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MEMO

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Scientific support for SwAMs government assignment: scientific project corresponding to an extended trawl limit

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1. Question at issue and order

By a government decision of 19 May 2022, the Swedish Agency for Marine and Water Management (SwAM) has been tasked with performing a fixed-term scientific project that corresponds to a relocation of the trawl limit for vessels that fish for pelagic species in the Baltic Sea, for the purpose of evaluating the effects on the biomass of the Baltic herring population, as well as its size, population and age structure. SLU Aqua has been tasked with assisting SwAM with scientific data for the government assignment. The aim of this knowledge base is to present a compilation and analysis of catches of vessels, regardless of flag, that fished for herring in the Swedish economic zone in the Central Baltic Sea (SD 25-27, 28.2, 29, 32) and the Gulf of Bothnia (SD 30-31) during 2012- 2021. The aim is also to present what is known at present about genetic analyses of the herring in the Baltic Sea. SLU Aqua has also undertaken as part of this knowledge base to 1) extend to the entire central Baltic and Gulf of Bothnia the compilation of knowledge about the ecology and migration patterns of herring that was delivered in connection with SwAM’s request to SLU Aqua regarding herring in the northern Baltic Proper (SLUID: SLU.aqua.2022. 2022.5.5-46), and 2) present a compilation of ongoing and earlier surveys of particular interest for herring. The knowledge base has been formulated so as to represent a background to SwAM’s decision on appropriate trial areas.

2. Summary

The growth and condition of herring have decreased in the Baltic over the last 30 years. There has also been a reduction in large herring in parts of the central Baltic and Gulf of Bothnia, both in the open sea and in shallower coastal areas. Herring generally grow slower in the Gulf of Bothnia than in the central Baltic and normally reach a size of 18-20 cm at an age of about 6-8 years in the Gulf of Bothnia and 4-5 years in the central Baltic. The most important spawning areas for herring are in the shallow archipelago waters (0-15 m deep). Access to spawning areas is generally good throughout the Baltic and probably does not represent any limitation to the population. The coastal zone is also the main area for herring growth during their first years. Recruitment of herring in both the central Baltic and Gulf of Bothnia shows no marked change over the last three decades, which indicates that eutrophication and climate change, for example, have not led to any significant effect on recruitment thus far. However, knowledge about differences in recruitment between sub-populations is limited and it is therefore possible that smaller sub-populations may be affected if the spawning areas are damaged. Herring normally overwinter in areas deeper than 50-60 metres. These depths only exist to a limited

extent within the present trawl limit (4 nautical miles) in the central Baltic and the Gulf of Bothnia. This means that the great majority of the herring populations are exposed to trawling in winter. In subdivision 25 of the central Baltic and in the southern part of the Gulf of Bothnia, the overwintering areas between 4 nm and the territorial limit (12 nm) are also limited, which means that moving the trawl limit out to 12 nm would not protect herring in winter in these areas.

Analysis of VMS data and Swedish logbook data for vessels under 12 metres within the Swedish economic zone shows that most of the herring catches in Swedish waters occur within relatively clearly defined geographical areas. In the Gulf of Bothnia, the greatest quantity of herring is caught in the area outside the 12 nm limit and mainly in the southern part, where fishing is concentrated in the economic zone, mainly in the deeper areas around the Finngrunden banks. In the central Baltic, SD 27-29, a relatively large proportion of herring is caught within the 4-12 nm zone, while most of the fishing in SD 25 and 26 is outside 12 nm. Moving the trawl limit from 4 to 12 nm would thus probably have a greater effect on any local herring populations in the northern part of the central Baltic (SD 27-29) than in the Gulf of Bothnia (SD 30) and the southern part of the central Baltic (SD 25-26). In the Gulf of Bothnia, a relatively small quantity of herring is caught within the 12 nm limit.

Knowledge about genetic population patterns shows that Baltic herring have a complex genetic population structure that is not clearly linked to geographically defined areas or the distance between areas. The greatest genetic differences are between autumn-spawning and spring-spawning herring. A number of genetically unique local spawning populations as well as some genetic differences between sea areas have also been identified. Genetic differences are mainly found between herring from SD 25 and other areas of the Baltic Sea. Protection from fishing for large parts of the coast increases the probability of protecting local, genetically unique sub-populations, the frequency of which is not known at present.

In order to follow up on the effects of area closures, it is essential to monitor the populations both within and outside the trial areas. It is also important to increase our knowledge of the population structure and migration patterns of Baltic herring. Extending monitoring so as to follow the effects of closed areas could include: 1) increased fishing surveys in the areas that are judged to be interesting for the trial, 2) improved sampling of commercial fishing catches both near the coast and out at sea, 3) increased sampling of individual herring in existing monitoring programmes, as well as 4) increased genetic sampling and 5) chemical analysis of otoliths and other tissues. The details of the required monitoring that depend on the designation of the areas.

Based on the available information about the Baltic herring's ecology and migration patterns, fishing catches and genetic population patterns, as well as opportunities for follow up, SLU proposes the following trial areas in which regulation corresponding to an extension of trawl limits should be introduced:

An area in the southern Gulf of Bothnia that includes all the areas around the Finngrunden banks where there has been extensive trawling for herring in recent years. The trial area should also include the coastal areas near the Finngrunden banks and the waters between these and should apply all year, so that the regulation protects the herring throughout its life cycle, as well as both spring-spawning and autumn-spawning populations.

In addition to a large area around Finngrunden and in nearby coastal areas, but not as an alternative to this area, it is proposed to have one or more trial areas further north in the Gulf of Bothnia where catches of herring are greatest, such as the Hudiksvall-Sundsvall and Örnsköldsvik-Umeå coastal stretches, including the sea areas outside these.

In the central Baltic, a general extension of the trawl limit to 12 nautical miles is proposed in the areas where appropriate overwintering areas, i. e. areas with a depth >50 m, are found within 12 nm of the baseline. In SD25, the trawl limit should be moved out so as to at least include depths of 50-60 m, which in this area means moving the trawl limit outside 12 nm.

SLU has shown in earlier knowledge bases that the most secure method of increasing the biomass of Baltic herring is to reduce fishing mortality, i.e., to reduce the catch quotas as a whole. The effects of fishing regulation in limited areas are difficult to predict, since there is only limited detailed knowledge about the herring's population structure and migration patterns. SLU is not proposing any formal experimental design of trial or control areas with follow up before, during and after the trial. In order to increase the opportunities for effects on the population, SLU is instead recommending large trial areas and follow up based on the evaluation of trends.

3. Population status and development

As with other internationally managed fish populations, the ICES population estimates and advice on fishing opportunities represent the basis for political decisions on quotas for the herring population in the Baltic. The ICES advice is presented annually at the end of May and can be found. In summary, ICES determined in 2022 that for the herring population in the Baltic in 2022, fishing mortality was over the reference value for fishing mortality that gives maximum sustainable yield over time (F_{MSY}) and the spawning biomass was under the reference value that should be exceeded when fishing occurs at a level that gives F_{MSY} (MSY $B_{trigger}$). For the population in the Gulf of Bothnia, the spawning biomass is decreasing, but was in 2022 over the limit value MSY $B_{trigger}$. Fishing mortality was under F_{MSY}.

The population status and development of herring in Swedish waters have been described in more detail for in previous summaries from SLU Aqua, including in a Memo to SwAM on biomass trends for Baltic herring in SD 25-30 (Wennerström et al. 2022a) and a knowledge base on the effects of fishing on the size structure of Baltic herring in the Gulf of Bothnia SD 30-31 (Gilljam et al. 2022). In general, the detailed analyses of the Swedish sea areas show a decline in biomass and the proportion of large herring in both the open sea and shallower coastal areas, as well as a decreasing population of herring as a whole in the Gulf of Bothnia.

SLU has collected answers to many frequently asked questions about herring, fishing and management in the Baltic in this FAQ, which is aimed at the general public, government agencies and media.

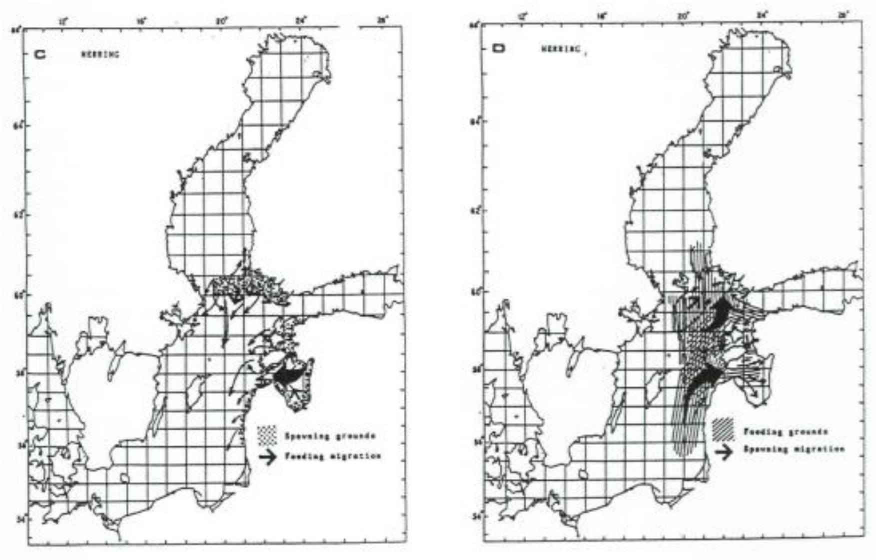
4. Herring life cycle in the central Baltic and the Gulf of Bothnia

In this section, we describe the herring life cycle, including migration patterns and spawning- and juvenile areas in the Baltic. The Baltic is an inland sea with great variations in many abiotic and biotic variables. For example, the water's salinity and temperature are both lower in the north than in the south, which affects the herring's age at maturity and growth. The structure and depth profile of the seabed also varies in different areas, which in turn affects the herring's spawning and growth opportunities and migration patterns. We therefore describe specifically, where possible, what we know about the southern and northern Gulf of Bothnia and the central Baltic respectively.

Migration

Herring is mainly a pelagic species which spends most of its life cycle in the open sea. They can be up to 25 years old, although they are seldom older than 10. The species forms large shoals and migrates vertically between different water depths. By day, they stay close to the bottom or in deeper water, then move towards the surface at dusk and spread out over a wide area at night in the search for food (Nilsson et al. 2003).

Knowledge of the herring's horizontal migrations in the Baltic is mainly of general patterns. More detailed knowledge is lacking at present about the presence of different spawning populations in the Baltic and thus also about how different spawning populations migrate. Baltic herring have traditionally been divided into spring-spawning and autumn-spawning populations (Ojaveer, 1981), which proved to be genetically distinct population components (Han et al. 2020). Spring spawners and autumn spawners have different migration patterns, but generally speaking the most extensive migrations occur between the coastal spawning and growth areas and the foraging and overwintering areas out at sea (Aro 1989). Herring generally overwinter in deep water, below the halocline at about 50-60 m deep, where the water is a little warmer in winter. A small part of the population, mainly juvenile fish, may remain in the shallower archipelago waters all year (Ojaveer 2003, Kaljuste et al. 2009). In spring, the herring migrate from the overwintering areas in the open sea towards shallower coastal waters to spawn and forage. A compilation of tagging data, on adult fish, shows that herring along the Swedish coast of the Gulf of Bothnia generally perform shorter migrations out to the open sea, while herring in the central Baltic can sometimes perform longer migrations to more southerly open sea areas where the temperatures and foraging conditions are more favourable in winter (Figure 1, Aro 1989, 2002). It is also likely that more stationary spawning populations also occur in some coastal areas (Aro 2002). Migration between the Gulf of Bothnia and the central Baltic has been shown to be limited (Jörgensen et al. 2005).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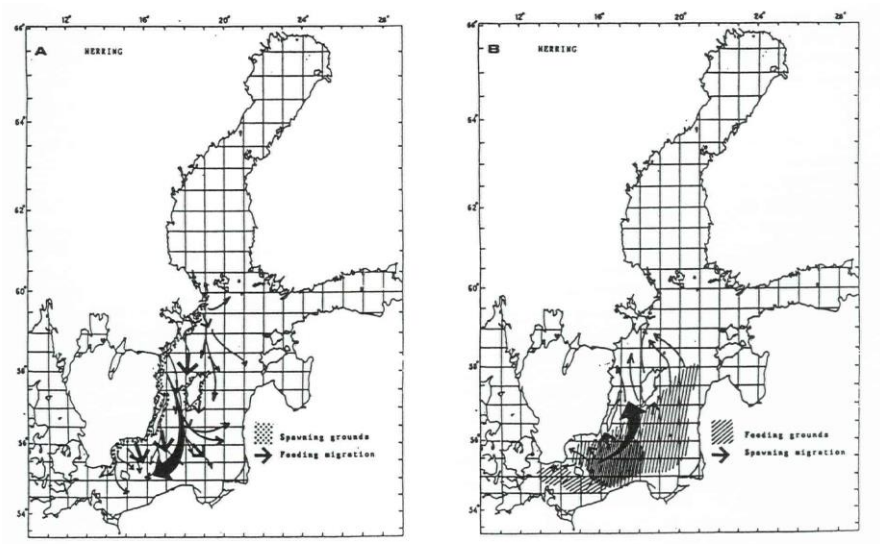
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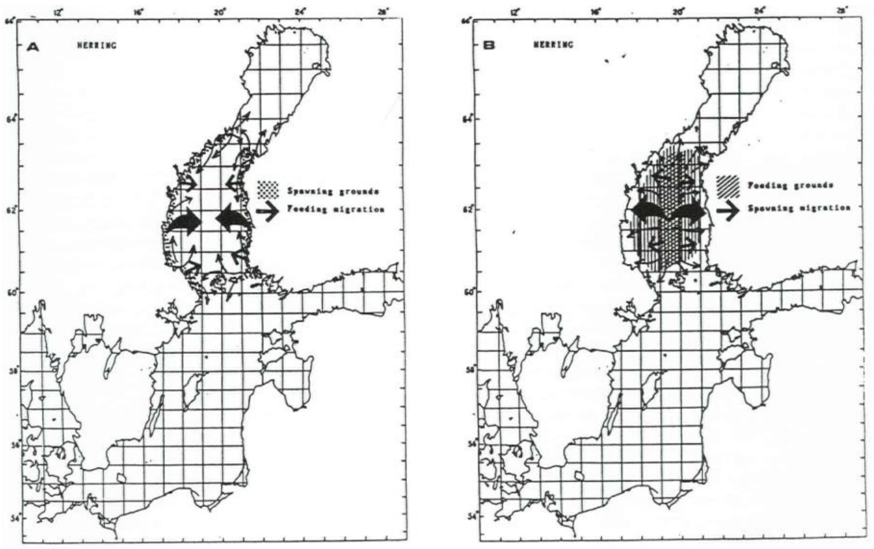
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Figure 1. Spawning and foraging migrations of spring-spawning herring on the Swedish coast in the central Baltic and the Gulf of Bothnia according to Aro (1989).

