Department of Marine Sciences

THE IMPACTS AND MAPPING OF SHIP INDUCED WAVES IN GÖTA ÄLV

Focusing on Atlantic Sturgeon and Pike

Photo by E. Fransson (2025-02-03)

Photo from: (Havsmiljö, n.d.)

Photo by E. Fransson (2025-06-16)

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Popular Science Text

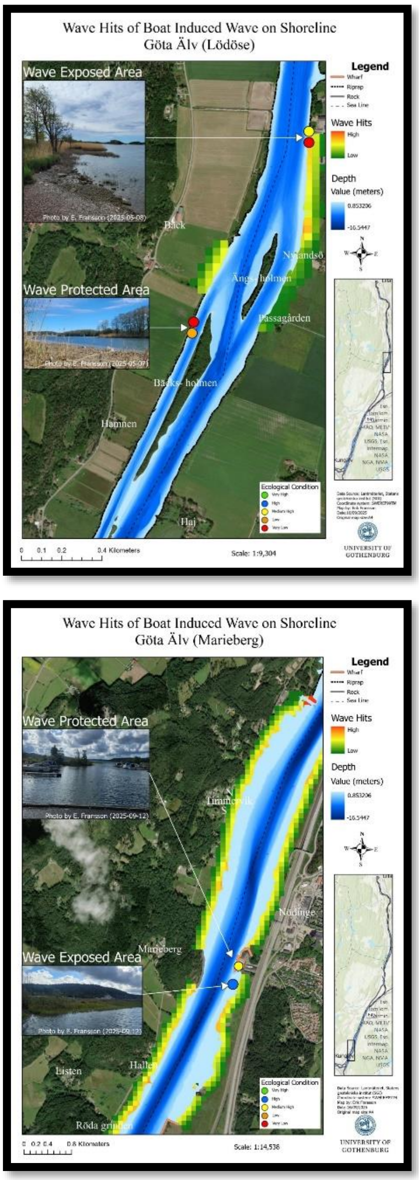
How Wake Waves Affect Pike and Atlantic Sturgeon in Göta Älv

Shipping have always been vital for transporting people and goods throughout history but can on the other side harm the environment. The purpose of this study is to map and determine how wake waves from boats affect the ecosystem with focus on Atlantic sturgeon (*Acipenser oxyrinchus*) and pike (*Esox lucius*), which are vital species for the ecosystem in Göta Älv.

The study was conducted by mapping the river and determining the wake wave impacts in ArcGIS Pro, collecting aquatic invertebrates in wave exposed and protected areas and examining the detachment rates on pike eggs from different water flows velocities with different vegetation.

Overall, the findings indicated that broad river sections and areas separated by shallow water between the shore and the shipping route had less wave impacts, leading to higher biodiversity and increased vegetation. These areas likely benefit pike that spawn in vegetation and juvenile Atlantic sturgeons that feed on aquatic invertebrates living there. Additionally, more invertebrates were found in protected areas, but the biodiversity was lower, indicating that wake waves might decrease the number of invertebrates. The lower biodiversity could be due to local habitat conditions such as hydropeaking regulations from Lilla Edets powerplant that may have influenced the results, and further research is needed to confirm this. The water flow tests on pike eggs showed that pike eggs were more dependent on vegetation than the water velocity which visualizes the need for wave protected areas as wake waves reduce vegetation.

Possible solutions for protecting the shores of Göta Älv from wake waves include speed restrictions and different kinds of erosion protections.



The figure shows the amount of boat induced wave hits in vegetated areas on the shores of Lödöse (A) and Marieberg (B) The wave hits scale is set from high to low. The Ecological condition is visualized with colours and is estimated with the Shannon index.

Abstract

Cargo shipping has always been vital for transporting people and goods throughout history, but it additionally contributes to several environmental impacts. The purpose of this study was to map and determine the ecosystem impacts of boat induced waves in Göta Älv, with a focus on the Atlantic sturgeon (*Acipenser oxyrinchus*) and pike (*Esox lucius*). The study was conducted by mapping wave impacts in Göta Älv using ArcGIS Pro, with particular focus on Marieberg and Lödöse, identified as hotspot zones for the Atlantic sturgeon according to previous telemetry studies. Benthic invertebrates were collected in exposed and protected habitats, and water flow resistance tests on pike eggs on different substrates were conducted in a laboratory. Overall, the findings indicated that broad river sections and areas where shallow depths separated the shoreline from the shipping line experienced less wave impact, which supports higher biodiversity and increased vegetation, benefiting pike spawning sites and providing foraging opportunities for juvenile Atlantic sturgeons. Additionally, invertebrates were found in higher quantities in protected areas, but biodiversity was lower, indicating that wake waves probably diminish benthic communities. However, the lower biodiversity results could as well be influenced by local habitat conditions such as hydropeaking regulations from Lilla Edets power plant, suggesting the need for further research to determine this. The water flow resistance tests showed that pike eggs are more dependent on vegetation density than on water flow velocity, emphasizing the need to mitigate wave impacts in the river, as wake waves reduce vegetation. Possible solutions for protecting the shores of Göta Älv from wake waves include implementing speed restrictions, establishing living shorelines, and planting vegetation.

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Introduction

Cargo shipping has always been a vital way to transport people and goods throughout history, and it is generally seen as a climate friendly and economical alternative to flights and trucks. Around 90% of all international cargo is transported by boat today, and due to the expected growth in trade, this number will probably increase (Trade & Development, 2019). Unfortunately, cargo ships pose environmental threats. For example, the release of carbon dioxide, sulphur dioxide and nitrogen oxides. In addition, the water is polluted by dangerous oil and chemical emissions, antifouling paints, and sewage water from toilets, laundry, and dishwashing onboard. Invasive species are additionally spread through ballast water or via the ship hull (Havs och vattenmyndigheten, 2018b).

This study focuses on the wake waves generated by cargo ships in Göta Älv River and how they impact the habitat, with a particular focus on pike eggs (*Esox lucius*) and the foraging potential of juvenile Atlantic sturgeon (*Acipenser oxyrinchus*). The river is located on the west coast of Sweden and stretches from Lake Vänern to its outlet into the sea in Gothenburg (Göta älvs vattenvårdsförbund, 2015). Around 3.5 million tons of cargo pass through Göta Älv each year, with an average of ten cargo ships per day and approximately 4,000 recreational boats navigating the system during the summer (Västsverige, 2025). Cargo ships cause several environmental impacts, and studies have shown that the long-term effects of boat traffic reduce biodiversity and cause changes in the food web. The wake waves can for example affect benthic invertebrates, particularly in habitats with low structural complexity and little or no vegetation (Gabel, 2012). This, in turn, impacts the entire ecosystem including the Atlantic sturgeon, which feeds on benthic invertebrates during its juvenile stage (Näslund et al., n.d.). The ship induced wake waves may as well harm other species such as pike, which depend on vegetation for spawning and egg attachment (Sandström et al., 2005).

Boat Induced Waves

Primary Waves

Boats generate several types of waves, which can be divided into primary and secondary waves. Primary waves include the bow wave, which is pushed straight ahead of the ship as it moves and elevates the water surface by a few centimetres, extending up to the length of the vessel (Figure 2B).

The movement of the boat additionally creates a return flow that travels along the hull from the bow to the stern. This particularly affects narrow rivers, as the return flow causes a significant drop in water level along the shore, known as a depression wave (Figures 1 and 2B) (Federal Institute of Hydrology & Federal Waterways Engineering and Research Institute, 2016) Granath (2004) suggests that the depression wave has the greatest impact on beach zones. It draws water away from the shoreline, carrying with it benthic material and organisms such as fish eggs, which can become buried under sediment or eaten by other organisms (Söhngen et al., 2008). The depression wave can as well cause short periods of drainage that may be fatal for juvenile fish or eggs (Federal Institute of Hydrology & Federal Waterways Engineering and Research Institute, 2016).

Shallow waters with reeds are especially vulnerable to boat induced waves, as the depression wave removes sediment from the banks, leading to root instability (Granath, 2013). The effects of waves in shallow areas depend on river width, depth, and bottom substrate. Broader and deeper sections experience weaker impacts since wave height decreases with distance from the shore (Granath, 2004; Sportfiskarna, 2024a). The wavelength of the three primary waves depends on the ship’s length, velocity, weight, shape (Granath, 2004), and distance to the shore (Federal Institute of Hydrology & Federal Waterways Engineering and Research Institute, 2016).

Secondary Waves

The secondary waves are formed after the primary waves and consist of diverging and transversal waves (Figure 2A). Transversal waves are oriented perpendicular to the ship’s direction of movement, while the diverging waves move outward and forward in the same direction as the ship. An interference line is formed where the transversal and diverging waves meet, creating the characteristic V-shaped pattern (19.3°–45°, depending on the ship's speed) that appears as a vessel moves (Figure 2A).

Secondary waves travel farther than primary waves, and their height is only slightly reduced with distance. In addition, waves generated by propeller wash are formed, particularly during the ship's manoeuvres (Figure 2B) (Federal Institute of Hydrology and Federal Waterways Engineering and Research Institute, 2016).

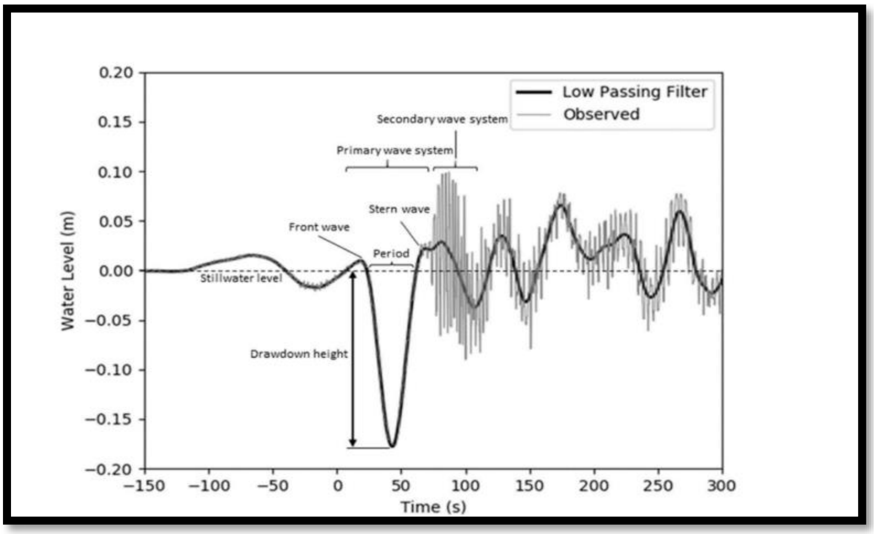


Figure 1 visualizes the wave generated by a large passing ship. The x-axis represents time, and the y-axis shows the water level. The dotted line indicates the normal water level. The grey areas display the measured values, while the black line has been generated from the observed values using a low-pass filter. The graph presents data from three sites in Furusundsleden (Almström & Larson, 2020).

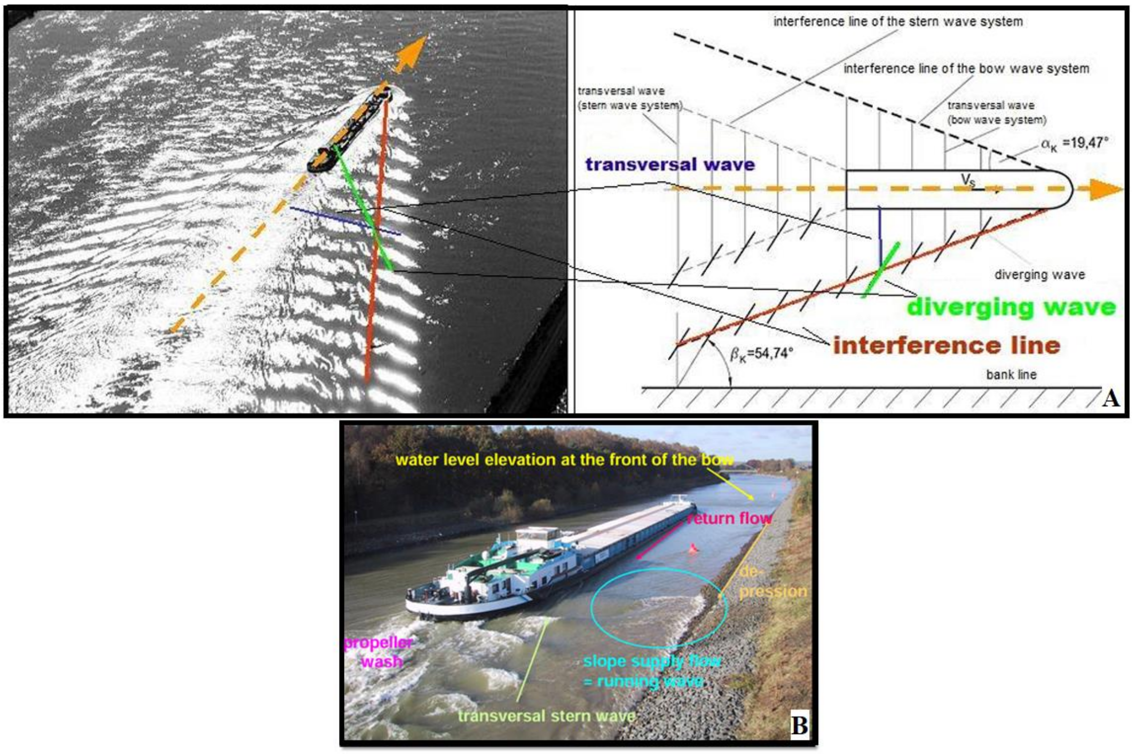


Figure 2A shows the secondary waves, which include the diverging and transverse waves that form an interference line visualized by a V-shaped pattern behind the ship. Figure 2B illustrates the elevated water surface ahead of the ship, along with the propeller wash, the primary wave, the return flow, and the depression wave (Federal Institute of Hydrology and Federal Waterways Engineering and Research Institute, 2016).

