Swedish Agency for Marine and Water Management

Draft Proposal

Date 2024-09-25

Draft proposal on the implementation of a Swedish government assignment to conduct a time limited scientific project corresponding to spatial fisheries management of vessels fishing for pelagic stocks in the Baltic Sea

Healthy herring stocks are crucial for the Baltic Sea ecosystem. Negative development has been observed for herring in all Baltic Sea subdivisions along the Swedish coast, including declining trends in age and size structure, as well as in biomass and abundance of herring. This time limited scientific project will assess whether spatial fisheries management measures could improve the status of herring along the Swedish coast. A study area in the Central Baltic Sea is proposed, with the aim to test and evaluate spatial fisheries management measures based on annual restriction for Union fishing vessels that fish for pelagic stocks, using towed gears. A derogation is proposed for Union fishing vessels of less than 24 meters length overall, that fish for pelagic stocks for direct human consumption. Since this project is implemented as a Swedish government assignment, both study areas have been proposed with a main emphasis on Swedish fisheries. The fishing regulations are suggested to be implemented as national measures in accordance with Article 20 of the Basic Regulation. The project will evaluate the efficiency of spatial fisheries management measures, and if appropriate, suggest how such measures could be applied to improve the status of Baltic Sea herring stocks.

This draft proposal has been approved by Mats Svensson, Director, Department of Marine Management.

Mats Svensson

Havs- och vattenmyndigheten
Box 11 930
404 39 Göteborg

Besök och leverans
Gullbergs Strandgata 15
41104 Göteborg

Telefon 010-698 60 00
havochvatten@havochvatten.se
www.havochvatten.se

Bankgiro 199-6669
Organisationsnummer
202100-6420

Table of Contents

1 Introduction

Healthy stocks of herring are crucial for the Baltic Sea ecosystem as well as for a long-term sustainable fisheries and food production. During the last decade a negative development has been observed for herring in all Ices subdivisions along the Swedish coast, including declining trends in age and size structure, as well as in total biomass and abundance. Negative trends have particularly been found for large herring above 18 cm, the size normally used for direct human consumption in the Swedish processing industry.

In March 2022 the Swedish Agency for Marine and Water Management (SwAM) reported on a government assignment aiming at investigating how fisheries management measures can be developed to protect coastal spawning herring stocks in the northern Central Baltic Sea (Ices subdivision 27 and 29). Within the assignment, spatial fisheries management measures were suggested as a potential measure to protect coastal spawning herring stocks. SwAM concluded that such measures can have a positive effect on the abundance and proportion of large herring if large areas of deeper water, where herring is distributed during winter and aggregate in the period close to the spawning season are protected from fishing. Furthermore, an extensive fishing in such areas, inside and outside Swedish territorial waters, was considered as a risk to affect abundance of local spawning stocks. However, since the knowledge of genetic stock structure, distribution and migration patterns of herring is limited, it was not possible to assess effectiveness and biological effects of spatial measures in regard to increased protection for the herring along the Swedish coast.

On May 19, 2022, the Agency received a new assignment from the Swedish government to conduct a time limited scientific project corresponding to spatial management of vessels fishing for pelagic stocks in the Baltic Sea. In the motivation, the government stress the importance to implement and evaluate such measures with the support of scientific data and in collaboration with relevant stakeholders and EU Member States. The implementation of the scientific project needs to include monitoring to evaluate the development of the herring stocks both in terms of biomass, stock- and size structure. Furthermore, the government emphasizes a holistic approach and that the effects of fisheries related measures need to be distinguished from other factors to strengthen the knowledge of causal relationships for herring stock development.

For an effective evaluation, the proposed areas and measures should be coordinated with relevant Member States. Located areas could include both Gulf of Bothnia and the Central Baltic Sea and need to be scientifically evaluated and compared with areas where fishing continues.

A competitive and robust fishing and processing industry that can meet present and future challenges is important for the Swedish government. The main objectives for the government are to achieve sustainable fishing including more sustainable fishing methods, increase resource efficiency and increase food production. When establishing study areas, the current fishing activity therefore needs to be considered not to be disproportionately affected, while at the same time, the effect on the proportion of large herring can be evaluated. The government clarifies the importance that fishing of local and regional importance and fishing for direct human consumption can continue without jeopardizing the purpose of the scientific project.

2 Government assignment

By the government decision of the 19th of May 2022, SwAM has been assigned to implement a time-limited scientific project corresponding to spatial management of vessels fishing for pelagic species in the Baltic Sea, with the aim to evaluate effects on the biomass of herring stocks as well as their age, size and stock structure along the Swedish coast. The project is to be carried out in designated study areas within the Swedish Economic Zone (EEZ) in the management areas for herring in the Central Baltic Sea and the Gulf of Bothnia. The aim is to include all vessels that have rights to fish in these areas, regardless of flag. SwAM must therefore accordingly, within the framework of the project, carry out the necessary consultations with the EU Member States concerned, stakeholders, and if necessary, with the European Commission.

For the designated study areas, SwAM should scientifically monitor and analyse the effects of the fisheries-related management measures on the herring stocks, in relation to the development of biomass, stock and population structure. The designation of the areas shall consider geographical and regional differences in order to continuously be able to evaluate how and to what extent the development of herring stocks is affected by other environmental factors, as well as predation from fish, birds, and seals. The implementation of the scientific project will should be performed to strengthen the knowledge of causal relationships between different factors in accordance with an adaptive ecosystem-based management. Furthermore, the evaluation of the measures shall include effects on other fish species, socioeconomic effects, as well as the economic and social consequences for the fisheries and the fish processing sector. The analyses shall also consider other management measures and other causal relationships that may influence the outcome and evaluation of the project.

Fisheries management measures within the designated study areas shall be evaluated during and following the implementation of the project and cease no later than 30th of April 2027. Based on these analyses, the final report shall include proposals for any subsequent fisheries management measures or measures that are non-fisheries related. In each of the designated study areas, some limited commercial fishing can be allowed for Union fishing vessels. Such fishing opportunities could be granted in regard to research activities, small-scale fishing and fishing that is of local or regional importance and fishing for direct human consumption. However, fishing is only to be permitted if not considered to jeopardize the purpose of the scientific project. The final report should include analyses of the consequences of such fishing.

3 Legal frame work

3.1 Common Fisheries Policy

In accordance with the Treaty on the Functioning of the European Union (TFEU), the EU has exclusive competence regarding the conservation of the marine biological resources through the Common Fisheries Policy. The Union thus has exclusive competence to legislate and adopt legally binding acts in the area. Member States are able to do so themselves only if empowered by the Union or to implement Union acts.

Regulation (EU) No. 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy (the Basic Regulation) states the objectives of fisheries management, the instruments and frameworks for various processes. Based on the objectives in

Article 2 of the Basic Regulation, the Common Fisheries Policy, shall amongst other things, ensure that fishing and aquaculture activities are environmentally sustainable in the long-term and are managed in a way that is consistent with the objectives of achieving economic, social and employment benefits and contributing to the availability of food supplies. The Common Fisheries Policy should apply the precautionary approach to fisheries management, and shall aim to ensure that exploitation of living marine biological resources restores and maintains populations of harvested species above levels which can produce the maximum sustainable yield. Furthermore, the Common Fisheries Policy shall implement the ecosystem-based approach to fisheries management, so as to ensure that negative impacts of fishing activities on the marine ecosystem are minimized, and shall endeavour to ensure that aquaculture and fisheries activities avoid the degradation of the marine environment (Article 2.3). From Article 2.5. j in the Basic Regulation, it appears that the Common Fisheries Policy shall be coherent with the Union environmental legislation, in particular with the objective of achieving a good environmental status by 2020 as set out in Article 1.1 of Directive 2008/56/EC, as well as with other Union policies. This objective also applies to the multi-annual plan for the stocks of cod, herring and sprat in the Baltic Sea (EU) 2016/1139[1] and the technical regulation (EU) 2019/1241[2].

3.2 Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) is the environmental pillar of the EU's integrated maritime policy. In accordance with the MSFD, the EU Member States shall achieve good environmental status in their marine waters by 2020 at the latest. They shall also define a number of environmental targets with indicators to guide progress in achieving good environmental status. In Sweden, environmental targets set out in the MSFD are implemented through environmental standards according to the Marine Environment Ordinance (2010:1341). Environmental quality standards are a legally binding instrument following Chapter 5 of the Swedish environmental code and are applicable in marine waters. Two of these environmental quality standards are of relevance to ensuring both healthy stocks and sustainable fishing. These standards are C.3[3] and C.4[4], incorporated into Swedish legislation through HVMFS 2012:18[5].

3.3 Access to waters in the Swedish EEZ and Swedish territorial waters

Article 5.1 of the Basic Regulation states as a main rule that Union fishing vessels have equal access to Union waters. However, Member States have some ability to restrict access to the area within 12 nautical miles of the baselines. Sweden has restricted access in a way that only Denmark and Finland are allowed to conduct fishing activities within 12 nautical miles of the baselines. The right to access Swedish waters in this area is specified in Annex I of the Basic Regulation, point 11. In the Central Baltic Sea and the Gulf of Bothnia, Denmark and Finland have access to conduct fishing in to four nautical miles from the baseline, and Sweden in

---

[1] Regulation (EU) 2016/1139 of the European Parliament and of the Council of 6 July 2016 establishing a multiannual plan for the stocks of cod, herring and sprat in the Baltic Sea and the fisheries exploiting those stocks

[2] Regulation (EU) 2019/1241 of the European Parliament and of the Council of 20 June 2019 on the conservation of fisheries resources and the protection of marine ecosystems through technical measures

[3] C.3 The populations of all naturally occurring fish species and shellfish that are affected by fishing have and age and size structure and a population size that guarantees their long-term sustainability

[4] The occurrence, species composition, and size distribution of the fish community should enable the maintenance of crucial functions in the food web.

[5] The Swedish Agency for Marine and Water Management's regulations (HVMFS 2012:18) on what characterises good environmental status, as well as environmental quality standards and indicators for the North Sea and the Baltic Sea.

principle[6] has the corresponding right to conduct fishing in Danish and Finnish waters. When vessels of another flag fish in Swedish waters within 12 nautical miles, each intergovernmental agreement define which rules they must follow. Both the agreement with Finland and the agreement with Denmark concerning the Gulf of Bothnia and the Central Baltic Sea stipulate coastal state jurisdiction. This means that each vessel must follow the legislation implemented by the coastal state provided that the legislation is adopted in accordance with EU regulations. In addition, Sweden has the possibility to regulate fishing out to four nautical miles from the coastline/baseline, i.e., in areas where fishing vessels of other Member States do not have access. Member States must inform the Commission of the restrictions introduced nationally. Section 13a of the Swedish Fisheries Act (1993:787) states that access to Swedish waters within 12 nautical miles is only permitted for vessels of other Member States, fishing on their own quota, that have such a right according to Annex I of the Basic Regulation.

3.4 Swedish fisheries legislation

According to the Swedish Fisheries Act (1993:787), the government or the agency the government decides is authorized to issue necessary regulations for fisheries conservation and for the operation of fisheries, i.e., measures to protect and preserve fish stocks. This include regulations that prohibit or restrict 1) fishing regarding what fish may be caught, 2) the use of fishing vessels, fishing methods or fishing gear, 3) fishing in certain areas or for certain purposes, and 4) the use of gear, bait, boats or anything else that can spread crayfish plague or any other disease. The Swedish Fisheries Ordinance (1994:1716) states that SwAM is authorized to issue these regulations.

In line with the Swedish Fisheries Act (1993:787) and the Swedish Fisheries Ordinance (1994:1716) the master of a fishing vessel and the holder of a fishing license or a personal fishing license according to the Swedish fisheries legislation, is obliged to provide information on fishing that is required according to regulations issued by SwAM. For such fishing SwAM has the authorization to issue regulations on 1) obligation to provide information about a) fishing vessel, fishing gear, fishing method, catch, time and place of catch, transhipment, landing, sale, and b) other conditions relating to fishing and which are of importance for the implementation of the Common Fisheries Policy and 2) that fishing vessels must have equipment that automatically transmits information about the vessel location.

SwAM also has the authorization to issue regulations for the conduct of fishing related to the allocation of fishing opportunities according to Articles 16.6 and 16.7 of the Basic Regulation (i.e., how the fishing opportunities that are allocated to it, and which are not subject to a system of transferable fishing concessions, may be allocated to vessels flying its flag). In the Swedish Act (2009:866) on transferable fishing rights and the Ordinance (2009:867) on transferable fishing rights, there are additional provisions that authorizes SwAM to introduce regulations. SwAM is also authorized to issue regulations on how fishing opportunities may be transferred during the year or management period in which the fishing opportunities may be used.

A large part of the national regulations issued by SwAM relevant for fishing in the Baltic Sea can be found in FIFS 2004:36 on fishing in Skagerrak, Kattegat and the Baltic Sea, HVMFS 2014:19

[6] Sweden has access to Danish coastal waters in to 3 nautical miles from the baseline in the Baltic Sea.

on licenses and permits for commercial fishing in the sea and FIFS 2004:25 on resource access and control of fisheries.

3.5 Referral process

In order to adopt Swedish national regulations SwAM applies a routine for regulatory work that must be taken into account. Documents required in the referral process to relevant stakeholders are background description, proposals for the regulation, impact assessment and results of any consultation. Regulations are adopted after a referral procedure that includes an impact assessment in accordance with Ordinance (2007:1244) on impact assessment when introducing regulations. The referral time must be assessed on a case-by-case basis but needs to be at least three weeks.

4 State of knowledge

Herring is a key species in the Baltic Sea food web. The following sections provide an overview of the knowledge about herring ecology, size and age structure of the stocks, as well as migration patterns and population structure. Other important parameters for herring stock development are salinity, temperature, bathymetry and the structure of the seabed, causing natural variations in herring spawning, growth and migration patterns in the Baltic Sea area. A more detailed description of each section is given in Wennerström et al. 2023.

4.1 Lifecycle of herring including migration

Herring is a pelagic species with a maximum age of 25 year, but usually do not become older than 10 years. Herring live in large shoals which are characterized by diurnal vertical migration patterns to follow zooplankton prey species in the water column (Nilsson et al. 2003). Furthermore, herring migrates between coastal spawning areas and off-shore feeding areas during the year in the Baltic Sea (Aro 1989). Herring can be characterized by a homing behavior where different spawning stocks return to previous spawning- and feeding areas, even if some plasticity has been observed in other areas (Hannerz 1956, Otterlind 1957, Parmanne and Sjöblom 1986, Huse et al. 2010). Spawning usually takes place on hard substrate shallower than 10 m, in areas close to deeper water (Aneer 1989, Kääriä et al. 1997, Gunnartz et al. 2011). Spring spawning herring normally spawn in the archipelago in April-June but timing might differ between areas in the Baltic Sea. During autumn spawning occurs between August-October. Autumn-spawning herring usually spawn in the outer part of the archipelago and in shallow off-shore areas, but information on these spawning stocks is scarce (Gunnartz et al. 2011).

The general migration pattern of herring is determined by water depth and water temperature. Herring is spending the winter months beneath the halocline, in waters deeper than 50 m, where the water is somewhat warmer during winter. However, juvenile herring may stay in the coastal areas, in the archipelagos during the whole year (Ojaveer 1981, Ojaveer 2003, Kaljuste et.al 2009). In spring, herring migrates to coastal areas for spawning and foraging. Knowledge about coastal spawning areas, off-shore feeding areas as well as horizontal migrations between these areas for different spawning stocks are limited. Patterns in fishing activity in certain areas during certain times of the year likely reflect aggregations of herring in both coastal spawning areas and off-shore feeding areas. Results from historical tagging studies also indicate that herring in the Bothnian Sea tends to migrate shorter distances between spawning and off-shore areas while similar studies in the Central Baltic Sea indicate that parts of the herring stock tend to migrate longer distances to spend winter in the southern Baltic Sea (Aro 2002; Moll et al. 2019, Parmanne 1990, Bergström et.al. 2006).

4.2 Genetic stock structure of herring

Herring has traditionally been structured according to time of spawning, in which spring- and autumn spawners have been identified and separated genetically by genetic methods (Ojaveer, 1981). During the last five years Sweden has conducted an intensive sampling of herring caught along the Swedish coast. According to preliminary results different spawning components can be identified, in addition to the already known spring- and autumn spawners. Stocks with genetically distinct spawning components have been identified in the southern Bothnian Bay. Furthermore, differences in the genetic signals stemming from genetically differentiated spawning stocks can also be identified along the Swedish coast as a southern to north gradient (personal comm. Leif Andersson). In the Ices advice 2023 for herring in the Central Baltic Sea it is stated that the Central Baltic herring stock consists of several different spawning components that have been shown to be genetically distinct. Differences in genetics and migration patterns between spawning components, and spatial differences in growth and maturity, make the Central Baltic herring stock complex and vulnerable to loss in both genetic diversity and overall productivity.

4.3 Stock development

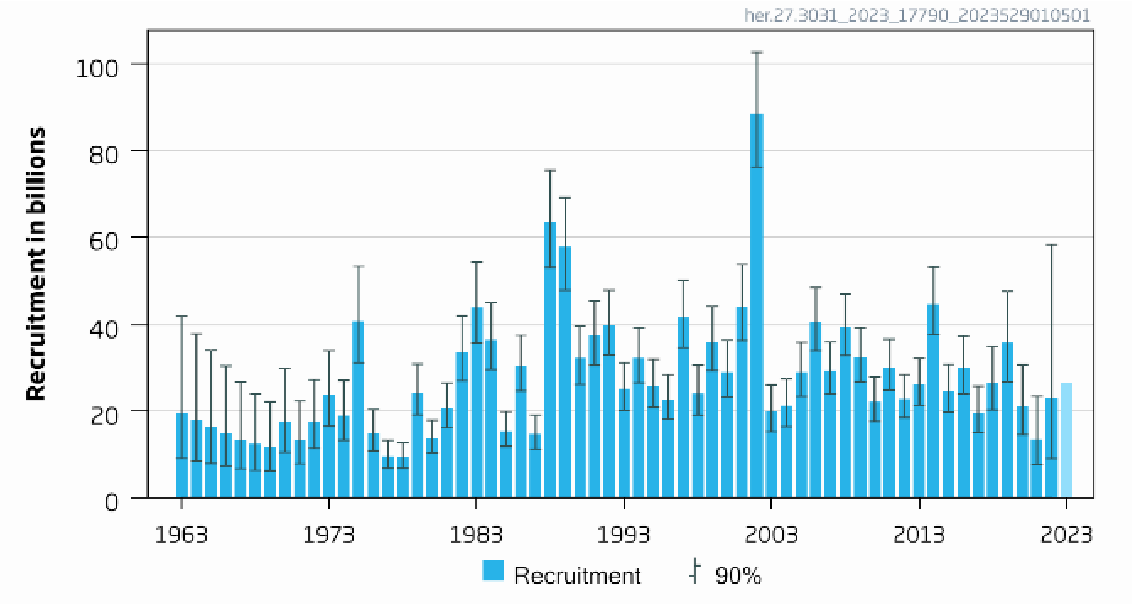
According to the latest ICES advice the spawning stock biomass (SSB) for herring in ICES subdivisions 25-29 and 32, excluding Gulf of Riga (Central Baltic Sea) is below MSY $B_{trigger}$ and B_{lim} (ICES 2023a). The fishing pressure for the stock is below F_{MSY} according to the latest ICES advice. The stock was recently benchmarked in 2023 resulting in higher reference points for both F and SSB.

A similar development has been observed for the herring stock in ICES subdivision 30 and 31 (Gulf of Bothnia). A decrease in SSB have been observed since 1995, falling to levels below MSY $B_{trigger}$ in recent years. However, F is below F_{MSY} and has been for a long time (ICES 2023b).

4.4 Recruitment

In the Central Baltic Sea, a clear drop in recruitment was observed in the middle of the 1980s. Since then, the recruitment has stabilized at a lower level and has remained relatively stable over the past 30 years (ICES 2023a). However, the knowledge of recruitment for different spawning stocks is limited and it cannot be excluded that recruitment success may differ between areas and between genetically distinct spawning components.

The low salinity in the Baltic Sea is challenging and likely affect reproductivity of female herring (Green 2008). Furthermore, salinity can define the overall fitness of female fecundity (Cardinale et al. 2009). It has also been shown that the occurrence of certain zooplankton (*Pseudocalanus* ap.) and temperature during summer affect fecundity (Margonski et al. 2010, Bartolino et al 2014, Pécuchet et al. 2015)



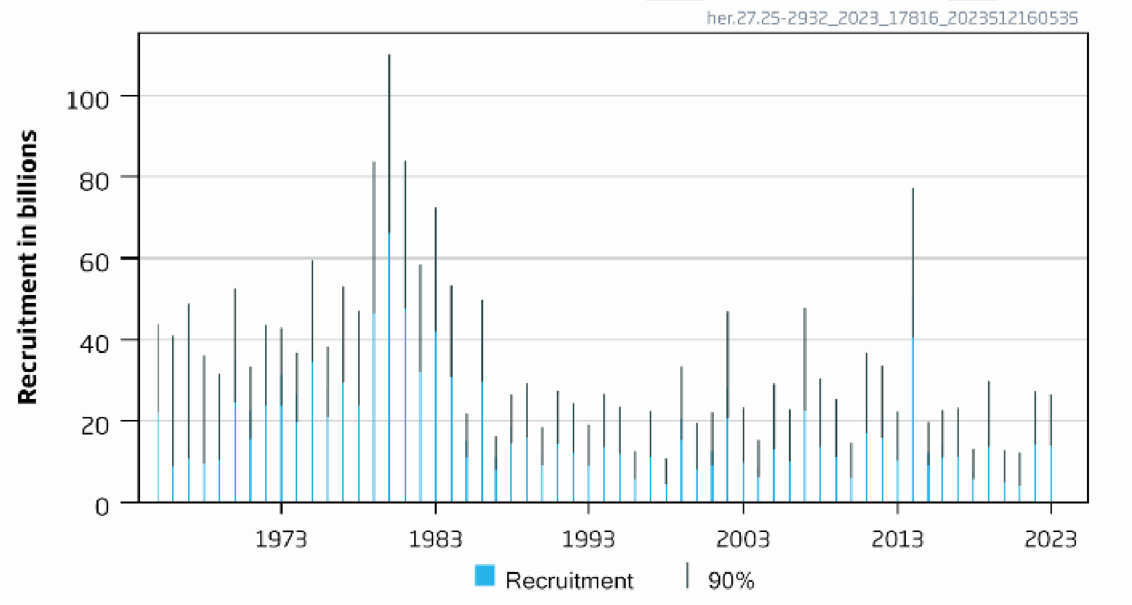


Figure 1. Recruitment (age 0) in the Gulf of Bothnia 1963-2023 (upper panel) and recruitment in the Central Baltic Sea 1965-2023 (lower panel). Full staples (including grey area) showing 90% confidence interval (ICES 2023a; ICES 2023b).