Spawning in spring normally occurs in April-June, but varies in different areas (Table 1) and mainly occurs on vegetation or hard seabed in the archipelago. Spawning later in the season occurs closer to the outer archipelago and the autumn spawning, which occurs in August-October, can also occur on shallows in the open sea (Gunnartz et al. 2011).

Table 1. County-by-county summary of information on main spawning time, depth, seabed substrate and population development along the Swedish east coast, based on an interview survey performed by Gunnartz et al. (2011). Where the information varies, this is shown as "unclear" and where information is lacking this is shown with the symbol –. Note that the assessment in the column "population development" is derived from Gunnartz et al. (2011). The interview study was performed in 2003, for which reason the stated population development reflects the situation up to that year.

Spring-spawning Baltic herring

County	Spawning time	Depth (m)	Bottom substrate	Stock trends
Norrbotten	June-July	0-15	Rocks	Declining
Västerbotten	May-Sept	0-15	Rocks, sand	Declining
Västernorrland	Apr-June	0-10	Rocks, sand, gravel, seaweed	Declining
Gävleborg	Apr-June	0-10	Rocks, sand, gravel, seaweed	Declining
Uppsala	May-June	0-10	Rocks, gravel	Declining
Stockholm	May-June	1-10	Stone, Rocks, seaweed	Declining
Södermanland	May-June	Varying	Varying	Declining
Östergötland	May-June	Varying	Varying	Delining
Kalmar	Varying	6-8	Seaweed, hard bottom	Unclear
Gotland	Apr-May	Varying	Stone, gravel, rocks, Fucus	Stable
Blekinge	Apr-May	2-3	Hard bottom, eelgrass	Declining
Skåne	Apr-June	-	-	Declining

Autumn-spawning Baltic herring

County	Spawning time	Depth (m)	Bottom substrate	Stock trends
Norrbotten	-	-	--	-
Västerbotten	Sept-Oct	3-30	Rocks	Unclear

Västernorrland	Sept-Oct	3-15	Rocks	Unclear
Gävleborg	Sept-Oct	3-15	Gravel, rocks	Increasing
Uppsala	Sept-Oct	3-15	-	Increasing
Stockholm	Aug-Sept	3-15	-	Increasing
Södermanland	Aug-Sept	0-20	Rocks, sand, gravel	Unclear
Östergötland	-	-	-	-
Kalmar	-	-	-	-
Gotland	-	-	-	-
Blekinge	-	-	-	-
Skåne	-	-	-	-

A number of tagging studies performed from the 1950s to the 1990s show that herring in the Gulf of Bothnia appear to exhibit homing behaviours and return to the same spawning area year after year (Hannerz 1955, 1956, Otterlind 1957, Parmanne and Sjöblom 1982, 1986, Bergström et al. 2007). Most recaptures were made within 150 km of the place of tagging (Saulamo and Neuman 2002, Figure 2). Another tagging study (Jönsson and Biester 1979) and otolith chemical studies of herring in the central Baltic have also shown homing behaviour tendencies (Moll et al. 2019).

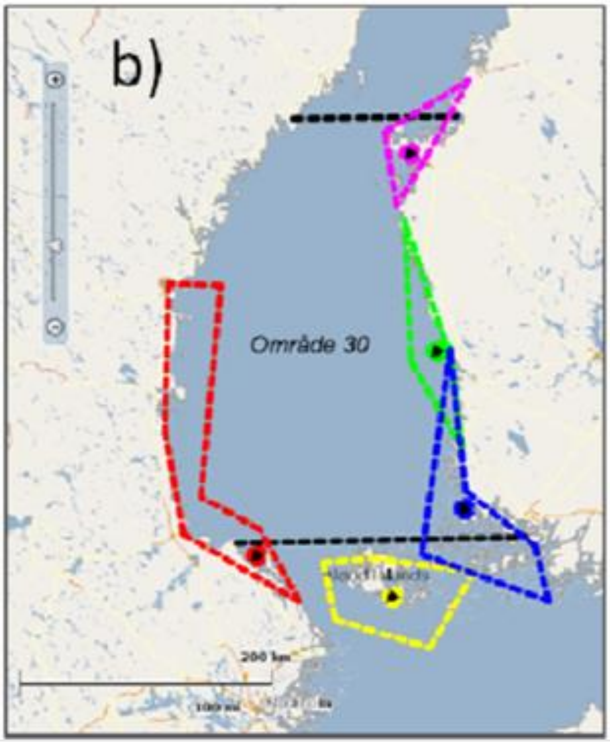


Figure 2. Summary of recaptures of herring that were tagged in the Gulf of Bothnia, based on Parmanne (1990) and Bergström et al. (2007). The dots show where the tagging was done and the dotted areas show the areas in which most recaptures occurred. The figure is from Lundmark 2010.

Growth and mortality

Herring in the Baltic 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 when herring are large enough for human consumption) at 6-8 years in the Gulf of Bothnia and 4-5 years in the central Baltic. Growth has slowed significantly since the early 1990s, when the fish reached the same size in 4-5 years in the Gulf of Bothnia and 3-4 years in the central Baltic (ICES 2022).

A decline can also be seen in body condition (the relation between an individual's weight and length) of herring in the central Baltic, which has been gradually declining since the 1980s (Casini et al. 2011). In the Gulf of Bothnia, the condition of larger herring has declined dramatically during 2020-2021 (ICES 2022).

Herring mainly feed on zooplankton. Changes in the availability of zooplankton (mainly copepods) and competition from sprats for food have been identified as important factors that have generally affected the growth of herring in both the central Baltic and the Gulf of Bothnia (Cardinale & Arrhenius 2000, Möllman et al. 2004, Casini et al. 2010, Lindegren et al. 2011, Rönkkönen et al. 2004, Karlson et al. 2020). Other correlative studies in the central Baltic have also 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 significant for the growth of herring (Bartolino et al. 2014, Cardinale and Arrhenius 2000, Casini et al. 2006, Kornilovs et al. 2001, Margonski et al. 2010, Smoliński, 2019). Changes in herring growth have also been linked to top-down factors, such as size-selective mortality caused by fishing, cod and seals (Beyer and Lassen 1994, Östman et al. 2014, Karlson et al. 2020) in both the central Baltic and the Gulf of Bothnia. Generally speaking, pelagic fishing and the seal population have increased in recent decades, while the low level of the cod population led to reduced predation by cod. The relationships have not been fully investigated, but these factors may have caused increased mortality in large herring compared to small ones (Kulatska et al. 2021), and a change in the age and size structure towards younger and smaller individuals (Gilljam et al. 2022).

Reproduction

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

Each female produces one set of eggs per year and these are released close to the seabed, where they are fertilised by the male, which swims a few centimetres above the female (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 free mass of water, usually in or close to the archipelago area (Polte et al. 2017)

For a marine species like herring, the low salinity of the Baltic is a challenge. This means that the body condition of the female can be expected to have a relatively greater effect on the quality of the offspring (Green 2008). For example, laboratory studies and studies in the Gulf of Bothnia show that the condition of the female affects the fertilisation, quality and survival of the egg (Laine and Rajasilta 1999, Rajasilta et al. 2021). There are a number of correlative studies of how environmental factors affect the herring's recruitment in the central Baltic, but since few conclusions about the main impact factors have been reproduced in other studies, it is difficult to draw clear conclusions. However, water temperature in summer (August) and the occurrence of zooplankton (especially *Psedocalanus* sp.) appear to have a positive correlation with the success of recruitment (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 be related to recruitment (Cardinale et al. 2009). This is supported by histological studies, which show a connection between weak individual body condition during the maturation process and reduced fecundity.

The Baltic herring as larva and juvenile

As the larvae grow and develop the ability to choose their habitat more actively (Moyano et al. 2016), they move towards growth 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 (Figure 3, 4, Polte et al. 2017). How large the population of adult Baltic herring will be is largely determined by mortality at the 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.

A schematic summary of the herring's migrations and use of habitat during the life cycle is shown in Figure 3.

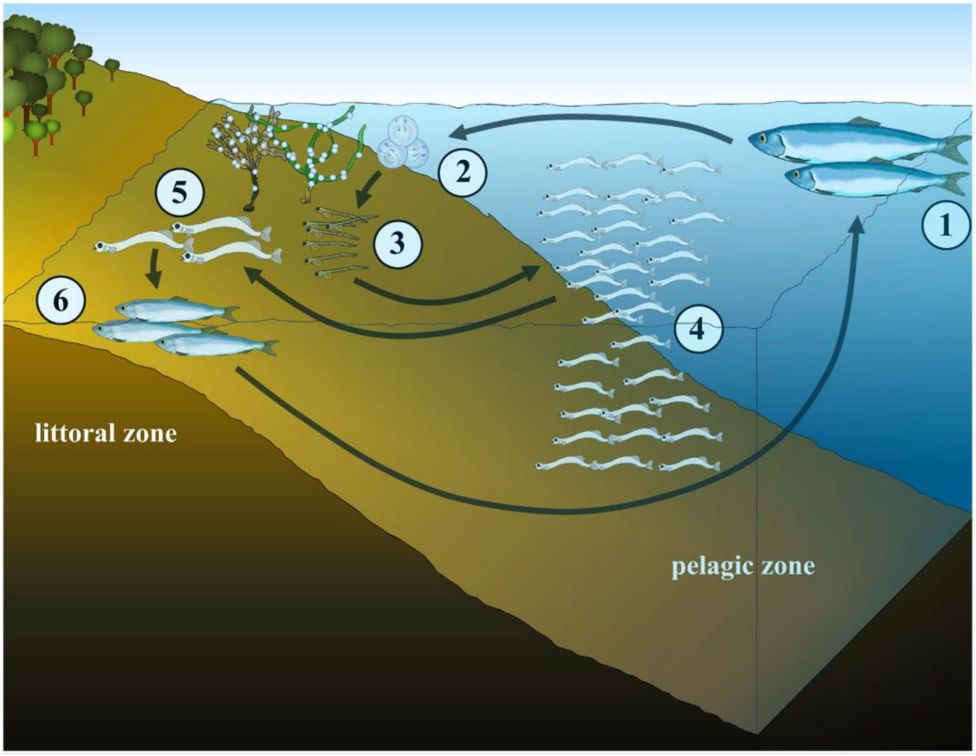


Figure 3. Baltic herring's use of habitats in different parts of the life cycle. Adult herring (1) migrate from the open sea to the coast for spawning, which occurs on a shallow, vegetation-clad hard seabed (2). Larvae at the yolk sac stage (3) are often concentrated close to the spawning areas. After the yolk sac has been consumed (4), the larvae are often horizontally dispersed in the immediate coastal area. Larvae at the last larval stage (5) then return to the littoral zone where they metamorphose into juveniles (6). The shoals of growing juveniles migrate successively to the open sea and then recruit to the adult population at an age of 1-3 years. From Polte et al. 2017.

Spawning and growth areas

Herring fry use different habitats in different stages of the life cycle and seem to have fewer specific requirements for spawning and growth areas than many other species in the Baltic (Erlandsson et al. 2021). Since there are large areas along the entire Baltic coast that are potentially suitable for herring reproduction, access to reproduction areas is probably not as a clear a limitation for the herring populations than for many warm water species (Figure 4). Since recruitment of herring, according to population estimates for both the central Baltic and the Gulf of Bothnia, has been relatively stable over the last 30 years (ICES 2022), the effects of, for example, eutrophication and climate change, do not thus far appear to have had any significant effect on reproduction success. However, knowledge about possible differences in recruitment between subpopulations is very limited. Polte et al. 2017 argues that, since different habitats are used at different stages in the life cycle, this can introduce a number of possible bottlenecks relating to availability of and connection to life environments for fish fry, and that effects of exploitation on different coastal habitats should be further investigated and considered in the management of regional coastal areas.

