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Uppföljningsprogram utflyttad trålgräns

Frågeställning/Beställning

För de försöksområden som HaV föreslagit ska SLU Aqua leverera förslag på vetenskaplig design och uppföljning i syfte att utvärdera effekterna på sill- och strömmingsbeståndens biomassa samt deras storleks-, bestånds- och åldersstruktur.

Upplägget och förutsättningar diskuterade mellan HaV och SLU Aqua under juni 2023. Förslaget ska innehålla undersökningar, övervakning och förslag till analys av data som svarar mot de leveranser som framgår av regeringsuppdraget. Planen ska beakta tidigare inhämtad kunskap om påverkan i samtliga delar av livscykeln. I detalj ska planen ge förslag på uppföljning för:

- Effekter av de fiskerirelaterade förvaltningsåtgärderna på sill- och strömmingsbeståndens biomassa samt deras storleks-, bestånds- och åldersstruktur inklusive analys av genetik och otolitkemi som kan vara till stöd för att utreda migrationsmönster samt förekomst och exploatering av genetiskt distinkta beståndsstrukturer inom och utanför områdena.
- Eventuella effekter av de fiskerirelaterade förvaltningsåtgärderna för andra fiskarter, som till exempel spigg
- Analys av i vilken utsträckning sillen och strömmingens utveckling påverkas av miljöfaktorer och predation från fisk, fågel och säl för att kunna utvärdera och stärka kunskapen kring olika orsakssamband.
- Effekter av naturlig predation, t.ex. av säl och fågel inom och utanför områden

Dessutom ska den plan som SLU Aqua utarbetar omfatta:

- Effekter från andra förvaltningsåtgärder i relevanta områden, till exempel årliga beslut om tillgängliga fiskemöjligheter.

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- Analys av konsekvenser för sådant fiske som eventuellt tillåts inom försöksområdena, bl.a. i förhållande till syftet med det vetenskapliga projektet och möjlig påverkan på försöksdesignen och uppföljning.
- Ekosystemeffekter, såsom kaskadeffekter i näringsväven.

Ett första förslag på ett uppföljningsprogram levererades den 2023-09-30. Rapporten redogjorde övergripande för programmets olika delar, inklusive vilka parametrar som kan följas upp, med vilken metod och om det redan finns befintligt övervakning/datainsamling som kan användas. Uppföljningsprogrammet som föreslogs är uppbyggt av 7 arbetspaket (Wp) med övervakning och analyser av:

Wp 0. Projektledning och kärngrupp
Wp 1. Abiotisk information
Wp 2. Pelagisk fisk (sill/strömming, skarpsill och spigg)
Wp 3. Genetik och otolitkemi
Wp 4. Pelagiskt fiske
Wp 5. Sälar och skarvar
Wp 6. Andra ekosystemeffekter

Den här rapporten som redovisar den slutliga planen på uppföljningen av det vetenskapliga försöket för 2024–2027 ligger med som en bilaga till kontraktet mellan HaV och SLU gällande arbetet från 2024-2026. Kostnaderna som specificeras i varje arbetspaket inkluderar endast 2024-2026, med undantag för Wp 5 Sälar och skarvar, som finansieras utanför detta kontrakt.

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 focussed 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 during, proposed methods to be used, and possible limitations 2024-2027. Included is also a budget for 2024-2026.

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**	
Proposed cost	2 078 522	1 862 375	1 959 151	**5 900 048**

*See Bilaga 2 for a more detailed breakdown of costs

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?