Wake Wave Impacts

Turbidity

Studies have shown that channels affected by higher boating activity have higher turbidity (Gregory & Levings, 1996) which is caused by the exchange between the bottom and surface water due to the wake waves (Lindholm et al., 2001).The turbidity causes negative impacts for juvenile fish (Gregory & Levings, 1996), depending on fish size and foraging behaviour. (Reid et al., 1999) Pike and perch (*Perca fluviatilis*) prefer clear water for feeding and turbidity will impact them negatively (Sandström et al., 2005). In addition, Lithophilic fish species are particularly sensitive to high frequency wake waves (Zajicek & Wolter, 2019).

Dredging is common to increase accessibility in areas where there is a high amount of boat traffic. In erosion sensitive areas this could lead to endured turbidity which is upheld through the ongoing traffic (Havs och vattenmyndigheten, 2018a). Dredging has additionally been shown to directly reduce the Atlantic sturgeon’s foraging areas and decrease its ability to locate suitable prey (Artdatabanken, 2025a). Vegetation can for instance become buried due to increased turbidity (Söhngen et al., 2008). Vegetation serves as habitat for macroinvertebrates which is a key food sources for juvenile Atlantic sturgeon (Medins Havs och Vattenkonsulter, 2022; Secor et al., 2000). Vegetation is additionally vital spawning and nursery habitat for numerous species of fish, and it provides refuge for juvenile fish to avoid predation (Sandström et al., 2005). Pike (*Esox lucius*) lay their eggs in the vegetation, and the larvae attaches themselves to the plants after hatching (Artdatabanken, 2025b).

Plants and macroalgae are the most fragile in shallow soft bottom habitats (0-15 meters) (Sportfiskarna, 2024a). Shallow waters do often have a complex structure with vegetation which contribute with vital habitats for organisms (Havs och vattenmyndigheten, 2020). Protected bays which seldom are affected by natural waves are additionally worse prepared if the number of wake waves increases. Exposed areas such as open coastal areas are more prepared for wave action as they have harder substrate which are more robust (Granath, 2004).

Trophic Cascades

Studies have shown that stable populations of predator fish in areas decreases the rapid growth of algae as they diminish the number of fish such as three-spined stickleback (*Gasterosteus aculeatus*) and European sprat (*Sprattus sprattus*). These fish forage on zooplankton, which in turn reduces algal blooms because zooplankton graze on algae (Östman et al., 2016). Algal blooms can lead to anoxic environments as detrivores use the available oxygen during consuming of the algea (Pitcher & Probyn, 2016). The populations of three-spined stickleback do in addition feed on the larger fish predators' eggs as for example pike eggs which causes further instability for the ecosystem (Hansen et al., 2020). It is vital to have several spawning habitats for perch and pike to resist the impact from the egg eating fish such as the three-spined stickleback. Therefore, losses of spawning habitat for pike or perch can have severe consequences for the ecosystem as the predator fish in the area decrease which increase the algal blooms and causes anoxic zones (Diaz & Rosenberg, 2008; Olin et al., 2024).

Increased upwelling of bottom sediment and exchange between bottom and surface water due to the wake waves could lead to eutrophication through increased oxygenation and increased bottom temperature (Lindholm et al., 2001). Eutrophication does in addition promote algal blooms which in the longer term could cause anoxic environments (Diaz & Rosenberg, 2008).

Atlantic Sturgeon

The Atlantic sturgeon is an anadromous species that reproduces and spends its juvenile stage in freshwater but migrates to the sea as an adult. It can reach an age of up to 140 years, a length of up to 500 cm, and a weight of around 600 kg. The species becomes sexually mature between 12 and 20 years of age. Males can reproduce every 1–2 years, while females spawn every 2–4 years. The spawning period varies depending on temperature and water flow but typically begins in May or June and continues until the water flow decreases and the temperature reaches 13–22 °C. Atlantic sturgeon usually spawns in the lower sections of rivers. The males arrive first and may wait in groups for up to ten days for the females. Spawning occurs at depths of 2–14 m, in areas with water velocities between 0.4–1.2 m/s and substrates composed of stones or blocks. A single female can lay millions of eggs, which hatch within 3.5 days when the water temperature reaches 20 °C. After hatching and absorbing the yolk sac, the larvae settle on fine sediment and feed on benthic invertebrates. When they reach one year of age, they move to deeper sand and mud substrates and remain in the river or estuary for 2–6 years before migrating to the sea. There, they typically inhabit coastal waters at depths of around 20 m, where they feed on polychaetes, crustaceans, molluscs, and demersal fish (Artdatabanken, 2025a).

The species has been severely exploited throughout history and has been extinct in Göta Älv for over 100 years due to overfishing. However, with the approval of the County Administrative Board, 95 juvenile Atlantic sturgeons originating from a hatchery at the Leibniz Institute of Freshwater Ecology and Inland Fisheries in Berlin were reintroduced into Göta Älv during the summer of 2024. The project, called *The Return of the Sturgeon*, is led by the Swedish Anglers Association (Sportfiskarna, 2024b; Störens återkomst, n.d.). The Atlantic sturgeon is vital for the ecosystem, as it feeds on benthic invertebrates, helping to aerate and oxygenate the riverbed (Secor et al., 2000; University of Gothenburg, 2024). However, the species now faces several challenges, such as limited food availability of benthic invertebrates in the river, which may be affected by the impact of ship induced waves.

Pike

The pike is a key top predator in freshwater systems within the Palearctic region. Females are larger and can reach over 150 cm in length and weigh between 23–30 kg. The species reaches reproductive maturity between 1–5 years of age. Spawning begins in early spring (around March in southern Sweden) in flooded areas. Pikes reproduce in groups over approximately one week, and a single female can produce up to 200,000 eggs, which attach to vegetation and hatch after 10–15 days. As fry, they feed on invertebrates and other fish larvae, including individuals of their own species. As adults, they primarily prey on fish, amphibians, small mammals, and birds. The species is largely sedentary and solitary, and individuals typically remain within a limited home range (Artdatabanken, 2025b).

In Göta and Nordre Älv, a low number of pike eggs were recorded in surveys conducted by the Swedish Anglers Association in 2021. The declining pike population is potentially linked to wake waves from cargo ships, which may cause egg detachment and reduce available spawning habitats (Sportfiskarna, 2021).

Purpose of the Project

The purpose of this study is to map and assess the ecological impacts of boat induced waves in Göta Älv, with a focus on the Atlantic sturgeon and pike. The research will involve mapping the river in ArcGIS Pro and conducting visual assessments during a boat survey to identify locations where boat induced waves have the greatest impact. Benthic invertebrates will be collected in both wave exposed and protected habitats to provide an indication of benthic biodiversity, which serves as an essential food source for juvenile Atlantic sturgeon. Laboratory experiments will be carried out to determine the detachment rates of pike eggs under varying water velocities, which will then be compared with actual measured wake wave velocities from ships in Göta Älv. This will provide insight into how wake waves affect the pike population in the river.

The study hypothesizes that narrow and wave exposed areas of the river will experience stronger wave impacts, resulting in reduced vegetation and lower biodiversity. It is further hypothesized that pike eggs will detach from vegetation once a certain water velocity threshold is exceeded.

The study area is limited to the section between Marieberg and Lilla Edet, with a particular focus on Marieberg and Lödöse. These areas are considered vital habitats for the Atlantic sturgeon, according to preliminary telemetry data indicating that Lödöse may represent a key hotspot zone (Jägerud, 2025). However, these assumptions are based on preliminary results and have not yet been confirmed. Previous studies have examined the impacts of cargo ship activity on Göta Älv. For example, Bondelind et al. (2015) investigated sedimentation and emissions in the river caused by wake waves (Bondelind et al., 2015). However, no prior research has specifically analysed the ecological effects of wake waves on the ecosystem with a focus on the Atlantic sturgeon or pike. This study aims to address this research gap.

Method and Material

Mapping Göta Älv

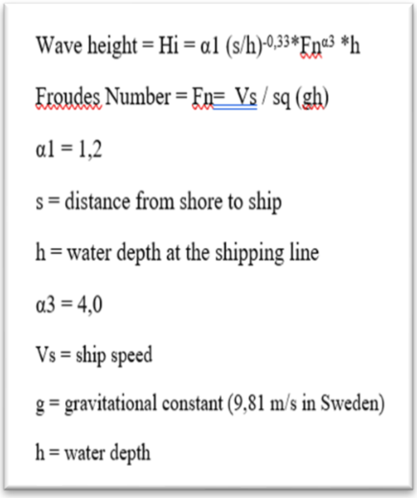
Wave impacts from passing cargo ships in Göta Älv were mapped in ArcGIS Pro (Esri, 2024) to visualize the number of wave occurrences and their height along the shoreline. The section between Marieberg and Lilla Edet was mapped, with particular focus on Marieberg and Lödöse. An additional field observation was conducted aboard the cargo ship *TUNA* to document wave behaviour in Göta Älv.

Wave Hits

To visualise the wave impacts along the shores of Göta Älv, a methodology inspired by a similar study on wave effects in the Baltic Sea by Nurmi (2012) was applied. Water polygons for Göta Älv were obtained from Lantmäteriet (Lantmäteriet, 2025), and bathymetric data showing river depth were provided by the Swedish Geotechnical Institute (Statens geotekniska institut, 2025). The shipping route was manually digitised by comparing AIS data from MarineTraffic.com. Points were generated every 50 meters along the route, with each point serving as the origin for multiple lines radiating in 360-degree directions at 10-degree intervals. These lines represented wake waves from cargo ships at each 50-meter interval. The wave lines were clipped to remain within the Göta Älv polygon layer and terminated when intersecting islands or land. The distance of the wave lines was not considered, as the river is sufficiently narrow for waves to dissipate well before reaching one kilometre, which is approximately the average propagation distance of wake waves in rivers (Chang et al., 2025). Intersection points were created where the wave lines met the land, and a heat map was generated using Kernel Density (five-class scale) to visualise areas where vessel generated waves most frequently impacted the shore, ranging from “high” to “low” (Nurmi, 2012). A polygon layer containing reeds and vegetation was obtained from Lantmäteriet (Lantmäteriet, 2025), and the wave impact heat map was clipped to display only these areas, as they represent key habitats for aquatic organisms in the river.

Wave Height

The calculation of wave height (Hi) along the shores of Göta Älv was conducted using a method adapted from Nurmi (2012). Froude’s number was calculated based on the depth at each point along the shipping route. The shape length of each line from the shoreline to the corresponding point on the shipping route was used as the distance to shore (s). Depth values (h) were extracted from the bathymetry raster. Vessel speed (Vs) was assumed to correspond to the speed limit in Göta Älv, set at 10 knots, except in the Tjurholmen area, where the limit is 5 knots. The calculated values for wave height (Hi) were stored at the intersection points along the shoreline and subsequently converted into a raster layer. A heat map of the raster layer was generated to visualise wave heights along the shore on a “high to low” scale (Nurmi, 2012). The wave height heat map was then clipped using the reeds and vegetation polygon to highlight areas of ecological relevance.



Wave height = $Hi = \alpha 1\ (s/h)^{-0,33} * Fn^{\alpha 3} * h$

Froudes Number = $Fn = Vs / sq\ (gh)$

$\alpha 1 = 1,2$

s = distance from shore to ship

h = water depth at the shipping line

$\alpha 3 = 4,0$

Vs = ship speed

g = gravitational constant (9,81 m/s in Sweden)

h = water depth

Equation 1 calculates the wave heigh (Nurmi, 2012).

Boat Trip

The boat trip was conducted aboard the ship *TUNA*, traveling from the harbour in Gothenburg to Lilla Edet. The vessel measured 89 meters in length and 13.35 meters in width, which ensured clear and distinct observations of wake waves.