4.5 Spawning stock biomass

The long-term trend of spawning stock biomass (SSB) for the herring stock in SD 25-29 and 32 (excluding gulf of Riga) is negative. SSB decreased until the early 1990s and has since stabilized at a lower level (figure 2). It is estimated that the stock biomass of herring in the area is reduced by 70-80% compared with the 1970s (ICES 2023a). The Swedish University of Agricultural Sciences has analyzed trends in biomass of different size classes and numbers of individuals from the acoustic surveys and Swedish coastal monitoring (Kaljuste 2022; table 1). Statistically significant negative trends have been observed in all areas (SD 25-30). The trends have been most obvious for larger herring above 18 cm length. However, the period from 2011-2021 shows negative trends for all analyzed parameters (number of individuals, biomass, average weight and proportion of large herring). The analysis was updated in 2023 (table 1), and the trends are also partly confirmed for larger herring by acoustic surveys (Kaljuste 2022; table 1). Studies of the development in more coastal areas are generally lacking. A recent study followed up on previous investigations of fish species composition in the Stockholm archipelago from 2000-2001 and 2002-2004, and compared these with an analysis of species composition conducted in 2022 (Svedäng et al. 2023). The result showed that young-of-the-year herring, previously dominant, had declined from 55% to 4% in numbers between the investigated periods.

Table 1. Trends for different parameters N/n.mi^2 tot = Number of individuals per square nautical mile; B/n.mi^2 tot = Biomass per square nautical mile; Mean W tot = Average weight; N/n.mi^2 ≥18 = Number of individuals larger than 18 cm per square nautical mile; B/n.mi^2≥18 = Biomass larger than 18 cm per square nautical mile, Mean W ≥18 = Average weight individuals larger than 18 cm; N share ≥18 / B share ≥18 = Share in % of individuals larger than 18 cm for number of individuals and biomass (Wennerström and Kaljuste 2022).

SD	N/n.mi^2 tot	B/n.mi^2 tot	Mean W tot	N/n.mi^2 ≥18	B/n.mi^2≥18	Mean W ≥18	N share ≥18	B share ≥18
All years 2011–2022								
25	**↗**	↑	↓	→	↑	**↓**	↘	↘
27	→	↘	↘	→	↑	**↓**	→	→
28	↗	↗	↓	↘	↓	**↓**	**↘**	**↘**
29	↗	↑	↗	→	↗	↗	→	→
30	↘	**↓**	↓	**↘**	**↓**	↓	→	→
Latest 10 years								
25	↘	**↓**	**↓**	**↘**	**↓**	**↓**	**↘**	**↘**
27	↓	↓	↓	↘	↓	**↓**	↘	↘
28	↘	↓	↓	**↘**	**↓**	**↓**	**↘**	**↘**
29	↘	↓	↘	↘	↓	↓	→	↘
30	↘	↘	↘	↘	↓	**↓**	→	**↘**
Latest 5 years (2018–2022)								
25	↘	**↓**	↓	↘	↓	↘	↘	↘
27	↘	↓	↑	→	↓	↑	→	→
28	↓	↓	↓	**↘**	**↓**	↑	↘	↘
29	↑	↑	↓	→	↓	↗	→	↘
30	↘	↓	↓	↘	↓	**↓**	↘	↘

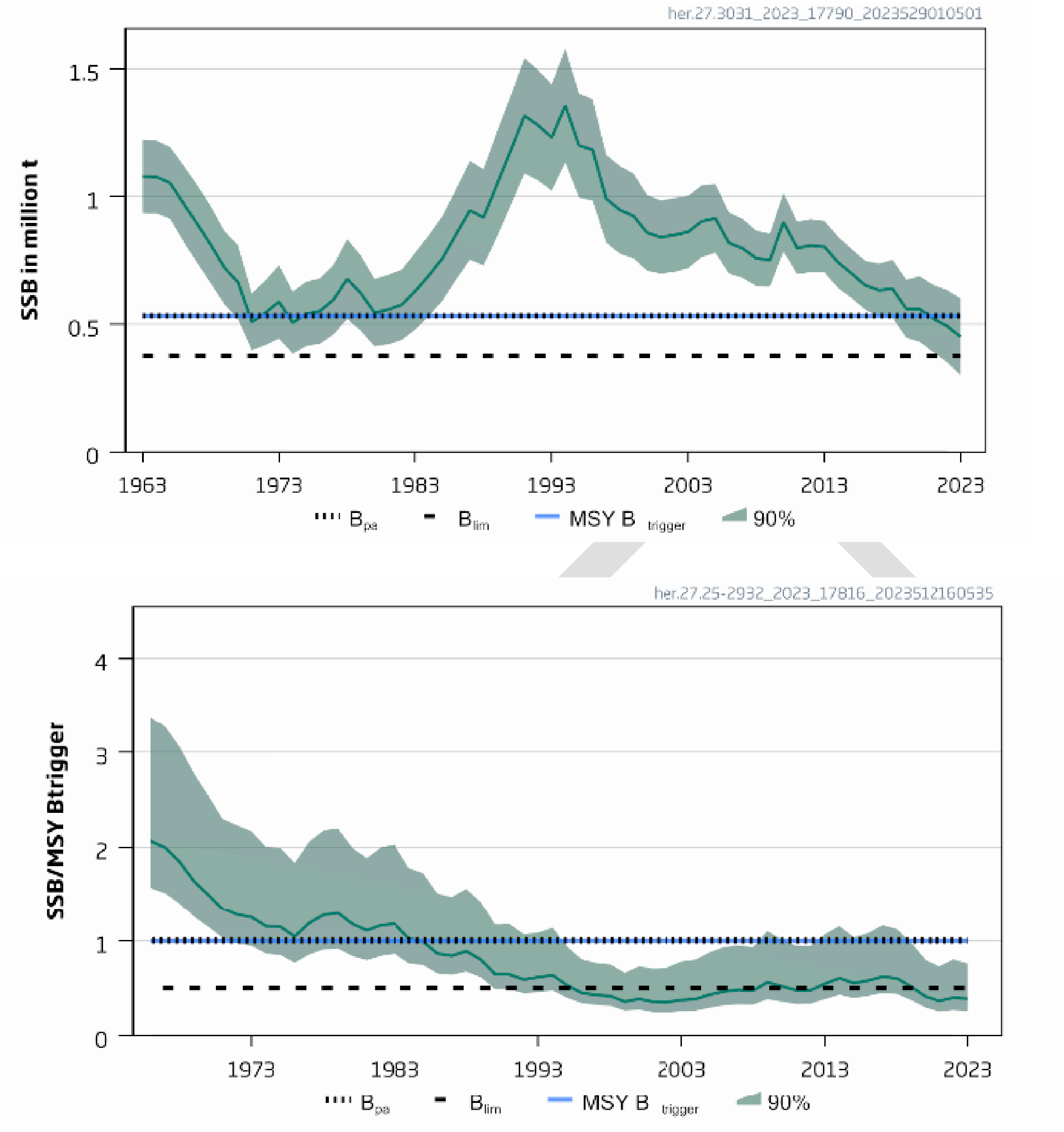


Figure 2. Relative Spawning Stock Biomass (SSB) for herring in the Gulf of Bothnia (SD 30-31) in upper panel, and in lower panel ICES SD 25-29 and 32, excluding the Gulf of Riga (ICES 2023a; 2023b).

4.6 Growth, size and age structure

Herring in the Baltic Sea grow more slowly than on the west coast and elsewhere in the Atlantic. As an example, Baltic herring normally reach a size of 18-20 cm (the size normally used for direct human consumption) at 6-8 years of age in the Gulf of Bothnia and 4-5 years in the Central Baltic Sea. Growth has decreased significantly since the early 1990s, when fish reached the same size in 4–5 years in the Gulf of Bothnia and 3–4 years in the Central Baltic Sea (ICES 2023a; 2023b). A decline has also been seen in body condition (the ratio between individual weight and length) of herring in the Central Baltic Sea, which has been gradually decreasing since the 1980s (Casini et al. 2011). In the Gulf of Bothnia, the body condition declined dramatically during 2020-2021 (ICES 2023b).

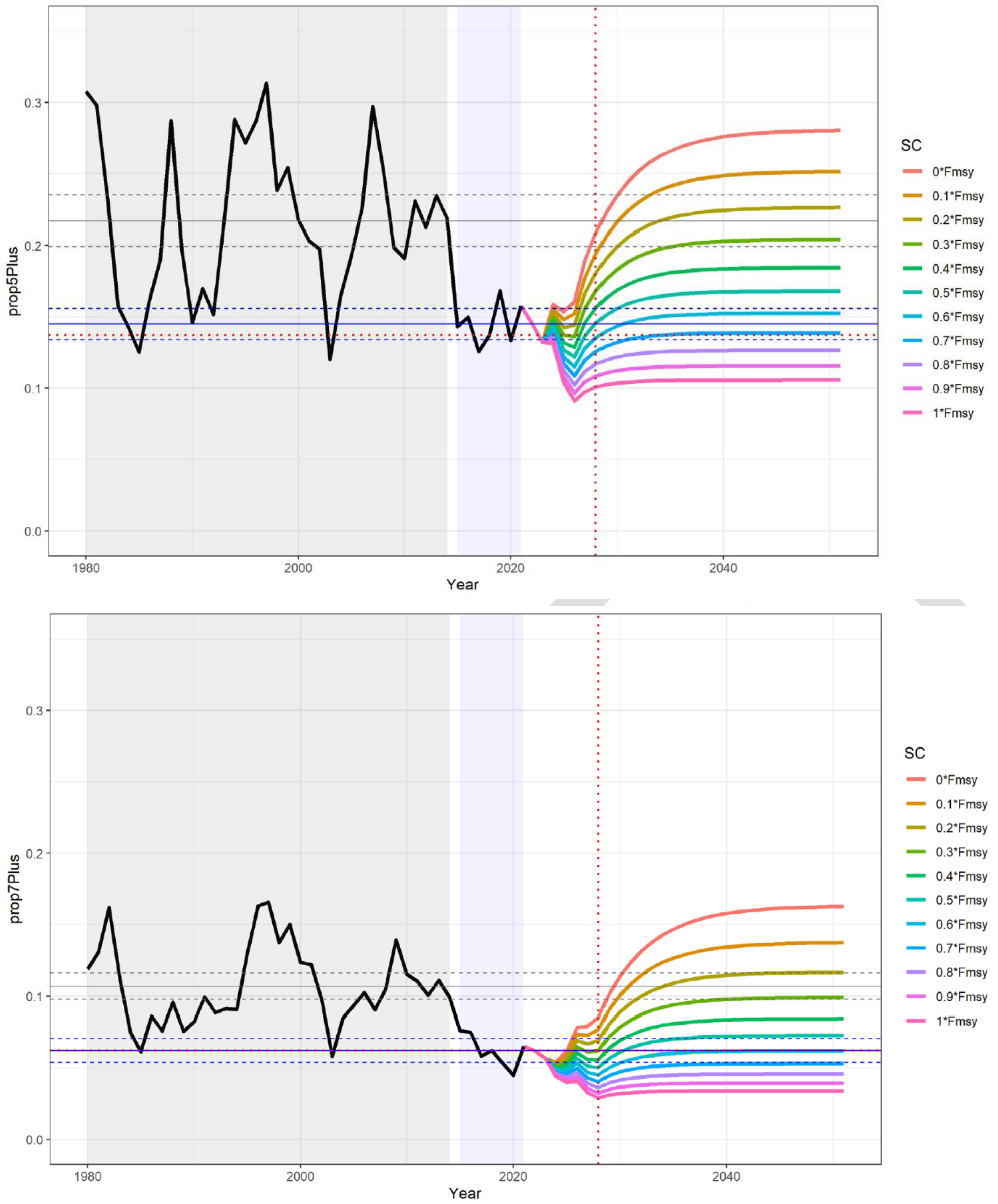


Figure 3. Age structure over time for 5-years and older (upper panel) and 7-years and older (lower panel). Historical trend is shown by the black line in the graphs. Modelled scenarios depending on fisheries mortality illustrated by different colors after 2018. Grey shading illustrates reference period, blue shaded period indicates significantly lower values, compared with reference period. Horizontal solid lines are the averages for respective period, with 95% confidence levels, dashed lines. (SLU Aqua 2023).

Griffiths et al. 2023 modelled the age structure of 72 commercially important stocks in the Northeast Atlantic in relation to the equilibrium age structure at F_{MSY}. The age distribution was significant lower for herring in the Central Baltic Sea but just at the equilibrium for F_{MSY} in the Gulf of Bothnia even if older individuals has declined significantly in the last decade. SLU Aqua conducted a modelling approach to analyze whether age distribution might improve based on different fishing scenarios (figure 3; Gilljam 2022). The results indicated that both the proportion of 7-years-old individuals and 5-years-old individuals would decrease further until 2028 with a relative fishing mortality according to $F_{MSY.}$ Furthermore, the results showed that a reduction in relative fishing mortality would enhance the recovery of age structure. According to model estimates it would be necessary to reduce the relative fishing mortality to about 50-70 percent of F_{MSY} in order to restore age distribution to the levels observed in 2018.

4.7 Reproduction and habitats for spawning, nursery and growth

The herring in the Baltic Sea become sexually mature at 1-3 years. In the Gulf of Bothnia, the age of sexual maturity, has decreased over time, where the proportion of sexually mature two-year-olds has increased (ICES 2021). Before spawning, herring migrate from off-shore areas, which are normally deeper than 50 m (Ojaveer 2003, Kaljuste et al. 2009), to shallow coastal areas, where they form large spawning shoals. Spawning normally occurs on hard substrate shallower than 10 m, in areas close to deeper water (Aneer 1989, Kääriä et al. 1997, Gunnartz et al. 2011). In the Baltic Sea, the roe is normally placed onto vegetation but herring are otherwise relatively flexible in terms of spawning habitat and can spawn in both exposed coastal areas and far into bays in the inner archipelago along the Swedish coast. Habitat models based on extensive field sampling show that the greatest densities of larvae occur within larger archipelago areas, or close to deep water (Kallasvuo et al. 2017, Erlandsson et al. 2021). Autumn-spawning herring usually spawn in the outer archipelago and shallow banks in the open sea (Gunnartz et al. 2011), but there is less information about these spawning stocks.

Each female produces one set of eggs per year and these are released close to the seabed, where they are fertilised by the male (Blaxter and Hunter 1982). The sticky eggs sink to the bottom where they create large accumulations that can sometimes be many layers thick and cover an area of up to a hectare (Blaxter and Hunter 1982). On average, each female produces between 10,000 and 60,000 eggs (ICES 2009). It takes up to two weeks for the eggs to hatch, depending partly on temperature (Blaxter and Hunter 1982). After hatching, the larvae live in the water column, usually in or close to the archipelagic area (Polte et al. 2017)

The low salinity in the Baltic Sea is challenging and likely affect reproductivity of female herring (Green 2008). Furthermore, laboratory studies and studies in the Gulf of Bothnia show that the body condition of females affects the fertilisation, quality and survival of the egg (Laine and Rajasilta 1999, Rajasilta et al. 2021). There are also a number of correlative studies of how environmental factors might affect the Baltic herring's recruitment in the Central Baltic. Water temperature in summer (August) and the density of zooplankton prey (especially *Psedocalanus* sp.) appear to have a positive correlation with recruitment success (Cardinale et al. 2009, Margonski et al. 2010, Bartolino et al. 2014, Pécuchet et al. 2015). The body condition of spawning fish also seems to relate to recruitment (Cardinale et al. 2009). This is supported by histological studies, which show a connection between weaker individual condition during the maturation process and reduced fecundity.

As the larvae grow and develop, they choose their habitat more actively (Moyano et al. 2016) and they move towards areas in shallow coastal areas where they develop into juveniles that live in shoals near the coast for 1-3 years before moving out towards the open sea (Polte et al. 2017). The size of the adult herring stock is largely determined by mortality at this critical larval stage (Hjort 1914), where predation (Bailey and Houde 1989), access to food (Cushing 1974) and temperature (Peck et al. 2012; Margonski et al. 2010) are important factors.

5 Identified threats to the development of herring stocks

In preparation of the latest update of the national program of measures for MSFD, fisheries in combination with other large-scale pressures, such as eutrophication and hazardous substances were identified as major pressures contributing to the poor status of fish populations in the Central Baltic Sea and the Gulf of Bothnia (Wennhage et al. 2022). The European Commission and the Helsinki Commission stated that the Baltic Sea is in very poor state (Helcom HOLAS III). This is also supported by the national reporting of EU members within the MSFD, stating poor status for most of the ecosystem components in the Baltic Sea area, as well as for relevant pressures, as eutrophication, hazardous substances, alien species, underwater noise and marine litter.

Fishing for herring is mostly conducted by pelagic trawls and seine nets but also bottom trawls are used to a lesser extent. Mixed landings fisheries of both herring and sprat are quite common depending on fishing area (ICES 2023a). Climate change has also been identified as a more dominant potential pressure in the future. The Central Baltic herring will likely be directly affected by lower salinity, while indirectly affected by decreased prey availability, or altered physiological boundaries for herring in future climate. Eutrophication has been identified as an important pressure for the entire ecosystem. Other correlative studies in the Central Baltic Sea have highlighted that large-scale climate conditions, mainly in connection with direct and indirect effects of temperature and salinity, and also precipitation in the drainage basin can be of significance for herring growth (Bartolino et al. 2014, Cardinale and Arrhenius 2000, Casini et al. 2006, Kornilovs et al. 2001, Margonski et al. 2010, Smoliński, 2019). Additionally, natural predation from grey seals might provide an additional pressure, especially since population size of grey seals has increased during the last decades, However, the impact of natural predation on the herring population in the Central Baltic Sea is so far unknown. Hansson et al. 2018 showed that coastal fish populations were more likely impacted by predation from both seal and cormorants than more pelagic fish species. During 2015 to 2018 new diet samples from grey seals were collected along the Swedish coast. These studies identified cod as the main prey species in the seal diet of the southern and Central Baltic Sea Proper (Scharff-Olsen et al. 2018). Herring, sprat, white fish and flatfish, as well as cyprinids, complemented the grey seal diet in these areas. Changes in herring growth have been linked to top-down factors, such as size-selective fishing mortality, and through predation by cod and seals (Beyer and Lassen 1994, Östman et al. 2014, Karlson et al. 2020). A relative increase in mortality due to fishing and seal predation in relation to cod predation may have increased mortality of large individuals, compared to smaller individuals (Kulatska et al. 2021), deteriorating the age and size structure towards younger and smaller individuals (Gilljam et al. 2022).

The situation for the herring in the Gulf of Bothnia is somewhat similar. Climate change will probably have a similar effect as in the Central Baltic Sea. However, eutrophication is not as prominent. In 2023, new diet samples from grey seals in the Bothnian Sea have been analyzed. Results clearly show that herring is the most important prey species for grey seals in the Bothnian Sea in recent decades (Wennerström et al. 2023). Grey seals are also highly size-selective for larger herring, above 20 cm in length. Prey size distribution for grey seals has not changed noticeably during 2010-2019 and deviates from the average size distributions of herring in the Bothnian Sea (Wennerström et al. 2023).

Also, bottom-up effects, i.e., changes in the food web will continue to impact herring stock development in both the Central Baltic Sea and the Bothnian Bay. Herring mainly feed on zooplankton. Changes in zooplankton availability (mainly copepods) and competition for food from sprat have been identified as important factors affecting the growth of herring in both the Central Baltic Sea and the Gulf of Bothnia (Cardinale & Arrhenius 2000, Möllman et al. 2004, Casini et al. 2011, Lindegren et al. 2011, Rönkkönen et al. 2004, Karlson et al. 2020).

6 Rationale

6.1 Legal basis for the implementation of a time-limited scientific project

If EU Member States are to suggest conservation and management measures to be adopted outside their territorial waters, or within their territorial waters that are liable to affect fishing vessels of other Member States, such measures shall be adopted only after consulting the concerned EU Member States. Before an EU Member State proceed with a proposal for conservation and management measures that affects other EU Member States, the EU Member State should inform others about the need for the measures together with supportive scientific documentation on the anticipated effect of the proposed measures. In order to introduce measures that are liable to affect fishing vessels of other Member States, regionalisation according to Article 18 of the Basic Regulation is preferred, for example by introducing delegated acts according to Article 15 of the technical regulation (EU) 2019/1241. A procedure according to Article 15 results in a joint EU regulation that is available in all EU languages. At the same time, the procedure allows for an adaptive management if new scientific evidence emerges that shows that fisheries management measures need to be changed. In the Baltic Sea, this process is initiated via the regional forum Baltfish, which is represented by all EU Member States with fishing opportunities in the Baltic Sea. The work takes place through the development of joint recommendations, which also contributes to a transparent process. Based on previous experiences, it is difficult to predict the time required for such consultations. Any requirements for new scientific data, together with the formal process before approval of a joint recommendation, can take time as a result of political priorities and changes within individual Member States.