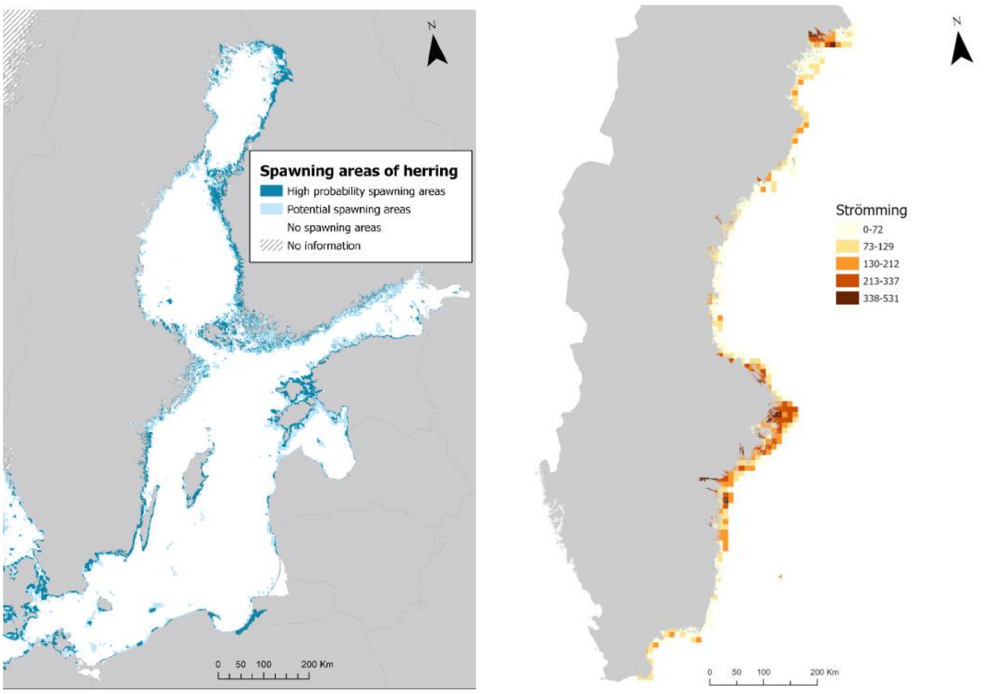
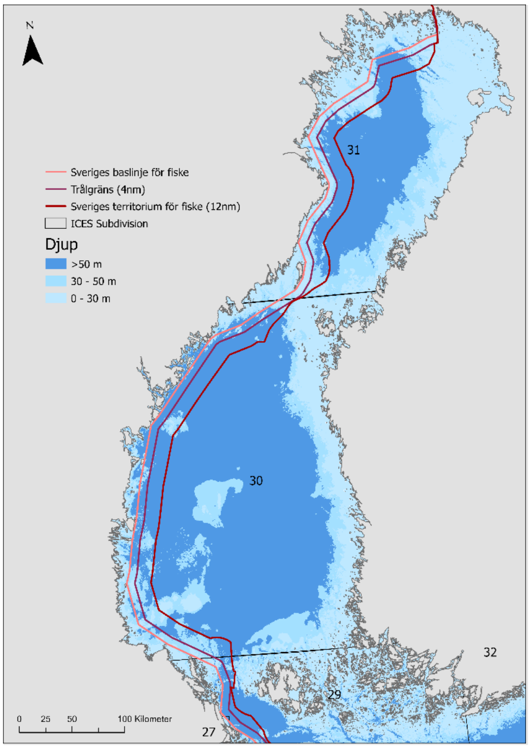


Figure 4. Left: potential spawning areas for herring in the Baltic based on an overview of vegetation-clad seabed areas (the figure is from Bergström et al. 2021). Right: modelled growth areas for herring along the Swedish coast from Hanö Bay to Norrbotten based on high resolution information on the occurrence of fish and habitat variables. For clearer visualisation, the model predictions in the map on the right have been aggregated to a cell size of 5x5 km (the figure is from Erlandsson et al. 2021). Spawning and growth areas occur along the whole east coast, with the larger archipelagos representing the most important areas.



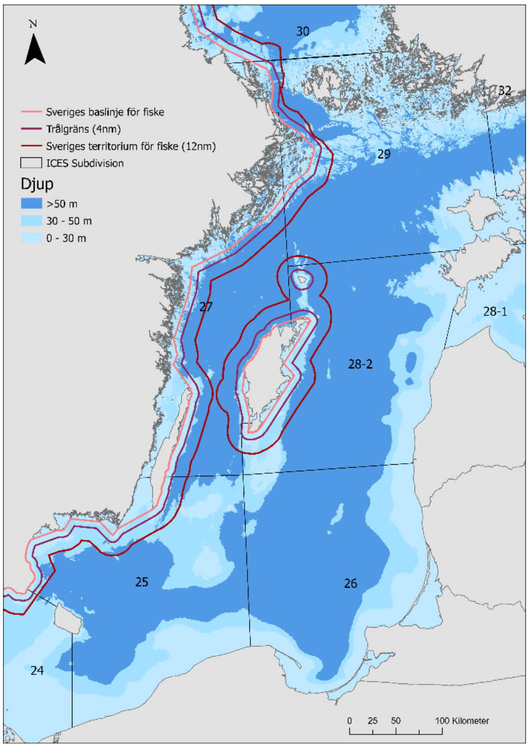


Figure 5. Map of the Gulf of Bothnia (above) and the central Baltic (below) with the Swedish base line for fishing (pink line), present trawl limit (4 nm; purple line), territorial limit (12 nm; dark red line), as well as water deeper than 30 metres, between 30 and 50 metres and deeper than 50 m (light to dark shades of blue).

5. Fisheries analyses

Method and data sources

To map the extent of herring fishery in the Baltic 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). Data as requested was received from all countries except Latvia and Germany. Since, in the last three years, Germany and Latvia have on average landed 0.5% and 3.4 % respectively of the total landings of herring in the central Baltic, these countries' catches in Swedish waters are of negligible significance for total landings. The data requested was logbook data linked to positions from fishing vessels' VMS systems (hereinafter called VMS data) from the countries fishing in the entire Baltic with the exception of the Gulf of Riga. Apart from this data, roughly resolved geographical data from logbooks (total catches per ICES rectangle (1° latitude × 0.5° longitude rectangles: WGS 84) from other fishing that could not be linked with VMS for the same areas was also requested. Since vessels under 12 metres are not obliged to use VMS equipment, supplementary data was also used for small vessels, so as to map in a more detailed way the activities of small vessels in Swedish waters. This part of the analysis only included Swedish logbooks.

The total catch of herring in Swedish waters was aggregated and analysed in different ways so as to investigate the geographical and temporal variation in the Baltic herring fishery. Results from this analysis are presented here in the form of tables and maps. The tables were produced by summing, in a GIS environment (detailed VMS data and Swedish logbook data for vessels less than 12 metres; point data), the total catches in different subareas (polygons) that represent: (i) the area inside the trawl limit (4 nautical miles from the baseline); (ii) the area between the trawl limit and the territorial water boundary (4-12 nautical miles from the baseline); (iii) water outside the territorial water boundary, i.e. Swedish economic zone, in various ICES areas (Figure 6). . In addition to analysing total catches, analyses on the distribution of the catch by vessel size (<12, 12-24 and >24 metres) and gear type (bottom trawl, pelagic trawl, seine net and passive equipment) were also made.

The maps in the report were created by rasterizing (0.05 ° latitude × 0.05 ° latitude; WGS84) the detailed VMS data received from all countries. Zones with depths deeper or shallower than 50 metres were obtained by creating polygons from raster data from the Baltic Sea Bathymetry Database (http://data.bshc.pro/ - 2/57.9/22.3).

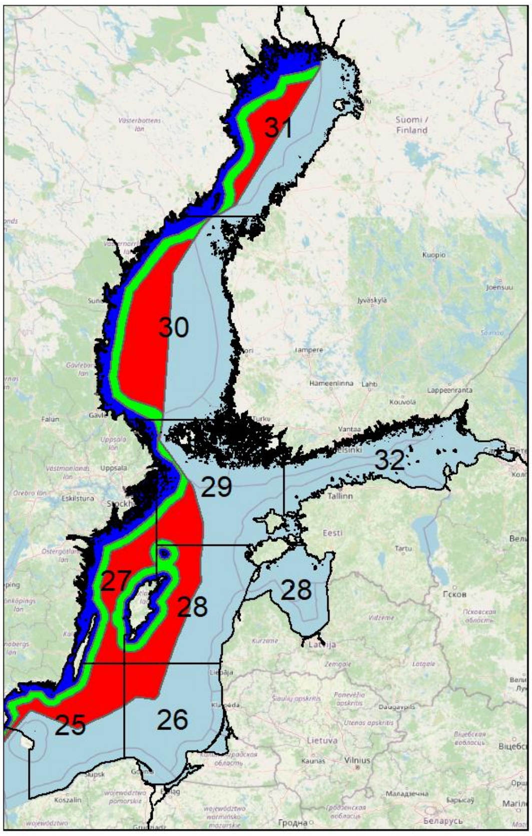


Figure 6. The analysed areas in Swedish waters. Blue shows the trawl ban area (4 nm), green shows the area between the trawl ban border and the border for Swedish territorial water (4-12 nm) and red shows the Swedish economic zone. Within the trawl ban area, there are areas of exception where some trawling occurs, but these are not shown on this map.

Total herring catches in Swedish waters

In total, the average annual catch of herring in the Baltic in 2012-2021 is approximately 230,000 tonnes (average catch for all available data), of which Swedish fisheries accounts for approximately 25%. In Swedish waters (Figure 6), the total average catch for all countries is approximately 73,500 tonnes per year^{-1}, and Swedish fishery accounts for approximately 57% of catches. In Swedish waters in the Central Baltic (SD areas 25-29), the Swedish fishery accounts for almost 75% of the total catches and in SD 27 and 28, the Swedish fishery is dominating accounting for almost 90% of the total catches (Table 2). In SD 25, foreign and Swedish catches are similar, while in SD 29, Swedish fishery accounts for 80% of the total catches. The largest catches in SD 27 and 28 stem from Swedish territorial waters (<12 nm). In SD 25, the largest Swedish catches are from the area 4-12 nm, while the largest foreign catches are from outside the territorial border (>12 nm). In SD 29, the largest catches are outside the territorial border for both Swedish and foreign fishing. The Fishery in SD 27-29 is dominated by pelagic trawling and most of the fishery is done with vessels larger than 24 metres, although there is some bottom trawling (Appendix Table 1).

Table 2. Swedish and foreign average catches (in tonnes per year for 2012-2021) of herring in Swedish waters. Catches are shown separately for three zones - within the trawl ban area (4 nm), between the trawl ban border (4 nm) and the border of Swedish territorial water (12 nm) and in the Swedish economic zone (EEZ). VMS data and Swedish logbook data for vessels under 12 metres have been used in creating this table.

Area	Catch country	<4 nm	4-12 nm	EEZ	Total
25	Sweden	459 (8%)	3138 (56%)	2017 (36%)	5614
25	Other country	14 (0%)	518 (11%)	4351 (89%)	4883
26	Sweden	0 (0%)	0 (0%)	2136 (100%)	2136
26	Other country	0 (0%)	0 (0%)	1766 (100%)	1766
27	Sweden	2152 (19%)	6739 (60%)	2430 (21%)	11321
27	Other country	23 (2%)	758 (57%)	558 (42%)	1339
28	Sweden	366 (4%)	5839 (63%)	3021 (33%)	9226
28	Other country	35 (2%)	560 (37%)	902 (60%)	1497
29	Sweden	24 (1%)	1320 (34%)	2506 (65%)	3850
29	Other country	17 (2%)	488 (45%)	585 (54%)	1090
30	Sweden	402 (4%)	589 (5%)	10148 (91%)	11139
30	Other country	211 (1%)	1132 (5%)	19466 (94%)	20809
31	Sweden	79 (100%)	0 (0%)	0 (0%)	79
31	Other country	0 (0%)	0 (0%)	2 (100%)	2

Herring catches in the Gulf of Bothnia (SD 30) accounts for approximately 43% of the total catches in Swedish waters. Here, the Swedish fishery accounts for only about a third of the total catch, while Finland accounts for the rest. The absolute largest catches occur outside the Swedish territory and only 5% of the total catches (both Swedish and Finnish) occur in the area 4-12 nm. Although some bottom trawling occurs, pelagic trawling dominates the fishery in this area. Almost 90% of the total catches are made by vessels larger than 24 metres fishing with pelagic trawls (Table A1).

A more detailed analysis shows that the herring catches are dominated by large vessels (vessels > 24 m) in large parts of both the Gulf of Bothnia and the central Baltic (Figure 7; Figure A1-A3). However, in coastal areas, some herring are caught by smaller vessels (12-24 metre vessels). Landing positions for the smallest vessels (<12 metre) fishing with both trawls and passive equipment (~21 % pelagic trawl; ~ 22% bottom trawl; ~49 % passive equipment; 8% seine nets) also tend to overlap areas where vessels of 12-24 metres dominate catches.