Sampling of Benthic Macroinvertebrates

Benthic invertebrates were sampled between March and June 2025 in Marieberg and Lödöse. In Marieberg, one sample was collected on 6 June 2025 in a sheltered harbour unaffected by wake waves from cargo ships, representing the wave protected area. The harbour accommodates only small boats, whose wave impact was considered negligible. Two additional samples were collected near the harbour on 14 May and 10 April 2025 in areas exposed to wake waves. In Lödöse, two samples were collected from a sheltered bay behind Ängsholmen (30 May and 7 May 2025) and two from an exposed area (28 March and 8 May 2025). During each sampling event, a 10 m transect at 50 cm depth was established, from which ten samples were collected at one-meter intervals, with a minimum spacing of 10 m between sampling occasions.

Sampling followed the standardized kick sampling method SS-EN ISO 10870. In summary, the method involves using a square shaped hand net (25 × 25 cm, mesh size 0.5 × 0.5 mm) held against the substrate while a 1 × 0.25 m area in front of the net is disturbed by kicking, allowing benthic material to be washed into the net (SIS, 2012). In this study, kicking was performed for one minute per sample for standardization. All samples were preserved on site in 95% ethanol and later divided into families and orders. Biodiversity of the benthic fauna community at each site was assessed using Shannon's diversity index (Naturvårdsverket, 2000; Nolan & Callahan, 2006) (Equation 2A and 2B). Pie charts illustrating the composition of collected invertebrates were generated in RStudio (R Core Team, 2025).

$$H = -\sum_{i=1}^{s} p_i \ln(p_i)$$

where

H = the Shannon index value

p_i = the proportion of individuals found in the ith species

ln = the natural logarithm

s = the number of species in the community

A

Class	Description	Shannon Diversity Index
1	Very high index	> 3.00
2	High index	2.33 – 3.00
3	Moderately high index	1.65 – 2.33
4	Low index	0.97 – 1.65
5	Very low index	≤ 0.97

B

Equation (2A) calculates the Shannon diversity index value. Equation (2B) represents the Shannon index values categorized into different biodiversity classes for the sampled areas.

Water Flow Resistance Test for Pike Eggs

The eggs were obtained from another study in which two pikes were caught in Lake Delsjön. Eggs and milt were manually stripped and mixed for fertilization, after which the fertilized eggs were stored in a refrigerator.

The laboratory work was conducted by master's student Erik Fransson at Natrium, University of Gothenburg. To estimate the average egg weight, a sample of 30 eggs was weighed using a precision balance. For the experimental setup, a 4 cm wide coconut mat, representing vegetation, was placed 30 cm in front of a submerged pump (Abyzz AFC150IPU Compact) that generated different water velocities (Figure 3B). The experiment was carried out in a closed flume aquarium that allowed water circulation (Figure 3A). A total of 1 gram of pike eggs (57 eggs) was randomly distributed across the mat within the pump's flow diameter. The pump generated water flow for four seconds, starting at 1% of its maximum power. A net was positioned behind the mat to collect detached eggs, which were counted after each four second interval. The eggs were then redistributed on the coconut mat (Figure 3C), the water flow was increased by 1% on the velocity scale, and the procedure was repeated. Testing continued until all eggs had detached from the mat or until it was visually determined that no further detachment would occur. Once all eggs had detached, a new batch of 1 gram of eggs was used, and the procedure was repeated. Six experimental rounds were performed in total. Three trials were conducted using only the coconut mat as substrate (sparse vegetation), and three included additional glued coconut fibres on top of the mat (dense vegetation). Water velocities were measured using an FP111 flowmeter. The experiment was conducted over two weeks, and the eggs were stored in a refrigerator overnight.

Figure 3A shows the closed flume aquarium that allowed water circulation. Figure 3B illustrates the experimental setup, where a 4 cm wide coconut mat representing vegetation was placed 30 cm in front of a submerged pump (Abyzz AFC150IPU Compact). Figure 3C shows the pike eggs positioned on the coconut mat.

Measurement of Wake Wave Velocities in Göta Älv

Measurements of water velocities from actual wake waves were conducted in Göta Älv to compare with the detachment rates of pike eggs under different water flows. The flow probe (Global Water FP111) was used to measure wake wave velocities at Tjurholmen and in the wave exposed areas of Marieberg and Lödöse (Figure 4). For standardization, measurements were taken 35 cm below the water surface and one meter from the shore at all sites.

Figure 4 shows the velocity measurements obtained using the flow probe (Global Water FP111) in Göta Älv.

Results

Mapping Göta Älv

Marieberg Wave Hits

Wave exposure in Marieberg was moderate overall, with higher wave frequency and height observed along headlands. The exposed area exhibited high invertebrate diversity, while the protected area showed moderately high diversity according to the Shannon index. Bathymetric data indicated shallow water near the banks (Figure 5).

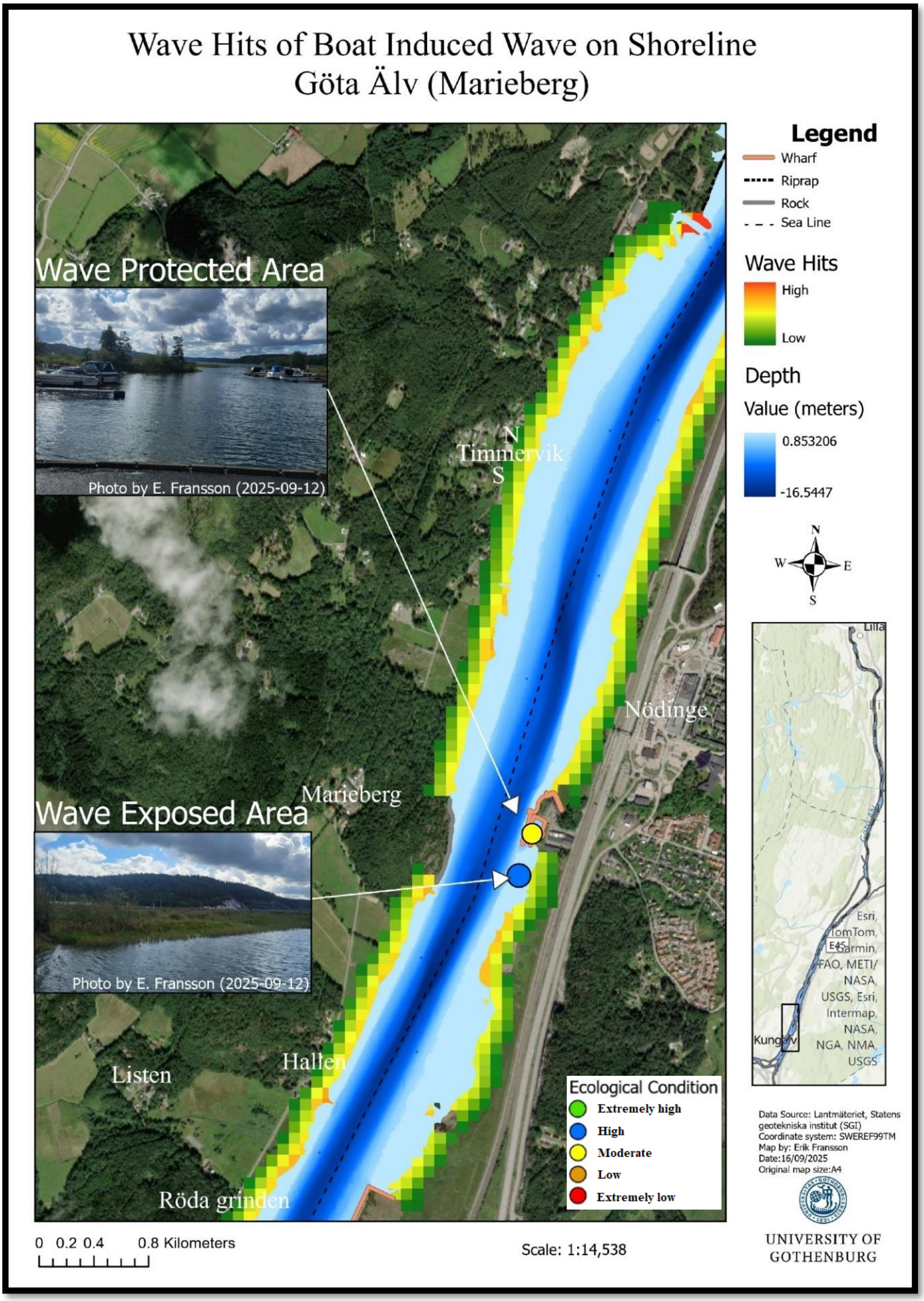


Figure 5 shows the amount of boat induced wave hits in vegetated areas on the shores of Marieberg. The wave hits scale is set from high to low. The Ecological condition is visualized with colours and is estimated with the Shannon index.

Marieberg Wave Height

Wave height in Marieberg was generally moderate compared with the rest of the river, with slightly higher values observed along headlands (Figure 6).

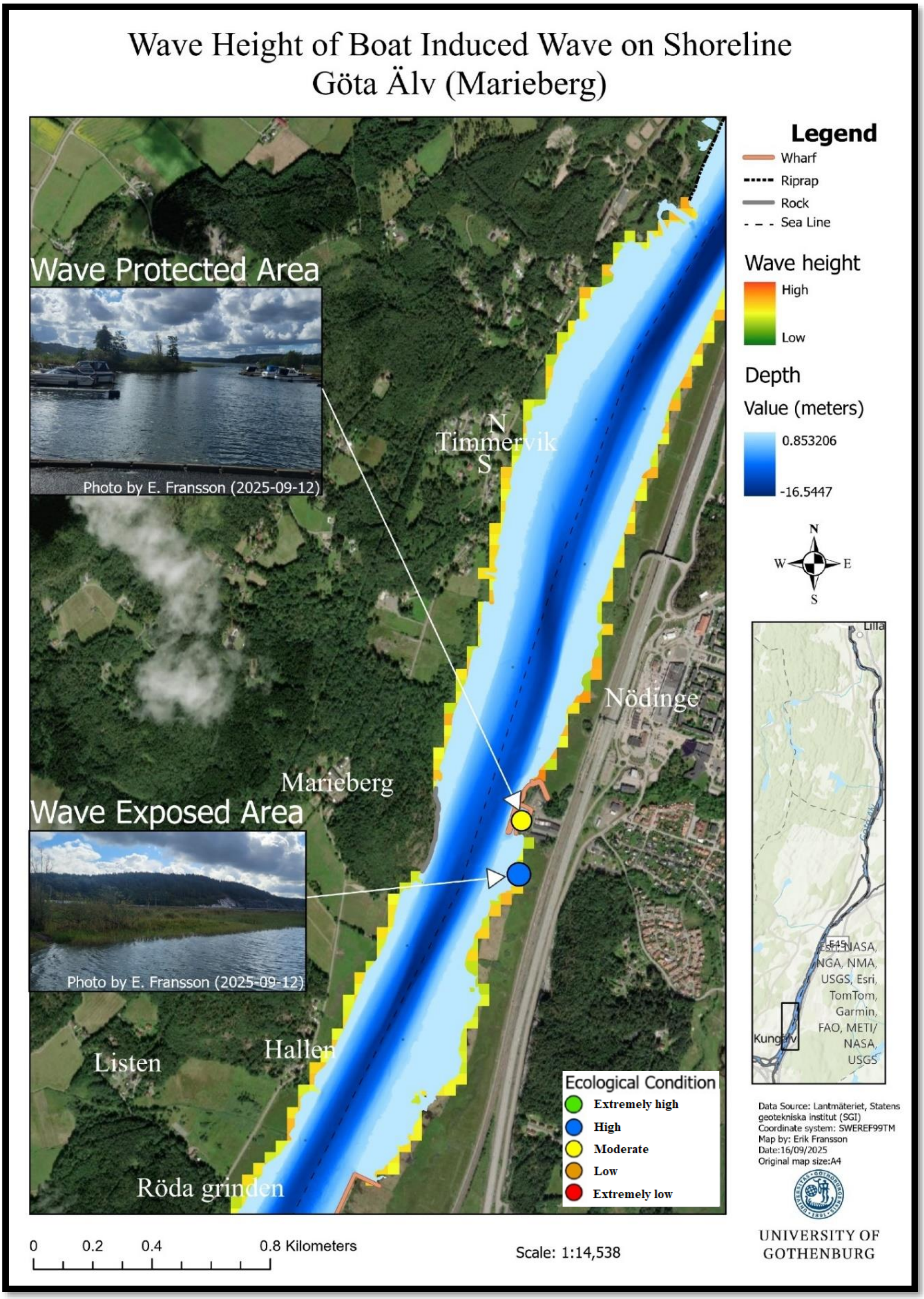
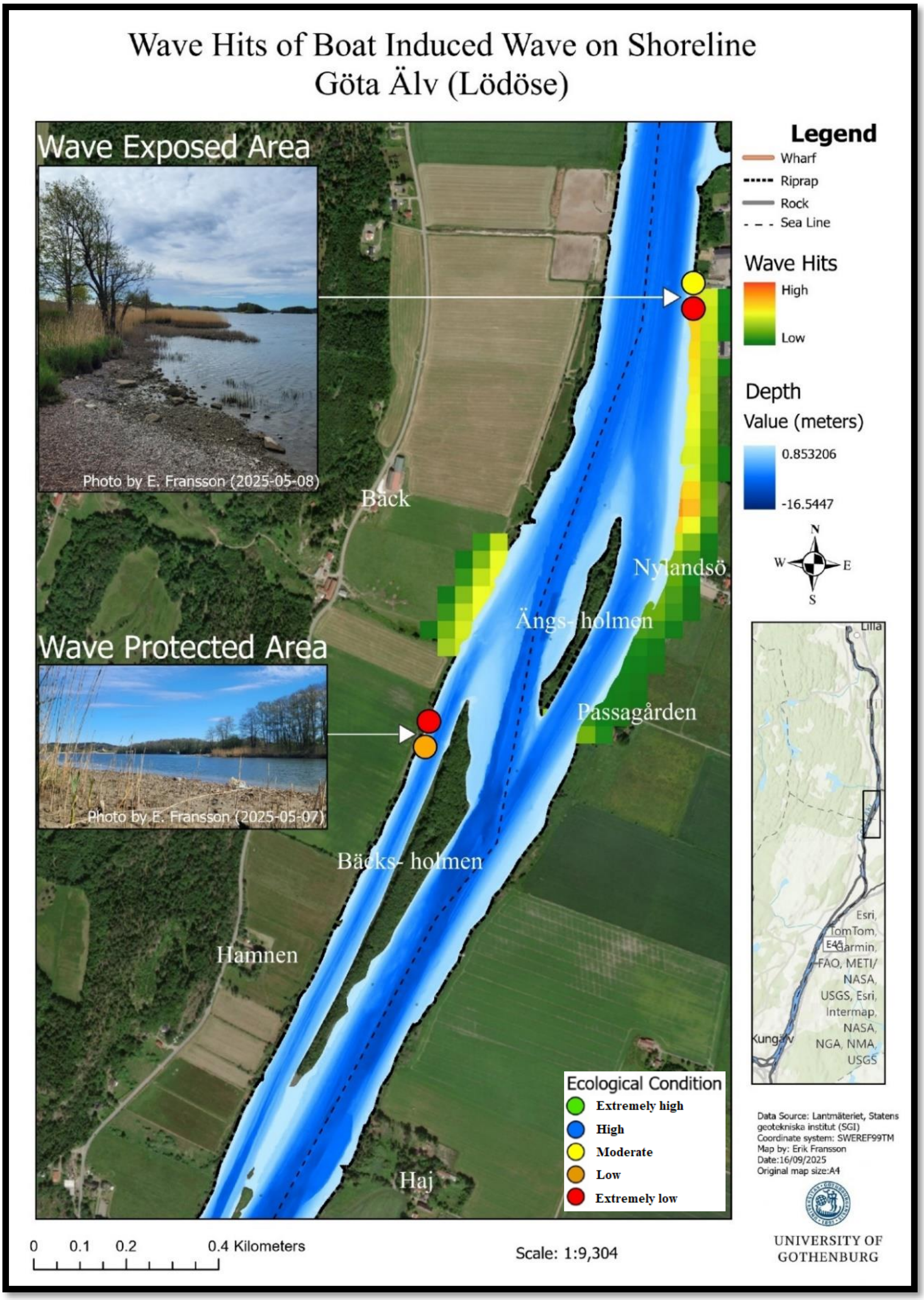