Furthermore, it needs to be considered that the implementation of this government assignment refers to a time-limited scientific project, where the proposed measures that target vessels fishing for pelagic species in time and space is a consequence of the scientific experimental design of the project. Lack of scientific data that demonstrates the anticipated effects of the measure complicates the possibility of presenting scientific documentation that supports the suggested measures. This deviates from the normal procedure for formulating a joint recommendation and adopting delegated acts based on scientific documentation. Since the scientific project has a limited time frame, it is also important to treat the process efficiently, and to decide on the appropriate implementation as soon as possible. A procedure of adopting delegated acts according to Article 15 of the technical regulation is therefore not considered as an option for implementing this time-limited project.

Instead, it is proposed that the measures needed to implement the time-limited scientific project should be carried out through the implementation of national measures in accordance with Article 20 of the Basic Regulation in areas within 12 nautical miles.

6.1.1 Article 20 of the Basic Regulation - Measures by Member States within the 12 nautical mile zone

A procedure according to Article 20 is proposed the study area within 12 nautical miles in the Central Baltic Sea. SwAM provides for such measures in its regulations, i.e., national measures, following a referral procedure (see section 3.5).

According to Article 20 of the Basic Regulation, a Member State may take non-discriminatory measures for the conservation and management of fish stocks and the maintenance or improvement of the conservation status of marine ecosystems within 12 nautical miles of its baselines. The Member State measures shall be compatible with the objectives set out in Article 2 and shall be at least as stringent as measures under Union law. Where conservation and management measures to be adopted by a Member State are liable to affect fishing vessels of other Member States, such measures shall be adopted only after consulting the Commission, the relevant Member States and the relevant Advisory Councils on a draft of the measures, which shall be accompanied by an explanatory memorandum that demonstrates, inter alia, that those measures are non-discriminatory (Article 20.2). For the purpose of such consultations, the consulting Member State may set a reasonable deadline, which shall, however, not be shorter than two months.

It appears from Article 6.4 of the Basic Regulation that Member States must coordinate with each other before adopting national measures pursuant to Article 20. Recital (41) of the Basic Regulation states that the measures must not discriminate against Union fishing vessels of other Member States.

7 Fisheries

7.1 Method and data

To map the extent of herring fisheries in the Baltic Sea in 2012-2021, SwAM requested data on catches of herring from Denmark, Finland, Latvia, Lithuania, Poland, Sweden and Germany (Swedish Agency for Marine and Water Management; Reg.No.1909-22). Requested data were received from all countries except Latvia and Germany. However, the catches from these two countries in Swedish waters are of negligible significance for the analysis of total landings, considering that during the last three years, Germany and Latvia correspond to an average of 0.5% and 3.4 % of total catches respectively. The data requested was logbook data linked to positions from the vessels VMS systems (hereinafter called VMS data) from the pelagic fishing in the entire Baltic Sea except for the Gulf of Riga. In addition, geographical data from logbooks of lower resolution was requested (total catches per ICES rectangle 1° latitude × 0.5° longitude rectangles in WG84) from fishing that could not be linked with VMS data. Since vessels under 12 meters are not obliged to use VMS equipment, supplementary data was also used to map the activities of smaller vessels in Swedish waters. Data for this part of the analysis only included Swedish logbooks.

Collected data also contained information about vessel length and type of equipment. Besides total landings, the distribution of catches was categorised into three sizes classes of vessels (<12, 12-24 and >24 meters), as well type of gear (bottom trawl, pelagic trawl, seine net and passive gear). The requested data did not include information on the economic value of herring catches, which instead have been compiled from economic data from the Scientific, Technical and Economic Committee for Fisheries (STECF), and was used to estimate the value of catches (see Appendix, section 14.2). Catches were also categorized into three sub-areas of Swedish waters (see Figure 4).

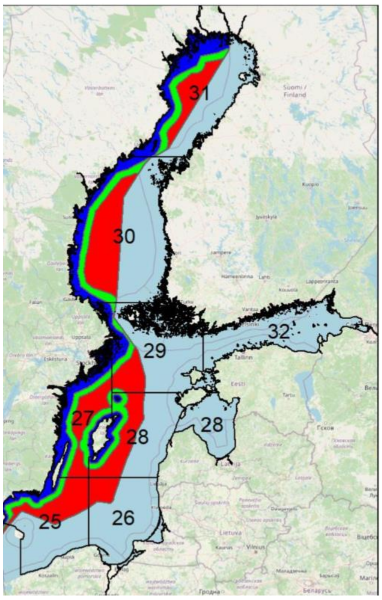


Figure 4. The sub-areas in Swedish waters used in this analysis. Blue area: within the Swedish trawl boarder (< 4 nm); green area: the area outside the Swedish trawl boarder and within the Swedish territorial waters (4-12 nm); and red area corresponding to the Swedish Exclusive Economic Zone.

7.2 Total herring catches in Swedish waters

The average annual catch of herring in the Baltic Sea in 2012-2021 is approximately 230,000 tons (average annual catch for all available data), of which Swedish fisheries accounts for approximately 25 percent. In Swedish waters (Fig. 4), the total average catch for all countries is approximately 73,500 tons per year, and Swedish fisheries accounts for approximately 57 percent of these catches. Swedish fisheries dominate the catches in Swedish waters in the Central Baltic Sea (SD areas 25-29), in which Swedish fisheries accounts for almost 75 percent of the total catches. This is especially pronounced in SD 27 and 28 for which the Swedish fisheries dominate, catching almost 90 percent of the total catches. In SD 27 and 28, the largest catches originate from the Swedish territorial waters (inside 12 nm). In SD 25 and 26, catches of other countries and Swedish catches are more similar. However, in SD 25, the largest Swedish catches are from the subarea between 4-12 nm, while the largest catches of other countries are from areas outside the territorial waters (outside 12 nm). In SD 29, the largest catches are made within the Swedish EEZ, both for Sweden and other countries.

Herring catches in the Gulf of Bothnia (SD 30) account for approximately 43 percent of the total catches in Swedish waters. Swedish fisheries accounts for about one third of the total catches, while Finland accounts for the rest. A large part of the total catch within the Swedish EEZ originates from areas outside Swedish territorial waters. Only about 5 percent of the total catches (both Swedish and Finnish) occur in the area between 4-12 nm.

Baltic Sea herring catches are dominated by large vessels above 24 meters length in large parts of both the Gulf of Bothnia and the Central Baltic Sea (see Figure 5). However, in coastal areas, some Baltic herring are generally caught by smaller vessels (12–24 meter). Landing positions for the smallest vessels (<12 meter) fishing with both trawls and passive gears (~21 % pelagic trawl, ~22 % bottom trawl, ~49 % passive gears, and 8 % seine nets), also tend to overlap with areas where vessels of 12-24 meters dominate the catches.

Table 2. Average catches of herring for Sweden and other countries in Swedish waters (in tons per year for 2012-2021). Catches are shown separately for three zones - within 4 nautical miles, between 4 nautical mile and the Swedish territorial water (12 nautical mile) and in the Swedish Economic Zone (EEZ). VMS data and Swedish logbook data for vessels under 12 meters have been used in creating this table.

Sub Division	Country	< 4 nm	4-12 nm	EEZ	Total
25	Sweden	459 (8 %)	3 138 (56 %)	2 017 (36 %)	5 614
25	Other country	14 (0 %)	518 (11 %)	4 351 (89 %)	4 883
26	Sweden	0 (0 %)	0 (0 %)	2 136 (100 %)	2 136
26	Other country	0 (0 %)	0 (0 %)	1 766 (100 %)	1 766
27	Sweden	2 152 (19 %)	6 739 (60 %)	2 430 (21 %)	11 321
27	Other country	23 (2 %)	758 (57 %)	558 (42 %)	1 339
28	Sweden	366 (4 %)	5 839 (63 %)	3 021 (33 %)	9 226
28	Other country	35 (2 %)	560 (37 %)	902 (60 %)	1 497
29	Sweden	24 (1 %)	1 320 (34 %)	2 506 (65 %)	3 850
29	Other country	17 (2 %)	488 (45 %)	585 (54 %)	1 090
30	Sweden	402 (4 %)	589 (5 %)	10 148 (91 %)	11 139
30	Other country	211 (1 %)	1 132 (5 %)	19 466 (94 %)	20 809
31	Sweden	79 (100 %)	0 (0 %)	0 (0%)	79
31	Other country	0 (0 %)	0 (0 %)	2 (100 %)	2

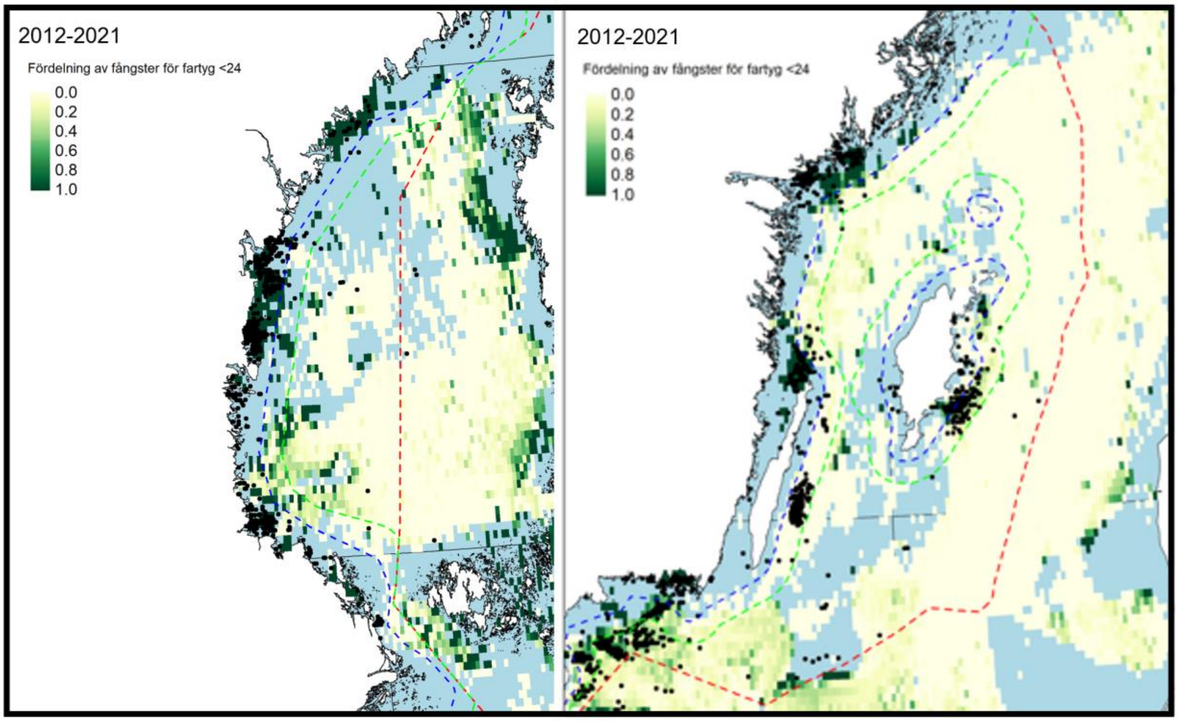


Figure 5. Geographical distribution of herring catches by small fishing vessels < 24 meter during 2012-2021. The maps show the quota between total catches by vessels between 12-24 meters and total catches by all vessels above 12 meters. Green indicates that vessels between12-24 meter dominates the fishing in an area while white indicates that larger vessels above 24 meters dominate the catches. Blue shows areas without herring catches during 2012-2021. The total catches are aggregated within a 0.05 x 0.05-degree grid (WGS 84). The panel on the left shows the Gulf of Bothnia and the panel on the right the Central Baltic Sea. Small black points show GPS positions from logbook data for vessels smaller than 12 meters. The logbook positions are less accurate than VMS data, but provide an overview of the areas where small-scale coastal fishing occurs.

7.3 Geographical and temporal variations of herring catch in Swedish waters.

Detailed analyses of VMS data show concentrations of herring catches within well-confined geographical areas, in both the Bothnian Sea and the Central Baltic Sea (**Figure 6.** Spatial distribution of total and annual catches during 2012-2021 for the Gulf of Bothnia (upper panel), and the Central Baltic6). The geographical distribution of herring catches has not varied significantly between years in the period 2012-2021. The aggregated total catches of herring during the period 2012-2021 thus give a relatively good representation of the annual geographical distribution of catches in both the Bothnian Sea as well as in the Central Baltic Sea.

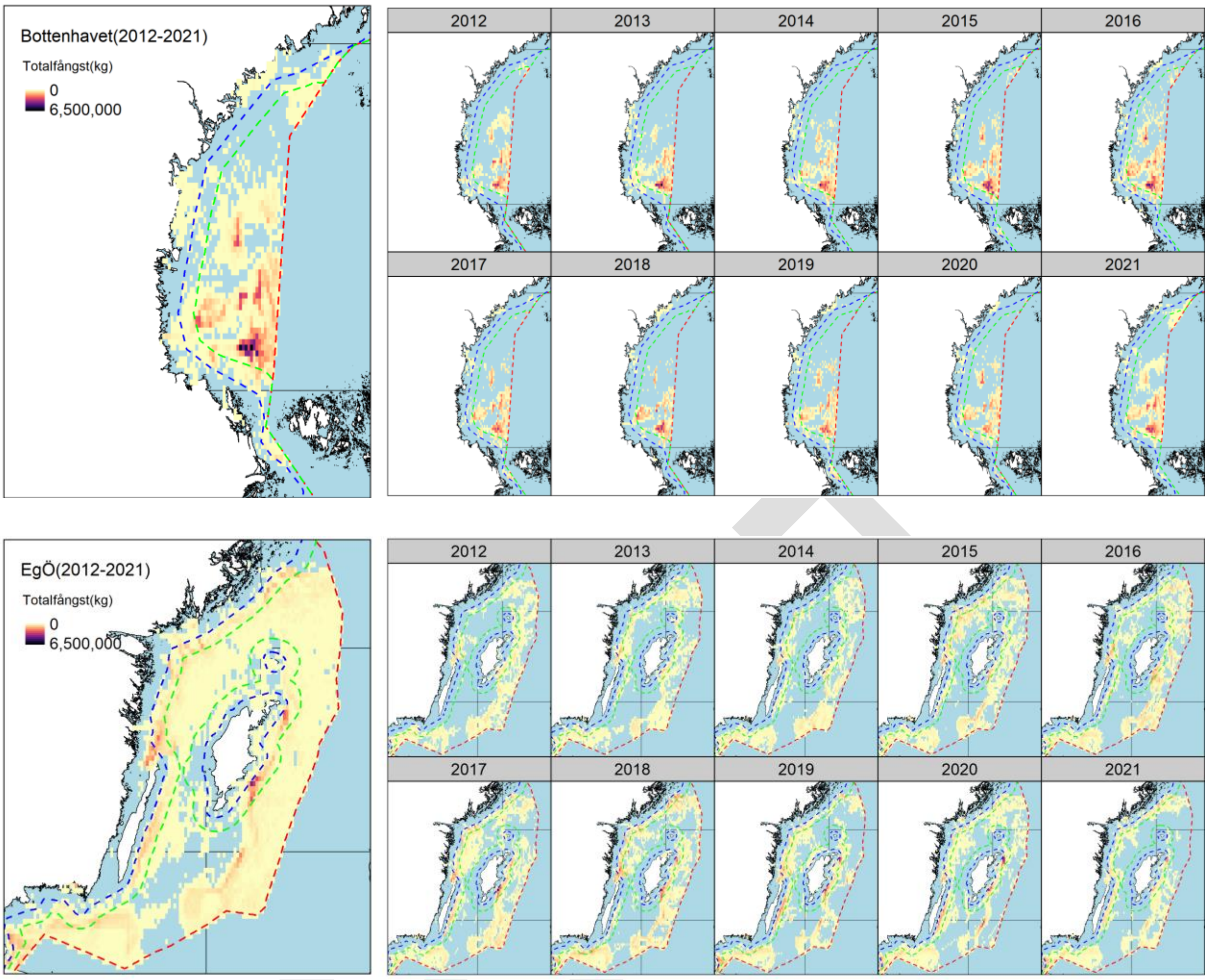


Figure 6. Spatial distribution of total and annual catches during 2012-2021 for the Gulf of Bothnia (upper panel), and the Central Baltic Sea (lower panel). The larger left panels show total herring catches for all countries, while the smaller panels show annual catches. The color scale in the small panel shows the catch in relation to the maximum catches in some squares for some years during 2012-2021. The blue dotted line shows the border of four nautical miles, the green dotted line shows the border of Swedish territorial waters (12 nm) and the red dotted line shows the border of the Swedish Exclusive Economic Zone (EEZ). The herring catches are summed across a 0.05 ° latitude × 0.05 ° longitude rectangles (WGS 84). All positions based on VMS data.

8 Expected effects and hypotheses

The time limited scientific project will assess whether spatial fisheries management measures could improve the status of herring along the Swedish coast in terms of biomass as well as their age, size and stock structure. Restrictions for vessels fishing for pelagic stocks within designated study areas, together with monitoring of stock development for herring inside and outside the areas, will enable a scientific evaluation of both direct and indirect effects of spatial measures. The scientific project aims to generate new knowledge about stock structure, distribution and migrations patterns of herring in the Central Baltic Sea and Bothnian Sea. Furthermore, to what extent the development of herring stocks is affected by other pressures such as environmental factors and natural predation. Overall, the scientific project will increase the understanding of mechanisms affecting the efficiency of spatial measures and, if appropriate, how such measures could be applied in the long term to improve the status of herring stocks.

A restricted fishing in areas where herring seems to aggregate is expected to reduce mortality of local spawning components and enhance size and age structure as well as abundance and recruitment in certain coastal areas. Proposed measures within each study area are therefore expected to positively affect the development of parameters describing the relative abundance of herring stocks within each study area, compared to areas outside where fishing still continues.

Hypotheses for the scientific investigation have been formulated for each work package in the proposed monitoring programme (see Annex II).

Expected effects and formulated hypotheses are based on the following conclusions and observations:

- Results from acoustic surveys and Swedish coastal monitoring have showed negative trends for herring stocks regarding number of individuals, biomass, average weight and proportion of large herring during the last decade. The negative trends have been most obvious for larger herring above 18 cm length.
- There are genetically distinct spawning components: spring spawners, autumn spawners and local spawning stocks, e.g., stocks with genetically distinct spawning components have been identified in the southern Bothnian Bay.
- The Central Baltic Sea herring stock consists of several different spawning components that have been shown to be genetically distinct.
- Differences in genetics and migration patterns between spawning components, and spatial differences in growth and maturity, make the herring stock complex and vulnerable to loss in both genetic diversity and overall productivity.
- High fishing induced mortality in delimited off-shore areas, where herring seems to aggregate during winter and in periods close to spawning, could negatively affect local spawning components, their size and age structure as well as abundance and recruitment of herring in certain coastal areas.

9 Proposed study area

Based on the information presented, a study area in the Central Baltic Sea is proposed, with the aim to test and evaluate spatial management measures of vessels fishing for pelagic species. The proposed study area is considered suitable to address the main purpose of the scientific project, and have been assessed and established according to several different selection criteria relating to spatial characteristics. Such characteristics obviously relate to the historical fishing patterns, but should also represent important herring habitats used during the entire life cycle. Areas of special importance for pelagic fisheries are quite easily identified by mapping the historical fishing patterns of more highly aggregated catches, as provided by the data call. When considering important herring habitats, the study areas should preferably include both feeding off-shore areas, as well as more shallow spawning areas. Such areas are thus identified as including water depths of at least 50 meters depth, covering adjacent areas used for spawning migrations and shallow coastal spawning areas. The study area should also be large enough to detect the anticipated effects of the fisheries management measures. Since this project is implemented as a Swedish government assignment, the study area has been proposed with a main emphasis on Swedish fisheries.

The study area covers a total area of 20 522 km^2 within the Swedish territorial water (12 nm from the baseline) in subdivisions 27 and 29 (see Figure 7). The proposed study area includes coastal areas as well deeper areas of about 50 meters depth, and hence, is considered important for the development of herring biomass, stock and population structure. The study area is also deemed large enough to cover seasonal migrations of possibly genetically distinct spawning components of the Central Baltic Sea herring stock. The proposed spatial measures in this area are thus expected to cover the whole life cycle of herring, including feeding habitats, as well as spawning migration towards the coast, and major spawning grounds.