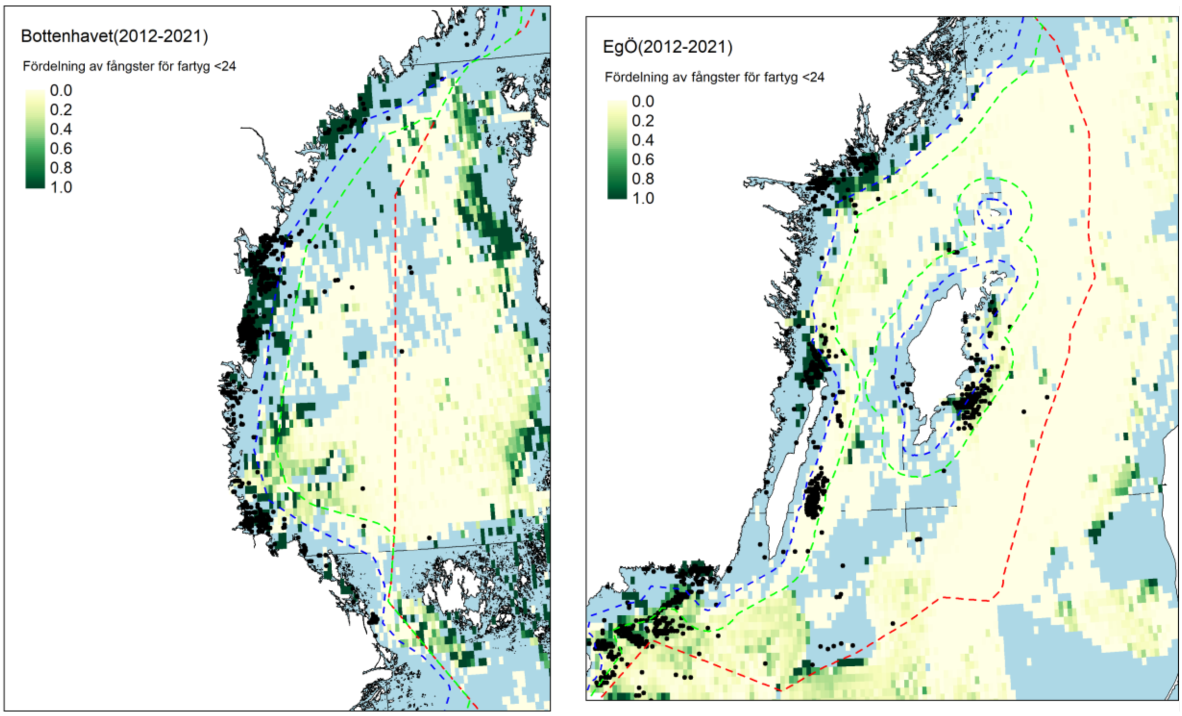


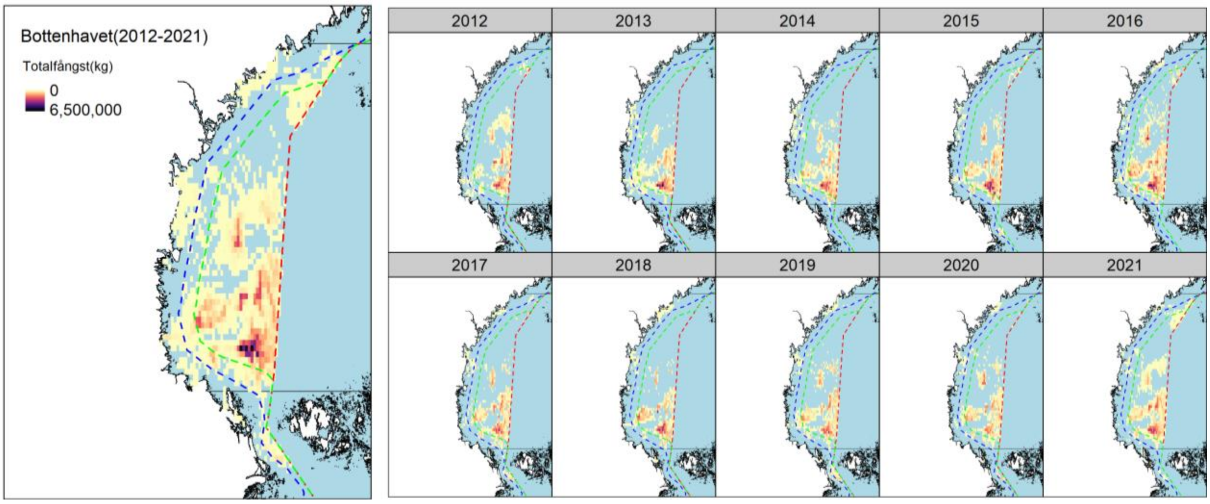
Figure 7. Geographical distribution of herring catches by small and large fishing vessels during 2012-2021. The maps show the ratio between total catch by small boats 12-24 metres and total catch by all boats. Green indicates that 12-24 metre vessels dominate the fishery in an area and white indicates that larger vessels (over 24 metres) dominate the fishery. Blue shows areas without herring catches during 2012-2021. The total catches are aggregated within a 0.05 ° latitude × 0.05 ° latitude raster (WGS 84) and the ratio has been calculated for each grid. The panel on the left shows the Gulf of Bothnia and the panel on the right the central Baltic. Small black points show GPS positions from logbook data for vessels smaller than 12 metres.

The logbook positions are less accurate than VMS data, but give an overview of the areas where small-scale coastal fishing occurs.

Geographical and temporal variations of herring catch in Swedish waters.

Detailed analyses of VMS data show that large quantities of herring are caught within well-confined geographical areas, in both the Gulf of Bothnia and the central Baltic (Figure 8).

Although the total catch in different areas varies somewhat from year to year (Figure A1-A3), the geographical distribution of herring catches has not varied significantly between the years over the period 2012-2021 (Figure 8). The total catches of herring during the period 2012-2021 thus give a relatively good picture of the annual geographical distribution of the fishery and show that certain areas are considered to be hot spots. It should be noted, however, that the fishery outside Swedish waters can also affect the herring within Swedish waters. Thus, some areas outside the Swedish economic zone could be important when considering the choice of trial areas for the scientific experiment.



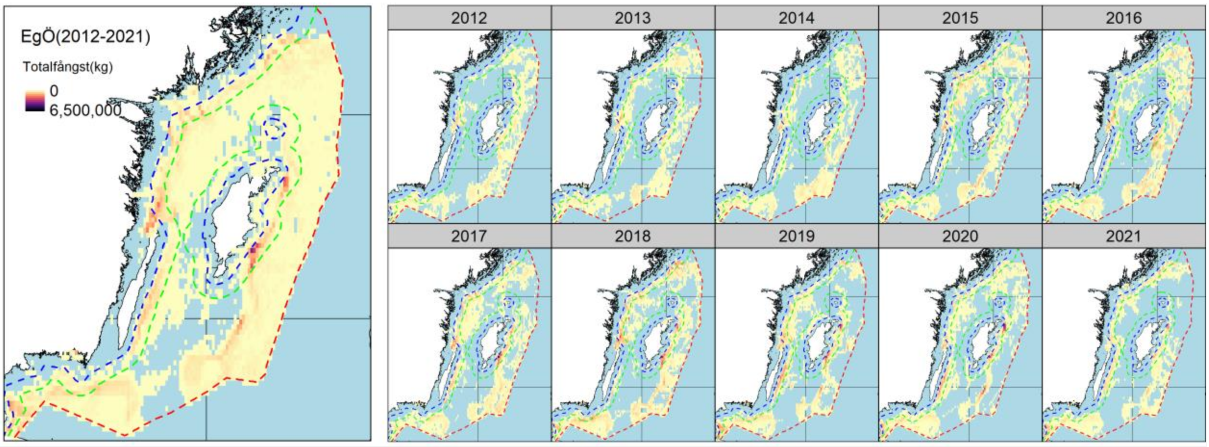


Figure 8. Herring catch per year in Swedish waters for the period 2012-2021. The large panels show all countries' total catch of herring in the Gulf of Bothnia (upper panels) and central Baltic (lower panels) respectively during the period 2012-2021. Small panels show annual catches of herring. The colour scale in the small panels shows the catch in relation to the maximum catch in some squares for some years during 2012-2021. The blue dotted line shows the trawl ban border (4 nm), the green dotted line shows the border of Swedish territorial waters (12 m) and the red dotted line shows the border of the Swedish economic zone. The herring catches are summed across a 0.05 ° latitude × 0.05 ° longitude raster (WGS 84). VMS data has been used to create this figure.

The seasonal variation in herring fishery is considerably larger than the annual variation or the fishery (cf. small panels in Figure 8 and Figure 9). Large catches of herring occur in the Gulf of Bothnia in all months of the year except July and August, when catches are lower. In the Gulf of Bothnia (upper panels Figure 9) large quantities of herring are caught in some well-confined geographical areas in the Swedish economic zone (between green and red dotted lines). The catches are spread between these areas for much of the year, but in May and June fishing is clearly concentrated in a geographical area in the southern part of the Gulf of Bothnia (Figure 9). In the central Baltic, herring catches are largest at the beginning of the year and lowest in July and August. Catches are more geographically spread during January-March, while later in the year (September-December) they are more concentrated in certain areas, such as east of Gotland.

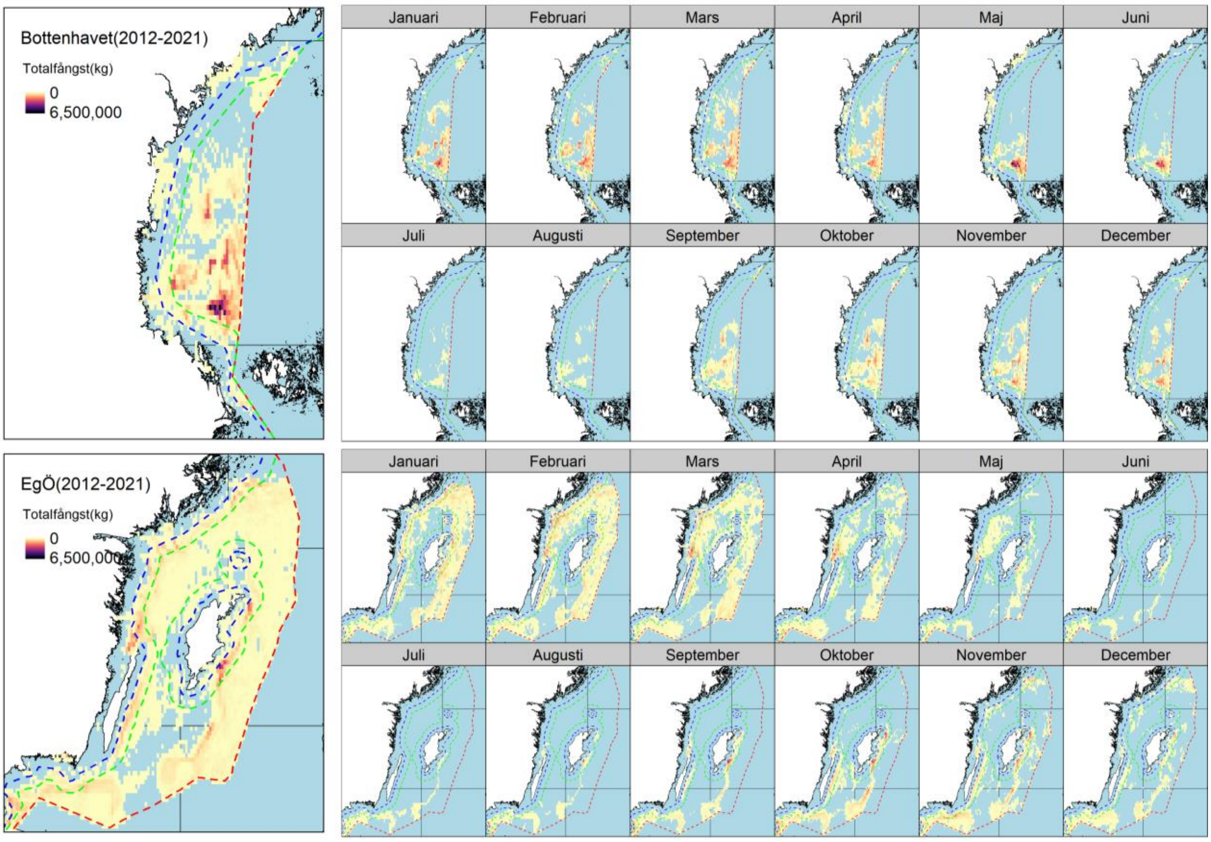


Figure 9. Average herring catch per month in Swedish waters for the period 2012-2021. The large panels show the total catch of herring in the Gulf of Bothnia (upper panels) and central Baltic (lower panels) during the period 2012-2021. Small panels show the average catch of herring per month during the period 2012-2021. The colour scale in the small panels is based on average catch in a month in relation to the maximum average catch in some squares for month during the period 2012-2021. The blue dashed line shows the trawl ban border (4 nm), the green dotted line shows the border of Swedish territorial waters (12 nm) and the red dotted line shows the border of the Swedish economic zone. The herring catches are summed across a 0.05 ° latitude × 0.05 ° longitude raster (WGS 84). VMS data has been used to create this figure.