Figure 6 shows the wave height in vegetated areas on the shores of Marieberg. The wave height scale is set from high to low. The Ecological condition is visualized with colours and is estimated with the Shannon index.

Lödöse Wave Hits

Wave exposure in Lödöse varied between sites. The eastern shore behind Ängsholmarna experienced fewer wave hits, while wave frequency increased further north in the exposed area. The western shore of Ängsholmen exhibited moderate wave activity. Invertebrate diversity in exposed areas ranged from extremely low (28 March 2025) to moderate (8 May 2025), whereas protected areas showed extremely low (30 May 2025) to low diversity (7 May 2025) according to the Shannon index. Bathymetric data indicated deeper water, with only narrow stretches of shallow habitat along the riverbanks (Figure 7).



Data Source: Lantmäteriet, Statens geotekniska institut (SGI)
Coordinate system: SWEREF99TM
Map by: Erik Fransson
Date:16/09/2025
Original map size:A4

Figure 7 shows the amount of boat induced wave hits in vegetated areas on the shores of Lödöse. The wave hits scale is set from high to low. The Ecological condition is visualized with colours and is estimated with the Shannon index.

Lödöse Wave Height

Wave height in Lödöse was generally high compared with the rest of the river, with indications of moderately high values along certain sections (Figure 8).

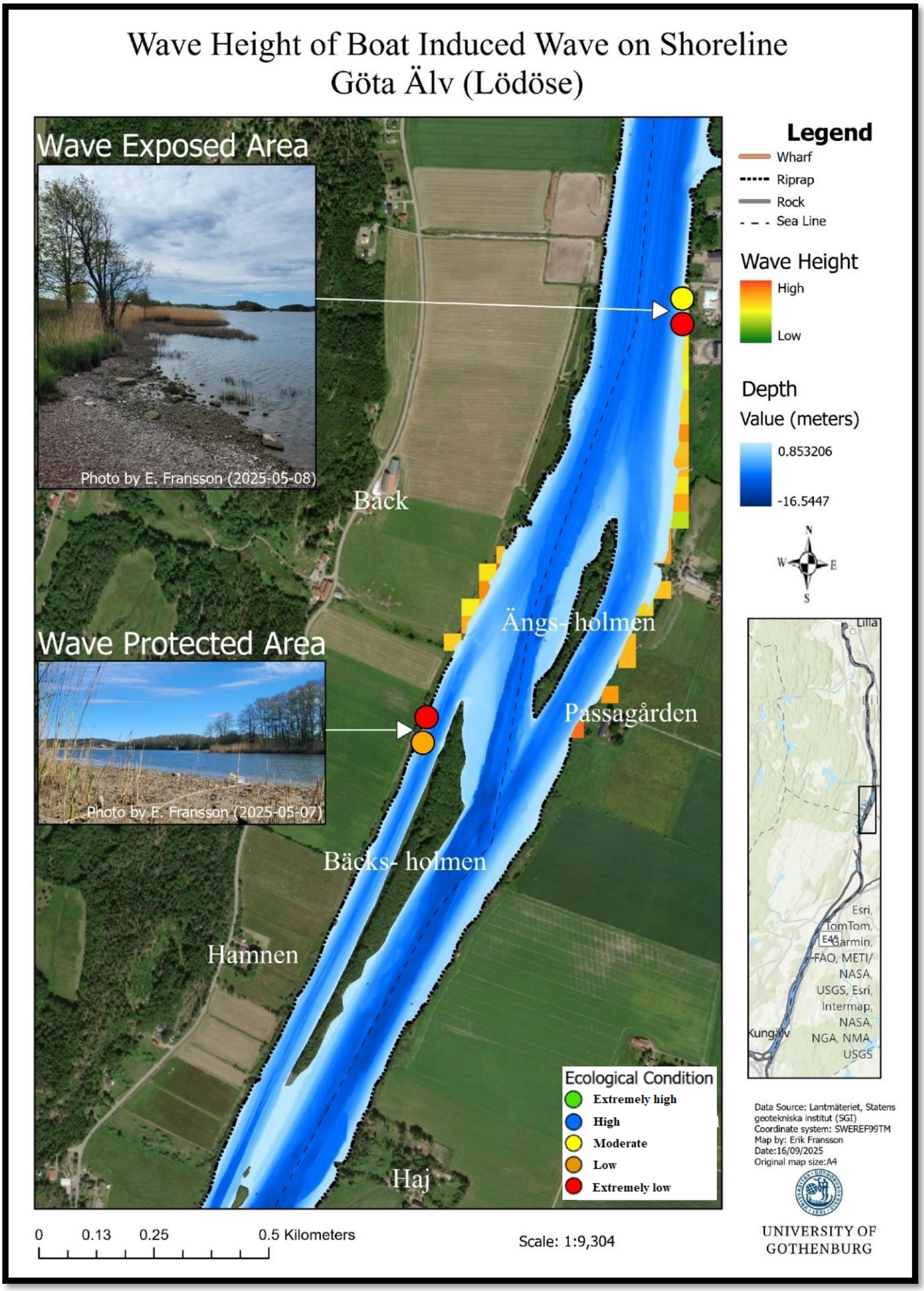


Figure 8 shows the wave height in vegetated areas on the shores of Lödöse. The wave height scale is set from high to low. The Ecological condition is visualized with colours and is estimated with the Shannon index.

Remaining River Sections

From Marieberg to Tjurholmen, reeds dominated the shoreline, with moderate wave activity and higher exposure along the headlands. The section north of Tjurholmen to Lilla Edet was narrower and experienced greater wave impact. Riprap structures were predominant, although small patches of reeds and vegetation remained along certain stretches (see Figures 16 and 17).

Boat Trip

In addition to the patterns observed in the GIS maps, the boat survey confirmed that the lowest wave impact occurred in the speed restricted section of the Tjurholmen Nature Reserve. Waves generally dissipated in areas with extensive, gently sloping, shallow shorelines throughout the river.


Photo by E. Fransson (2025-03-30)

Figure 9 visualize that larger waves were observed at Ängsholmen. The shorelines were covered with riprap for erosion protection.

Sampling of Benthic Macroinvertebrates

Marieberg Sample

Due to logistical constraints, only one invertebrate collection was conducted in the protected area instead of two. The exposed area contained 84 invertebrates across 16 families on 14 May and 45 individuals within 12 families on 10 April, while the protected area on 6 June comprised 90 invertebrates representing 11 families (see appendix for details, Figure 18). *Trichoptera*, dominated by *Sericostomatidae*, accounted for approximately one quarter of all individuals across sites. *Tubificidae* were mainly present in the protected area, whereas *Corixidae*, *Baetidae*, and *Diptera* were primarily found in exposed areas. *Gastropoda* (mainly *Valvatidae*), *Sialidae*, *Asellidae*, *Coleoptera*, *Sphaeriidae*, and *Glossiphoniidae* occurred at all sites in varying proportions (Figure 10).

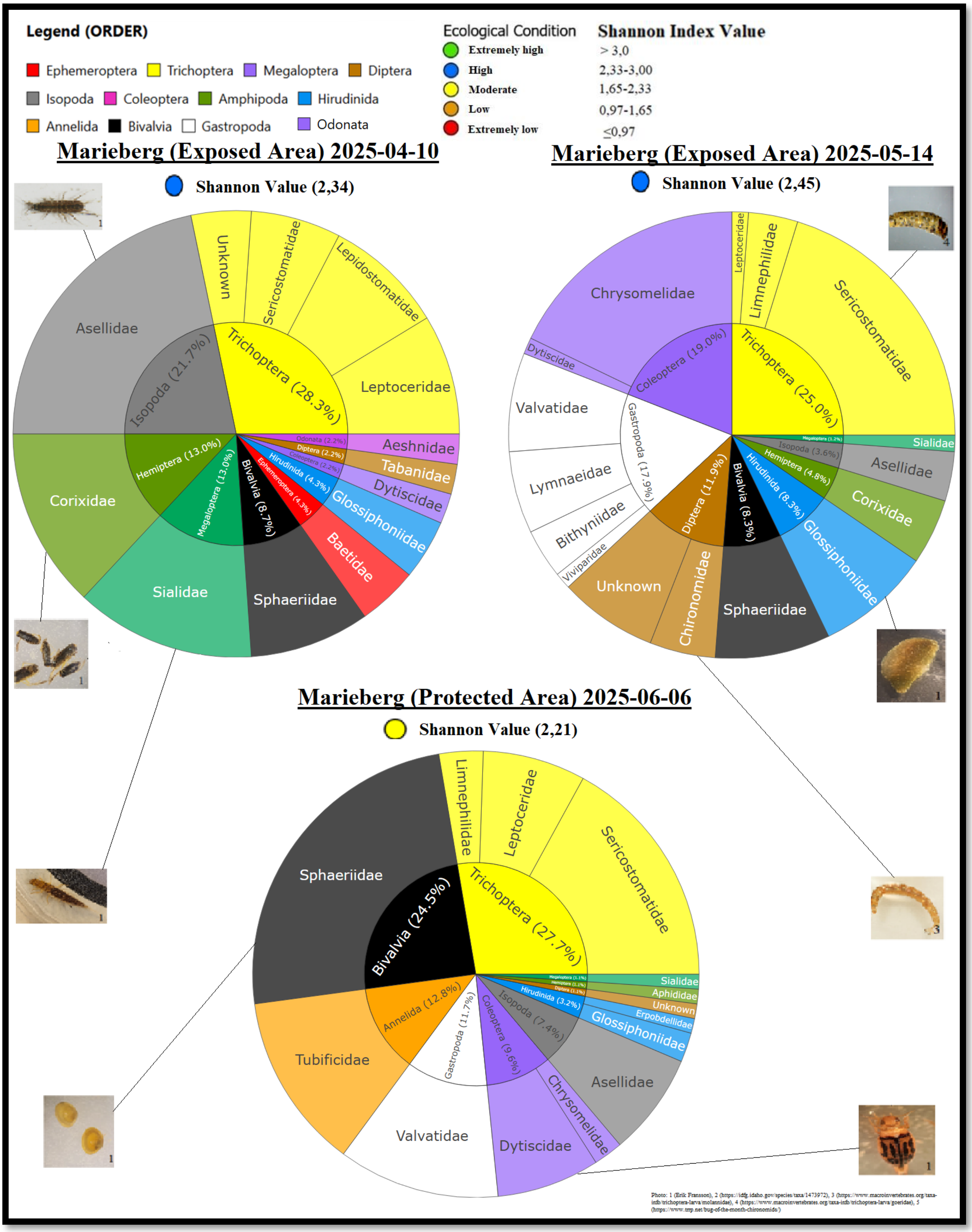


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Figure 10 visualise the distribution of invertebrate orders and families in exposed and protected areas of Marieberg collected during kick samples. The Shannon Diversity Index values indicate biodiversity levels. See appendix for detailed invertebrate sample list (figure 18).