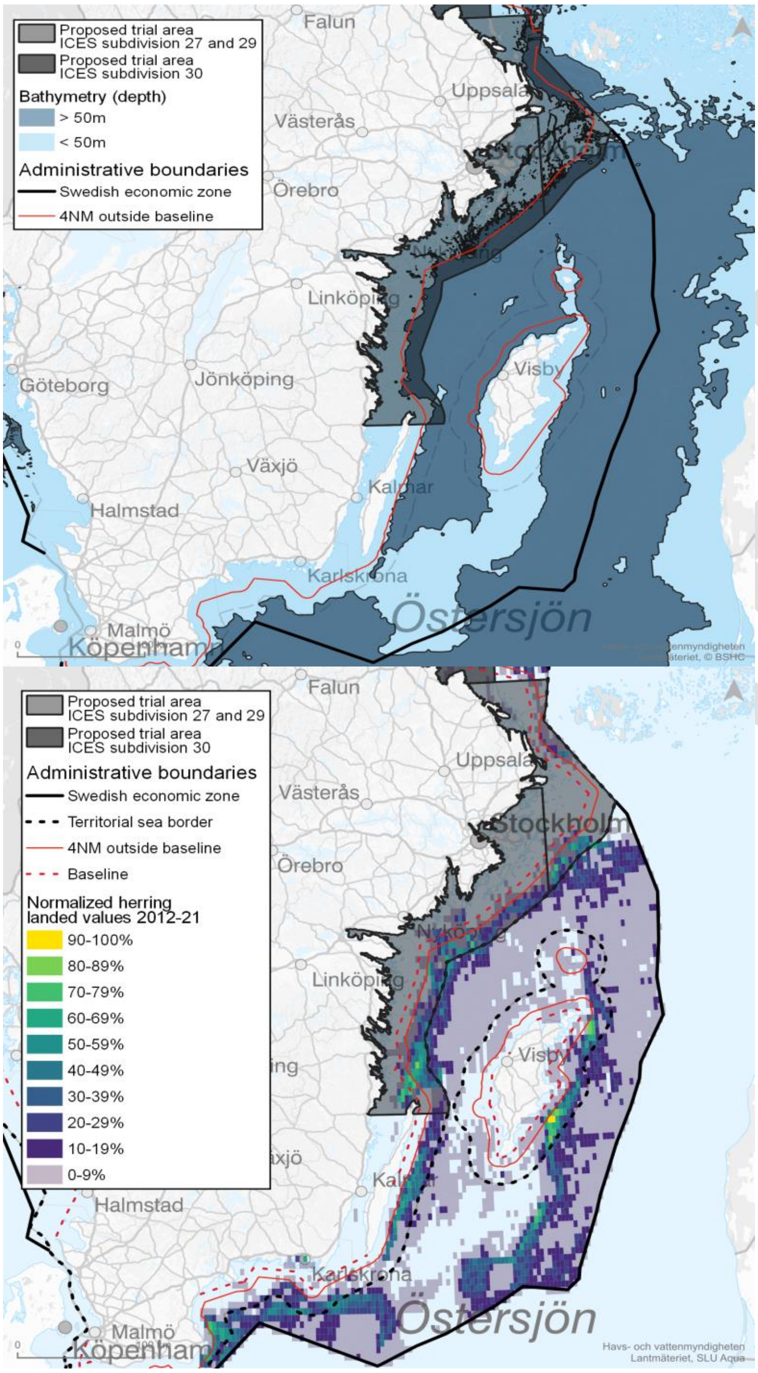


Figure 7. The proposed Central Baltic Sea study area. Upper panel shows the proposed study area in relation to depths above and below 50 meters, while lower panel shows the proposed study area in relation to geographical distribution of herring catches for vessels larger than 12 meters during 2012-2021.

9.1 Annual catches in the study area

9.1.1 Total catches in the study area

Total catches in the proposed study area amount to an annual average of 16 566 tons per year for the period 2019-2021, of which 82 percent are Swedish,15 percent are Danish, and 3 percent are Finnish catches. The national shares of the total catches in the study area, in relation to catches in the entire management area, is highest for Sweden at 16 percent, followed by Denmark at 8 percent. The Finnish catches in the area are quite limited, amounting to only 2 percent of their total catches in the management area. Total catches are dominated by larger vessels above 24 meters for all countries, and Sweden is the only country with catches from vessels in the segment between 12-24 m, corresponding to 2 896 tons per year. Total catches from Swedish vessels under 12 meters in the study area (not included in table 3) has been approximately 641 tons per year during the period (see Appendix table A1).

Table 3. Danish, Finnish, and Swedish average annual catches in tons for the period 2019-2021, for vessels between 12-24 meter, and above 24 meters, within in the study area, outside the study area and the entire management area (SD 25-29).

	Study area		Outside study area		Management area (SD 25-29)
Country	**Total catches**	**% of total catches**	**Total catches**	**% of total catches**	**Total catches**
DK 12-24 m	0	0 %	7 467	100 %	7 467
DK > 24 m	2 468	10 %	22 489	90 %	24 957
DK total	**2 468**	**8%**	**29 956**	**92%**	**32 424**
FI 12-24 m	0	0 %	10 773	100 %	10 773
FI > 24 m	448	2 %	18 543	98 %	18 991
FI total	**448**	**2 %**	**29 316**	**98 %**	**29 764**
SE 12-24 m	2 896	38 %	4 680	62 %	7 576
SE > 24 m	10 753	14 %	66 713	86 %	77 466
SE total	**13 649**	**16%**	**71 393**	**84%**	**85 042**
Total 12-24 m	2 896	11 %	22 920	89 %	25 816
Total > 24 m	13 670	11 %	107 744	89 %	121 414
Grand total	**16 566**	**11 %**	**130 664**	**89%**	**147 230**

9.1.2 Catch composition in the study area

The catch composition in the proposed study area has been different from the catch composition of pelagic catches in general during the period 2019-2021. Within the study area the proportion of herring catches is much larger, accounting for 10 821 tons per year compared to 5 745 tons of other catch (see Figure 8). Outside the study area, and for the entire management area, the relationship is reversed, with a lower proportion of herring catches of about 42 percent of total catches.

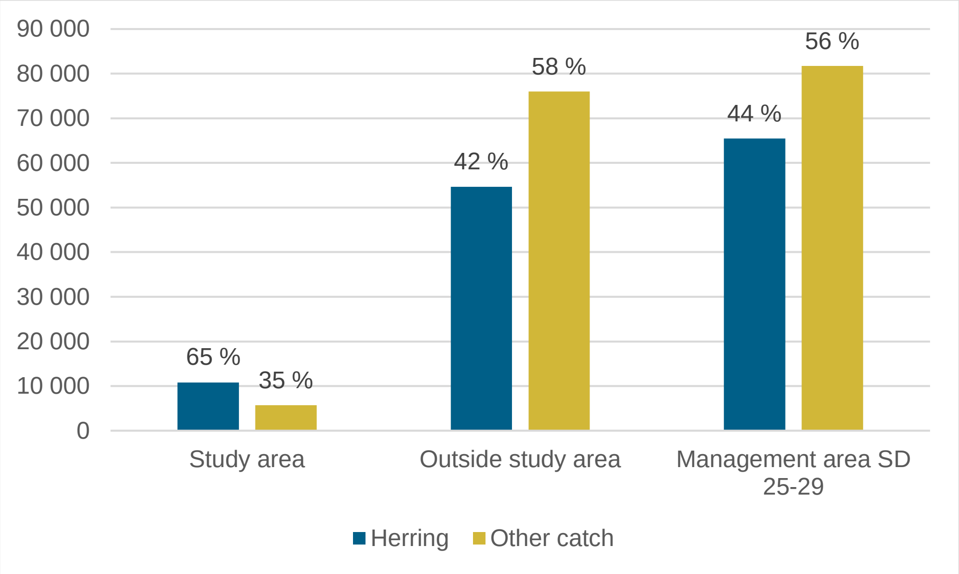


Figure 8. Herring catches compared to other catches, in tons per year for 2019-2021, in the study area, outside the study area, and in the rest of the management area.

9.1.3 Economic value of landings in the study area

The average value of the annual total landing in the study area is 5.35 million euro for the period 2019-2021 (table 4). The Swedish landings accounted for the majority of these, with an average annual landing value of 4.71 million euros per year. Swedish vessels under 12 meters account for merely 0.13 million euros. (See Appendix, table A2 for a more comprehensive account of estimated landing values for vessels under 12 meters). The Danish landings amounted to 0.55 million euros per year, and the Finnish ones to 0.09 million euros per year. Note that estimates of landing values as euros per ton can vary between countries, and this difference may be due to slight variations in reporting procedures to the STECF. (See Appendix, table A3 for a more comprehensive account of estimated landing values for vessels over 12 meters).

Table 4. The value of Danish, Finnish and Swedish annual catches within the study area (in euros per year for 2019-2021) for vessels larger than 12 meters.

Country	Species	2019	2020	2021	Yearly average
DK	Herring	303 000	170 000	239 000	237 000
	Other	263 000	205 000	475 000	314 000
	Total	**565 000**	**375 000**	**714 000**	**552 000**
FI	Herring	78 000	117 000	17 000	71 000
	Other	12 000	38 000	5 000	18 000
	Total	**90 000**	**155 000**	**22 000**	**89 000**
SE	Herring	4 898 000	3 208 000	1 932 000	3 346 000
	Other	1 628 000	965 000	1 495 000	1 363 000
	Total	**6 526 000**	**4 173 000**	**3 427 000**	**4 709 000**
Grand total	Herring	5 279 000	3 495 000	2 188 000	3 654 000
	Other	1 902 000	1 208 000	1 975 000	1 695 000
	Total	**7 181 000**	**4 703 000**	**163 000**	**5 349 000**

9.1.4 Temporal *variations of catches in the study area*

There have been clear seasonal variations in catches within the Central Baltic Sea study area, where the largest catches occur during the first three months of the year (Figure 9). From June to September there is almost no fishing activity, while the small catches landed during the last three months of the year are almost exclusively Swedish.

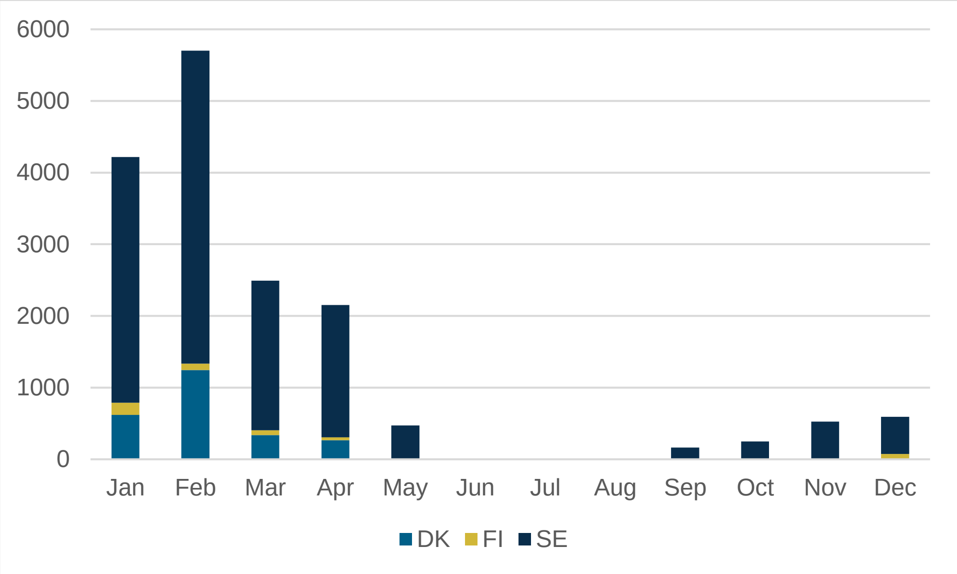


Figure 9. Danish, Finnish and Swedish average catches in tons per month in the proposed Central Baltic Sea study area during the period 2019-2021.

10 Proposals for fisheries management measures within the proposed study area

10.1 Purpose

There can be a large variation in the abundance of herring between different coastal areas. Despite a lack of knowledge, the genetic stock structure of herring probably includes several different spawning components within the two large management units in Gulf of Bothnia and Central Baltic Sea. An aggregated fishing within limited areas, where large quantities of herring are caught in a short period of time may influence size- and age structure as well as reduce the abundance of genetically distinct substocks and potentially the abundance of herring migrating to certain coastal areas for spawning.

A restricted fishing in areas where herring seems to aggregate may therefore protect genetically distinct and more stationary spawning substocks and enhance biomass, size and age structure as well as abundance and recruitment in certain coastal areas. The potential effect is assumed to increase if the stock is less migratory and remain within the study area throughout the year, not being exploited for fishing outside the area or in certain periods within the area. Hence, the probability of detecting effects of spatial measures for vessels fishing for pelagic stocks within each study area is likely to increase with the size of the area and if fishing is restricted all year. A restricted fishery throughout the year within each study area will also cover the entire spawning migration and positively effect both spring and autumn spawning herring stocks.

10.2 Measures

SwAM propose a prohibition for Union fishing vessels that fish for pelagic stocks, using towed gears, throughout the year.

By way of derogation, the proposed prohibition should not apply to 1) fishing operations conducted for the exclusive purpose of scientific investigations, 2) Union fishing vessels of less than 24 meters length overall, that fish for pelagic stocks for direct human consumption, using towed gears with a mesh size of 32 mm or more, and whose landings are sorted.

The proposed measures shall be evaluated during and following the implementation of the project. The fisheries management measures will cease no later than the 30th of April 2027.

10.3 Assessment of proportionality and non-discrimination

Measures presented in this draft proposal aims to scientifically evaluate spatial fisheries management measures within the given time frame of the scientific project. The proposal has been assessed in balance between expected consequences for fishing vessels fishing for pelagic stocks and the processing industry, while at the same time implementing a scientific design likely to detect the anticipated effects of proposed measures.

Since this project is implemented as a Swedish government assignment, both study areas have been proposed with a main emphasis on Swedish fisheries. According to historical landings in the study area (2019-2021), effects for the Swedish fishery is expected to be predominantly in both actual quantities as well as relative quantities compared to the total landings of concerned Member States within the management area of Central Baltic Sea (see table 4).

In the proposal, current fishing activity of different fleet segments within each study area has been considered to ensure proportionality for the fishery and the processing industry. Due to these considerations, a derogation is proposed for fishing vessels of less than 24 meters length overall, that fish for pelagic stocks for direct human consumption, using towed gears with a mesh size of 32 mm or more, and whose landings are sorted. The proposed derogation could be justified without jeopardizing the purpose of the scientific project, due to negligible landings for the use of direct human consumption within these segments.

On the basis of above information, the proposed measures are considered to be non-discriminatory against Union fishing vessels of other Member States.

10.4 Displacement, economic value and financial consequences for the fisheries

The proposed measures include a prohibition for pelagic trawling for vessels over 24 meters in length within both study areas, which lead to a relocation of fishing activities within the management areas. This relocation could result in less efficient fishing operations, as fishermen may need to spend more time identifying new fishing grounds, potentially yielding lower catches in these alternative locations.

The potential cost of these effort displacements depends on several variables, including the total allowable catch and fluctuations in fuel costs. To facilitate a quantifiable assessment of the impact, a scenario analysis was conducted, with estimates for vessels over 24 meters derived from Swedish DCF data (EU) 2017/1004. In the analysis, we assume that the costs for Swedish vessels over 24 meters are comparable to those of the Danish and Finnish fleets (see Appendix for a detailed description of the methodology for estimating economic impact of proposed measures).

The proposed study area in the Central Baltic Sea is mainly an important area for Swedish vessels trawling for pelagic stocks. Total landings amount to an annual average of 16 566 tons per year for the period 2019-2021, of which 82 percent (13 649 tones) are Swedish, 15 percent (2 468 tons) are Danish, and 2 percent (448 tons) are Finnish (see table 3). Compared to total annual landings in the entire managements area of the Central Baltic Sea, about 16 percent of the Swedish landings, 8 percent of the Danish landings and 2 percent of the Finnish landings originate from the proposed study area (see table 3). This corresponds to an annual landing value of approximately 5.35 million euros for the Swedish fisheries, 0.55 million euros per year for the Danish fisheries and 0.09 million euros for the Finnish fisheries (see table 4).

The pelagic fishery inside the study area is a mixed landings fishery, targeting both herring and other species (sprat). Herring is the dominant species in regards to total landings as well as total landing value, accounting for about 69 and 65 percent of the annual average in 2019-2021 (see table 4 and Figure 8).

Union fishing vessels above 24 meters of length overall account for more than 85 percent of the total landing in the proposed study area. Since the proposed measure include a prohibition for these vessels, implications involve a displacement of fishing activities to areas outside the proposed study area until the end of the project. These shifts may result in increased costs if added fishing effort is required for fishing activities in less optimal areas. This, in turn, may lead to a decrease in profit and gross value added, even though the anticipated effects of proposed measure are likely not to affect the total landings within the management area of Central Baltic Sea. The scenario analysis used to estimate the range of potential costs, as measured by a decrease in gross value added (GVA), indicates that Swedish GVA would decrease by 196 000 EUR per year under the low scenario and by 457 000 EUR per year under the high scenario (Table 5). The impact on the Danish fleet is projected to be smaller, with a reduction in GVA ranging from 46 000 to 107 000 EUR per year, while the impact on the Finnish fleet is relatively minor, ranging from 4 000 to 9 000 EUR per year.

Table 5. Estimated decrease in Gross Value Added (GVA) per year for Swedish, Danish and Finnish Fleets under Low and High Scenarios in the Central Baltic Sea.

Country	Low scenario	High scenario
SE	196 000 EUR	457 000 EUR
Margin of error +/-	46 000 EUR	107 000 EUR
DK	23 000 EUR	55 000 EUR
Margin of error +/-	5 000 EUR	13 000 EUR
FI	4 000 EUR	9 000 EUR
Margin of error +/-	1 000 EUR	2 000 EUR

Furthermore, displacement of fishing effort as a direct consequence of the proposed measures may increase exploitation and fishing mortality in areas outside the proposed study area. Dependence of the proposed study area and the anticipated effects of displacement are expected to vary depending on the annual decision of fishing opportunities for pelagic stocks within the management area. Furthermore, the ratio between annual fishing opportunities of herring and sprat is expected to influence fishing patterns and fishing activities within the area. In 2024, the total fishing opportunities for herring in the Central Baltic Sea was reduced by 43 percent, corresponding to 40 368 tons. This reduction will probably alter fishing pattern and result in a more pronounced fishery targeting sprat, in areas outside the proposed study area. This conclusion is supported by biological sampling on board Swedish vessels in the pelagic fishery. Results from 24 fishing trips and 145 individual hauls indicates a differentiation in distribution between herring and sprat. Individual hauls dominated by herring occurs exclusively within 12 nautical miles from the Swedish base line, also including hauls inside the proposed study area (Bergenius Nord et al. 2023).

It is anticipated that the Swedish fleet segment of vessels below 24 meters length over all, using towed gears, and not fishing for the use of direct human consumption will face more profound economic consequences. These vessels may not have the same ability to reallocate their fishing to areas outside the study area. The average total landing of these fleet segment is 3 570 tones, corresponding to about 14 percent of the total annual landing in the study area (2019-2021). Historical landings for the use of direct human consumption have been negligible and the economic consequences for this fleet are therefore expected to be significant within the time frame of the scientific project.

11 Control and enforcement

In order to enable effective monitoring and control of the study areas a requirement for the use of AIS class A (AIS-A) transponders that transmit position, speed, course etc., is proposed for all commercial fishing vessels that fish for pelagic stocks with towed gear. The AIS-A transponders transmit detailed real-time information by VHF radio, depending on the speed of the vessel multiple times per minute. The radio signals are picked up by operators and are forwarded to fisheries authorities. In accordance with Article 10 of the Control Regulation (EC) No 1224/2009 Member States shall ensure that data from AIS for fishing vessels flying their flag are available to their national fisheries control authorities.

AIS is mandatory for EU fishing vessels above 15 meters and VMS for fishing vessels over 12 meters. In this proposal, all commercial fishing vessels that fish for pelagic stocks with towed gear (including those below 15 metres) are required to transmit AIS-A reports. The AIS-A has to be functioning, turned on and transmitting positioning data during the whole trip if the vessels at some point during a trip is present in the study areas. In the case of malfunctioning of the AIS-A system the master/captain shall immediately inform the fisheries monitoring centre of the flag Member State. The flag Member State is required to inform the coastal state of any malfunctioning of the AIS-A of their vessels.

The rationale for the requirement of using AIS-A is to enable effective and appropriate monitoring of all vessels, including vessels less than 12 meters fishing for pelagic stocks with towed gear, by the use of position reporting at high frequency.

While entering the study areas all vessels above 24 meters with prohibited gears carried on board should be lashed and stowed during the transit and the speed during transit should not be less than six knots, except in case of force majeure or adverse conditions. In such cases, the master shall immediately inform the fisheries monitoring centre of the flag Member State which shall then inform the competent authorities of the coastal Member State.

11.1 Compliance

Compliance, i.e., the level of adherence to regulations, can be assessed by detecting infringements either in post-landings or in real time. Within fisheries control, both methods are often used (inspection at sea/landing and administrative control of reported logbooks etc.). By using AIS-A for monitoring, the position of the vessels can be determined both post landing and in real time. Even though AIS-A reports does not contain information of fishing activity the change of speed and course of the vessel can be analysed to detect if a vessel is setting or hauling a gear.

11.1.1 Detecting fishing activity with the use of AIS-A

In addition to using AIS-A for monitoring of the position of fishing vessels, SwAM has developed an analytic method that can detect if trawling activity occurs. By combining the speed and the direction of the vessel from the AIS-reports, the time and position of settings and hauls of the trawl can be detected. This information is compared with the haul as recorded in the electronic logbook. By using the analysis, it is in most cases possible to determine whether trawling occurs in a marine protected area (in close to real time), whereby infringements can be detected. The possibility to identify and detect if trawling activity occurs within the study areas will also facilitate monitoring and compliance of proposed derogation for vessels less than 24 meters of length overall that fish pelagic stocks for direct human consumption, using towed gears with a mesh size of 32 mm or more and whose landing shall be sorted.

11.1.2 Targeted sea inspections

Analysing haul tracks will also provide the possibility to identify risk objects, i.e., vessels with deviating fishing patterns. These risk objects in turn can constitute the basis for targeted sea and air borne surveillance and inspection activities at sea.

11.1.3 Administrative control

As soon as haul details are reported in the electronic logbook it is also possible to cross-check these data with vessel position data in order to obtain haul tracks. Within an administrative control process, logbook errors or infringements can be detected by analysing the haul tracks with the method described above.