An important parameter, which may particularly affect the occurrence of herring in winter, is water depth. Figure 10 therefore shows the distribution of total herring catches during 2012-2021 in relation to depth. The analysis shows that the largest catches of herring are made close to the 50-meter depth curve (corresponding figures for 30 and 70 metres respectively are shown in Figures A4 & A5). In the central Baltic, the largest herring catches are concentrated near the 50-metre depth curve. In the Gulf of Bothnia, the largest herring catches are made in areas deeper than 50 metres (Figure 10).

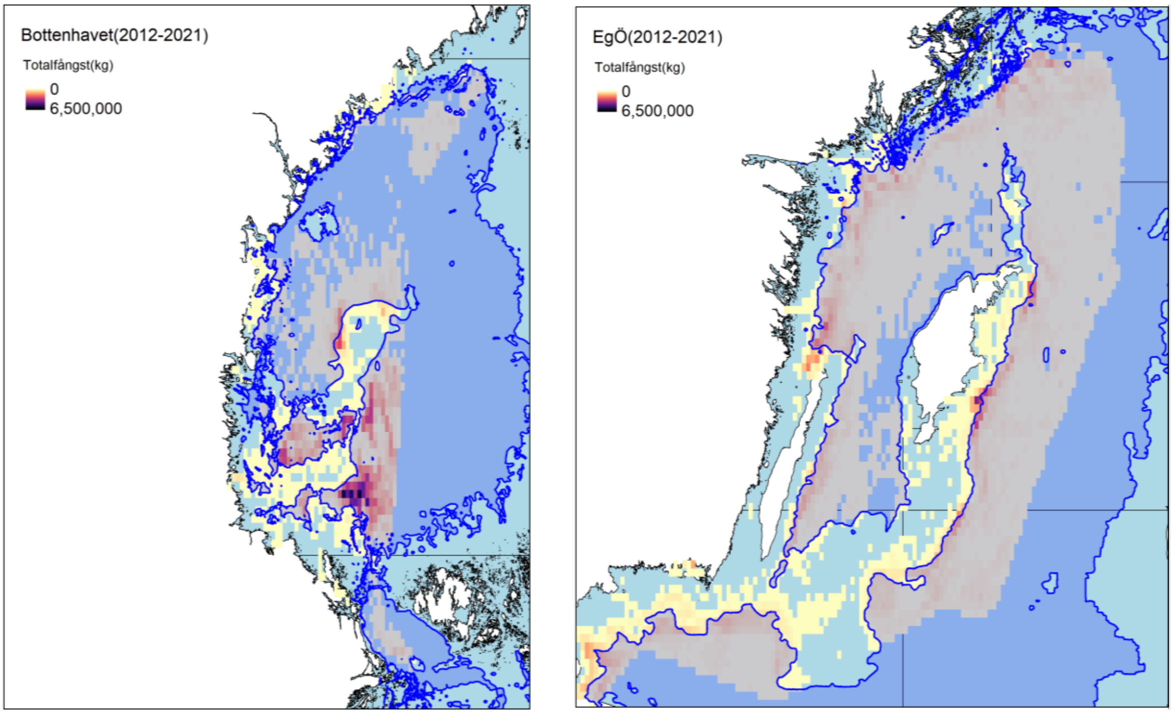


Figure 10. The relationship between depth and herring catches in Swedish waters. The maps show the total catch of herring (yellow squares small catch and dark squares large catch) in Swedish waters in the Gulf of Bothnia ((left panel) and the central Baltic (right panel) for 2012-2021. The dark blue line shows the 50-meter depth curve. The darker blue areas, bounded by the depth curve, show water deeper than 50 metres. VMS data has been used to create this figure.

6. Genetic population patterns in herring in the central Baltic and Gulf of Bothnia

Ongoing studies

At the time of writing, a large number of herring samples are being analysed with regard to genetic population patterns. These samples are mainly from spawning fish from Swedish coastal fisheries, as well as from pelagic fisheries in the open sea, and represent herring at different stages of maturity. This section of the report presents preliminary results from mature, spawning herring collected along the Swedish coast during 2021. A summary of samples and available genetic data is presented in Table 3.

Table 3. Summary of samples in ongoing analysis of approximately 5,000 SNPs (Single Nucleotide Polymorphisms, variation in individual base pairs in the genetic code). Available data is presented in this report.

Type of sample	Geographical coverage	Number of	Number for sequencing	Data available	Responsible university

		samples total			
Samples of spawning fish	Whole east coast	11932	2637	Presented in this report	SU/SLU
Samples of pelagic fish	SD 25-29, 30	750 +	757	Analysed during 2023-2024	SLU/SU/UU
Mainly spawning samples, associated with dioxin levels	SD 30, SD 25	496	496	Presented in this report	UU/SLU
Samples with associated diet analyses	Whole east coast	2474	60	Analysed during 2023-2024	SLU/UU

Genetic population patterns in the central Baltic and Gulf of Bothnia

Genetic studies of herring in the Central Baltic and Gulf of Bothnia have identified differences between herring from different areas and spawning times and linked these differences to ecological adaptations, primarily associated with spring and autumn spawning and to some extent also summer spawning (e. g. Lamichhaney et al. 2012; Martinez-Barrio et al. 2016; Hill et al. 2019; Pettersson et al. 2019; Han et al. 2020).

In 2022, SLU and SU delivered data to SwAM: Preliminary report regarding the question at issue: are there genetic differences among spring-spawning herring in ICES subdivisions 27 and 29 (Wennerström et al. 2022). This material represents the results of analyses of primarily spring-spawning herring in ICES SD 27 and 29, but also from two samples of autumn-spawning herring from the Uppland coast and a few samples from SD 25, 30 and 31 (Figure 11). For the analyses, 47 genetic markers (SNPs, Single Nucleotide Polymorphisms) were used. These markers were mainly developed to distinguish between autumn and spring-spawning herring.

Figure 11. Collection locations for Baltic herring in Wennerström et al. (2022). All samples represent spring spawners except Upp10 and Upp11, which represent autumn spawners

These analyses showed that there are genetic differences between populations in the Central Baltic Sea and the Gulf of Bothnia (Wennerström et al. 2022). The greatest genetic differences were identified between samples that represented autumn and spring-spawning herring (Figure 12, Table 4), but some genetic differences were also found between samples of spring-spawning herring. One sample in particular, from Kalmar County, differed from other samples of spring-spawning herring. Statistically significant genetic differences were also found between samples from ICES area 31 and other spring spawning populations from the Swedish east coast.

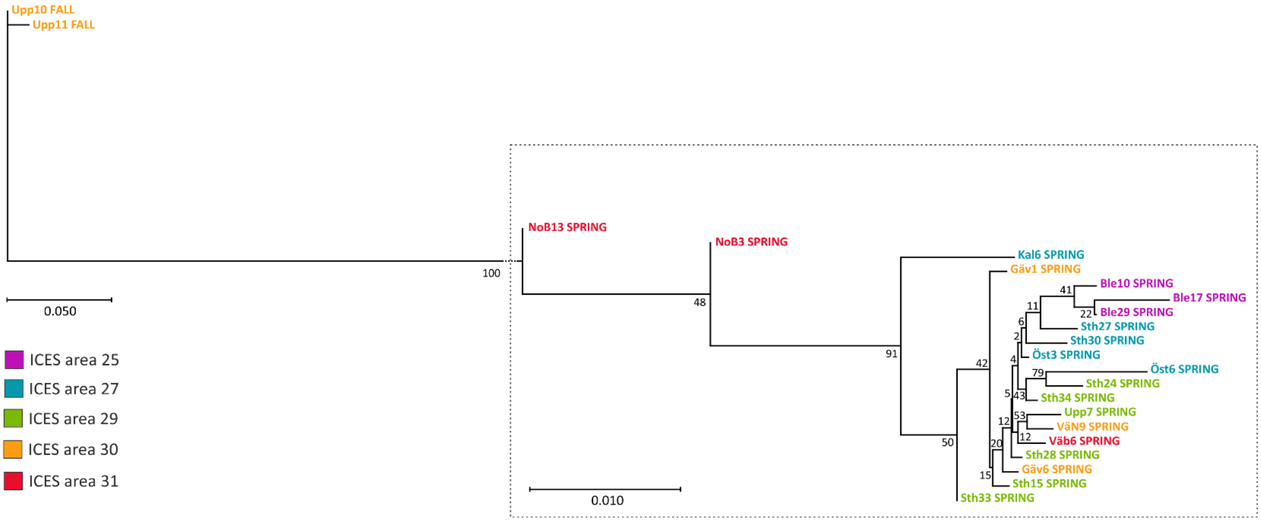


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Figure 12. A phylogenetic tree that illustrates the genetic relationship between random samples from ICES areas 25, 27, 29, 30 and 31, where ”FALL” and ”SPRING” indicate samples from autumn and spring spawners. The tree is based on Nei's D_A distance, which is a measurement of the genetic distance, where greater branch distance indicates greater genetic difference. The bootstrap values (in per cent) along the branches indicate the probability that they represent an actual difference. Note that the tree is divided into two parts that have different scales for branch length. From Wennerström et al. 2022.

Table 4. Paired F_{ST} values between samples of individuals in maturation stage 6 (ongoing spawning) and sample size >20. The samples are sorted from north to south within ICES subdivisions, but samples from autumn-spawning Baltic herring (SD 30) are placed last (furthest right or furthest down). Statistically significant comparisons are in bold and coloured; the higher the F_{ST} value, the darker the colour. Statistical tests have been performed with the aid of the programme Genepop. SD=ICES subdivision. Negative F_{ST} values are interpreted as F_{ST}=0. From Wennerström et al. 2022.

	NoB13	NoB3	Väb6	VäN9	Gäv1	Gäv6	Upp7	Sth15	Sth28	Sth24	Sth34	Sth33	Sth30	Sth27	Öst3	Öst6	Kal6	Ble29	Ble10	Ble17	Upp10	Upp11
NoB13			SD 31																			
NoB3	0.008																					
Väb6	**0.014**	**0.011**																				
VäN9	**0.023**	**0.019**	0.001			SD 30																
Gäv1	**0.022**	**0.017**	0.002	0.009																		
Gäv6	**0.022**	**0.021**	0.001	0.012	-0.003																	
Upp7	**0.010**	**0.014**	-0.001	-0.001	0.006	0.008																
Sth15	**0.030**	**0.017**	-0.001	0.005	-0.004	-0.007	0.007				SD 29											
Sth28	**0.023**	**0.016**	-0.004	0.000	0.000	-0.004	0.000	-0.007														
Sth24	**0.058**	**0.050**	0.009	0.020	**0.012**	0.003	**0.021**	-0.001	0.003													
Sth34	**0.020**	**0.026**	-0.006	0.000	0.002	-0.004	0.001	-0.006	-0.009	0.001												
Sth33	**0.018**	0.010	-0.002	0.012	-0.004	-0.005	0.004	-0.010	-0.005	0.012	-0.004											
Sth30	**0.040**	**0.035**	**0.011**	0.015	0.006	0.002	**0.016**	0.000	0.004	0.009	-0.001	-0.004										
Sth27	**0.028**	**0.019**	0.001	0.004	0.013	0.006	0.000	0.004	-0.002	0.010	0.003	0.002	0.008			SD 27						
Öst3	**0.027**	**0.026**	0.002	0.003	0.007	-0.001	0.000	0.003	-0.002	0.009	-0.002	0.007	0.005	0.001								
Öst6	**0.042**	**0.044**	0.013	0.021	0.001	-0.002	0.011	0.006	0.002	0.010	0.001	0.005	**0.011**	0.013	0.005							
Kal6	**0.098**	**0.052**	**0.081**	**0.070**	**0.069**	**0.086**	**0.069**	**0.068**	**0.073**	**0.108**	**0.086**	**0.053**	**0.064**	**0.060**	**0.086**	**0.106**						
Ble29	**0.044**	**0.036**	**0.026**	**0.034**	**0.019**	**0.019**	**0.024**	**0.019**	**0.022**	**0.036**	**0.024**	0.007	0.012	0.011	**0.028**	**0.026**	**0.038**			SD 25		
Ble10	**0.038**	**0.037**	**0.020**	**0.026**	**0.019**	**0.018**	0.017	**0.020**	**0.017**	**0.027**	**0.025**	**0.017**	**0.020**	0.007	**0.017**	**0.026**	**0.067**	0.009				
Ble17	**0.061**	**0.046**	**0.049**	**0.055**	**0.041**	**0.038**	**0.038**	**0.041**	**0.042**	**0.063**	**0.050**	**0.027**	**0.028**	**0.023**	**0.042**	**0.048**	**0.042**	0.005	0.007			
Upp10	**0.564**	**0.549**	**0.607**	**0.628**	**0.617**	**0.627**	**0.624**	**0.625**	**0.624**	**0.664**	**0.636**	**0.597**	**0.628**	**0.628**	**0.638**	**0.668**	**0.591**	**0.600**	**0.627**	**0.616**		Höst
Upp11	**0.569**	**0.552**	**0.612**	**0.636**	**0.623**	**0.633**	**0.632**	**0.633**	**0.630**	**0.672**	**0.644**	**0.603**	**0.635**	**0.637**	**0.643**	**0.678**	**0.602**	**0.606**	**0.635**	**0.625**	0.003	

F_{ST} (%)	NS	0-2.5	2.5-5	5-7.5	7.5-10	>10

NS= not significant

In subsequent work, 4,838 individuals were sequenced from a total of 151 samples of spawning Baltic herring for approximately 4,000 SNPs (Figure 13). The sequenced individuals represented all individuals with maturity stage 5 (close to spawning) or 6 (ongoing spawning). In the following figures, only results from individuals with maturity stage 6 (e. g. spawning fish) are presented. The first results from this work tend to indicate a genetic structure that is complex and does not have a simple geographical link to nearby geographical areas or distance between these (Laikre and Johannesson 2023). In general, the greatest genetic differences were found between autumn and spring-spawning herring and these differences linked to spawning time were greater than genetic differences between sea areas along the Swedish east coast. However, a number of samples from spring-spawning herring were grouped genetically with autumn-spawning herring and the opposite also occurred, i.e. herring that were caught during spawning in the autumn were genetically grouped with spring-spawning herring (Figure 14). It is important to point out that this mismatch between spawning time and how individuals were grouped genetically did not apply to single individuals but to all or most of the individuals from a particular sample. Autumn spawners that were genetically grouped with spring spawners also showed genetic differences compared with other autumn spawners. It appears therefore that this is not about individuals that spawn at a different time of year but local populations that have a unique genetic pattern.