Lödöse Sample

Due to logistical constraints, eight kick samples were collected on 28 March instead of ten. The exposed area contained 128 invertebrates across 16 families (8 May) and 85 individuals within 5 families (28 March), while the protected area (7 May) comprised 207 invertebrates representing 10 families and 115 individuals within 14 families (30 May) (see appendix for details, Figure 18). *Tubificidae* dominated the exposed sites as well as the protected sample collected on 30 May. *Ephemeridae* dominated the protected area on 7 May. *Chironomidae* showed significantly higher abundance in the exposed area, and *Diptera* occurred exclusively in this area. *Gammaridae* were found only in protected habitats. *Trichoptera*, *Gastropoda*, *Glossiphoniidae*, *Asellidae*, *Sphaeriidae*, and *Sialidae* were present across all sites with similar abundance (Figure 11).

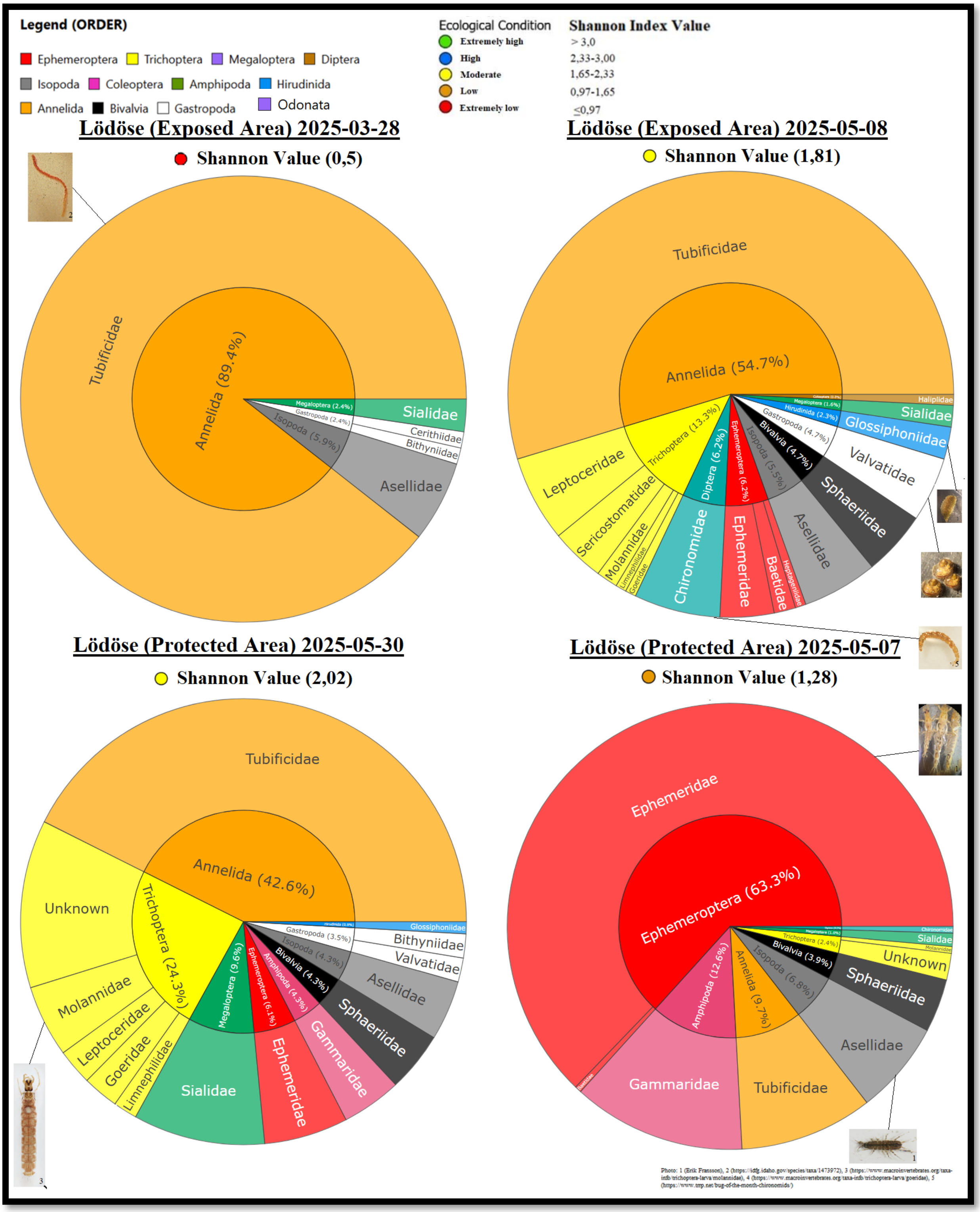

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Figure 11 visualise the distribution of invertebrate orders and families in exposed and protected areas of Lödöse collected during kick samples. The Shannon Diversity Index values indicate biodiversity levels. See appendix for detailed invertebrate sample list (figure 18).

Water Flow Resistance for Pike Eggs

Detachment Rate for Sparse Vegetation

The detachment rate was highly explained by the velocity and followed a trend with increased detachment rate relative to the increasing velocity (Coefficient of determination, (R^2) figure 12). The result was significant ((P-value) figure 12). However, at times eggs detached at the lowest flow velocity, yet in other cases some eggs remained attached under high velocities.

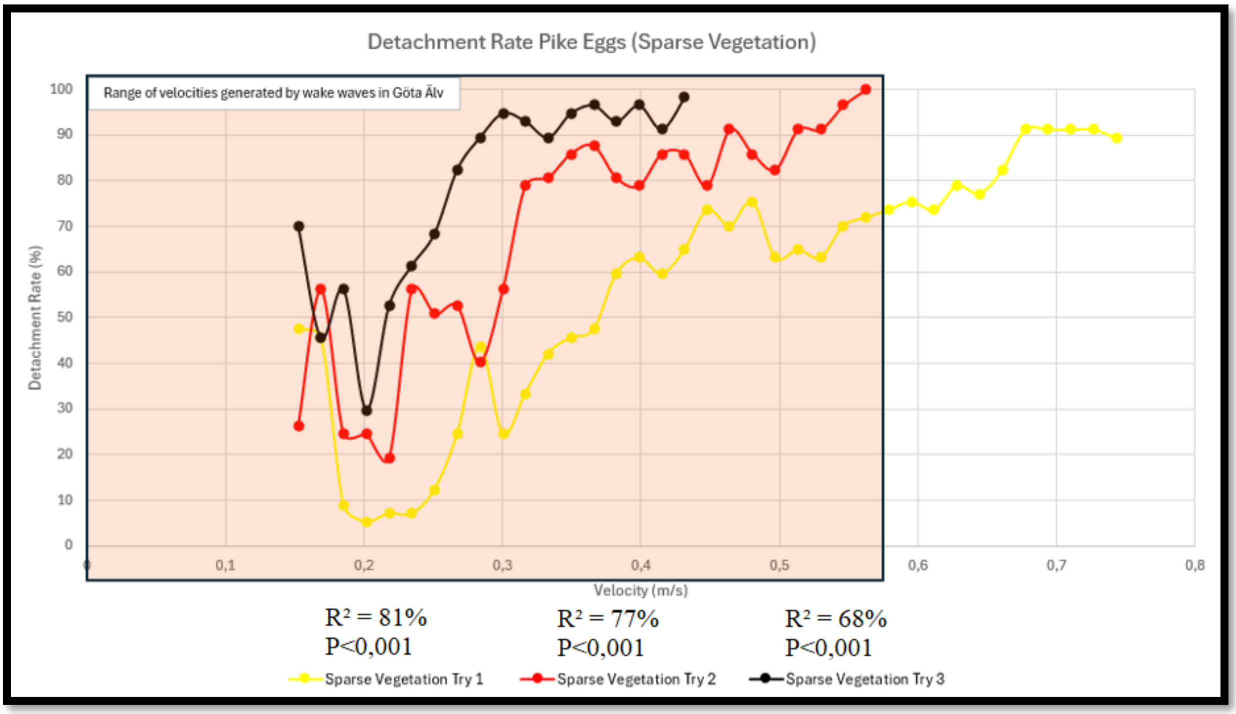

Figure 12 shows the detachment rate (%) of 1 g of pike eggs from different water velocities on sparse vegetation substate. Three series of attempts was done symbolised by each colour.

Detachment Rate for Dense Vegetation

The variation in detachment rate was not strongly explained by water velocity, and no clear trend was observed (coefficient of determination, R²; Figure 13). The result was statistically significant (P-value; Figure 13). High detachment rates occasionally occurred at low flow velocities and, conversely, low detachment rates were sometimes observed at higher flows. During the third trial, the detachment rate decreased as velocity increased. It was as well noted that the distribution of eggs on the vegetation had a considerable influence on the outcome. Eggs that became lodged between vegetation strands were less likely to detach due to water flow.

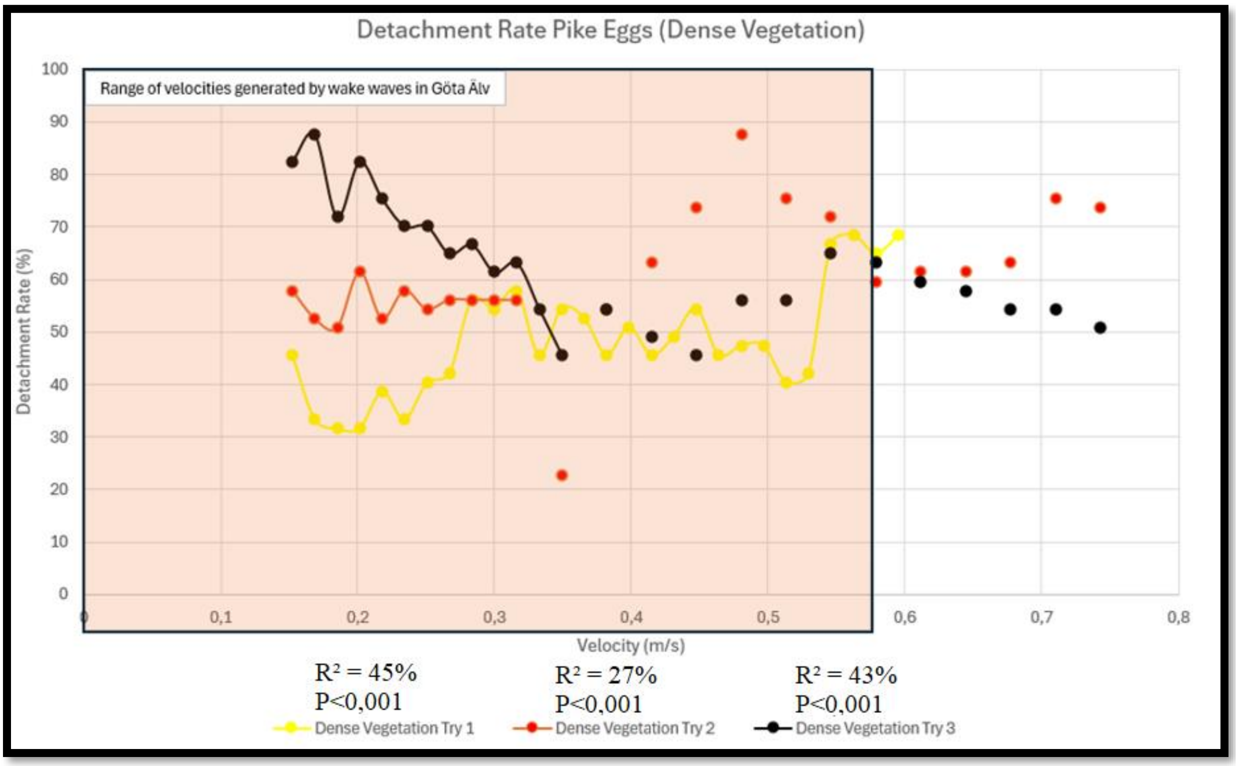

Figure 13 shows the detachment rate (%) of 1 g of pike eggs from different water velocities on dense vegetation substate. Three series of attempts was done symbolised by each line.