12 Experimental set-up and monitoring of the scientific project

The experimental set up will be finalized by the beginning of 2024. In general, parameters will be monitored in six different work packages (1) Abiotic information; (2) Pelagic fish (herring, sprat and stickleback); (3) Genetics and otolith chemistry; (4) Pelagic fisheries (5) Seals and cormorants; (6) Other ecosystem effects. In addition to this general set-up, the socioeconomic consequences for the fisheries and the fish processing sector will be analyzed throughout the study period. The experimental set-up and monitoring program will be designed to detect the effects of the spatial fisheries management measures and increase the knowledge about herring population structure.

Already existing time series of monitoring data will also be used when appropriate. The short time frame of the scientific project requires specific monitoring of such parameters that could show a rapid response in relation to the planned measures. The scientific reference group assigned to the project, has recommended a special focus on changes in stock structure as indicated by monitoring of genetic markers, along with more traditional stock parameters, such as abundance, size and age structure.

12.1 Effects on population structure: Genetics and otolith chemistry

This work package will describe changes in relative abundance of possible sub-populations or groups of individuals which can be distinguished by genetic methods. This work package will also contribute to methodological developments within the field of fish population genetics in general, and Baltic Sea herring genetics in particular.

More recent studies on herring population genetics in the Baltic Sea indicate a complex genetic structure. However, the genetic differences are generally small and it is important to advance methodologies and increase the precision of genetic analysis. However, genetic differences have already been established between spring- and autumn spawning herring in the Baltic Sea (Han et al. 2020). Furthermore, a distinct local herring population in the Bothnian Sea has also been identified. During earlier studies of herring genetics, partly as a preparation of this scientific project, a sampling and sequencing protocol has been established for spawning populations along the Swedish coast. Sample sizes of 25-50 individuals are sufficient to capture and describe the genetic variation between sampling sites. SwAM and SLU Aqua in cooperation with scientists at Uppsala University are identifying possible genetical markers during autumn 2023 in order to monitor changes in genetic stock structure and groups of individuals. The biological material will be collected through sampling in the work package for “pelagic fish” (see 12.2 for details).

Otolith chemistry will be used to assess differences in migration patterns between sampling sites. As shown in other Baltic Sea species such as cod it is possible to identify distinct chemical “finger prints” for different sub-populations, or groups of individuals, based on their homing behavior and foraging areas etc. in which produces distinct chemical traces in the otoliths. For example, analyzing the levels of both strontium and barium could assess and identify differences among sub-populations or groups of individuals. Otoliths will be collected from several locations, representing both spring- and autumn spawning herring, and possibly more genetically distinct local sub-populations.

12.2 Pelagic fish

This work packages intends to monitor the effects of the spatial fisheries management measures for all dominant pelagic fish species in the Central Baltic Sea and the Bothnian Sea. The government assignment specifically requests an analysis of the effect on other fish species besides herring. In line with these demands, also sprat and stickleback will be included in the sampling. Samples of pelagic fish will be collected during spawning, wintering and pre-spawning, both inside and outside the proposed study areas. The monitoring set-up will be similar for both study areas in the Central Baltic Sea and in the Bothnian Sea. Four different monitoring methods will be used in conjunction, and consist of multimesh gill nets, hydroacoustic (by the research vessel Svea), extended logbooks and biological sampling, as well as onboard self-sampling by commercial trawling vessels. Monitoring schemes will be different between coastal areas and offshore areas. Gillnet samplings and hydroacoustic could be combined in coastal areas, whereas off shore areas are only suitable to monitoring by hydroacoustic and trawling.

Gillnet samplings will be used to describe the coastal fish communities. Abundance and biomass will be expressed as catch per unit effort. Sampling will be made both in reference areas, where sampling has been conducted in the past, as well as in new sampling areas in relevant parts of SD 27, 29 and 30. Small-scale fisheries could also provide additional sampling in the form of extended logbooks, in combination with onboard biological sampling.

Data gained by hydroacoustic monitoring with BIAS and SPRASS will be used to analyze the development of species abundance and size distributions in the open sea in SD 27, 29 and 30. Historical trends will be complemented by acoustic monitoring inside and outside the proposed study areas. The acoustic monitoring will follow agreed standards within DCF/BIAS. Sampling might be combined with the use of drones or a wideband autonomous transceiver (WBAT) in parallel to the acoustic monitoring by the research vessel Svea. These autonomous devices could intensify sampling in certain coastal areas or delimited offshore areas.

12.3 Monitoring of pelagic fisheries

This work package intends to monitor changes in pelagic fisheries. The spatial fisheries management measures introduced by this scientific project will by necessity alter the pelagic fishing patterns in the waters surrounding the study areas. This means that some areas might be more heavily fished than they used to be, also depending on the overall fishing opportunities for each respective management area. The resulting fishing effort displacements are difficult to foresee and need to be monitored extensively. The monitoring of all major fisheries needs to include effort, catches and bycatches and biological sampling of individuals fish in the catches. The latter one will be combined with sampling described in 12.1.2.

12.4 Abiotic information

Abiotic information is needed to support the interpretation of the results and parameters such as temperature, salinity, pH levels, dissolved oxygen levels, turbidity and nutrient concentrations are continuously monitored in the Baltic Sea. Some additional measurements of abiotic parameters inside the proposed study areas might also be needed, depending on the location of sampling sites within already existing monitoring programs.

12.5 Effects of seals and birds

Natural predation will also be monitored within the project. SwAM is already conducting monitoring of seals, including collections of diet samples, in order to assess the effects of license hunting along the Swedish coast line. This sampling will be incorporated in the monitoring program of the government assignment. It includes the monitoring of seal movements, changes in distribution patterns in known colonies, as well as estimates of population size and biological sampling, like size of individuals, screening for diseases, blubber thickness and diet samples.

12.6 Other ecosystem effects

The monitoring program will include an integrated ecosystem analysis to connect the different work packages. Initially three different studies are planned, one focusing on coastal ecosystems in the Bothnian Bay and the Central Baltic Sea, another one focusing on offshore areas and a third, with the aim to connect the coastal and the offshore study. The coastal study will include the observed regime shifts in these areas during the last decade, described by decreases in predatory fish species while planktivores such as stickleback have increased in numbers, resulting in a loss of habitat-forming vegetation (Donadi et al. 2017, Eklöf et al 2020). To evaluate the effects on the coastal ecosystem an extensive field survey of the coastal food web will be conducted, combined with spatiotemporal statistical modelling. The off shore study will be conducted in cooperation with the Helcom Expert group on Food webs (EG FOOD WEB). Combining existing data with monitoring data from this scientific project, could provide for an integrated trend analysis (ITA), coupled with generalized additive models. Both the coastal and offshore studies will be used to update or generate new ecosystem models. For Swedish waters, the EwE (Ecopath with Ecosim) models are currently available for the open Central Baltic Sea and the Kattegat. SLU Aqua is planning to develop a full EwE model for the open sea in the Gulf of Bothnia ecosystem in collaboration with Finland. This work will progress over the years 2024-2025 and is led by The Finnish environment institute (SYKE) and Åbo Akademi University.

12.7 Socioeconomic effects

Knowledge regarding socioeconomic effects, as well as the economic and social consequences for the fisheries and the fish processing sector will be generated during the project. Luleå University of Technology is conducting a study with the aim of mapping how Swedish catches are utilized in different regional herring fisheries. This involves aspects such as the catch quantities sold for further processing in other companies and the amount used by fishermen themselves in other business activities. The study will not only look at the added value from herring fishing but will also examine the regional economic ripple effects generated by these activities. The result of the study will be used as a baseline to monitor changes in economic parameters for the duration of the scientific project. Implementation of the proposed spatial fisheries management measures will result in altered fishing patterns for vessels over 24 meters that would normally operate within the proposed study areas. Economic effects on this segment will be evaluated through analyses of economic data throughout the project implementation.

To better understand the socio-economic effects, it is Central to examine the significance of herring by mapping out the ecosystem components and ecosystem services in relation to the herring stocks. As part of Sweden's Action Program for the Marine Environment in accordance with the Marine Environment Ordinance (2010:1341), the development of a regional ecosystem-based marine management is ongoing in three pilot areas, two of which Stockholm Archipelago and Southern Bothnian Sea are connected to the proposed study areas. Various methods for mapping the ecosystem are being developed within the project, which will contribute to better understanding of the socio-economic effects of the implemented measures. Stockholm University has conducted a study using conceptual models for the ecosystem in the Stockholm Archipelago, focusing on the role of herring in the ecosystem. Models have been developed in collaboration between fishing stakeholders and researchers, where a joint model is presented, offering a comprehensive view of both stakeholder knowledge and the state of research.

SLU Aqua, in collaboration with Stockholm University, is conducting a mapping of marine ecosystem services, which is expected to provide a comprehensive picture of the potential supply of ecosystem services in the Southern Bothnian Sea and Stockholm Archipelago. Both these studies will be published in early 2024 and will form the basis for the continued mapping of ecosystem services and socioeconomic effects related to herring that will be ongoing during the project implementation.

13 References

Aneer, G. 1989. Herring (Clupea harengus L.) spawning and spawning ground characteristics in the Baltic Sea. Fisheries Research 8, 169-195.

Aro, E. 1989. A review of fish migration patterns in the Baltic. Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer 190: 72-96.

Aro, E. 2002. Fish migration studies in the Baltic Sea—a historical review. In ICES Marine Science Symposia 215, 361-370.

Bartolino, V., Margonski, P., Lindegren, M., Linderholm, H.W., Cardinale, M., Rayner, D., Wennhage, H., Casini, M., 2014. Forecasting fish stock dynamics under climate change: Baltic herring (Clupea harengus) as a case study. Fish. Oceanogr. 23, 258–269. https://doi.org/10.1111/fog.12060.

Bailey, K. M. & Houde, E. D. 1989. Predation on Eggs and Larvae of Marine Fishes and the Recruitment Problem. Adv. Mar. Biol. 25, 1–83.

Bergenius Nord, M., Valentinsson, D., Hjelm, J., Ringdahl, K., Prista, N., Wennerström, L., Bergström, U. and Gilljam, D. 2023 Beställning TAC Östersjön, korrigerande åtgärder för sill. SLU.aqua.2023.5.4-337

Bergström, L. Karås, P. Modin, J. 2006. Biologiska förändringar hos strömming vid Forsmark och i Bottenhavet. Fiskeriverkets Kustlaboratorium, Öregrund.

Beyer J.E., Lassen H. 1994. The effect of size-selective mortality on the size-at-age of Baltic herring, Dana, vol. 10 (pg. 203-234).

Blaxter, J. H. S. and J. R. Hunter 1982 - The biology of clupeoid fishes. Adv. Mar. Biol. 20: 1-223.

Cardinale, M., Arrhenius, F., 2000. Decreasing weight-at-age of Atlantic herring (Clupea harengus) from the Baltic Sea between 1986 and 1996: a statistical analysis. ICES J. Mar. Sci. 57, 882–893. https://doi.org/10.1006/jmsc.2000.0575.

Cardinale M., Möllmann C., Bartolino V., Casini M., Kornilovs G., Raid T., Margonski P., Grzyb A. 2009. Effect of environmental variability and spawner characteristics on the recruitment of Baltic herring Clupea harengus populations. Mar. Ecol. Prog. Ser. 388: 221-234.

Casini, M., Cardinale, M., Hjelm, J., 2006. Inter-annual variation in herring, Clupea harengus, and sprat, Sprattus sprattus, condition in the Central Baltic Sea: what gives the tune. Oikos 112, 638–650.

Casini, M., Kornilovs, G., Cardinale, M., Möllmann, C., Grygiel, W., Jonsson, P., Raid, T., Flinkman, J. and Feldman, V. (2011), Spatial and temporal density dependence regulates the condition of Central Baltic Sea clupeids: compelling evidence using an extensive international acoustic survey. Popul Ecol, 53: 511-523. https://doi.org/10.1007/s10144-011-0269-2.

Cushing, D. H. 1974. The natural regulation in fish populations. In Sea Fisheries Research (ed. Harden Jones, F. R.) 399–412. Elek Science, London.

Erlandsson M, Fredriksson R, Bergström U 2021. Kartläggning av viktiga uppväxtområden för fisk i grunda kustområden i Östersjön. Aqua reports 2021:17, Sveriges lantbruksuniversitet.

Gilljam, D., Bartolino, V., Bergenius Nord, M., Cardinale, M., Valentinsson, D. 2022. Beställning storleksstruktur strömming i Bottniska viken (SD 30-31). SLU.aqua.2022.5.5.309. Sveriges lantbruksuniversitet.

Green, B. S. (2008). Maternal effects in fish populations. Adv. Mar. Biol. 54, 1–105. doi: 10.1016/S0065-2881(08)0000.

Griffiths, C. A., Winker, H., Bartolino, V., Wennhage, H., Orio, A., & Cardinale, M. (2023). Including older fish in fisheries management: A new age-based indicator and reference point for exploited fish stocks. Fish and Fisheries, 00, 1–20. https://doi.org/10.1111/faf.12789.

Gunnartz U, Lif M, Lindberg P, Ljunggren L, Sandström A, Sundblad G 2011. Kartläggning av lekområden för kommersiella fiskarter längs den svenska ostkusten - en intervjustudie. Finfo 2011:3.

Han F., M. Jamsandekar, M. E. Pettersson, L. Su, A. P. Fuentes-Pardo, B. W. Davis, D. Bekkevold, F. Berg, M. Casini, G. Dahle, E. D. Farrell, A. Folkvord, L. Andersson. 2020. Ecological adaptation in Atlantic herring is associated with large shifts in allele frequencies at hundreds of loci. eLife 9: e61076.

Hannerz, L. 1956. Preliminary results of the herring investigations in the Bothnian Sea 1954. Annales Biologiques du Conseil International pour l'Exploration de la Mer, 11:156-158.

Hansson, S., Bergström, U., Bonsdorff, E., Härkönen, T. 2018. Competition for the fish - fish extraction from the Baltic Sea by humans, aquatic mammals, and birds. ICES Mar Fish Sci 75:3, 999-1008.

HELCOM (2023): State of the Baltic Sea. Third HELCOM holistic assessment 2016-2021. Baltic Sea Environment Proceedings n°194.

Hjort, J. 1914. Fluctuations in the great fisheries of Northern Europe - viewed in the light of biological research. Rapp. P.-v. Réun. Cons. Int. Explor. Mer. 20, 1–288.

Huse, G., Fernö, A., Hols, J. C. 2010. Establishment of new wintering areas in herring co-occurs with peaks in the 'first time/repeat spawner' ratio. MEPS 409: 189-198.

ICES, 2009. Report of the Herring Assessment Working Group for the Area South of 62 N, 17-25 March 2009. ICES Headquarters, Copenhagen. 648 p.

ICES. 2021. Herring (Clupea harengus) in subdivisions 25-29 and 32, excluding the Gulf of Riga (central Baltic Sea). In Report of the ICES Advisory Committee, 2021. ICES Advice 2021, her.27.25-2932. https://doi.org/10.17895/ices.advice.7767.

ICES Advice 2023a – her.27.25-2932 – https://doi.org/10.17895/ices.advice.21820506

ICES Advice 2023b – her.27.3031 – https://doi.org/10.17895/ices.advice.21820521

Kaljuste, O., Blass, M. och Söderberg, K., (2009). Research report from the Bothnian Sea spring survey (Vårsurvey, 16–25.03.2009), Fiskeriverkets Kustlaboratorium, 19 pp.

Kallasvuo, M., Vanhatalo, J., & Veneranta, L. 2017. Modeling the spatial distribution of larval fish abundance provides essential information for management. Canadian Journal of Fisheries and Aquatic Sciences 74, 636-649.

Karlson, A.M.L., Gorokhova, E., Gårdmark, A. 2020. Linking consumer physiological status to food-web structure and prey food value in the Baltic Sea. Ambio 49, 391–406.

Kornilovs, G., Sidrevics, L., Dippner, J.W. 2001. Fish and zooplankton interaction in the Central Baltic Sea. ICES J. Mar. Sci. 58, 579–588. https://doi.org/10.1006/jmsc. 2001.1062.

Kulatska, N., Woods, P. J., Elvarsson, B. Þ., and Bartolino, V. Size-selective competition between cod and pelagic fisheries for prey. – ICES Journal of Marine Science, 78: 1900–1908.

Kääriä, J., Rajasilta, M., Kurkilahti, M., Soikkeli, M. 1997. Spawning bed selection by the Baltic herring (Clupea harengus membras) in the Archipelago of SW Finland. ICES J. Mar. Sci. 54: 917–923.

Laine, P. & Rajasilta, M. 1999. The hatching success of Baltic herring eggs and its relation to female condition. J. Exp. Mar. Biol. Ecol. 237: 61-73.

Lindegren, M., Östman, Ö., Gårdmark, A. 2011. Interacting trophic forcing and the population dynamics of herring. Ecology 92, 1407–1413.

Margonski, P., Hansson, S., Tomczak, M.T., Grzebielec, R., 2010. Climate influence on Baltic cod, sprat, and herring stock-recruitment relationships. Prog. Oceanogr. 87, 277–288. https://doi.org/10.1016/j.pocean.2010.08.003.

Moll, D., Kotterba, P., Jochum, K. P., von Nordheim, L., Polte, P. 2019. Elemental inventory in fish otoliths reflects natal origin of Atlantic herring (Clupea harengus) from Baltic Sea juvenile areas. Frontiers in Marine Science, 6, 191.

Moyano, M., Illing, B., Peschutter, P., Huebert, K. B. and Peck, M. A. 2016. Thermal impacts on the growth, development and ontogeny of critical swimming speed in Atlantic herring larvae. Comp. Biochem. Physiol. A Mol. Integr. Physiol. 197, 23–34, doi: 10.1016/j. cbpa.2016.02.020 (2016).

Möllmann, C., Kornilovs, G., Fetter, M. and Köster, F.W. 2004. Feeding ecology of central Baltic Sea herring and sprat. Journal of Fish Biology, 65: 1563-1581. https://doi.org/10.1111/j.0022-1112.2004.00566.x.

Nilsson, L., Thygesen, U., Lundgren, B., Nielsen, B., Nielsen, J., Beyer, J. 2003. Vertical migration and dis-525 persion of sprat (Sprattus sprattus) and herring (Clupea harengus) schools at dusk in the Baltic Sea.526 Aquatic Living Resources 16:317–324.

Otterlind, G. 1957. Från strömmingsmärkningarna på ostkusten (Tagging of herring in the East coast). Ostkusten (East Coast), 3:24-30.

Ojaveer, E. 1981. Marine pelagic fishes. In The Baltic Sea. Elsevier Oceanography Series No. 30, pp. 276-292. Ed. By A. Voipio. Elsevier Scientific Publishing Company, Amsterdam-Oxford-New York.

Ojaveer, E., 2003. Baltic herring, Clupea harengus membras L. In: Fishes of Estonia, pp. 58-79. Editors Ojaveer, E., Pihu, E., Saat, T. Estonian Academy Pub.

Parmanne, R., and Sjöblom, V. 1986. Recaptures of Baltic herring tagged off the coast of Finland in 1982-85. ICES CM 1986/J:28. 12 pp.

Parmanne, R. 1990. Growth morphological variation and migrations of herring (Clupea harengus L.) in the northern Baltic Sea. Finnish Fisheries Research 10: 1-48.

Peck, M. A., Kanstinger, P., Holste, L., and Martin, M. 2012. Thermal windows supporting survival of the earliest life stages of Baltic herring (Clupea harengus). – ICES Journal of Marine Science, 69: 529–536.

Pécuchet L., Nielsen J.R., Christensen A. 2015. Impacts of the local environment on recruitment: a comparative study of North Sea and Baltic Sea fish stocks. ICES J. Mar. Sci. 72: 1323-1335.

Polte, P., Kotterba, P., Moll, D. and Von Nordheim, L. 2017. Ontogenetic loops in habitat use highlight the importance of littoral habitats for early life-stages of oceanic fishes in temperate waters. Sci. Rep. 7:42709. doi: 10.1038/srep42709.

Rajasilta, M., Mäkinen, K., Ruuskanen, S. Hänninen, J., Laine, P. 2021. Long-term data reveal the associations of the egg quality with abiotic factors and female traits in the Baltic herring under variable environmental conditions. Frontiers in Marine Science; Marine Fisheries, Aquaculture and Living Resources. Doi: https://doi.org/10.3389/fmars.2021.698480.

Rönkkönen, S., Ojaveer, E., Raid, T., Viitasalo, M., 2004. Long-term changes in Baltic herring (Clupea harengus membras) growth in the Gulf of Finland. Can. J. Fish. Aquat. Sci. 61, 219–229. https://doi.org/10.1139/f03-167.

Scharff-Olsen, C. H., Galatius, A., Teilmann, J., Dietz, R., Andersen, S. M., Jarnit, S., Kroner, A.-M., Botnen, A. B., Lundstro¨m, K., Møller, P. R., and Olsen, M. T. 2018. Diet of seals in the Baltic Sea region: a synthesis of published and new data from 1968 to 2013. – ICES Journal of Marine Science, 76: 284–297.

Smoliński, 2019. Sclerochronological approach for the identification of herring growth drivers in the Baltic Sea Ecol. Indic., 101 (2019), pp. 420-431, 10.1016/j.ecolind.2019.01.050.

Svedäng, H., Almqvist, G., Axenrot, T. 2023. A Baltic pelagic fish community revisited: Indications of profound changes in species composition in the Stockholm Archipelago. Fisheries Research 266.

Wennerström, L., Kaljuste, O. & Bergström, U. 2022. Trender i biomassa för strömming i SD 25-20. SLU Aqua.2022.5.5.309.