Figure 13. Locations of collected samples of herring in 2021 and 2022 that are included in the genetic mapping of the species' genetic structure. From Laikre and Johannesson 2023.

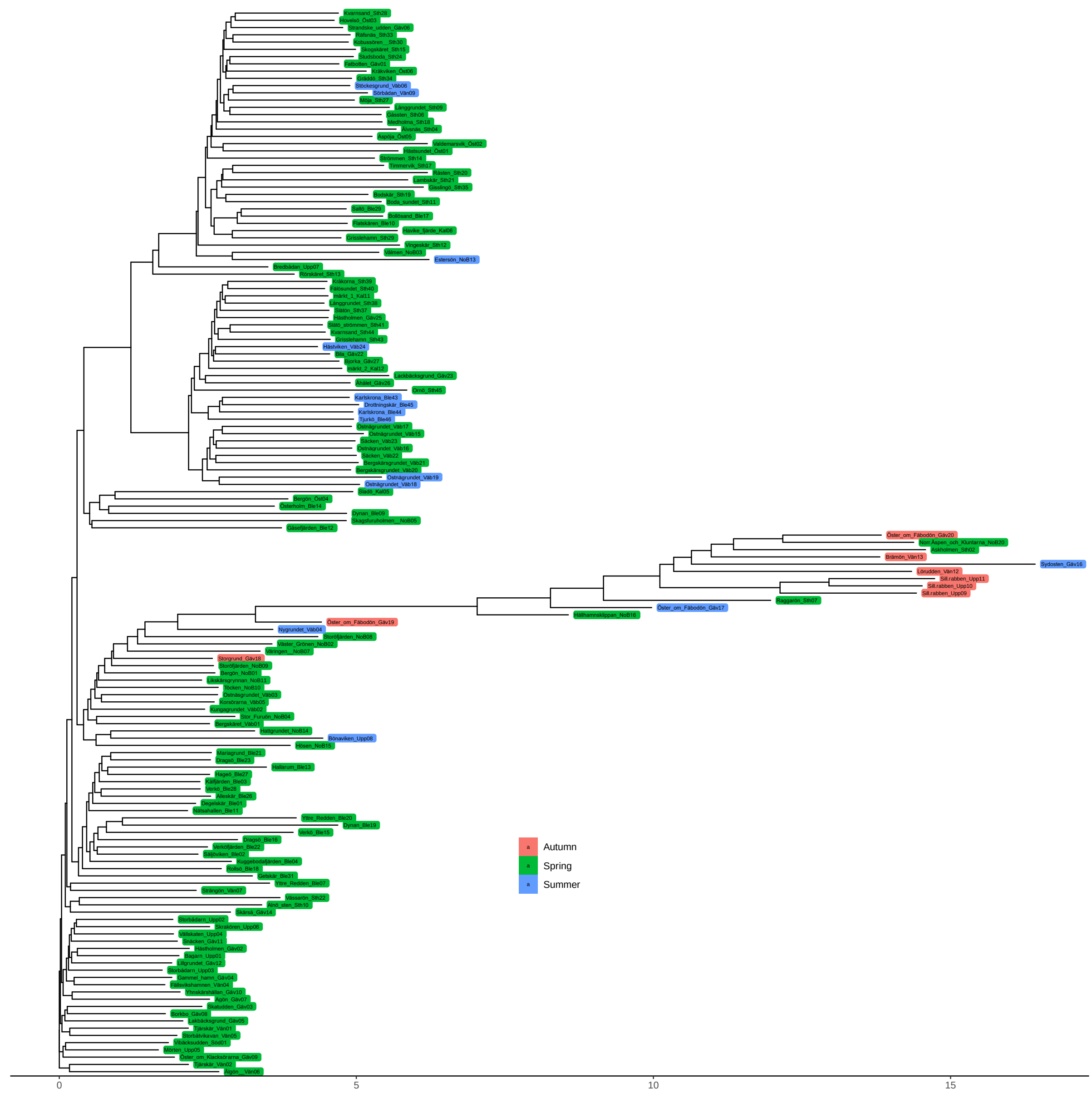

Figure 14. A "Neighbour joining dendrogram" that is based on both adaptive and neutral SNPs (n=4003) obtained with the programme Ape (Paradis and Schliep 2019). The figure is based on a distance matrix that is calculated on the basis of similarity in allele frequencies between different samples, with the aid of the programme Plink2 (Purcell et al. in press). The samples (n=149) are colour coded by season when they are collected, where green=spring, blue=summer, red=autumn. All samples are from spawning fish (maturity stage 6). A clear structure appears in which autumn spawners create a separate group. But the figure also shows that many spring-spawning populations are genetically grouped with autumn spawners, and the opposite for two samples of summer spawners and two autumn-spawning populations that are genetically grouped with spring spawners. From Laikre and Johannesson (2023).

During 2022 and 2023, a study was performed that was funded by the Swedish Board of Agriculture and BalticWaters2030 in which herring from Gävle Bay (SD 30) and Hanö Bay (SD 25) were studied and sequenced for approximately 2,500 SNPs (Andersson 2023). The purpose of this study was to identify populations especially suitable for human consumption by also analysing dioxin levels in the samples. Eight samples from Gävle Bay and nine samples from Hanö Bay were analysed. The results of the study showed once again that the greatest genetic differences are found between Baltic herring collected as mature for spawning in autumn and spring respectively. One sample that was collected in late autumn, after spawning, at Eggegrund in the southern Gulf of Bothnia contained herring that were grouped as both autumn and spring spawning, which indicates that in this area the populations are mixed after spawning time. In Hanö Bay, no genetic differences were found between herring caught in May and July. This indicates that the spring-spawning herring probably remain in the area after spawning.

One of the samples from Gävle Bay was from the so-called ”Slåttersillen” herring, which was pointed out by a local coastal fisherman as being an unusually large-sized population that spawns somewhat later in the year than other herring in the area. The ”Slåttersillen” was clearly genetically different from other samples of spring spawners from Gävle Bay. The ”Slåttersillen” was also considerably larger than other herring from Gävle Bay. The “Slåttersillen” was on average 28.5 cm long and weighed 192 grams on average, which can be compared with the other samples from Gävle Bay where the average length was 18.5-19.9 cm and average weight 38-51 g. The “Slåttersillen” also had lower dioxin levels than other samples from Gävle Bay (Andersson 2023).

There are generally genetic differences between the spring-spawning herring from Gävle Bay and those from Hanö Bay. These differences were, however, smaller than between autumn and spring-spawning herring and also smaller than between the unique ”slåttersill” population and other samples from Gävle Bay.

7. Data for extended sampling

The herring population in the Baltic is monitored along the coast by means of various national surveys and in the open sea by means of scientific surveys. There are also comprehensive monitoring programmes of commercial fishery catches. Some of the monitoring is regulated by the EUs data collection regulation (EU 2017/1004) while other monitoring is on national initiatives. SLU is the main performer of monitoring, but the County Administrative Boards also perform monitoring. Monitoring along the coast is most often done with standardised gillnets while monitoring in the open sea is done with the aid of hydro acoustics (echo sounders) and float trawling.

The aim of the monitoring is to spot trends in the size of populations, locally or for the population's whole management area. To this end, the fish are counted, measured and age-assessed. Sampling of individuals is also performed, partly to study condition and sexual maturity. Improved opportunities for analysing the DNA of herring have also meant that the biological sampling is supplemented, where possible, with genetic sampling.

To be able to monitor the effects of area closure, it is essential to increase our knowledge of the Baltic herring's population structure and migration patterns. In addition to genetic sampling, chemical analysis of various tissues, such as otoliths and scales, is also important for increasing this knowledge.

Extending monitoring so as to follow the effects of enlarging closed areas/trawl limits could therefore include:

- Extended fishing surveys along the coast in areas judged to be of interest for the trial. It could be of interest both to resume surveys in areas where there is older data and to commence new fishing where there is no previous data.
- Improved sampling of catches from the commercial fisheries (coastal and open sea).
- Extended individual sampling of herring in existing monitoring programmes.
- Extended genetic sampling and chemical analysis of otoliths and other tissues for the herring that are sampled biologically.

Exact details of the monitoring that will need to be done depend on the final formulation of the areas.

Ongoing and proposed extended fishing surveys

Table 5 shows ongoing monitoring programmes where herring is one of the target species. The table also shows what type of data is collected and possible proposals for expansion. In some areas, extended fishing is also proposed so as to cover a longer period of the year for the purpose of evaluating spawning periods for spring and autumn-spawning herring. This is shown in Table 6. Note that some further extensions may be proposed, depending on how the areas are formulated.

Other surveys that are not primarily aimed at herring can also provide information (trends) about the status of Baltic herring populations. SLU performs a number of such national surveys with nets along the coast every year. Where these occur is shown in Figure 15. The annual bottom trawling expedition BITS can help in a similar way to provide information about herring, even though this is not a target species for the expedition.

What is meant by individual sampling and extended individual sampling is summarised in Tables 7 and 8.

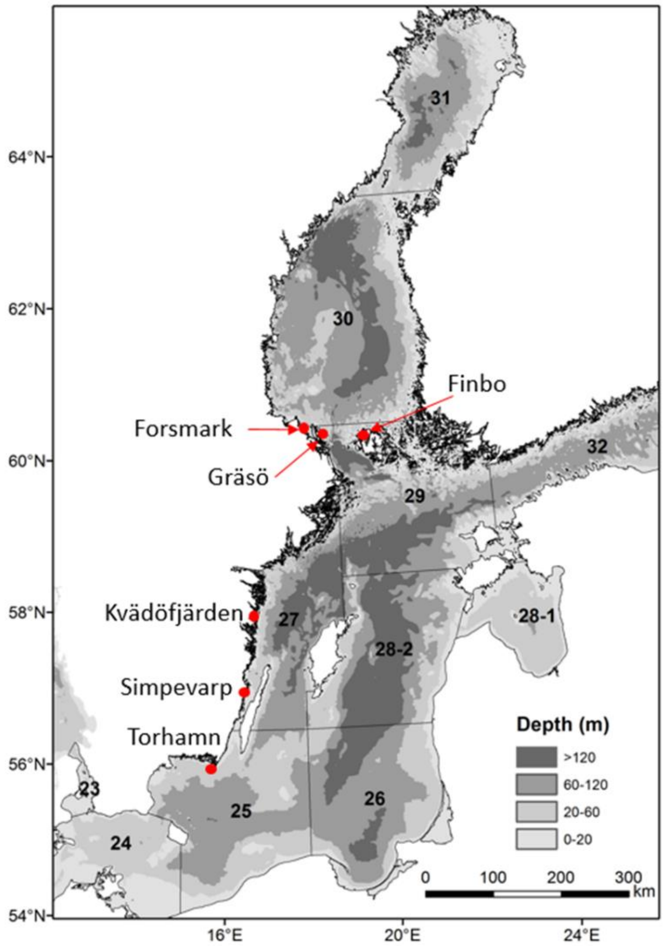

Figure 15. Map of ICES subdivisions (ICES SD) and proposed locations for fishing surveys according to Tables 5 and 6.

Table 5. Ongoing monitoring of herring in the Baltic.