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Velocity Measurement of Wake Waves

The results of the wave measurements ranged from 0.061 to 0.58 m/s (Figure 14). Marieberg recorded the highest velocity at 0.58 m/s, generated by the ship *Nordic Sira*. Lödöse reached a peak velocity of 0.49 m/s from the ship *Aspen*, but overall, wave velocities were similar to those observed in Marieberg. The speed restricted area at Tjurholmen generally exhibited the lowest wave velocities, although a peak of 0.55 m/s was recorded from the ship *Wilson Alster* on one occasion.

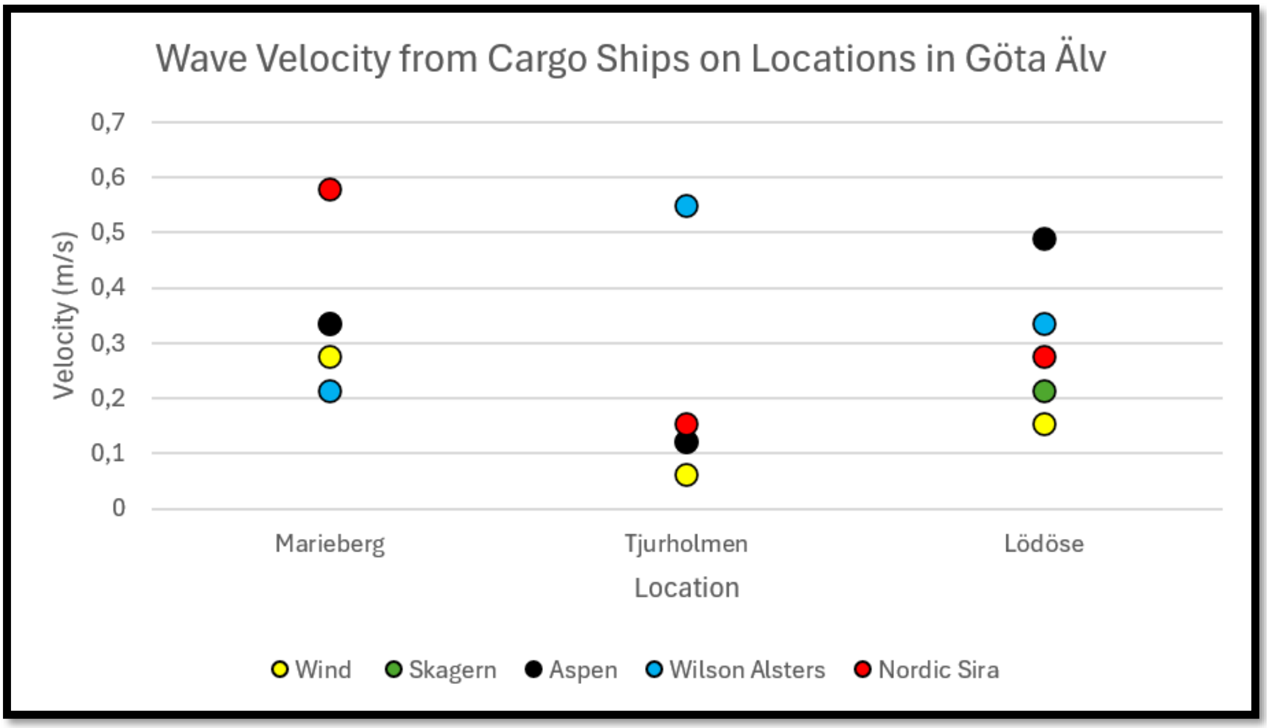


Figure 14 visualises the measured velocity from ship induced wake waves from different ships on three different locations along the shore in Göta Älv.

Discussion

Mapping Göta Älv

Marieberg Area

Marieberg (Figures 5 and 6) was less affected by waves compared to Lödöse (Figures 7 & 8). The river at Marieberg was wide, with extensive shallow areas along the shoreline. The width of the river reduced wave impact, as wave height decrease with distance from the source and depression waves has a lower impact (Federal Institute of Hydrology and Federal Waterways Engineering and Research Institute, 2016). The varying distance between the ship and shore explained the alternating zones of high and moderate wave intensity along the riverbank on the GIS-map. In contrast, headlands were closer to the ship route and more exposed which therefore caused a greater wave impact compared to bays or areas located behind islands. Based on the GIS visualizations of higher wave intensity, it is likely that pike avoided headlands for spawning due to the increased risk of egg detachment.

Additionally, larger shallow areas acted as natural wave breakers, as waves dissipated at depths less than 1.3 times their height (SMHI, n.d.). These findings suggests that wave impact was lower in areas where shallow depths separated the shoreline from the shipping line which might support higher benthic biodiversity. Such habitats may provide favourable foraging conditions for juvenile Atlantic sturgeon and other fish species. Pike may as well prefer these areas for spawning, as they are less affected by waves capable of detaching their eggs.

Lödöse Area

The channel in Lödöse (Figures 7 and 8) was narrower, which caused greater wave impact on the shores, as the waves did not diminish in height due to the short distance between the ship and the shoreline (Federal Institute of Hydrology and Federal Waterways Engineering and Research Institute, 2016). Additionally, the area was dominated by deeper water, allowing waves to travel undisturbed to the shore and generate stronger impacts (Sportfiskarna, 2024a).

The islands of Ängsholmen and Bäcksholmen provided protection to parts of the shoreline, offering refuge for aquatic organisms. The reeds along the shore in Lödöse may serve as crucial spawning habitats for pike and other fish species, as well as refuge areas for benthic invertebrates that juvenile Atlantic sturgeon feed on. It is likely that the reeds and the sheltered areas behind the islands in Lödöse contributes to essential habitats for pike during the spawning season and supports a higher abundance of benthic invertebrates available to juvenile Atlantic sturgeons.

Remaining Stretches of the River

The speed limit in Tjurholmen clearly reduced wave impact (Granath, 2004). The areas with riprap structures along the shores north of Tjurholmen to Lilla Edet (Figure 9) were less relevant for this study, as benthic invertebrates prefer vegetated habitats (Medins Havs och Vattenkonsulter, 2022). The small patches of reeds and vegetation extending from north of Tjurholmen to Lilla Edet (Appendix, figure 16 and 17) were likely crucial habitats for aquatic organisms. Future research could employ kick sampling or pike egg counts to further examine the ecological significance of these areas.

Sampling of Benthic Macroinvertebrates

Invertebrate Collection in Marieberg

The higher biodiversity in the wave exposed area compared with the protected area in Marieberg could be explained by several factors (Figure 10). One possible reason is that the exposed area contained more vegetation than the protected boat harbour, which had likely been dredged to allow vessel access (Havs och vattenmyndigheten, 2018a). The presence of vegetation is a key factor, as it provides shelter for organisms, attachment surfaces for pike eggs, and food resources for grazers (Medins Havs- och Vattenkonsulter, 2022). Furthermore, the boat harbour may have been affected by additional sources of emissions which can negatively influence benthic invertebrate communities (Havs- och vattenmyndigheten, 2018b). Ideally, the protected area in Marieberg would have been more comparable to the sheltered site in Lödöse and not located within a harbour. This may have influenced the results. However, no alternative protected habitat was available for sampling in the area.

Trichoptera was the dominant invertebrate group in both the exposed and protected areas of Marieberg, which is favourable, as insect larvae such as *Trichoptera* form a major part of the Atlantic sturgeon's diet (Näslund et al., n.d.). Aquatic sowbugs (23% of the juvenile Atlantic sturgeon diet according to studies in Nanticoke River and Chesapeake Bay; Secor et al., 2000), *bivalves*, and *gastropods* were additionally present in both exposed and protected sites and are essential food sources for juvenile Atlantic sturgeon (Näslund et al., n.d.). Additionally, 6.2% of the invertebrates in the exposed area of Marieberg belonged to *Chironomidae*, a group that makes up around 1.6% of the juvenile Atlantic sturgeon diet (Secor et al., 2000).

Invertebrate Collection in Lödöse

The lower biodiversity in the protected area compared with the exposed area in Lödöse may have been due to sampling constraints, as data collection was conducted in a small, shallow nearshore zone that was the only accessible site. A steep and deep slope was located just beyond this area, limiting available shallow habitat and, consequently, the space required to support higher biodiversity. On one occasion, most of the shallow area was observed to be drained, possibly due to low tide or hydropeaking regulation from Lilla Edet's power plant (Göta Älvs Vattenvårdsförbund, 2015), which may have contributed to lower biodiversity. The hydropeaking regulation generates uncertainty in the benthic fauna and further studies are required to better understand this relationship.

Both the exposed and protected areas in Lödöse exhibited lower biodiversity compared with Marieberg (Figure 11). A potential source of error was that only eight kick samples were collected in Lödöse on 28 March instead of ten, which may have influenced the biodiversity results. The exposed area in Lödöse had as well less vegetation than the exposed area in Marieberg, possibly due to stronger waves, as indicated by the GIS map, which may have reduced vegetation over time (Sandström et al., 2005). Reduced vegetation provides less habitat complexity for invertebrates, which may have further contributed to the lower biodiversity (Medins Havs- och Vattenkonsulter, 2022). The exposed area in Lödöse did contain stretches of reeds, but these were inaccessible by foot, and it is possible that they supported higher biodiversity.

Tubificidae dominated the samples from both exposed and protected areas, together with *Ephemeridae* in the protected area (7 May). *Tubificidae*, which constitutes approximately 61% of the juvenile Atlantic sturgeon's diet, and *Ephemeridae* are key food sources for the species (Näslund et al., n.d.; Secor et al., 2000). Furthermore, *Ephemeridae* is considered a useful bioindicator of water quality, as it is sensitive to pollution and changes in habitat structure (Savić et al., 2011). *Asellidae*, *Chironomidae* (1.6% of the juvenile Atlantic sturgeon's diet), Gammaridae (10%), *Trichoptera*, *bivalves*, and *gastropods* were as well found in Lödöse and are crucial components of the juvenile Atlantic sturgeon's diet (Näslund et al., n.d.; Secor et al., 2000). The high abundance of invertebrates recorded in Lödöse may help explain why Atlantic sturgeon were more frequently observed there compared with Marieberg, according to telemetry studies (Jägerud, 2025), even though biodiversity was lower. This suggests that the Atlantic sturgeon may not be highly selective in its diet but instead utilizes areas with the greatest overall availability of food resources.

The Shannon index is primarily developed for use in small forest lakes and streams rather than large river systems such as Göta Älv. Therefore, it may not fully represent the ecological conditions in this study area. Nonetheless, it was the most appropriate option available, as no standardized benthic fauna indices currently exist for large rivers. Overall, the presence of these invertebrates indicates that wake waves do not eliminate benthic fauna. However, the abundance of benthic organisms could potentially be higher if protective structures or other mitigation measures were implemented to reduce wave impacts, as greater abundance was observed in protected compared with exposed areas. Further research is needed to confirm this pattern.

Water Flow Resistance Test for Pike Eggs

The results from the water flow resistance experiment on pike eggs indicated that vegetation density was a key factor influencing egg attachment. Eggs in the dense vegetation treatment exhibited lower detachment rates, with no rates exceeding 90% (Figure 13), while this level of detachment was reached at velocities of 0.3 m/s in the sparse vegetation test (Figure 12). No clear critical velocity threshold was identified in either the sparse (Figure 12) or dense vegetation (Figure 13) experiments, but the results suggested that vegetation density was more influential than water velocity. The coefficient of determination (R^2) showed that detachment rate variation in the sparse vegetation experiment (Figure 12) was more strongly explained by velocity compared with the dense vegetation test (Figure 13). In the sparse vegetation test, detachment rates increased more clearly with rising velocity (Figure 12). In contrast, in the dense vegetation test, increased velocity did not appear to significantly affect detachment rates, as eggs detached more randomly across both low and high velocities (Figure 13). Detachment therefore seemed to depend more on vegetation complexity and egg placement on the substrate than on velocity. A more complex substrate provided greater protection from the water flow by increasing the likelihood of eggs becoming lodged between vegetation strands.

The experiment highlighted the significance of vegetation for pike spawning success. In Göta Älv, wake waves generated by ships could, over time, reduce the amount of vegetation (Sandström et al., 2005), which may lead to a decline in available spawning zones for pike (Artdatabanken, 2025b) and reduced food availability for juvenile Atlantic sturgeon, as benthic invertebrates depend on vegetated habitats (Näslund et al., n.d.).