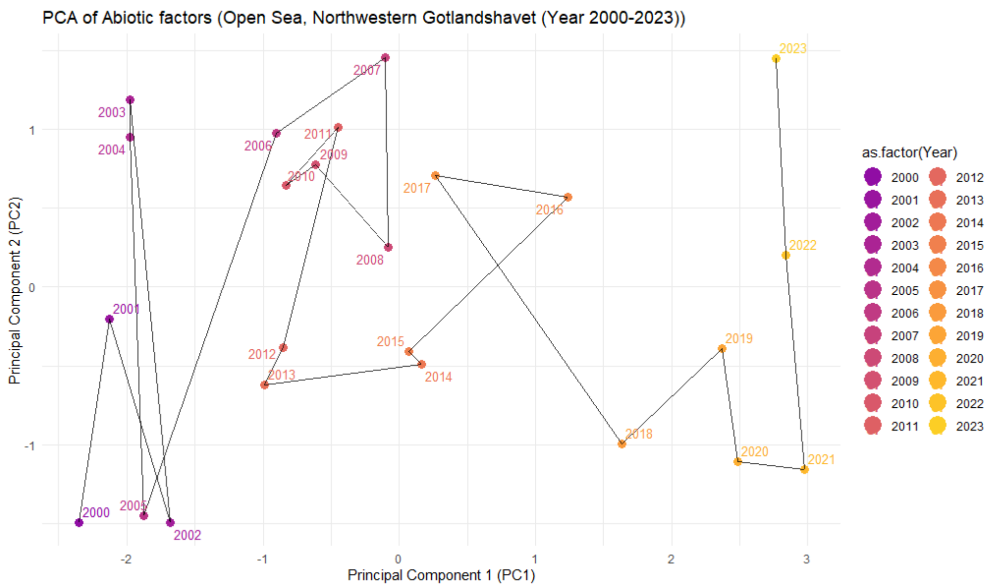
- What is the development of the proposed biotic variables (zooplankton, phytoplankton, benthic organisms) inside and outside the closed areas during the project?
- Is the development of abiotic and biotic variables correlated?

Methods

Abiotic factors

We suggest two approaches: we will analyse available abiotic information from ongoing monitoring programs (SMHI, Sverige's vattemiljö 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**	
Proposed cost	185 742	191 314	197 053	**574 109**

*See Bilaga 2 for a more detailed breakdown of costs

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)

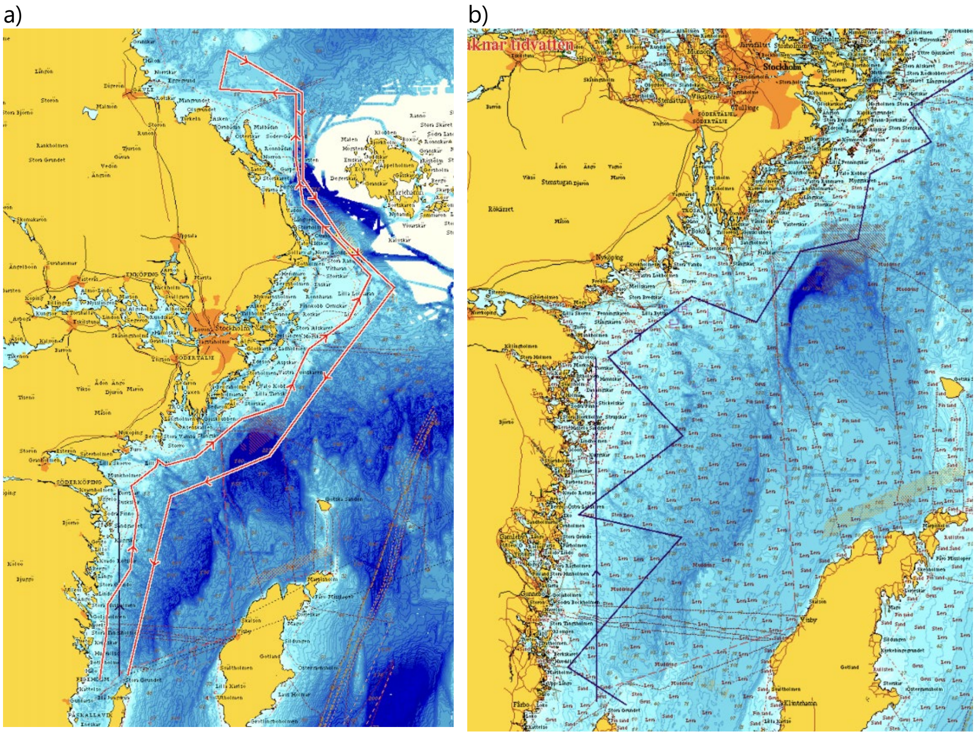


Figure 1. Proposed routs with R/V Svea. a) Rout during BITS Q1 and Q2 and b) during SPRAS and BIAS.