Wennerström, L., Lundström, K., Andersson, M., Kaljuste, O. and Heimbrand, Y. 2023. Strömming i gråsälens diet i Bottenhavet (SD 30). SLU.aqua.2022.5.4-76

Wennerström, L., Bergenius Nord, M., Adill, A., Bergström. U., Fredriksson. R., Gilljam, D., Heimbrand. Y., Ringdahl. K., Säterberg. T. and Valentinsson, D. 2023. Scientific support for SwAMs government assignment: scientific project corresponding to an extended trawl limit. SLU.aqua.2022.5.2-392

Wennhage, H., Naddafi, R., Mustamäki, N., Orio, A., Bergström, L., Sköld, M., Bergenius, M., Valentinsson, D. & Olsson, J. (2021). Påverkansanalys fisk – till åtgärdsprogram för havsmiljön. Aqua reports 2021:22. Institutionen för akvatiska resurser, Sveriges lantbruksuniversitet (SLU), Lysekil. 81 s.

Östman, Ö., Karlsson, O., Pönni, J., Kaljuste, O., Aho, T. and Gårdmark, A. 2014. Relative contributions of evolutionary and ecological dynamics to body size and life‐history changes of herring (Clupea harengus) in the Bothnian Sea. Evolutionary Ecology Research, 2014, 16: 417–433.

14 Appendix I

14.1 Catches of herring and sprat in tonnes for vessels under 12 meters in study area

All tables are based on VMS data and Swedish logbook data for vessels under 12 meters.

Table A1. Herring and sprat catches in tons for vessels under 12 meters in the study area.

		2019	**2020**	**2021**	**Yearly average**
Herring	Active	555	624	488	556
	Passive	7	12	12	10
Sprat	Active	6	17	202	75
	Passive	0	0	0	0
Total		568	653	702	641

14.2 Value of catches for vessels under 12 meters in the study area

Estimations of the value of catches in the proposed study areas for Swedish vessels under 12 meters are based VMS data and Swedish logbook data. Value of catches have been calculated using Swedish data for landing value from Havsbanken[7]. The landing values has been converted from SEK to EURO using historical data from the Swedish Riksbank[8].

Table A2. Value of catches in euros for vessels under 12 meters in the study area.

Species	**Gear**	**Unit**	**2019**	**2020**	**2021**	**Yearly average**
Herring	Active	ton	555	624	488	577
Herring	Active	EUR/ton	181	192	215	196
Herring	Active	EUR	100 234	119 736	104 800	108 257
Herring	Passive	ton	7	12	12	10
Herring	Passive	EUR/ton	850	863	804	839
Herring	Passive	EUR	6 345	10 055	9 633	8 678
Sprat	Active	ton	6	17	202	97
Sprat	Active	EUR/ton	179	189	208	179
Sprat	Active	EUR	1 055	3 190	42 034	15 417
Total		EUR	107 606	132 982	156 468	132 352

[7] https://havsbanken.havochvatten.se/

[8] https://www.riksbank.se/sv/statistik/rantor-och-valutakurser/

14.3 Value of catches for vessels over 12 meters in the study area

Estimations of the value of catches in the proposed study area are based on catch data obtained from the data call. The values of catches have been estimated using historical data from the Scientific, Technical and Economic Committee for Fisheries (STECF). Since only herring catches were specified in the data call, all other catches were assumed to be sprat.

Table A3. Value of catches in euros per country and species in the study area. The values for catches are based on historical landing values for SD 27 and 29.

Country	Species	Unit	2019	2020	2021	Yearly average
DK	HER	ton	1 947	853	1 867	1 556
DK	HER	EUR/ton	220	219	226	222
DK	HER	EUR	302 602	169 960	238 874	237 145
DK	SPR	ton	1 172	891	2 133	1 398
DK	SPR	EUR/ton	224	230	223	226
DK	SPR	EUR	262 743	205 249	475 283	314 425
FI	HER	ton	391	567	81	347
FI	HER	EUR/ton	199	206	206	204
FI	HER	EUR	77 796	116 927	16 798	70 507
FI	SPR	ton	67	209	29	102
FI	SPR	EUR/ton	176	180	180	179
FI	SPR	EUR	11 788	37 626	5 300	18 238
SE	HER	ton	10 192	6 752	6 610	7 851
SE	HER	EUR/ton	471	457	276	402
SE	HER	EUR	4 798 254	3 088 010	1 827 418	3 237 894
SE	SPR	ton	7 628	3 481	6 285	5 798
SE	SPR	EUR/ton	213	276	231	240
SE	SPR	EUR	1 626 713	962 024	1 452 617	1 347 118
Grand total		EUR	7 079 896	4 579 797	4 016 290	5 225 328

Data on the economics of fishing from the STECF: https://stecf.jrc.ec.europa.eu/reports/economic/-/asset_publisher/d7Ie/document/id/41044387

14.4 Estimation of economic impact for vessels over 24 meters

The underlying data for this analysis is based on the work conducted under the EU Data Collection Regulation (EU) 2017/1004. The impact of the proposed measure in the study area is calculated based on the costs per day at sea. These costs are divided into four categories: variable costs, repair and maintenance costs, fuel costs, and labour costs. It is reasonable to assume that all these categories would increase for the specific fishing activities affected by a restriction of trawling areas. These standard costs were derived using linear regression for each cost category per day at sea.

The impact factor has been calculated for each area and is presented as effort (days at sea). This effort needs to be relocated to other areas, resulting in less economically efficient fishing operations. Fishermen will need to spend more time finding new fishing grounds, which may not be as productive as the previous areas. The impact is presented as a percentage increase in effort.

However, quantifying the extent of this impact is challenging due to the many influencing factors. To provide a quantifiable assessment, a scenario analysis was developed to present possible outcomes of a trawling ban within the study area. The scenario analysis includes three different scenarios over a three-year period, resulting in 27 possible outcomes. For simplicity, only three scenarios (low, medium, high) are presented. Table A4 outlines the different scenarios for each year.

Tabell A4. Percentage increase in effort for three scenarios (low, medium, high)

Year	*Scenario*	*Percentage increase in effort*
År 1	Scenario 1	10,0%
	Scenario 2	15,0%
	Scenario 3	20,0%
År 2	Scenario 1	7,5%
	Scenario 2	12,5%
	Scenario 3	17,5%
År 3	Scenario 1	5,0%
	Scenario 2	10,0%
	Scenario 3	15,0%

For simplicity, only three scenarios (low, medium, high) are presented. Each estimated impact is accompanied by a confidence interval derived from the data used in the analysis. The decrease in gross value added was calculated by summing variable costs, repair and maintenance costs and fuel costs. The landing values has been converted from SEK to EURO using historical exchange rates from the Swedish Riksbank[9].

Tabell A5. Estimated decrease in Gross Value Added (GVA) for Swedish, Danish and Finnish Fleets under Low, Medium and High impact scenarios in SD 25-29

Country	**Decrease in GVA per year**	**Margin of error +/-**
SE		
Low impact	195 730 €	45 791 €
Medium impact	326 217 €	76 318 €
High impact	456 704 €	106 846 €
DK		
Low impact	23 488 €	5 495 €
Medium impact	39 146 €	9 158 €
High impact	54 805 €	12 821 €
FI		
Low impact	3 915 €	916 €
Medium impact	6 524 €	1 526 €
High impact	9 134 €	2 137 €

[9] https://www.riksbank.se/sv/statistik/rantor-och-valutakurser

15 Appendix II

A new environmental monitoring program to evaluate the effects of closed areas in the Baltic Sea

Summary

The current project is designed to increase the scientific knowledge regarding herring stocks within the Baltic Sea as a result of the planned extension of the trawl border. The project will evaluate the effect of the proposed fishing regulations on the herring stock biomass, size and age distribution, and the stock structure. Additionally, the project will study the possible migration patterns of herring using cutting edge otolith chemistry analyses, as well as use genetic analysis to study potentially distinct populations. In order to better understand the importance of predation, the project will also study the grey seal and great cormorant populations in the area. With the information obtained on abiotic and biotic dynamics related to water conditions, phytoplankton and zooplankton, coastal fish as well as open sea fisheries and predator interactions the current monitoring program hopes to understand the greater ecosystem effects related to the proposed fishing regulations.

Introduction

The fish populations in the Baltic are monitored along the coast by means of various national surveys, and in the open sea by means of internationally coordinated scientific surveys. There are also comprehensive monitoring programs of commercial fishery catches. SLU is the main performer of monitoring, but the County Administrative Boards also perform such activities. Fish monitoring along the coast is most often undertaken with standardised gillnets, while monitoring in the open sea is done with hydroacoustics (echo sounders) and different trawl gears.

The aim of this biological monitoring program is to detect trends in the different fish populations/stocks, locally or for the whole management areas of populations, as well as to follow the development of fisheries and ecosystem effects. To this end, the fish will be counted, measured, weighed, and aged. Sampling of individuals will also be performed, to study age, growth, condition, sexual maturity, genetics etc.

To be able to monitor the effects of area closures in the Baltic Sea, it is essential to increase our knowledge about different fish populations living there. This commission is focused on Baltic herring's population structure and development, but attention is also paid to other species in the ecosystem that may also be affected by the area closures.

Here we propose a broad monitoring program to follow the effects of extending the trawl border or equivalent measures in certain areas of the Swedish Baltic Coast. The program includes 7 work packages of monitoring and analyses of:

Wp 0. Project leading and operational group

Wp 1. Abiotic information and a screening of invertebrates and phytoplankton

Wp 2. Pelagic fish (herring, sprat, and stickleback)

Wp 3. Genetics and otolith chemistry

Wp 4. Pelagic fisheries

Wp 5. Seals and cormorants

Wp 6. Other ecosystem effects

The different work packages include a description of the main research questions addressed, proposed methods to be used, possible limitations and a total budget for 2024-2027.

WP 0. Project leading including core group

The aim of this work package is to lead and coordinate this multi-year monitoring program. The budget associated with WP 0 will be used to cover the cost of the project leaders' hours required to overall organize and coordinate project staff, budgets and meetings, including those with SWaM and the scientific committee, and compiling reports and summary documents. Included in this work package is also the time required for WP leaders to lead, coordinate and report the work within their respective work packages.

Cost

Work package 0	**Year**				**WP total**
	2024	**2025**	**2026**	**2027**	
Proposed cost	2 078 522	1 862 375	1 816 641	2 016 426	**7 773 964**

WP 1. Abiotic information and a screening of invertebrates and phytoplankton

Introduction

Abiotic variables refer to non-living factors in an environment, and studying and analysing them is crucial for understanding ecosystems. In the case of the Baltic Sea and Bothnian Sea, there are several important abiotic variables to consider. By analysing these, we can gain valuable insights into the health and functioning of the Baltic environment, including the impact these variables have on fish populations and ecosystem dynamics. Furthermore, understanding the effects of abiotic variables is crucial for detecting any changes or disturbances in the Baltic ecosystem. For example, variations in temperature, salinity or dissolved oxygen can directly affect the growth and distribution of organisms.

With biotic variables we refer here to living factors including zooplankton, benthic invertebrates, and phytoplankton which are, similarly to abiotic variables, important for understanding ecosystems. Compared to abiotic data, biotic data are scarce. Thus, the first step will include the screening of available information.

The Baltic Sea is influenced by various abiotic factors that significantly affect its ecology and ecosystem dynamics. Some key abiotic factors impacting the Baltic Sea include:

Salinity: The Baltic Sea is relatively low in salinity compared to other oceans due to the influx of freshwater from rivers and limited connection to the North Sea. Salinity levels vary across different regions of the Baltic Sea, with lower salinity in the northern parts and higher salinity in the south.

Temperature: Seasonal variations in temperature play a crucial role in the Baltic Sea's ecology. The surface temperature fluctuates greatly throughout the year, impacting the distribution and behaviour of marine organisms, as well as influencing nutrient cycling and biological processes.

Nutrient levels: The Baltic Sea experiences issues with nutrient loading, primarily due to excessive inputs of nitrogen and phosphorus from agricultural runoff, industrial activities, and wastewater. These high nutrient levels lead to eutrophication, fostering excessive algal growth and subsequent oxygen depletion in bottom waters, which can result in dead zones with limited oxygen availability for marine life.

Oxygen levels: Oxygen availability in the Baltic Sea is vital for the survival of marine organisms. Eutrophication and stratification of water layers contribute to oxygen depletion in deeper areas, creating hypoxic (low oxygen) or anoxic (absence of oxygen) conditions, which can be harmful to marine life and biodiversity.

pH and acidity: The pH levels in the Baltic Sea can be influenced by a range of factors, including nutrient inputs and climate change. Changes in pH can affect the physiology of marine organisms, particularly those with calcium carbonate shells or structures, such as certain shellfish and planktonic organisms.

Some key biotic factors in the Baltic Sea include:

Phytoplankton

Zooplankton

Benthic organisms

These biotic objects in the Baltic Sea form an essential part of the food web, serving as a primary food source for many marine organisms.

Understanding the interactions between abiotic and biotic factors is vital for comprehending the overall health and functioning of higher trophic levels and the whole Baltic Sea ecosystem. These factors interact in complex ways, influencing the Baltic Sea's ecosystem dynamics, biodiversity, and productivity. Human activities such as pollution, climate change, and overfishing, can exacerbate these factors, leading to ecological imbalances and challenges for the sustainability of the Baltic Sea's marine environment.

Main research questions

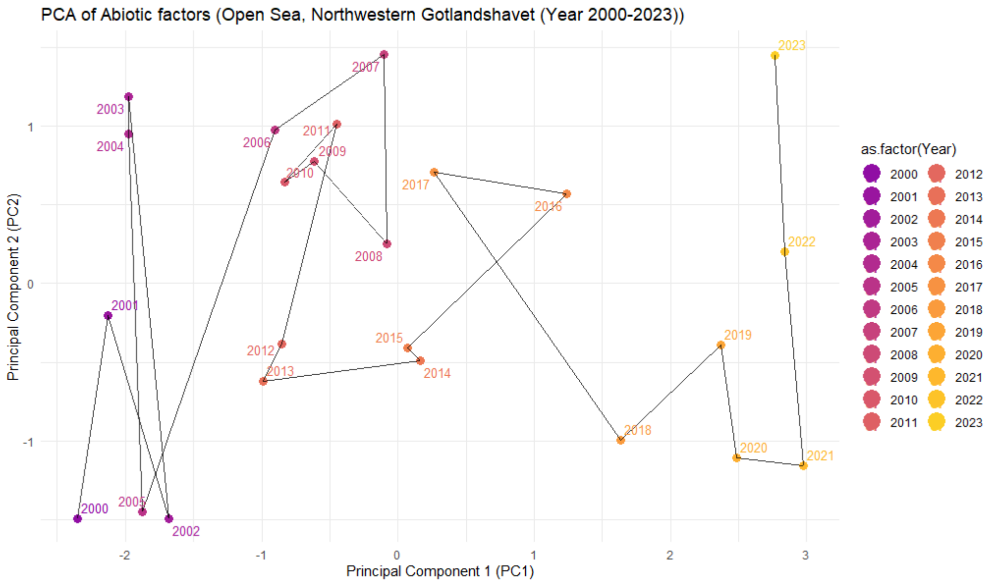
- What is the historical development of proposed abiotic variables inside and outside the closed areas?
- What is the development of the proposed abiotic variables inside and outside the closed areas during the project?
- What is the historical development of proposed biotic variables (zooplankton, phytoplankton, benthic organisms) inside and outside the closed areas?
- What is the development of the proposed biotic variables (zooplankton, phytoplankton, benthic organisms) inside and outside the closed areas during the project?
- Is the development of abiotic and biotic variables correlated?

Methods

Abiotic factors

We suggest two approaches: we will analyse available abiotic information from ongoing monitoring programs (SMHI, Sverige's vattenmiljö and regional monitoring) to determine the development of the abiotic variables in the selected areas over time. The second approach includes additional sampling at the same time as the collection of other biological variables in the designated areas (see other work packages). This will allow us to get information and the development of these variables before and during the project.

Historical development: The first set of analyses of the abiotic factors will include historical development in different years, areas and seasons and a set of graphs and maps produced where potential changes in patterns should be highlighted as well as development. We have grouped these data into open sea stations and costal stations and explored the combined development over time.



Example of combined (PCA) of the open sea stations for the Gotland Sea.

Additional abiotic sampling: The different platforms used during biological sampling including R/V Svea, drones and costal monitoring will be used for additional sampling of abiotic parameters. These sets of data will be compiled and analysed once a year and a set of graphs and maps produced.

Biotic factors

Similarly, to the abiotic factors, we suggest analysing available information from ongoing monitoring programs (SMHI, Sverige's vattemiljö, regional monitoring and Copernicus) to determine the development of these variables in the same areas over time as for the abiotic samples. We have also discussed with SMHI the possibility to collect zooplankton, but not reached any conclusions about additional sampling.

For the first step of analysis of biotic parameters we will use Sverige's vattemiljö for screening phytoplankton parameters (biovolume; phytoplankton, chaetoceros, dinoflagelates, and cyanobacteria). Benthic invertebrates and zooplankton will be also screened in this way to get an overview of available information, but at present we focus on total number of benthic invertebrates and total number of Gammarus. In an analogous way we will screen available information from Copernicus.

Potential limitations and risks

There are no apparent risks with this part of the project.

Cost

Work package 1	**Year**				**WP total**
	2024	**2025**	**2026**	**2027**	
Proposed cost	185 742	191 314	0	202 965	**580 020**

WP 2. Pelagic fish (herring, sprat and sticklebacks)

Introduction

This work package aims at monitoring spatiotemporal changes in the abundance, size and age distribution, body growth, condition, diet and maturity of herring, sprat, and stickleback during spawning, wintering, and pre-spawning, close to the coast (part 1) and offshore areas (part 2). This general approach will therefore be irrespective of how the closed areas are set up.

We propose three different monitoring methods: multimesh gill net sampling, hydro acoustics (on R/V Svea combined with scientific trawling, using a sail drone and an echo sounder) and sampling from onboard commercial fisheries.

Part 1: Coastal Sea monitoring

Main research questions

Do protected areas affect the herring stocks and if so, are changes seen in abundance (assessed via catch per unit effort (CPUE)) and size structure before and after the regulations are implemented?

What are the long-term changes in herring stocks surveyed in coastal areas such as the Forsmark area? Are differences seen in the CPUE and size structure between historical surveys and the current sampling?

Methods

Gillnet sampling

Gillnet sampling with multimesh gillnets in coastal areas aims to describe the entire fish community in the investigated area, with respect to species composition and relative abundance of species, expressed as number and/or weight per fishing effort. We will focus on herring, sprat, and stickleback, but will sample the entire fish fauna from the catches.

At present there is an ongoing sampling program in SD 27 where we will extend the biological sampling to herring, when and if herring is caught in the ongoing surveys. We propose to resume the historical sampling program in the Forsmark area where 6 stations are fished for one night on five occasions, week 17, 19, 21, 23, 25, during which time herring is expected to migrate to the coast for spawning. Data from this survey will be compared to similar surveys conducted in the 1970’s, and also in 2022 and 2023. A similar survey has been conducted in the Åland archipelago in the 1970’s and in 2022. If a collaboration can be established with the Åland

Government Bureaeu of Fisheries, that survey could also be included as a reference area to the Forsmark area.

Potential limitations and risks

Gillnet sampling only covers a very limited spatial area and general conclusions for a larger area may be limited.

Methods

Fish monitoring via commercial coastal fishing vessels

In order to follow the development of herring CPUE, size and age distribution, and maturity inside and outside designated areas over the course of the experiment, we suggest the use of extended logbooks for small-scale commercial coastal fishing vessels in combination with biological sampling. This method builds upon the assumption that a restricted, small-scale fishery is allowed (and we strongly suggest that it is allowed on scientific quotas) inside the trawl limit. We propose that fishermen who fish herring over multiple months along the coast in SD 27, 29 and 30 are contracted to log fishing efforts and catches of herring in their fisheries. This approach would result in measurements of CPUE in several locations along the coast and at various times during the year.

We will also collect a subset of individuals from the commercial catch for analyses of biological parameters.

Potential limitations and risks

A reliable and consistent measure of effort might be difficult depending on how the fisheries are conducted along different parts of the coast.

Part 2: Open Sea monitoring

Main research questions

The general aim is to assess whether there have been any changes over time (the last 20 years) regarding herring, sprat and sticklebacks during different seasons inside and outside the closed areas.

With closed areas, we expect:

- Greater number of herring (total/coast)
- Larger average size of herring (offshore/coast)
- Decreased WAA (weighted age analysis) for herring (offshore/coast)
- Decreased condition of herring due to potential increase in competition (offshore/coast)

- Decreased growth of herring due to potential increase in competition (offshore/coast)
- Lower abundance of sticklebacks (total/coast)
- Lower abundance of sprat (total/coast)

In addition, we will follow up on the development of all three species in relation to the thermocline and halocline, as well as their diet in different areas and seasons, both as a function of the closed areas. We will also follow the development of sprat in SD 30.

Methods

This part is divided into two fields; analysing available acoustic data from BIAS and SPRS from R/V Svea (and partly from acoustics from the sail drone used in the Stora Karlsö research area) and using innovative platforms including acoustic sail drones.

Analysing historical acoustic data

Available acoustic data from both BIAS, SPRAS and the Stora Karlsö research area will be used to analyse the past spatial and temporal development of species abundance and size distribution in the open sea in SD 27 and SD 29. This analysis will give us a measure of variability in the past data and the historical development over time. The analysis will also focus on whether there are differences in species abundance and size distribution as a function of distance from the coast, and as a function of depth and season.

Potential limitations and risks

There are no apparent risks related to this method, however there are potential limitations based on the quality of the historical data.