Area	ICES SD	Period	Equipment	What is collected?	Comments	Proposal
Forsmark	30	August	Nordic coast monitoring net	Species composition, catch per effort, length distribution	Analysis of ages and DNA not financed	Extra collection of herring for sampling biological parameters and DNA
Forsmark	30	October	Coast monitoring net	Species composition, catch per effort, length distribution	Analysis of ages and DNA not financed	Extra collection of herring for sampling biological parameters and DNA
Forsmark	30	weeks 17–24	Screen station at	Species composition,	Analysis of ages and	Extra collection of herring for

		and 38–49	nuclear power station	length distribution	DNA not financed	sampling biological parameters and DNA
Kvädö-fjärden	27	August and October	Nordic coast monitoring net and net links	Species composition, catch per effort, length distribution	Analysis of ages and DNA not financed	Extra collection of herring for sampling biological parameters and DNA
Simpevarp	27	Spring	Coast monitoring net	Species composition, catch per effort, length distribution	Analysis of ages and DNA not financed	Extra collection of herring for sampling biological parameters and DNA
Torhamn	25	August	Nordic coast monitoring net	Species composition, catch per effort, length distribution	Analysis of ages and DNA not financed	Extra collection of herring for sampling biological parameters and DNA
Finbo, Åland	29	August	Nordic coast monitoring net	Species composition, catch per effort, length distribution	Analysis of ages and DNA not financed	Catch and individual data, Åland Government performs the fishing Extra collection of herring for sampling biological parameters and DNA SLU performs individual sampling
Gulf of Bothnia	30	weeks 38– 40	Float trawl, acoustic (BIAS Aranda)	Density of herring, length distribution, biological parameters		Extra collection of herring for sampling biological parameters and DNA.
Central Baltic	29N	weeks 38– 40	Float trawl (BIAS Aranda)	Density of herring, length distribution, biological parameters		Extra collection of herring for sampling biological parameters and DNA.

Central Baltic	28	weeks 40– 42	Float trawl (BIAS Svea)	Density of herring, length distribution, biological parameters		Extra collection of different types of tissue samples from herring for sampling biological parameters and DNA.
Central Baltic	27	weeks 40– 42	Float trawl (BIAS Svea)	Density of herring, length distribution, biological parameters		Extra collection of different types of tissue samples from herring for sampling biological parameters and DNA.
Central Baltic	25	weeks 40– 42	Float trawl (BIAS Svea)	Density of herring, length distribution, biological parameters		Extra collection of different types of tissue samples from herring for sampling biological parameters and DNA.
Central Baltic	27	May	SPRAS expedition trawl	Density of herring, length distribution, biological parameters		Extra collection of different types of tissue samples from herring for sampling biological parameters and DNA.
Central Baltic	25-29	All year when fishing is done	Sampling of commercial catches (trawlers)	Length distribution, biological parameters, DNA	Analysis of DNA not financed	Extra collection of herring for sampling biological parameters and DNA
Central Baltic	25-29	All year when fishing is done	Sampling of commercial catches (net fishing)	Length distribution, biological parameters, DNA	Started 2022 Logistically challenging. Greater focus	Extended sampling so as to sample more catches. Extra collection of herring for

					needed for more success. Analysis of DNA not financed	sampling biological parameters and DNA.
Gulf of Bothnia	30-31	Quarter 2-3	Sampling of commercial catches (drift nets)	Length distribution, biological parameters	Analysis of DNA not financed	Extra collection of herring for sampling biological parameters and DNA
Gulf of Bothnia	30	Quarter 2-4	Sampling of commercial catches (trawlers)	Length distribution	Analysis of DNA not financed	Incorporate SD30 in the existing design for 25-29 so that individual samples can be taken. Extra collection of herring for sampling biological parameters and DNA
Central Baltic	25-29	All year when fishing is done	On-board sampling of commercial fishing catches	Species composition catches, bycatches, size distribution	Analysis of DNA not financed	On board sampling SD30.
Gulf of Bothnia	30	All year when fishing is done	On-board sampling of commercial fishing catches	Species composition catches, bycatches, size distribution	Analysis of DNA not financed	Extra collection of herring for sampling biological parameters and DNA

Table 6. Proposal for extended coastal fishing surveys/collection from commercial fishing in the Baltic

Area	ICES SD	Period	Equipment	Purpose
Forsmark	30	Spring (weeks 17, 19, 21, 23, 25)	Coast monitoring net	Extended period so as to cover the whole spawning period in spring and repeat surveys from the 1970s and 1980s and 2022.

				Extra collection of herring in connection with environment checks for sampling biological parameters and DNA
Forsmark	30	week 38	Herring net	Extra collection of herring in connection with environment checks for sampling biological parameters and DNA
Gräsö	30	October	Coast monitoring net	Repeat time series 1989–2000 Extra collection of herring in connection with environment checks for sampling biological parameters and DNA
Kvädöfjär den	27	May and June	Herring net	Extra collection of herring for sampling biological parameters and DNA from commercial fishing in May and June

Table 7. Individual sampling.

Biological parameter	Unit	Purpose
Total length	Millimetre, semi stratified sampling, n=10 per half centimetre length group.	Length distribution, growth, condition index
Weight	gram	Condition index
Gender	female/male	Gender distribution
Gonad stage	8-Level ICES scale	Proportion of sexually mature spring or autumn spawners, timing of spawning
Otoliths	2 *Sagittae*	Age determination, growth and otolith chemistry, migration studies

Table 8. Biological parameters with extended individual sampling

Biological parameter	Unit	Purpose
Genetic sample	muscle	Spawning type and population affiliation
Scale	Minimum 10	Age determination, growth and scale chemistry

Eye lenses	2	Chemical analysis

Digitalisation of diaries

Some older diaries exist only as paper records in the archive. It is proposed to digitalise these to enable comparison of historical catch data. Analysis and possible digitalisation of information in old marking studies of Baltic herring in the 1970s is also proposed.

8. Proposed trial areas

SLU has shown in earlier knowledge bases that the most appropriate method for increasing the biomass of large herring is to reduce fishing mortality, i. e. to reduce the catch quotas for the population as a whole (Valentinsson et al. 2021; Gilljam et al. 2022). The main underlying reason why a general reduction in fishing mortality is the preferred action is that the effects of fishing regulations in limited areas are difficult to predict, since there are still large gaps in the knowledge about the population structure and migration patterns of herring in the Baltic.

Against this background and for this government commission, of which the basis is not reduced fishing opportunities but the introduction of spatio-temporal measures corresponding to movement of the trawl limit, SLU Aqua has identified a number of criteria to work from in indicating possible trial areas for limited or closed fishing. These criteria are as follows:

- Current fishing pressure
- Appropriate water depth for aggregations for spawning and overwintering
- Genetic population structure
- Migration patterns
- Signs of aggregations of large herring
- Opportunities for monitoring effects on the population

The criteria have been weighted unevenly when choosing the trial areas, mainly because of the variability in available knowledge.

A trial area should have had high fishing pressure in recent years, since this likely reflects high concentrations of herring, and also because an area closed to fishing or with limited fishing could give markedly reduced mortality on a local scale. Of the above criteria, there is a good knowledge base primarily regarding fishing patterns and water depths in the Baltic. For this reason, these two criteria have had a large weight in the selection process of potential areas. The information available regarding herring migration patterns and genetics has only been used as supporting information, since knowledge is more limited. Aggregations of large herring is a key criterion for this assignment, but analyses of these patterns are expected to be performed later in 2023 and have therefore not been taken into account in this knowledge base.

To increase the effectiveness of the trial areas, they should include habitats that are used by herring throughout its life cycle. The most important spawning areas for herring are shallow archipelago waters (0-15 m deep). There is no trawling in these areas, but there is fishing with other gears. Baltic herring accumulate in winter and before spawning in deep areas (>50-60 m) outside the archipelago. Depending on the depth profile of the coast (Figure 5), these areas are found both within and outside the current trawl limit (4 nm) and territorial limit (12 nm). However, only a small proportion of these depth areas are found within the present trawl limit (4 nm) and they are thus largely in areas exposed to trawling. Moving the trawl limit from 4 to 12 nm would probably have a greater effect on herring populations in the central Baltic (SD 27-29) than in the Gulf of Bothnia (SD 30) and the southern part of the central Baltic (SD 25). Based on fisheries analyses, the areas east of Gotland and north of Öland have the highest fishing pressure in the central Baltic. These areas lie both within the trawl limit (4 nm) and in the 4-12 nm zone. Fishing in the southern Gulf of Bothnia is concentrated to the economic zone, mainly in the deep areas around the Finngrunden banks. There, closure of areas in the economic zone, where there is a high level of fishing, would probably be an effective measure.

The occurrence and extent of local spawning populations in the Baltic as a whole are unknown. To avoid the risk of depleting such local populations, as much of the coast as possible should be protected. The regulation of fishing should be in force all year, to allow the measure to be effective on both spring and autumn spawning populations.

Opportunities for monitoring the trial areas are good along the coast of the southern Gulf of Bothnia, where both ongoing monitoring of fishing and resuming older trial fishing can be used to describe changes in abundance and size distribution of herring on a local scale. In the central Baltic, it is possible to increase the ongoing sampling programme so as to increase knowledge about herring. Both in the Gulf of Bothnia and in the central Baltic, there are also opportunities for using commercial fishing for collecting data and monitoring population development. SLU is not proposing any formal experimental design, including trial and control areas with monitoring before, during and after the trial. In order to increase the opportunities for effects on the population, SLU is instead recommending large trial areas and follow up based on the evaluation of trends in response variables over time. The effects of the proposed regulation can only be expected to be seen after several years.

Based on the data presented in this report, SLU proposes that the following regulation could be introduced:

Gulf of Bothnia

SLU proposes that a trial area may be introduced in an area around the Finngrunden banks. This trial area should be large enough to include all the areas around the Finngrunden banks with large catches of herring. SLU further proposes that the trial area includes waters from the Finngrunden banks and all the way in to the coast. Regulation in this area can be expected to affect the whole life cycle of the herring, based on the assumption that herring that forage and overwinter around the Finngrunden banks migrate to the coast in the southern Gulf of Bothnia to spawn. In addition to that a large trial area is introduced around the Finngrunden banks and in the coastal zone nearest to Finngrunden, fishing closures can be introduced in one or two areas further north in the Gulf of Bothnia where there are relatively large catches of herring. Such areas are within the Hudiksvall-Sundsvall coastal stretch, as well as Örnsköldsvik-Umeå, including the open sea area in the Swedish economic zone. These trial areas should also be large enough to include areas with high fishing pressure and should be considered as a supplement, not an alternative, to the proposed trial area around the Finngrunden banks and waters in to the coast.

Central Baltic

In the central Baltic, fishing is less concentrated to specific areas than in the Gulf of Bothnia. It is also known that herring migrate further in the central Baltic than in the Gulf of Bothnia. A general extension of the trawl limit in the central Baltic therefore gives greater opportunities for observable effects on the population than limited areas. SLU therefore proposes a general extension of the trawl limit to 12 nautical miles in the areas where appropriate overwintering areas, i. e. areas deeper than 50 m, are found within 12 nm of the coast. In areas 27, 28 and 29, the zone out to 12 nm largely includes appropriate overwintering areas with depths greater than 50 m (Figure 5). In area 25, access to appropriate overwintering areas within 12 nm of the baseline is limited. In this area, therefore, the trawl limit should be moved out so as to at least cover water depths of 50-60 m where herring are exposed to fishing in winter.

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10. Appendix

Table A1. All countries' total catches of Baltic herring in Swedish waters by fishing gear and vessel length. Catches are shown separately for three zones - within the trawl ban border (4 nm), fishing between the trawl ban border (4 nm) and the Swedish territorial border (12 nm) and fishing in the Swedish economic zone (EEZ) for the period 2012-2021. VMS data and Swedish logbook data for vessels under 12 metres have been used in creating this table.