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).

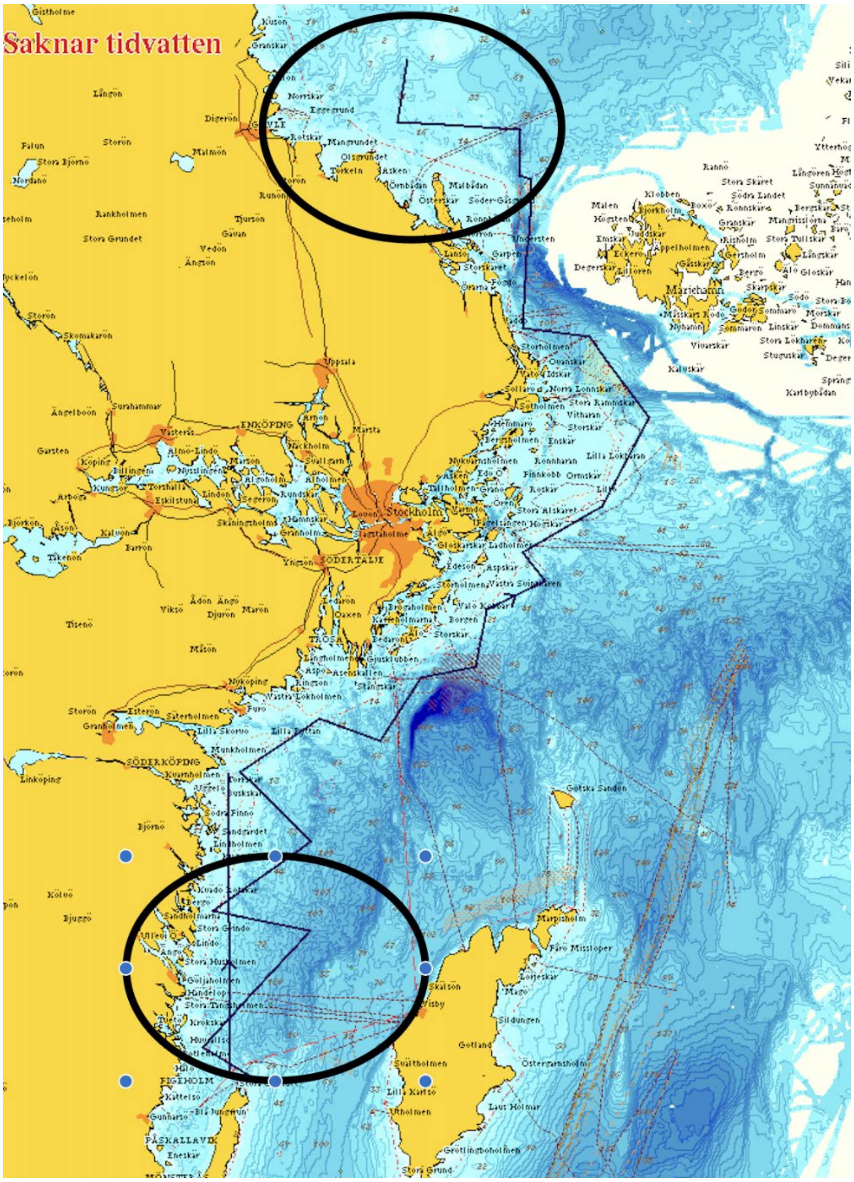


Figure 2. The two primary areas in SD 27 and SD 30.

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**	
Proposed cost	7 005 870	8 068 781	8 620 439	**23 695 090**

*See Bilaga 2 for a more detailed breakdown of costs

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**	
Proposed cost	200 230	138 420	220 285	**558 935**

*See Bilaga 2 for a more detailed breakdown of costs

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.

Costs

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**	
Proposed cost	183 034	188 289	240 470	**611 792**

*See Bilaga 2 for a more detailed breakdown of costs

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 haul out 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 post	**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**	
Proposed cost	857 122	910 023	3 011 849	**4 778 993**

*See Bilaga 2 for a more detailed breakdown of costs

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