic anomalies, rather than broad, continuous river stretches (Suciu et al., 2008).

4.3. Methodological Strengths and Limitations

The integration of 500 kHz interferometric bathymetric sonar (GeoSwath 4R) with LiDAR and ADCP data represents a significant methodological advancement over traditional point-based monitoring. Traditional sediment grab sampling often entirely misses narrow bands of hard substrate hidden beneath deep, fast-flowing water. By segmenting acoustic backscatter into continuous vector polygons based on precise 8-bit radiometric thresholds (Blondel, 2009; Collier & Brown, 2005), this study successfully visualized the abrupt transition zones between spawning-grade gravel and soft alluvial dunes without physical sampling (Lucieer et al., 2013).

However, some limitations persist. Hydroacoustic surveys conducted during high spring discharge (e.g., the April 2025 NatureFirst campaign) face challenges regarding vessel maneuverability and elevated suspended sediment loads, which can occasionally induce signal attenuation (GeoAcoustics, 2020). Furthermore, while backscatter segmentation accurately delineates relative hardness boundaries, acoustic responses can sometimes blur the distinction between heavily compacted clay and small gravel, requiring localized ground-truthing to ensure absolute classification accuracy (Brown et al., 2011).

4.4. Management and Policy Recommendations

The spatial outputs of this study offer critical tools for the Danube Delta Biosphere Reserve (DDBR) management authorities. We strongly recommend that:

- The 17 m scour pool and associated right-bank gravel beds at Isaccea/Noviodunum be designated as a strict micro-reserve during the spring spawning window to prevent disruption from commercial navigation and illegal poaching.

- Standardized hydroacoustic multibeam and backscatter mapping should become a mandatory prerequisite for any Environmental Impact Assessments (EIAs) related to commercial dredging or riverbank enforcement along the Lower Danube, as dredging often targets the exact morphological features (gravel bars and deep pools) that sturgeons require (Friedrich et al., 2018).

5. Conclusions

This study successfully demonstrates the efficacy of high-resolution, multi-frequency hydroacoustic mapping to characterize the hidden physical complexities of the Danube riverbed, providing a critical baseline for the conservation of highly endangered sturgeon species. By deploying a 500 kHz phase-measuring bathymetric sonar integrated with LiDAR and GIS-based backscatter segmentation, we generated continuous, sub-meter spatial models of three critical habitats within the Danube Delta Biosphere Reserve: Nufăru, Bălteni, and Isaccea.

The findings establish a clear functional dichotomy among these sites driven by their localized geomorphology and hydrodynamics. The deep (30–35 m), bedrock-controlled pools at Nufăru and Bălteni function as essential overwintering and resting refugia for upstream-migrating adults. In contrast, the shallower (17 m) but highly turbulent pool at Isaccea—structurally maintained by the submerged archaeological remains of the ancient city of Noviodunum—provides the distinct gravel-cobble substrate required for active spawning.

Ultimately, this research bridges the gap between abiotic river dynamics and endangered species management. It proves that sturgeon habitats in the Lower Danube are not broad, uniform stretches of river, but rather highly localized, micro-topographic anomalies. Protecting these remnant populations requires moving away from traditional, low-resolution environmental monitoring and embracing continuous, high-definition acoustic mapping to identify, monitor, and legally protect the precise riverbed features upon which these ancient species depend. Integrating these advanced spatial methodologies into regional policies and dredging impact assessments—as championed by the NatureFirst initiative—will be a decisive factor in preventing the extinction of Danube sturgeons.

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