New acoustic monitoring using R/V Svea (RUAS)

We will use the existing acoustic surveys in the Baltic and extend them with extra sampling days (RUAS). The BIAS quarter one (Q1) and quarter four (Q4) will be extended 4 days in order to gather additional data for the current project. The design will be a transect close to the coast (inside the trawl border) from Västervik to Finngrundet and back (outside the trawl boarder, see Fig. 1). The SPRAS survey will be extended 2 days and cover SD 27 and SD 29. Similarly, BIAS will be extended with one day. For these two last surveys, the design will be slightly different with a zig-zag pattern along the coast surveying coastal and open sea habitats (see Fig. 1). Sampling (trawling) will take place in comparable way as during BIAS and SPRAS, but due to the limited number of available days the numbers of trawl hauls will be fewer.
This monitoring task will give information on abundance, spatial distribution and biological information including size distribution, age distribution, growth, condition, diet, and maturity. The trawl samples can also be used for genetics and otolith chemistry.

a) b)

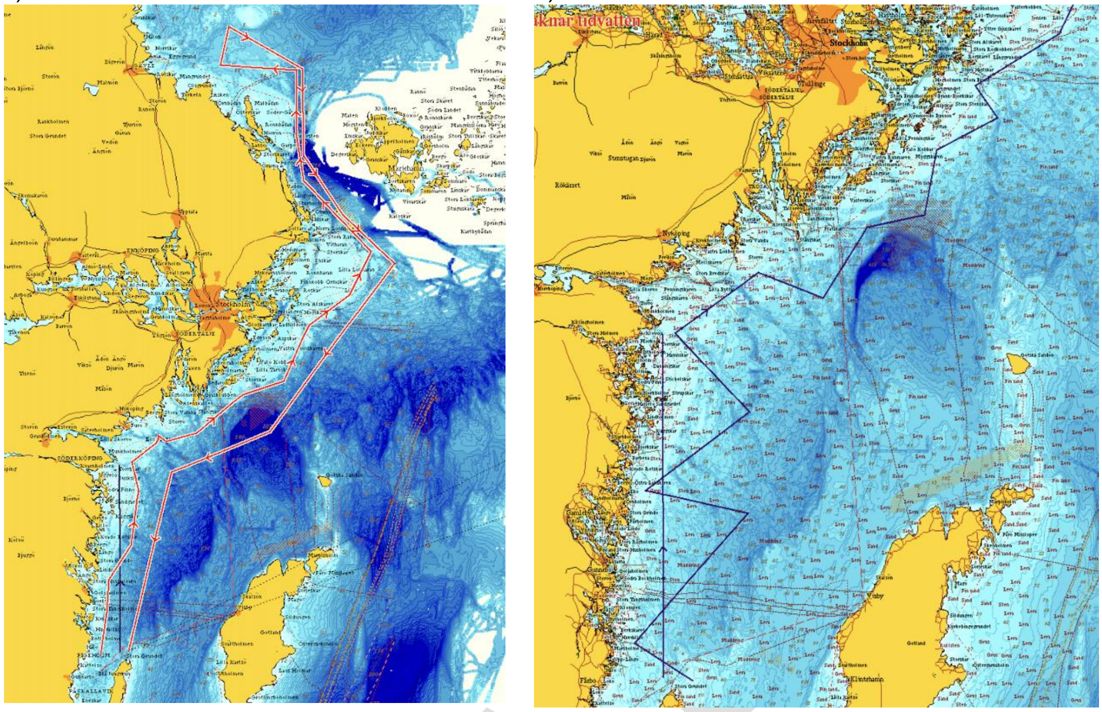


Figure 1. Proposed routs with R/V Svea. a) Rout during BITS Q1 and Q2 and b) during SPRAS and BIAS.

Potential limitations and risks

These surveys are weather dependent and therefore some areas may be inaccessible at the time the survey is scheduled. There is also the risk that the running costs for being on board R/V Svea will increase beyond the proposed budget which would lead to a reduction in the number of survey days possible.

Innovative acoustic platforms

The acoustic monitoring in the open sea with R/V Svea will be supplemented with acoustic monitoring performed by sail drones (see text above). The sail drones will be used in two primary areas (Fig 2). One in the southern SD27 in the area outside Västervik and one around Finngrundet in SD 30. The areas are used to complement the gill-net survey at the coast in the same areas (part 1). We will use the sail drone that we presently have and purchase another within the project. Using the sail drone has the disadvantage of not collecting samples of fish which means that biological samples need to be collected with other methods (this will be covered by sampling onboard R/V Svea and commercial vessels, as well as coastal sampling).

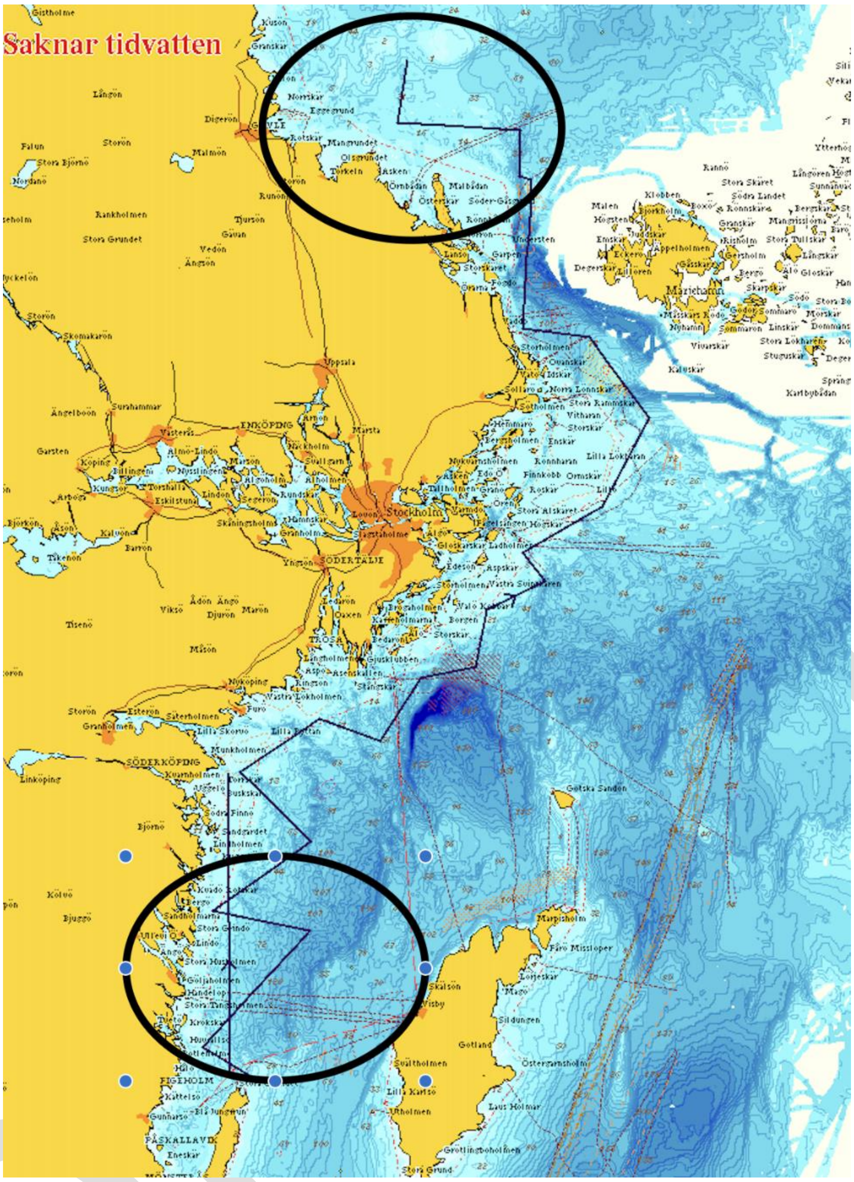


Figure 2. The two primary areas in SD 27 and SD 30.

When possible, we will also use a combined real-time fish echo sounder and fish imagery data sensor that can be used to count fish (Deep vision) with an embedded algorithm and functionality for automatic identification of species and size. This instrument will, in combination with a traditional fish echo sounder, be used to reduce catches (over-extraction) in our trawl surveys.

Potential limitations and risks

Acoustic data can be limited by the quality of the data coming in based on where in the water column the fish are detected, with fish closer to the sea floor more difficult to identify. There is a potential risk of the technology failing or for the sail drone to be damaged.

Cost

Work package 2	Year				WP total
	2024	**2025**	**2026**	**2027**	
Proposed cost	7 005 870	7 768 781	7 943 246	8 510 246	**31 228 142**

WP 3. Genetics and otolith chemistry

Introduction

The combination of genetics and otolith chemistry is an approach that gives the opportunity to study population structure at a specific point in time (genetics) and also migration patterns and habitat choice over an extended period of time (otolith chemistry). Together, the methods have the potential to describe and explain stock structure, which is crucial background information for designing fisheries regulations.

Main research questions

What is the genetic structure of spawning populations in the Baltic Sea?
To what geographic extent can populations be identified?
Do protected areas affect population segments/subpopulations differently?
What subpopulations are targeted in the fisheries?
Can otolith chemistry and migratory behavior identify sub-populations of Baltic herring?

Genetics

The emerging picture of population genetic patterns of herring in the Baltic Sea suggests a complicated genetic structure with small genetic differences among geographic areas, as well as a small number of local populations with unique genetic signatures. The most obvious pattern is clear genetic differences between spring- and autumn spawning herring. These two groups are readily identifiable with genetic methods and the genetic differences are large enough that a single individual should be possible to assign as either a spring- or autumn spawner with high accuracy. Preliminary data indicate that within spring spawning herring individuals could be assigned to sea basins, i.e. Bothnian Bay, Bothnian Sea, Central Baltic Sea, with reasonable accuracy.

During initial studies of herring genetics of spawning populations along the Swedish coast, a sampling and sequencing protocol has been established. Sample sizes of 25-50 individuals are sufficient to capture genetic variation. Samples have been sequenced using the MultiFish SNPChip_1.0 array developed in collaboration between Leif Andersson's lab at Uppsala University and Identigen Ireland. The array consists of c 4000 markers that have been selected based on previous data to show maximum differentiation among North Atlantic and Baltic Sea herring populations (e.g. Han et al. 2020). The array is used for herring stock identification on the west coast (distinguishing western Baltic herring from North Sea herring) and has been suggested as a valuable common tool for herring stock identification in order to make results comparable among countries and institutes (Report from Ices WKSIDAC, not published).

Otolith chemistry

Studies of otolith chemistry on Baltic Sea herring are still in the pilot stage. Otoliths will be studied from a number of locations where we hope to capture both spring- and autumn spawning herring and local populations. We will also sample herring caught in the pelagic during scientific surveys. Trace elemental concentrations will be analysed along a line transect from the core to the edge of the otolith with the aim to identify distinct chemical "finger prints" for the different herring populations. Using a discriminant analysis of individual fish, the chemical fingerprints in the core of the otolith can be used to identify to what degree fish caught in the pelagic can be assigned to spawning populations at the coast.

By identifying the level of trace elements such as strontium and barium over the course of the life of individuals, fish migration patterns can be identified and differences among subpopulations can be inferred.

Results from genetic studies and studies of otolith chemistry should be viewed primarily as a prerequisite and a rationale for designing spatial fisheries regulations, rather than a method to follow up effects of such regulations. However, there is a possibility that regulations might have an effect on the relative frequency of spawning components, e.g. spring- and autumn spawners, which can be followed up using genetic methods.

We suggest completing ongoing studies of genetic structure on spawning populations of herring, studies of genetic variation of herring caught in the pelagic fisheries and pilot studies on otolith chemistry on spawning herring populations and pelagic herring from scientific surveys in order to, as far as possible, create a baseline for herring population genetic structure and migration patterns in the Baltic Sea and the Gulf of Bothnia (SD 25-31). Further, we propose ongoing sampling from scientific surveys and commercial catches within and outside the study areas to follow potential temporal patterns in the genetic diversity on both coastal spawning grounds and offshore feeding areas.

In order to increase the understanding of stock structure in the Baltic Sea and Gulf of Bothnia and identify and follow populations genetically, samples from the entire Baltic Sea are vital. Spawning samples from the Finnish coast, Estonia, Lativa, Lithuania, Poland and Germany would be highly valuable.

Possible outcomes

To be able to follow the relative frequency of spring- and autumn spawning herring in pelagic surveys in- and outside of trial areas by means of genetic assignment. Potential effects of the scientific experiment: If the regulations affect spring- and autumn spawning herring differently there might be an effect of the scientific experiment on the relative frequency of spring- and autumn spawning herring. The likelihood of detecting a change in relative frequency of spring- and autumn spawning herring is low within the short time frame of the experiment.

This WP will aid in increasing knowledge of migration patterns inferred by otolith chemistry in different parts of the Baltic Sea and Gulf of Bothnia. The scientific experiment is expected to have little or no effect on these patterns.

This WP will also enable us to detect temporal patterns of genetic composition in coastal and pelagic samples. The scientific experiment, i. e. a change in fishing pressure on some stock components in the closed area, may have some temporal effects on genetic diversity.

Potential limitations and risks

There may be a potential lack of clear genetic structure related to geography within the major groups of spring- and autumn spawning herring, which will make population and stock identification based on genetics unlikely in the Baltic Sea over geographic areas smaller than sea basins. Instead, genetic information should be complemented with other stock identification techniques such as, body and otolith morphology, life history characteristics and meristics.

Potential lack of different patterns in otolith chemistry related to geography would make it unlikely to use the method for stock identification and for studying migration patterns of herring in the Baltic Sea. Results from the pilot study need to be analysed before the value of the data in this scientific experiment can be evaluated.

Cost

These costs are estimated for this project based on the assumption that costs for genetic sequencing will be covered by other projects (pelagisk provtagning och migrerande arter) and lab costs and initial analyses of otholith chemistry are covered by other projects (migrerande arter). It is also assumed that samples will be obtained from other projects, the above mentioned and other WPs in this project, and that sampling costs are covered.

Work package 3	**Year**				**WP total**
	2024	**2025**	**2026**	**2027**	
Proposed cost	200 230	138 420	220 285	226 593	**785 528**

WP 4. Pelagic fisheries

Introduction

The protection of areas from all fishing and/or trawl fisheries specifically will unconditionally change the overall fishing pattern, as the purpose of the measure is to reallocate the fishery from certain areas. In this case, the expectation is that the change in fishing patterns will over time fulfil the objective of more and/or larger herring in the coastal zone. A change in the spatial fishing patterns will, however, most likely lead to (if the fishing effort is the same) that other areas will be more heavily exploited than they used to be. This could imply that the fishery would instead be associated with other types and volumes of bycatches and exploit different size classes and other subpopulations of herring compared to the current case with business-as-usual fishing patterns. It might also imply that the fishery becomes less effective (lower CPUE), and that more effort is needed to utilize the available quota. To better understand the possible connection between changes in fishing effort and catches and potential responses (or non-responses) in the coastal zone, it is important to monitor all major fisheries in the management area with a high spatial and temporal resolution. This monitoring needs to include monitoring of fishing effort, catches (including bycatches) and biological data of the individuals caught. The monitoring needs to be carried out through the entire implementation phase of project as well as after the regulations are in place.

Main research questions

How will the closed areas impact fishing effort from different segments of the fleet (gillnetters, small trawlers, large trawlers)?

Will the change in fishing effort impact the catches (CPUE, species composition, size composition) for the different segments of the fleet?

Methods

Effort

Data on fishing effort are primarily collected via logbooks and monthly journals through the fisheries control regulation and are normally made available for follow-ups and scientific analysis. These data can primarily be used to monitor if fishing effort increases/decreases over time and how it is distributed between gears. Effort data can also be used to get a broad understanding of how the fishing effort is spatially distributed. Vessel Monitoring System (VMS) data, and potentially also Automatic Identification System (AIS) data, are needed for a more high-resolution understanding of how fisheries are distributed and how this distribution change when fishing grounds are closed for fishing. Analysis of fishing effort data from all fisheries and countries impacted by the closed fishing grounds should preferably be done once a year as a part of the follow up of the measures. This might require a yearly data call and/or an agreement between countries to perform the analysis jointly. The outcome of the analysis would be a set of graphs and maps showing e.g. spatial distribution of fishing effort and how this has changed with the implementation of the closed fishing grounds, as well as overall trends in fishing effort by gear type and fleet.

Catches/Landings

Data on landings are primarily collected through fisheries control regulations, through logbooks and monthly fishing journals, and are made available for follow-ups and scientific analysis. Self-reported landings are however, not equivalent to actual catches. Examples are unintended bycatches returned to sea that might not always turn up in the logbooks. The same goes for bycatches in large pelagic catches as they may not even be spotted by the crew. Therefore, the statistics on landings should preferably be complemented by data from observers at sea (to have more precise estimates of actual catches). Follow-ups of landings and catches need to, as for the fishing effort, be followed up on a proper spatial scale. This implies that data on landings need to be combined with VMS and other spatial data. Analysis of the catch data should, as for fishing effort, be done to represent a subset of the fishing operations and a set of graphs and maps produced. Potential changes in patterns (spatial, season, gear) between years should be highlighted.

Catches – data from individual fish

Biological data (e.g. individual weight, length, age, sex, maturity stage, potentially DNA) from individuals of the target species within the catches are needed to understand which part(s) of a population(s) a fishery is exploiting. To understand how reallocation of fishing effort impacts exploitation patterns of different stock components it is important to collect, for the fishery, representative biological data with as accurate as possible information of the spatial origin of the fish. This means that the individual fish for sampling need to be collected at haul level and not at the landing (in which fish from several hauls can mix). Such sampling will be done by observers at sea, but also through co or self-sampling programs conducted together with the fishers. Biological data will need to be collected from all important fisheries and all seasons in the areas of interest. Analysis of such data will reveal if e.g. trawl and gillnet fisheries target the same size classes of fish (and potentially also the same subpopulations). The analysis will also reveal if the importance (absolute and relative) of different size classes in the catches will develop or not in a similar way between fisheries, or if the pattern will be different in different fisheries.

Possible outcomes

The fisheries will need to adapt to the closed areas, meaning that we will be able to monitor a response. We assume that we will see a shift in effort and catches from the coast to more open sea areas as a result of the extended closed areas. We also assume that we will see less herring in the catches as the fishery moves more into the open sea areas. Both these assumptions are dependent of the extent of closed areas, as well as the fishing quotas set for both herring and sprat.

Potential limitations and risks

It is uncertain if we will detect a desired response in the coastal herring catches. If we do, it will be challenging to understand if this is due to the closed areas or due to broader changes in the regulatory framework at the EU level (e.g. reduced fishing mortality). An interesting issue will be to follow if the herring catches develop in a similar or different way between different coastal and open sea fisheries.

The analysis should preferably be done on a regional level including data from all countries participating in the fishery. This will require a yearly data call and/or an agreement between countries to perform the analysis jointly. It is not certain that all countries would like to participate in such analysis and/or share data due to confidentiality and ownership concerns.

Most of the monitoring needed for the follow up of the fisheries response to closed areas is included in the Swedish Multiannual programs for data collection 2023-2024 and 2025-2027. However, the coverage in some monitoring programs is presently not sufficient for the monitoring program described herein. What is needed beyond what is presently covered by DCF is monitoring of the trawl fishery in the Bothnian Bay (SD 30) with on board observers, a self-sampling program of trawlers in the Bothnian Bay and a sufficient co-sampling program of gillnetters in the Baltic proper (SD 25-29). The DCF will be revised prior to 2025 and it may be possible that parts of the required monitoring will be included after that revision (SwAM to decide). If parts are not funded through DCF they might potentially be funded through the project "Provtagning pelagiskt fiske". Assignment of catches to potential subpopulations require sampling of DNA (also to be covered by the project "Provtagning pelagiskt fiske").

The remaining costs for the monitoring of fisheries, in relation to the proposed closed areas, are costs related to the analysis and presentation of data.

Work package 4	**Year**				**WP total**
	2024	**2025**	**2026**	**2027**	
Proposed cost	183 034	188 289	193 938	247 684	**812 944**

WP 5. Monitoring of grey seals and great cormorants

The work within this part of the project will be financed by other sources.

Introduction

The assignment to implement fisheries management measures aims to regulate fishing for Baltic herring along the coast of the Baltic Sea by moving the trawl limit from the Bothnian Sea to north of Kalmarsund. The measure will reduce fishing pressure on herring and other fish species along the coast. The aim of this project, which is a subproject of the government assignment, is to produce data on the feeding habits, numbers, distribution and condition of grey seals and great cormorants, known predators of herring. The data produced will, within the framework of the government assignment, enable an evaluation of the importance of herring and other fish species as food for grey seals and great cormorants, as well as how the relocation of the trawl limit will affect the populations of grey seals and great cormorants.

Main research questions

The research questions concern general biology of grey seals and great cormorants, focusing on prey choice, abundance, distribution and condition. More specific and detailed hypotheses, relevant for the project, need to be outlined together with other WPs. All questions could be related to *before/after* the fishery regulation.

The overall goal is to:
1. Support other WPs with data on abundance, distribution, food choice and condition of grey seals and great cormorants in different parts of the Baltic Sea.
2. Produce baseline data on grey seals and great cormorants and their roles in the Baltic Sea ecosystem *before* the relocation of the trawl boarder.
3. Follow up on how the populations of grey seals and cormorants respond to the fishery regulation, i.e. data on grey seals and great cormorants *after* the relocation of the trawl boarder.

Specific questions related to:

1) Abundance and distribution

- How does abundance and distribution vary over years and seasons?
    - Grey seal moult counts
    - Grey seal abundance during other seasons (summer, autumn)
    - Grey seal abundance in focus areas over seasons
    - Great cormorant breeding numbers
    - Great cormorant abundance during other seasons (autumn, winter)
    - Great cormorant abundance in focus areas over seasons

2) Prey choice and consumption

- Which fish species and sizes contribute to the diet of grey seals and great cormorants?
    - How important is herring as a prey species?
    - How does diet relate to availability of prey?
    - How does the prey choice vary between areas and over time?
    - How much fish do grey seals and cormorants consume of different species and sizes of fish?