The Velocities in Göta Älv

In the field, the highest measured wake wave velocity was 0.58 m/s. This velocity was sufficient to detach over 90% of the eggs in two of the trials conducted in the sparse vegetation experiment (Figure 12) and nearly 90% in the dense vegetation experiment (Figure 13). These findings confirmed the relevance of the laboratory detachment tests, as the measured wake wave velocities in the river were comparable to those generated by the submerged pump. Measuring wake wave velocities in situ is complex, and the results should therefore be interpreted with caution (Figure 14). Factors such as ship design, speed, weather conditions, and the actions of the boat operator can influence the velocity of wake waves (Granath, 2004). Despite these variations, the measured velocities provided a valuable indication of how the wake wave intensities in the river related to those observed in the laboratory experiments.

Possible Solutions

There are several possible measures to mitigate the impact of wake waves in Göta Älv. Some potential solutions include:

Speed Limits

A reliable way to mitigate wave impact appears to be through speed restrictions, as observed in Tjurholmen, where no wake waves were detected within the speed limited section. One possible approach would be to impose a 5-knot speed limit during the spawning period of Atlantic sturgeon and pike, which occurs approximately from March to September (Artdatabanken, 2025a; Artdatabanken, 2025b). Such restrictions could be applied in key areas such as Marieberg and Lödöse.

Living Shorelines

Another effective method is the use of “living shorelines,” which involve creating natural erosion protection structures using materials sourced from the local environment (Figure 15) (Bilkovic, 2017). In a project conducted in Södertäljeleden, a living shoreline was constructed by placing a barrier of large, blasted stones further from the shore and covering them with smaller natural stones, arranged to still allow fish passage (Sportfiskarna, 2024a). The barrier may consist of any suitable hard structure depending on local conditions (Bilkovic, 2017). Vegetation naturally occurring in the habitat was planted on the inner side of the stone barrier. Living shorelines help reduce wave energy before it reaches the shore while enhancing habitat quality and benefiting local species (Statens geotekniska institut, 2023).

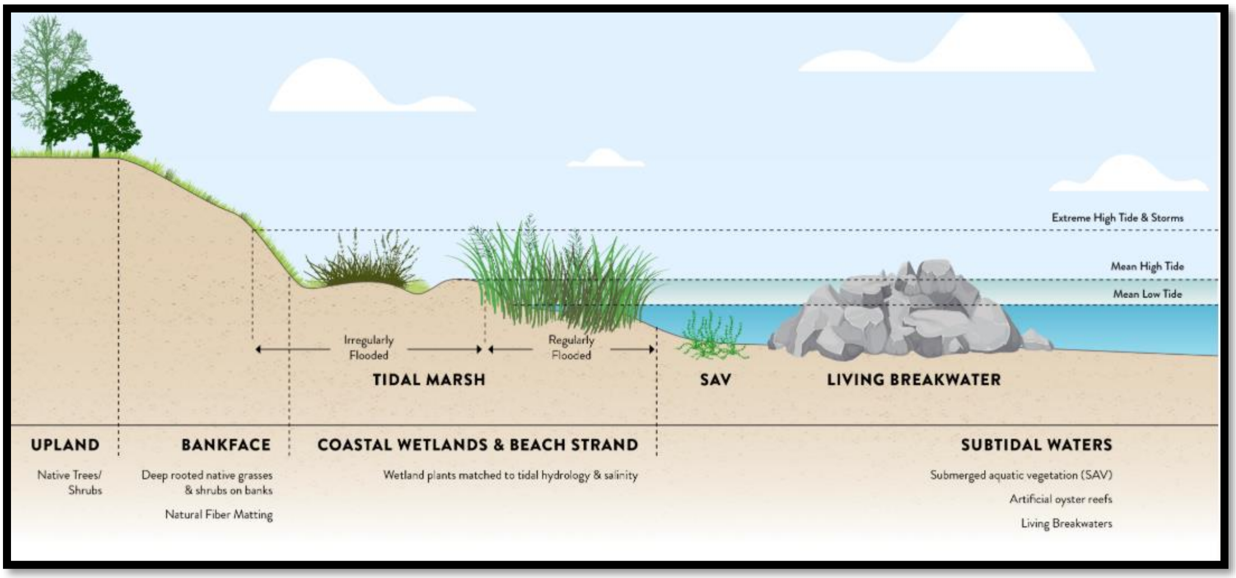


Figure 15 is a schematic example of a living shoreline (Texas General Land Office, 2025).

Vegetation

Several plant species possess natural erosion resistance through their root systems. Vegetation is effective in reducing the impact of smaller waves, although it may have limited influence on larger wave forces. However, vegetation provides vital habitat for aquatic organisms such as fish and invertebrates and contributes to stormwater filtration. Planting native vegetation is a cost-effective method for stabilizing shoreline sediments, although it requires time to establish and is sensitive to disturbance during the early growth stages. In areas where vegetation has been reduced, it may be beneficial to combine plant restoration with additional erosion protection measures, such as those used in living shorelines, as vegetation alone may not be sufficient (Johansson, 2003).

Conclusion

Conclusively, the wake waves in Göta Älv affected the river differently depending on location. The distance between the ship and the shore was a crucial factor, providing insight into where wave impact was greatest. It was evident that narrower sections, such as Lödöse, experienced stronger wave impacts compared with broader sections like Marieberg (Granath, 2004). Wave intensity was lower in areas where shallow depths separated the shoreline from the shipping line, highlighting the significance of protected zones in narrow and deeper sections of the river. The islands in Lödöse likely provided refuge from wake waves, enabling vegetation and aquatic organisms to remain relatively undisturbed.

Regarding the collection of invertebrates, the hypothesis that exposed areas would have lower biodiversity than protected areas was not supported, as exposed areas displayed higher biodiversity. Local environmental conditions and external factors may have influenced these results, such as hydropeaking regulation from the Lilla Edet power plant affecting shallow areas in Lödöse (Göta älvs vattenvårdsförbund, 2015). However, additional studies are needed to confirm this. Despite this, the number of invertebrates was higher in the protected areas of both Marieberg and Lödöse, which highlights that wake waves probably reduce the benthic community abundance (Gabel, 2012). The greater number of invertebrates found in Lödöse compared with Marieberg indicates that the Atlantic sturgeon might not be highly selective in its diet but rather thrives in areas with the highest overall food availability. This remains a hypothesis, and further research is required for verification.

No critical velocity threshold was identified in the water flow resistance experiment, which did not align with the initial hypothesis. However, the results indicated that detachment rates were more dependent on vegetation density than on water velocity. This emphasizes the significance of mitigating wave impacts, as wake waves reduce vegetation that is essential for pike spawning success(Sandström et al., 2005).

Potential measures to reduce wave impacts in Göta Älv include implementing speed restrictions in specific areas during certain periods, establishing living shorelines (Bilkovic, 2017), and planting vegetation (Johansson, 2003). These actions would likely enhance biodiversity, and future research could investigate changes in biodiversity following the implementation of such wave protection measures.

Appendix

Wave Hits

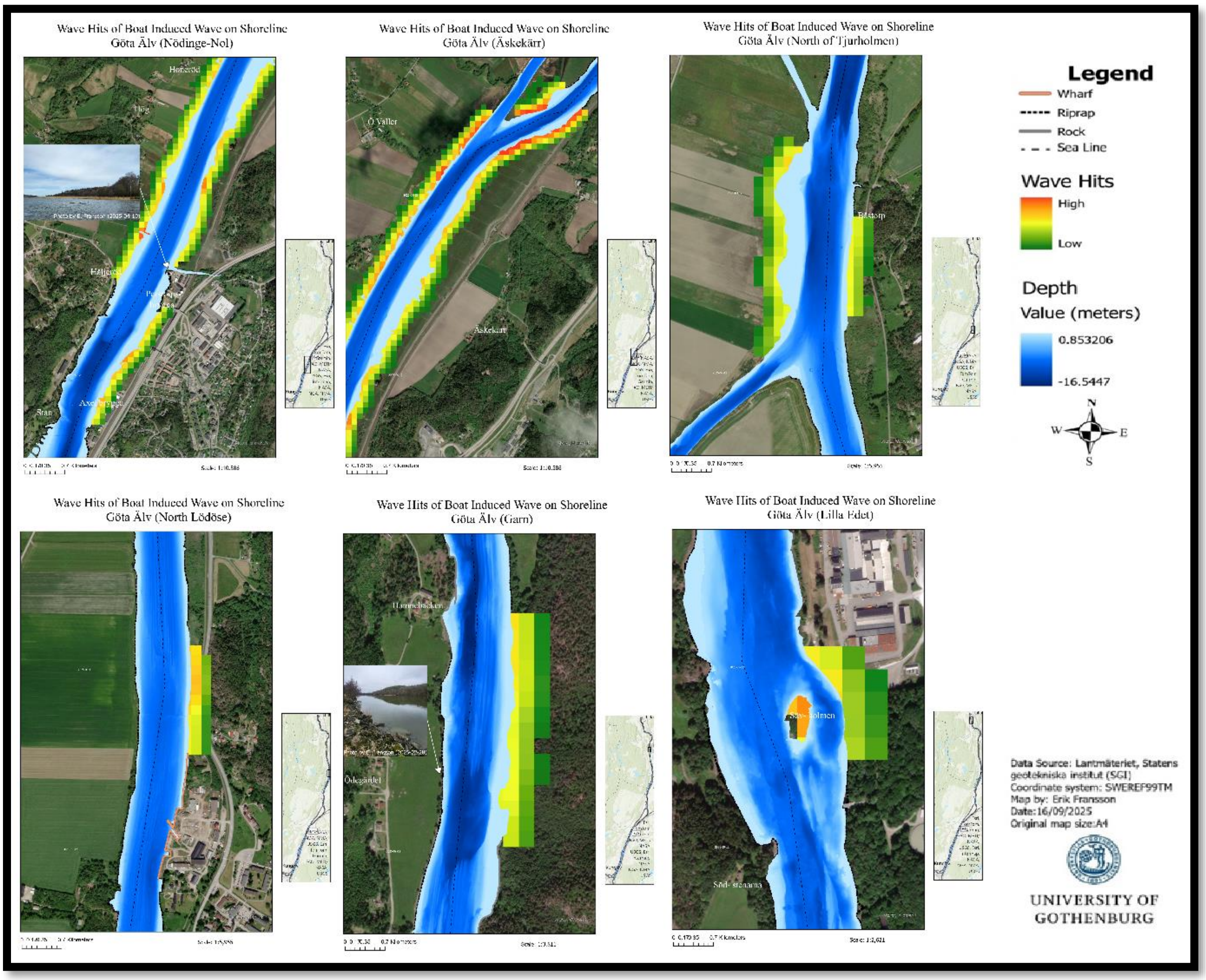


Figure 16 shows the amount of boat induced wave hits in vegetated areas on the shores of the remaining stretches of Göta Älv. The wave hits scale is set from high to low. The Ecological condition is visualized with colours and is estimated with the Shannon index.