Subdivision	Vessel length	Gear type	<4nm	4-12nm	EEZ	Total
25	12-24m	Bottom trawling	3 (0%)	332 (49%)	337 (50%)	672
25	12-24m	Seine net	153 (100%)	0 (0%)	0 (0%)	153
25	12-24m	Passive gear	0(NaN%)	0(NaN%)	0(NaN%)	0
25	12-24m	Pelagic trawling	16 (1%)	514 (37%)	844 (61%)	1374
25	<12 m	Bottom trawling	0 (0%)	32 (45%)	39 (55%)	71
25	<12 m	Seine net	101 (100%)	0 (0%)	0 (0%)	101
25	<12 m	Passive gear	58 (40%)	51 (35%)	36 (25%)	145
25	<12 m	Pelagic trawling	0(NaN%)	0(NaN%)	0(NaN%)	0
25	>24 m	Bottom trawling	1 (0%)	135 (45%)	163 (55%)	299
25	>24 m	Pelagic trawling	140 (2%)	2591 (34%)	4948 (64%)	7679
26	12-24m	Bottom trawling	0 (0%)	0 (0%)	1 (100%)	1
26	12-24m	Pelagic trawling	0 (0%)	0 (0%)	44 (100%)	44
26	<12 m	Passive gear	0(NaN%)	0(NaN%)	0(NaN%)	0
26	>24 m	Bottom trawling	0 (0%)	0 (0%)	9 (100%)	9
26	>24 m	Seine net	0 (0%)	0 (0%)	2 (100%)	2
26	>24 m	Pelagic trawling	0 (0%)	0 (0%)	3847 (100%)	3847
27	12-24m	Bottom trawling	661 (89%)	72 (10%)	8 (1%)	741
27	12-24m	Pelagic trawling	1001 (61%)	495 (30%)	140 (9%)	1636
27	<12 m	Bottom trawling	16 (32%)	34 (68%)	0 (0%)	50
27	<12 m	Passive gear	143 (95%)	7 (5%)	0 (0%)	150
27	<12 m	Pelagic trawling	168 (99%)	1 (1%)	0 (0%)	169
27	>24 m	Bottom trawling	4 (7%)	45 (78%)	9 (16%)	58
27	>24 m	Pelagic trawling	183 (2%)	6843 (69%)	2832 (29%)	9858
28	12-24m	Bottom trawling	28 (4%)	661 (94%)	17 (2%)	706
28	12-24m	Pelagic trawling	48 (8%)	550 (90%)	13 (2%)	611
28	<12 m	Bottom trawling	55 (49%)	57 (51%)	0 (0%)	112
28	<12 m	Passive gear	75 (69%)	33 (31%)	0 (0%)	108
28	<12 m	Pelagic trawling	58 (56%)	45 (44%)	0 (0%)	103

Subdivision	Vessel length	Gear type	<4nm	4-12nm	EEZ	Total
28	>24 m	Bottom trawling	0 (0%)	239 (92%)	20 (8%)	259
28	>24 m	Seine net	0(NaN%)	0(NaN%)	0(NaN%)	0
28	>24 m	Pelagic trawling	136 (2%)	4814 (55%)	3873 (44%)	8823
29	12-24m	Bottom trawling	0 (0%)	0 (0%)	1 (100%)	1
29	12-24m	Passive gear	0(NaN%)	0(NaN%)	0(NaN%)	0
29	12-24m	Pelagic trawling	3 (4%)	72 (86%)	9 (11%)	84
29	<12 m	Passive gear	2 (100%)	0 (0%)	0 (0%)	2
29	>24 m	Bottom trawling	1 (10%)	9 (90%)	0 (0%)	10
29	>24 m	Pelagic trawling	36 (1%)	1728 (36%)	3081 (64%)	4845
30	12-24m	Bottom trawling	66 (60%)	16 (15%)	28 (25%)	110
30	12-24m	Passive gear	117 (100%)	0 (0%)	0 (0%)	117
30	12-24m	Pelagic trawling	45 (3%)	247 (14%)	1489 (84%)	1781
30	<12 m	Bottom trawling	27 (84%)	5 (16%)	0 (0%)	32
30	<12 m	Passive gear	164 (92%)	3 (2%)	11 (6%)	178
30	<12 m	Pelagic trawling	1 (100%)	0 (0%)	0 (0%)	1
30	>24 m	Bottom trawling	2 (0%)	177 (14%)	1119 (86%)	1298
30	>24 m	Pelagic trawling	192 (1%)	1273 (4%)	26966 (95%)	28431
31	12-24m	Bottom trawling	0(NaN%)	0(NaN%)	0(NaN%)	0
31	12-24m	Passive gear	8 (100%)	0 (0%)	0 (0%)	8
31	12-24m	Pelagic trawling	0(NaN%)	0(NaN%)	0(NaN%)	0
31	<12 m	Bottom trawling	37 (100%)	0 (0%)	0 (0%)	37
31	<12 m	Passive gear	34 (100%)	0 (0%)	0 (0%)	34
31	<12 m	Pelagic trawling	0(NaN%)	0(NaN%)	0(NaN%)	0
31	>24 m	Pelagic trawling	0 (0%)	0 (0%)	2 (100%)	2

Figure A1. Catches of Baltic herring in the trawl ban area (4nm). The figure shows how much Baltic herring is caught in the trawl ban area by vessels of different sizes (<12 metres - red lines; 12-24 metres – blue lines; >24 metres – green lines). The panels show the annual development of fishing in different ICES subdivisions. VMS data (all countries) and Swedish logbook data for vessels under 12 metres have been used in creating this figure.

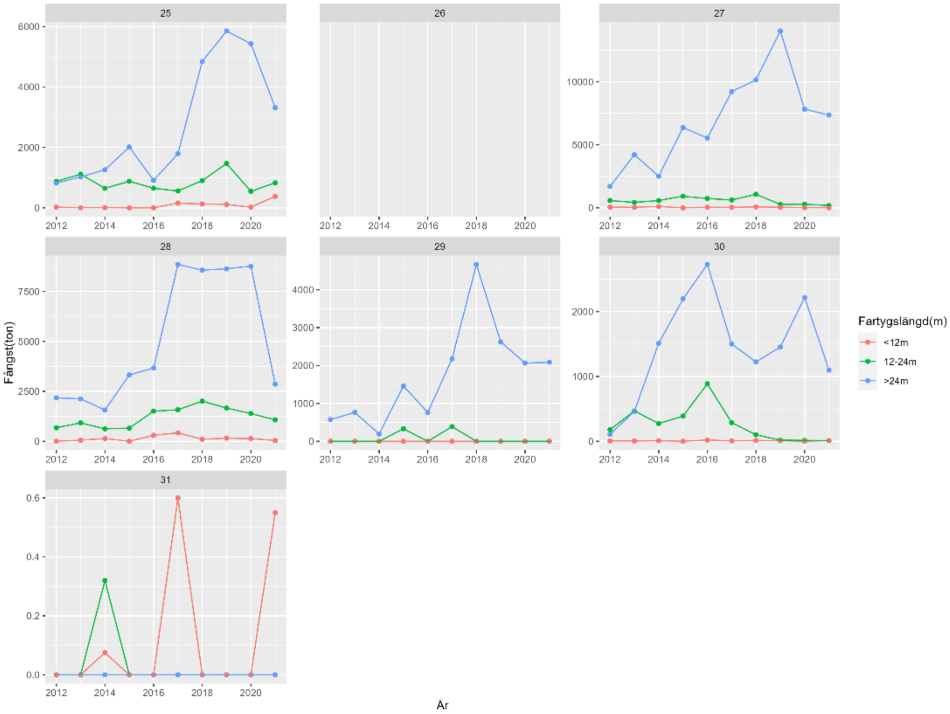

Figure A2. Catches of Baltic herring in the 4-12 nm area. The figure shows how much Baltic herring is caught in the area in between the trawl ban border (4 nm) and the border of Swedish territorial waters (12 nm) by vessels of different sizes (<12 metres - red lines; 12-24 metres – blue lines;< 24 metres – green lines). The panels show the annual development of fishing in different ICES subdivisions. VMS data (all countries) and Swedish logbook data for vessels under 12 metres have been used in creating this figure.

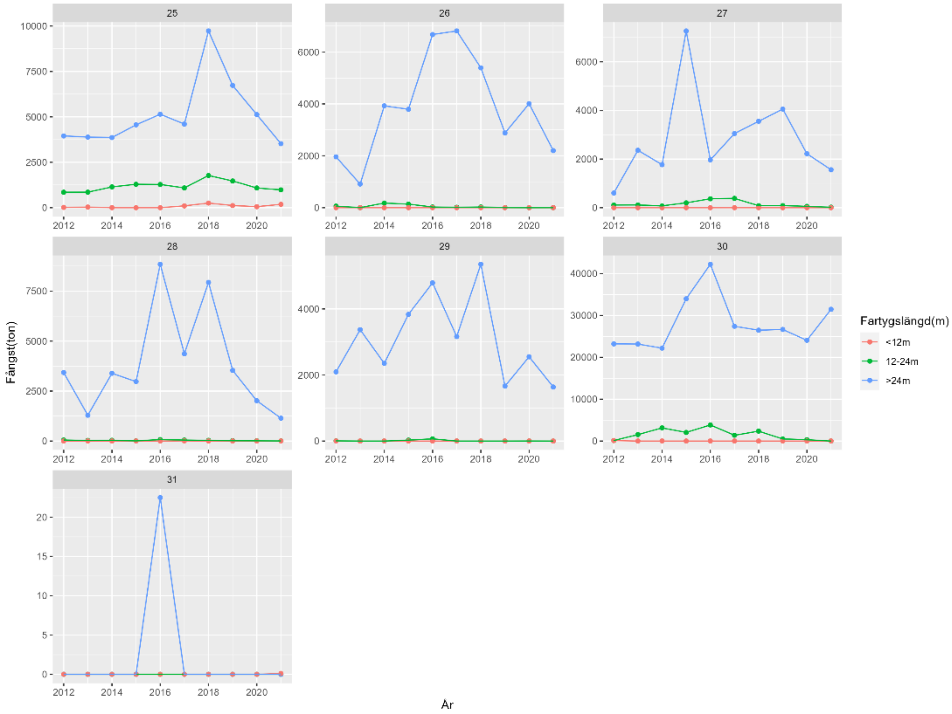

Figure A3. Catches of Baltic herring in the Swedish economic zone. The figure shows how much Baltic herring is caught in the Swedish economic zone by vessels of different sizes (<12 metres - red lines; 12-24 metres – blue lines;< 24 metres – green lines). The panels show the annual development of fishing in different ICES subdivisions. VMS data (all countries) and Swedish logbook data for vessels under 12 metres have been used in creating this figure.

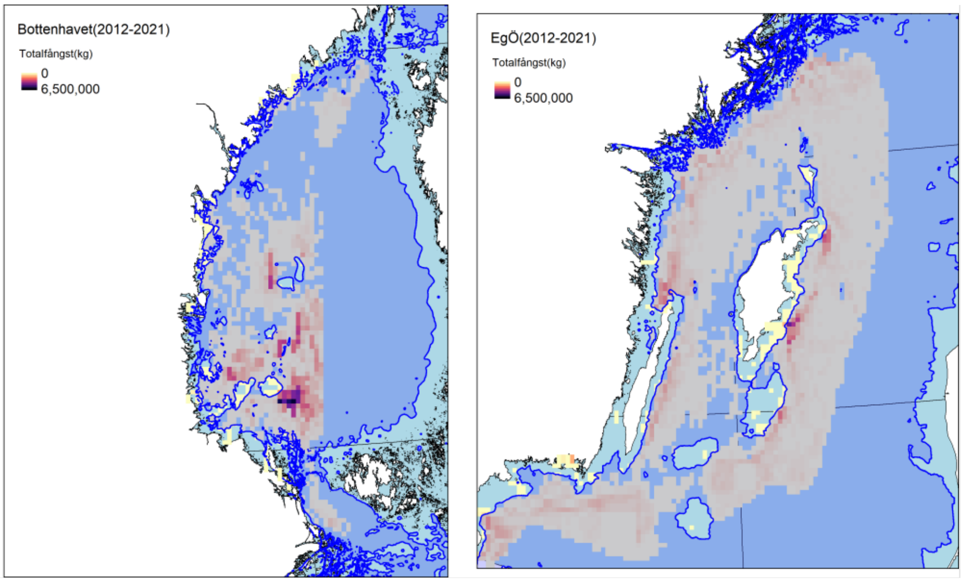

Figure A4. All countries' total Baltic herring catches in relation to areas deeper than or shallower than 30 metres. The maps show the total catch of Baltic herring (yellow squares small catch and dark squares large catch) in Swedish waters in the Gulf of Bothnia ((left panel) and the central Baltic (right panel) for 2012-2021. The dark blue line shows the 30-meter depth curve. The dark blue areas, bounded by the depth curve, show water deeper than 30 metres. VMS data (all countries) has been used to create this figure.

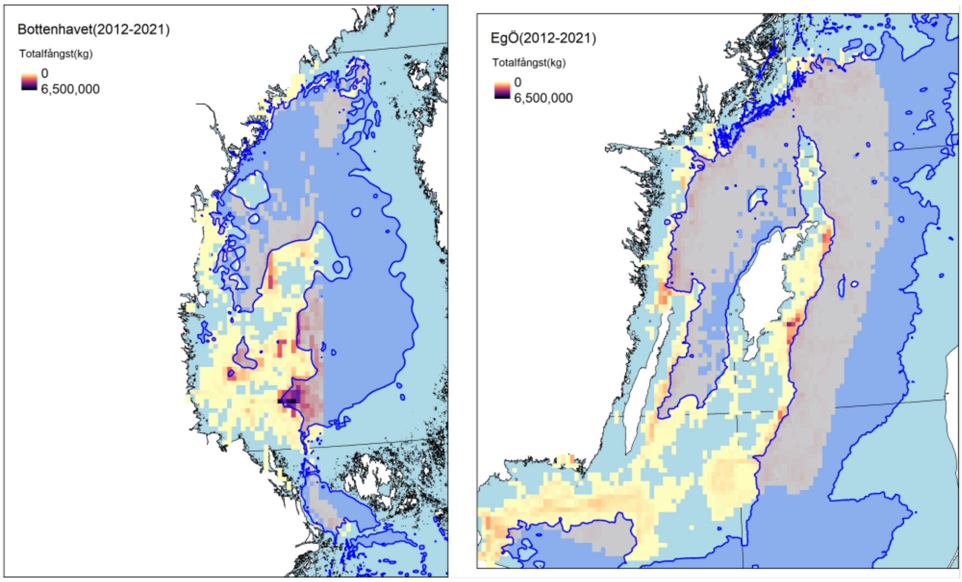

Figure A5. All countries' total Baltic herring catches in relation to areas deeper than or shallower than 70 metres. The maps show the total catch of Baltic herring (yellow squares small catch and dark squares large catch) in Swedish waters in the Gulf of Bothnia ((left panel) and the central Baltic (right panel) for 2012-2021. The dark blue line shows 70-meter depth curve. The dark blue areas, bounded by the depth curve, show water deeper than 70 metres. VMS data has been used to create this figure.