3) Spatial dynamics and behaviour

- What feeding areas and habitats do grey seals and great cormorants use?
    - Important foraging areas and habitat.
    - Large- and fine-scale movement patterns.
    - Dive profiles.
    - Proportion of grey seals on land and in the water in different seasons (to relate the number of seals counted on land to the number of seals that can be assumed to be in the water).
    - Great cormorant over-wintering areas

4) Condition

- Blubber thickness of grey seals.
- Pup production of grey seals
- Body condition parameters of great cormorants
- Breeding success of great cormorants

Methods

The monitoring covers the coastal stretch from the Bothnian Sea to the northern Kalmar Sound. Two focus areas will be specified with more detailed monitoring planned, one in the Bothnian Sea and one in the Baltic Proper.

Abundance and distribution

The national environmental monitoring of grey seals will be supplemented with additional aerial surveys of the Bothnian Sea-Kalmarsund coast during August-September and in October. The aerial inventories will be carried out in collaboration with the Swedish Museum of Natural History. In addition to these aerial surveys, smaller areas will be selected for more frequent surveys through a combination of observations from boats and drones, possibly supplemented with surveillance cameras and aerial surveys.

Great cormorant breeding colonies will be inventoried during the breeding period for data on distribution and sizes of the great cormorant population. As well as with the seal surveys more detailed monitoring will be carried out in smaller areas through a combination of observations from boats and drones, possibly supplemented with surveillance cameras and aerial surveys. Supplementary data will be obtained from ongoing autumn and winter count data from the

Swedish national seabird monitoring programme. The work will strive to develop collaborations with regional expertise and local partners.

Prey choice and consumption

The species and size composition of the grey seal and cormorant diet will be investigated through the collection and analysis of diet samples from the ongoing hunting initiatives, supplemented by the collection and analysis of scats (seals) and pellets (cormorants) to improve sample sizes.

Traditional dietary analysis of collected samples will be supplemented with DNA-based analysis to obtain as high an accuracy of the diet as possible.

Spatial dynamics and behaviour

For grey seals, the behaviour of individuals and foraging areas will be investigated using GPS/GSM transmitters and flipper tags. GPS/GSM tags will provide position and dive data, while flipper tags provide important information about the seals' behaviour even during/after the moulting period (when the GPS/GSM transmitters are detached from the seals). Flipper tag data can thus be used, among other things, to get an idea of what proportion of the population is on land or in the water during different seasons (information which cannot be obtained for the aerial surveys regarding the proportion in the water). Capturing and tagging of grey seals will be carried out in collaboration with the Swedish Museum of Natural History.

For great cormorants, GPS/GSM transmitters will also be used, but which will be able to contribute position and dive data for a significantly longer period of time because these transmitters do not come off in connection with moulting and are also equipped with solar cells that charge the batteries as they go. Complementary information on the large-scale movements of the cormorants can be obtained from ring and colour marking of cormorants in the survey areas. Catching and tagging of cormorants will be carried out in collaboration with regional collaborators.

Condition

The condition of grey seals will be investigated through analysis of the blubber thickness of grey seals collected from the hunt, which is supplemented with information on pregnancy frequency, pathology and pup production from the Swedish Museum of Natural History.

The condition of great cormorants will be investigated by analyzing the body index of hunted birds (weight, musculature, subcutaneous fat, etc.) which will be supplemented with data about the breeding success of different colonies.

Potential Limitations and Risks

Capturing of great cormorants and, in particular, grey seals is challenging, labor intensive and costly. Ongoing hunting of grey seals and great cormorants can be intense, which could have an impact on numbers, as well as distribution of seals and cormorants in different areas. Additionally, current knowledge on fish abundance, i.e. prey availability, is limited and prey choice assessed from collected diet samples can be biased towards coastal habitats.

Costs

Note: This WP is financed outside of the current project and therefore the below costs are not considered within the proposed budget in Bilaga 2. The table below is for reference. Considering the challenges concerning capturing and tagging of grey seals and great cormorants, money is likely to be reallocated between budget posts and/or years.

Budget	**2024**	**2025**	**2026**	**2027**	**2028**	**Sum**
Salaries	102 115	1 076 645	1 490 772	1 396 523	1 317 636	5 383 691
Travels	30 000	50 000	50 000	50 000	30 000	210 000
OH*	65 701	692 714	959 163	898 523	847 767	3 463 867
External costs	835 000	2 150 000	2 150 000	1 830 000	100 000	7 065 000
Other costs	199 000	2 230 000	2 030 000	530 000	0	4 989 000
Total	**1 231 816**	**6 199 359**	**6 679 935**	**4 705 045**	**2 295 403**	**21 111 558**

WP 6. Other ecosystem effects

Part 1: Coastal food web study in the Bothnian Sea and Central Baltic Sea

Introduction

The coastal ecosystem of the Swedish Baltic Sea is heavily affected by a regime shift, which is linked to changes in the open sea. The regime shift involves a loss of coastal predatory fish and an increase of three-spined stickleback, where the effects cascade down the food web, resulting in an increase in filamentous algae and a loss of habitat-forming vegetation (Donadi et al. 2017, Eklöf et al, 2020). The loss of predatory fish and increase in stickleback is linked to changes in the open sea ecosystem, where the decline in herring populations is likely contributing to the changes through several mechanisms (Olin et al. 2022).

Main research questions

Will an extension of the trawl border or establishment of a no-take zone may increase the abundance of large herring? If so, will there be a positive effect on the coastal ecosystem through the following mechanisms?

- A shift in grey seal and cormorant predation, from coastal predatory fish to herring, which will increase the survival of perch and pike in the coastal zone (Hansson et al. 2018, Bergström et al. 2022a, b, Olin et al. 2023)
- Higher abundances of large herring, perch and pike will decrease stickleback abundances, and thus improve recruitment success of perch and pike in the coastal zone through a higher survival of eggs and larvae (Byström et al. 2015, Nilsson et al. 2019, Eklöf et al. 2020)
- A decrease in stickleback abundances due to an increase in predation pressure (Hyp. 1-2) will lead to a trophic cascade lowering the overgrowth of filamentous algae on habitat-forming vegetation, thus counteracting eutrophication effects (Donadi et al. 2017, Eklöf et al. 2020)

Method

To evaluate the effects on the coastal ecosystem we suggest an extensive field survey of the coastal food web, combined with spatiotemporal statistical modelling. The study will utilize data from a previous ecosystem survey made in 2014, covering ca 30 locations along the Swedish coast (SD27 and 29; Donadi et al. 2017), and will be extended to include 8-additional locations in the Bothnian Sea (SD30), thus including the whole coast that is covered by the trawl boarder extension.

The suggested coastal ecosystem study can join forces with a new FORMAS project FORCE (led by Stockholm University and SLU), which is planning to repeat the 2014 ecosystem (Donadi et al. 2017) survey in SD 27 and 29 in 2024. A similar survey is also planned for the Åland Island by the government of Åland, thereby extending the geographical scope of the study. The 2014 and 2024 surveys would serve as a baseline for the situation before the trawl border extension, and be compared to the situation in 2027. Thus, the planned survey within FORCE is suggested by the current project to be extended by 8 locations in the Bothnian Sea in

2024 and around 30 locations in 2027, covering previously sampled locations of the Central Baltic Sea and Bothnian Sea coasts.

For each location, the survey includes the following parameters and survey methods:

- The fish community composition in spring, focusing on the abundance of local spawning populations of perch, pike, herring, cyprinids and stickleback, using multimesh gillnets
- The recruitment of perch, pike, herring, cyprinids and stickleback in late summer, using small underwater detonations
- Underwater vegetation in spring and late summer in connection to the fish surveys, using visual census (snorkelling) and quantitative sampling
- Water quality parameters: Chl-a, turbidity, nutrients etc
- Diet analysis of herring in gillnet survey, to estimate predation on stickleback

The suggested field sampling program is downscaled compared to the sampling scheme of FORCE, though the current project will benefit from the collaboration with the FORCE project sampling. For each location, data on a number of additional variables will be compiled from existing monitoring programs. Seal and cormorant abundance information is retrieved from existing data from the county administrative boards, the Swedish Museum of Natural History and by SLU (WP 5, above), while diet information is used from the separate seal and cormorant studies suggested by SLU (WP 5, above). Landings by coastal commercial and recreational fisheries is estimated based on existing data from SwAM (see WP 4 above), while offshore abundances of herring and stickleback will be retrieved from the BIAS hydroacoustic survey (see WP 2 above).

The food web configurations will be compared across all sampling locations, to assess the local ecosystem regime (perch and pike abundance in relation to stickleback), and cascading effects down to habitat-forming vegetation and filamentous algae. To understand the relative importance of different drivers, the local food web configuration will be related to water quality parameters, coastal fisheries landings and offshore abundances of herring and stickleback as explanatory variables applying cutting-edge causal (e.g. structural equation) modelling to quantify impact pathways. By comparing across sampling years (2014, 2024 and 2026/2027) and locations, the possible effects of the extension of the trawl border will be singled out.

Possible outcomes

The study is expected to shed light on whether increasing survival of herring in the open sea has positive effects on the coastal ecosystem by decreasing the impact from stickleback, seal and cormorant predation on populations of perch and pike, and whether this may gain coastal habitat-forming vegetation by relieving eutrophication symptoms.

Potential Limitations and Risks

Given the complex interactions in coastal ecosystems, previous experiences (Donadi et al. 2017, Eklöf et al. 2020) suggest that it will take a large sampling effort to capture potential impacts from an extended trawl border. If effects on herring populations remain small, no detectable effects on the coastal ecosystem can be expected. However, if herring populations increase, the suggested field survey setup would have a good chance of detecting effects on the coastal food web, especially on fish. The cascading effects down to vegetation may be more difficult to capture given the high level of natural spatiotemporal variability.

Part 2: Open Sea ecosystem trend analysis for the Bothnian Sea and Central Baltic Sea

Introduction

Currently the Baltic Sea and Bothnian Sea food webs are under extreme external pressures arising from human activities. In the Bothnian Sea herring have a central role in the food web as the most abundant planktivores (Kiljunen et al. 2020) and can drive top-down effects on the plankton, while themselves being influenced by top-down predation and the bottom-up availability of zooplankton (Cardinale et al. 2009, Östman et al. 2016). However, assessing the status of marine food webs is difficult due to their complexity and the wide range of pressures they experience. Hence, there is currently a lack of standardized methods and reporting of food web status for the Marine Strategy Framework Directive (MSFD) has been inconsistent across countries (Boschetti et al. 2021). Here, we will take advantage of work being done in the HELCOM Food webs group and the ICES working group for integrated assessments of the Baltic Sea, which are currently conducting an integrated trend analysis method to assess food web status over time (1970s-present) and identify regime shifts in six of the Baltic Sea basins.

Main research questions

We hypothesise that extending the trawl limits could change the food web dynamics of the open sea if the total herring mortality is significantly reduced, or the mortality of certain age or size classes of herring is reduced. Integrated trend analysis assesses changes in trends in open sea food webs over time, and here we can compare a control period to an experimental period.

Method

To assess how the diversity within and balance between trophic guilds in the open sea ecosystem has changed over time in response to environmental and anthropogenic pressures (i.e. according to MSFD D4 guidelines) we can deliver an integrated trend analysis (ITA) (Olsson et al. 2015) using a long time series (1979-present) coupled with generalized additive models. With this method, we can examine how food web dynamics change over time in response to multiple pressures, including climate, nutrients and fishing pressure. This analysis meets the requirements to assess food web status according to the marine strategy framework directive guidelines, i.e. how the balance between and diversity within trophic guilds is affected by anthropogenic pressures. By updating the current study with future data, we can determine if the extension of the trawl border has had an effect on the open sea food web. All data required for the ITA is available from national and international databases.

Possible outcomes

We will determine if the status of the open sea food web in terms of the MSFD D4 guidelines, i.e. diversity within and balance between trophic guilds, has changed in response to the extension of the trawl border.

Potential Limitations and Risks

The success of the analysis is dependent upon the continuation of the current open sea sampling programs for phytoplankton, zooplankton, benthos, fisheries surveys, seals and chemical and physical parameters. The analysis is currently best suited to identifying large regime shifts (Tomczak et al. 2022) and will be adjusted in order to find changes occurring over the relatively short experimental period. The outcome of the analysis can be used for reporting food web status for the MSFD.

Part 3: Ecosystem model for the Bothnian Sea

Introduction

Ecosystem models enable integrated evaluations of how different parts of the food web interact and how they are affected by different drivers. Ecopath with Ecosim (EwE) is the most applied tool for modelling marine and aquatic ecosystems globally and includes methods to compare ecosystems, and to model both temporal and spatial dynamics (Heymans et al. 2016).

Main research questions

The EwE approach is able to address questions asked by managers on marine policy issues such as fishing effects on the food-web, climate change and eutrophication effects, natural variability and the relative importance of these. By this, the models can be used for evaluating management measures and testing management actions, including addressing changes in ecosystem services, environmental changes, and progress towards "Good Environmental Status" of the ecosystem for the EU Marine Strategy Framework Directive (Hyder et al. 2015, Steenbeek et al. 2016).

Method

For Swedish seas, EwE models are currently available for the open Central Baltic Sea and the Kattegat. SLU Aqua is planning to develop a full EwE model for the open sea Gulf of Bothnia ecosystem in collaboration with Finland. This work will progress over years 2024-2025 and is led by The Finnish environment institute (SYKE) and Åbo Akademi University.

We suggest that this new model is adjusted to addressing questions about the effects of the extension of the trawl border in the Bothnian Sea. This will enable evaluating the relative role of the measure in driving changes in herring populations (including ontogenetic shifts), effects of potential changes in the role of herring as a prey and food-source for top-predators (seals and other fish), and top-down cascades through the predation of herring on lower trophic levels.

A spatiotemporal EwE modelling framework can inform on couplings between coastal and open sea areas. This would be achieved by linking the open sea model with a new coastal model, and aligning the compartments of the open sea model with the questions to address. A model version based on the current situation would be constructed initially, and then compared with an updated version based on data from open sea and coastal surveys carried out after the extension of the trawl border.

Possible outcomes

Comparing outputs for the two model versions (current and updated) will address immediate as well as potential longer-term effects of the extension of the trawl border with regards to changes in food web structure, functionality and capacity for ecosystem services provision, including whole-ecosystem indices (representing e.g. amount of cycling, stability resilience and carbon flows). This will also inform on potential changes in biodiversity and food web status in relation to descriptors 1,3 and 4 for EU Marine Strategy Framework Directive (MSFD) criteria for good environmental status.

Potential Limitations and Risks

A limitation for the coastal model is that small-scale coastal ecosystems (such as small bays) are driven by the interplay of local pressures and high variability of drivers, which are not possible to capture in the coastal zone model. Rather, general patterns would be in focus.

Although not described here, a corresponding model framework for the Central Baltic Sea could also be developed, by combining a new coastal model with an existing model for the Central Baltic Sea (Tomczak et al. 2013, 2022). However, as opposed to the situation for the Bothnian Sea, it is not yet ascertained if sufficient data are in place to build a robust coastal EwE model for the Central Baltic Sea coastal zone.

Costs

Costs include WP coordination, collating data, model development and testing, analysis and report writing.

Work package 6	**Year**				**WP total**
	2024	**2025**	**2026**	**2027**	
Proposed cost	857 121	910 023	3 011 849	919 360	**5 698 352**

References

Bergström, U., Larsson, S., Erlandsson, M., Ovegård, M., Stabo, H.R., Östman, Ö. and Sundblad, G., 2022a. Long-term decline in northern pike (Esox lucius L.) populations in the Baltic Sea revealed by recreational angling data. *Fisheries Research*, *251*, p.106307.

Bergström, U. and Erlandsson, M. 2022b. Spiggens påverkan på rekryteringsområden för abborre och gädda i Östersjön. Sveriges lantbruksuniversitet, Aqua notes 2022:1

Boschetti, S., Piroddi, C., Druon J.-N. and A. Palialexis. 2021. Marine Strategy Framework Directive, Review and analysis of Member States' 2018 reports. Descriptor 4: Food webs, EUR 30652 EN, doi:10.2760/32522

Byström, P., Bergström, U., Hjälten, A., Ståhl, S., Jonsson, D. and Olsson, J., 2015. Declining coastal piscivore populations in the Baltic Sea: where and when do sticklebacks matter?. *Ambio*, *44*, pp.462-471.

Cardinale, M., Möllmann, C., Bartolino, V., Casini, M., Kornilovs, G., Raid, T., Margonski, P., Grzyb, A., Raitaniemi, J., Gröhsler, T. and Flinkman, J., 2009. Effect of environmental variability and spawner characteristics on the recruitment of Baltic herring Clupea harengus populations. *Marine Ecology Progress Series*, *388*, pp.221-234.

Donadi, S., Austin, Å.N., Bergström, U., Eriksson, B.K., Hansen, J.P., Jacobson, P., Sundblad, G., Van Regteren, M. and Eklöf, J.S., 2017. A cross-scale trophic cascade from large predatory fish to algae in coastal ecosystems. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1859), p.20170045.

Eklöf, J.S., Sundblad, G., Erlandsson, M., Donadi, S., Hansen, J.P., Eriksson, B.K. and Bergström, U., 2020. A spatial regime shift from predator to prey dominance in a large coastal ecosystem. *Communications biology*, *3*(1), p.459.

Han F., M. Jamsandekar, M. E. Pettersson, L. Su, A. P. Fuentes-Pardo, B. W. Davis, D. Bekkevold, F. Berg, M. Casini, G. Dahle, E. D. Farrell, A. Folkvord, L. Andersson. 2020. Ecological adaptation in Atlantic herring is associated with large shifts in allele frequencies at hundreds of loci. eLife 9: e61076.

Hansson, S., Bergström, U., Bonsdorff, E., Härkönen, T., Jepsen, N., Kautsky, L., Lundström, K., Lunneryd, S.G., Ovegård, M., Salmi, J. and Sendek, D., 2018. Competition for the fish–fish extraction from the Baltic Sea by humans, aquatic mammals, and birds. *ICES Journal of Marine Science*, *75*(3), pp.999-1008.

Heymans, J.J., Coll, M., Link, J.S., Mackinson, S., Steenbeek, J., Walters, C. and Christensen, V., 2016. Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. *Ecological modelling*, *331*, pp.173-184.

Hyder, K., Rossberg, A.G., Allen, J.I., Austen, M.C., Barciela, R.M., Bannister, H.J., Blackwell, P.G., Blanchard, J.L., Burrows, M.T., Defriez, E. and Dorrington, T., 2015. Making modelling count-increasing the contribution of shelf-seas community and ecosystem models to policy development and management. *Marine Policy*, *61*, pp.291-302.

Kiljunen, M., Peltonen, H., Lehtiniemi, M., Uusitalo, L., Sinisalo, T., Norkko, J., Kunnasranta, M., Torniainen, J., Rissanen, A.J. and Karjalainen, J., 2020. Benthic-pelagic coupling and trophic relationships in northern Baltic Sea food webs. *Limnology and Oceanography*, *65*(8), pp.1706-1722.

Nilsson, J., Flink, H. and Tibblin, P., 2019. Predator–prey role reversal may impair the recovery of declining pike populations. *Journal of Animal Ecology*, *88*(6), pp.927-939.

Olin, A.B., Olsson, J., Eklöf, J.S., Eriksson, B.K., Kaljuste, O., Briekmane, L. and Bergström, U., 2022. Increases of opportunistic species in response to ecosystem change: the case of the Baltic Sea three-spined stickleback. *ICES Journal of Marine Science*, *79*(5), pp.1419-1434.

Olin, A.B., Bergström, U., Bodin, Ö., Sundblad, G., Eriksson, B.K., Erlandsson, M., Fredriksson, R. and Eklöf, J.S., 2024. Predation and spatial connectivity interact to shape ecosystem resilience to an ongoing regime shift. *Nature Communications*, *15*(1), p.1304.

Olsson, J., Tomczak, M.T., Ojaveer, H., Gårdmark, A., Pollumäe, A., Müller-Karulis, B., Ustups, D., Dinesen, G.E., Peltonen, H., Putnis, I. and Szymanek, L., 2015. Temporal development of coastal ecosystems in the Baltic Sea over the past two decades. *ICES Journal of Marine Science*, *72*(9), pp.2539-2548.

Steenbeek, J., Buszowski, J., Christensen, V., Akoglu, E., Aydin, K., Ellis, N., Felinto, D., Guitton, J., Lucey, S., Kearney, K. and Mackinson, S., 2016. Ecopath with Ecosim as a model-building toolbox: source code capabilities, extensions, and variations. *Ecological Modelling*, *319*, pp.178-189.

Tomczak, M.T., Heymans, J.J., Yletyinen, J., Niiranen, S., Otto, S.A. and Blenckner, T., 2013. Ecological network indicators of ecosystem status and change in the Baltic Sea. *PLoS one*, *8*(10), p.e75439.

Tomczak, M.T., Müller-Karulis, B., Blenckner, T., Ehrnsten, E., Eero, M., Gustafsson, B., Norkko, A., Otto, S.A., Timmermann, K. and Humborg, C., 2022. Reference state, structure, regime shifts, and regulatory drivers in a coastal sea over the last century: The Central Baltic Sea case. *Limnology and Oceanography*, *67*, pp.S266-S284.

Östman, Ö., Eklöf, J., Eriksson, B.K., Olsson, J., Moksnes, P.O. and Bergström, U., 2016. Top-down control as important as nutrient enrichment for eutrophication effects in North Atlantic coastal ecosystems. *Journal of Applied Ecology*, *53*(4), pp.1138-1147.