Wave Height

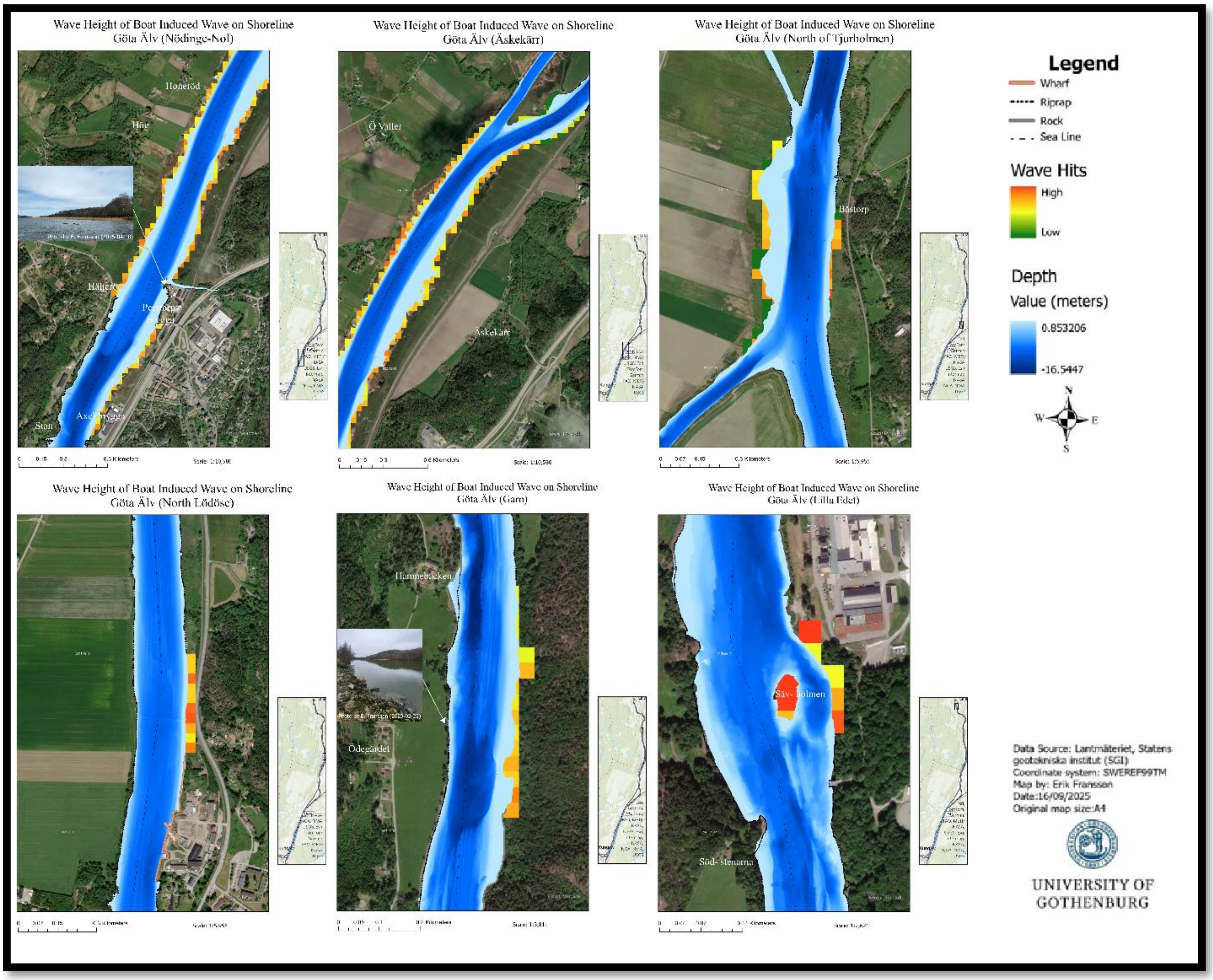
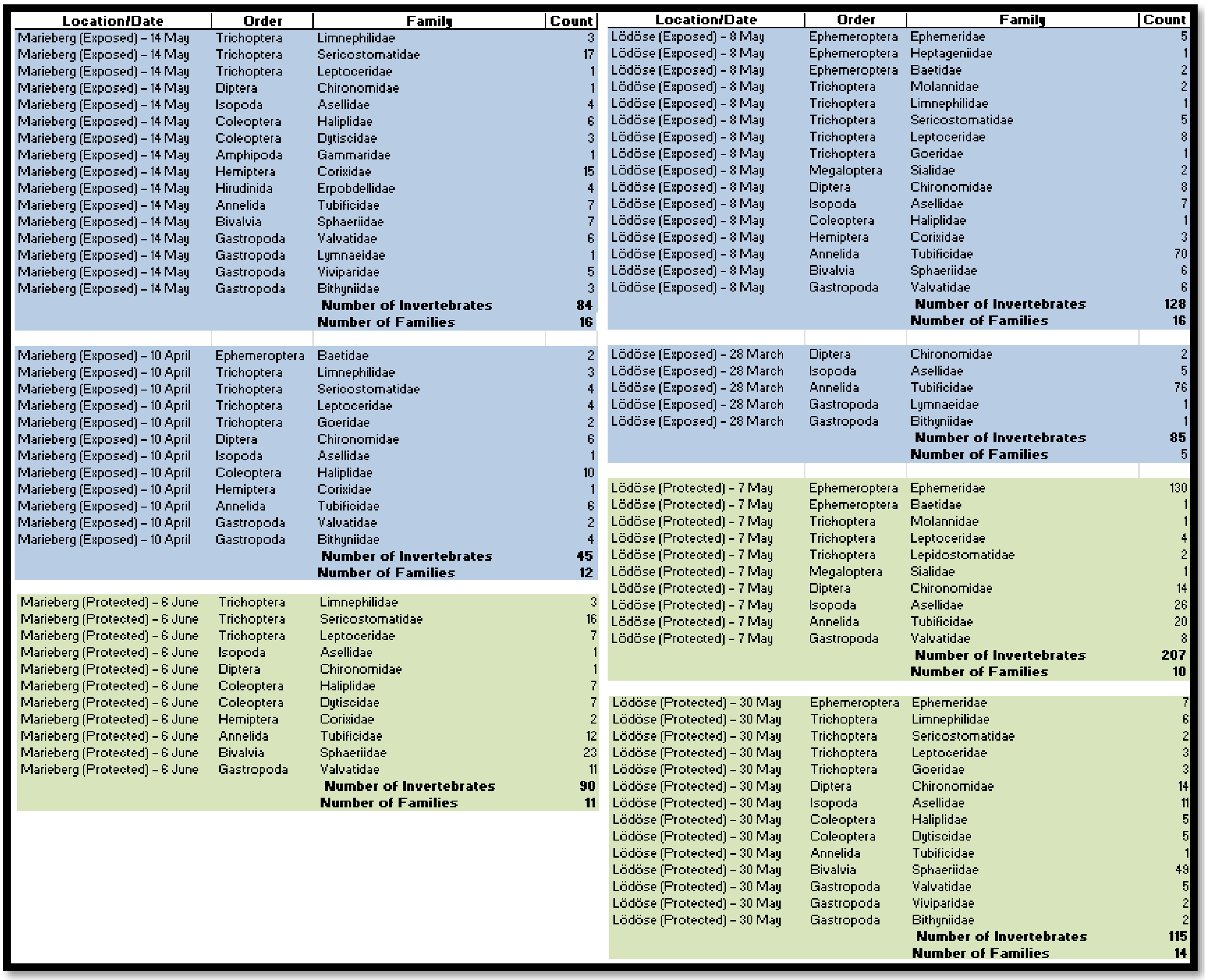


Figure 17 shows the wave height in vegetated areas on the shores of the remaining stretches of Göta Älv. The wave height scale is set from high to low. The Ecological condition is visualized with colours and is estimated with the Shannon index.



Location/Date	Order	Family	Count
Marieberg (Exposed) – 14 May	Trichoptera	Limnephilidae	3
Marieberg (Exposed) – 14 May	Trichoptera	Sericostomatidae	17
Marieberg (Exposed) – 14 May	Trichoptera	Leptoceridae	1
Marieberg (Exposed) – 14 May	Diptera	Chironomidae	1
Marieberg (Exposed) – 14 May	Isopoda	Asellidae	4
Marieberg (Exposed) – 14 May	Coleoptera	Haliplidae	6
Marieberg (Exposed) – 14 May	Coleoptera	Dytiscidae	3
Marieberg (Exposed) – 14 May	Amphipoda	Gammaridae	1
Marieberg (Exposed) – 14 May	Hemiptera	Corixidae	15
Marieberg (Exposed) – 14 May	Hirudinida	Erpobdellidae	4
Marieberg (Exposed) – 14 May	Annelida	Tubificidae	7
Marieberg (Exposed) – 14 May	Bivalvia	Sphaeriidae	7
Marieberg (Exposed) – 14 May	Gastropoda	Valvatidae	6
Marieberg (Exposed) – 14 May	Gastropoda	Lymnaeidae	1
Marieberg (Exposed) – 14 May	Gastropoda	Viviparidae	5
Marieberg (Exposed) – 14 May	Gastropoda	Bithyniidae	3
		Number of Invertebrates	**84**
		Number of Families	**16**
Marieberg (Exposed) – 10 April	Ephemeroptera	Baetidae	2
Marieberg (Exposed) – 10 April	Trichoptera	Limnephilidae	3
Marieberg (Exposed) – 10 April	Trichoptera	Sericostomatidae	4
Marieberg (Exposed) – 10 April	Trichoptera	Leptoceridae	4
Marieberg (Exposed) – 10 April	Trichoptera	Goeridae	2
Marieberg (Exposed) – 10 April	Diptera	Chironomidae	6
Marieberg (Exposed) – 10 April	Isopoda	Asellidae	1
Marieberg (Exposed) – 10 April	Coleoptera	Haliplidae	10
Marieberg (Exposed) – 10 April	Hemiptera	Corixidae	1
Marieberg (Exposed) – 10 April	Annelida	Tubificidae	6
Marieberg (Exposed) – 10 April	Gastropoda	Valvatidae	2
Marieberg (Exposed) – 10 April	Gastropoda	Bithyniidae	4
		Number of Invertebrates	**45**
		Number of Families	**12**
Marieberg (Protected) – 6 June	Trichoptera	Limnephilidae	3
Marieberg (Protected) – 6 June	Trichoptera	Sericostomatidae	16
Marieberg (Protected) – 6 June	Trichoptera	Leptoceridae	7
Marieberg (Protected) – 6 June	Isopoda	Asellidae	1
Marieberg (Protected) – 6 June	Diptera	Chironomidae	1
Marieberg (Protected) – 6 June	Coleoptera	Haliplidae	7
Marieberg (Protected) – 6 June	Coleoptera	Dytiscidae	7
Marieberg (Protected) – 6 June	Hemiptera	Corixidae	2
Marieberg (Protected) – 6 June	Annelida	Tubificidae	12
Marieberg (Protected) – 6 June	Bivalvia	Sphaeriidae	23
Marieberg (Protected) – 6 June	Gastropoda	Valvatidae	11
		Number of Invertebrates	**90**
		Number of Families	**11**

Location/Date	Order	Family	Count
Lödöse (Exposed) – 8 May	Ephemeroptera	Ephemeridae	5
Lödöse (Exposed) – 8 May	Ephemeroptera	Heptageniidae	1
Lödöse (Exposed) – 8 May	Ephemeroptera	Baetidae	2
Lödöse (Exposed) – 8 May	Trichoptera	Molannidae	2
Lödöse (Exposed) – 8 May	Trichoptera	Limnephilidae	1
Lödöse (Exposed) – 8 May	Trichoptera	Sericostomatidae	5
Lödöse (Exposed) – 8 May	Trichoptera	Leptoceridae	8
Lödöse (Exposed) – 8 May	Trichoptera	Goeridae	1
Lödöse (Exposed) – 8 May	Megaloptera	Sialidae	2
Lödöse (Exposed) – 8 May	Diptera	Chironomidae	8
Lödöse (Exposed) – 8 May	Isopoda	Asellidae	7
Lödöse (Exposed) – 8 May	Coleoptera	Haliplidae	1
Lödöse (Exposed) – 8 May	Hemiptera	Corixidae	3
Lödöse (Exposed) – 8 May	Annelida	Tubificidae	70
Lödöse (Exposed) – 8 May	Bivalvia	Sphaeriidae	6
Lödöse (Exposed) – 8 May	Gastropoda	Valvatidae	6
		Number of Invertebrates	**128**
		Number of Families	**16**
Lödöse (Exposed) – 28 March	Diptera	Chironomidae	2
Lödöse (Exposed) – 28 March	Isopoda	Asellidae	5
Lödöse (Exposed) – 28 March	Annelida	Tubificidae	76
Lödöse (Exposed) – 28 March	Gastropoda	Lymnaeidae	1
Lödöse (Exposed) – 28 March	Gastropoda	Bithyniidae	1
		Number of Invertebrates	**85**
		Number of Families	**5**
Lödöse (Protected) – 7 May	Ephemeroptera	Ephemeridae	130
Lödöse (Protected) – 7 May	Ephemeroptera	Baetidae	1
Lödöse (Protected) – 7 May	Trichoptera	Molannidae	1
Lödöse (Protected) – 7 May	Trichoptera	Leptoceridae	4
Lödöse (Protected) – 7 May	Trichoptera	Lepidostomatidae	2
Lödöse (Protected) – 7 May	Megaloptera	Sialidae	1
Lödöse (Protected) – 7 May	Diptera	Chironomidae	14
Lödöse (Protected) – 7 May	Isopoda	Asellidae	26
Lödöse (Protected) – 7 May	Annelida	Tubificidae	20
Lödöse (Protected) – 7 May	Gastropoda	Valvatidae	8
		Number of Invertebrates	**207**
		Number of Families	**10**
Lödöse (Protected) – 30 May	Ephemeroptera	Ephemeridae	7
Lödöse (Protected) – 30 May	Trichoptera	Limnephilidae	6
Lödöse (Protected) – 30 May	Trichoptera	Sericostomatidae	2
Lödöse (Protected) – 30 May	Trichoptera	Leptoceridae	3
Lödöse (Protected) – 30 May	Trichoptera	Goeridae	3
Lödöse (Protected) – 30 May	Diptera	Chironomidae	14
Lödöse (Protected) – 30 May	Isopoda	Asellidae	11
Lödöse (Protected) – 30 May	Coleoptera	Haliplidae	5
Lödöse (Protected) – 30 May	Coleoptera	Dytiscidae	5
Lödöse (Protected) – 30 May	Annelida	Tubificidae	1
Lödöse (Protected) – 30 May	Bivalvia	Sphaeriidae	49
Lödöse (Protected) – 30 May	Gastropoda	Valvatidae	5
Lödöse (Protected) – 30 May	Gastropoda	Viviparidae	2
Lödöse (Protected) – 30 May	Gastropoda	Bithyniidae	2
		Number of Invertebrates	**115**
		Number of Families	**14**

Figure 18 displays a detailed version of the collected invertebrates in wave exposed and protected areas of Marieberg and Lödöse showing number of found invertebrates from each family (Count), the total number of families and the total number of collected invertebrates.

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