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Fish and Water Research no. 331

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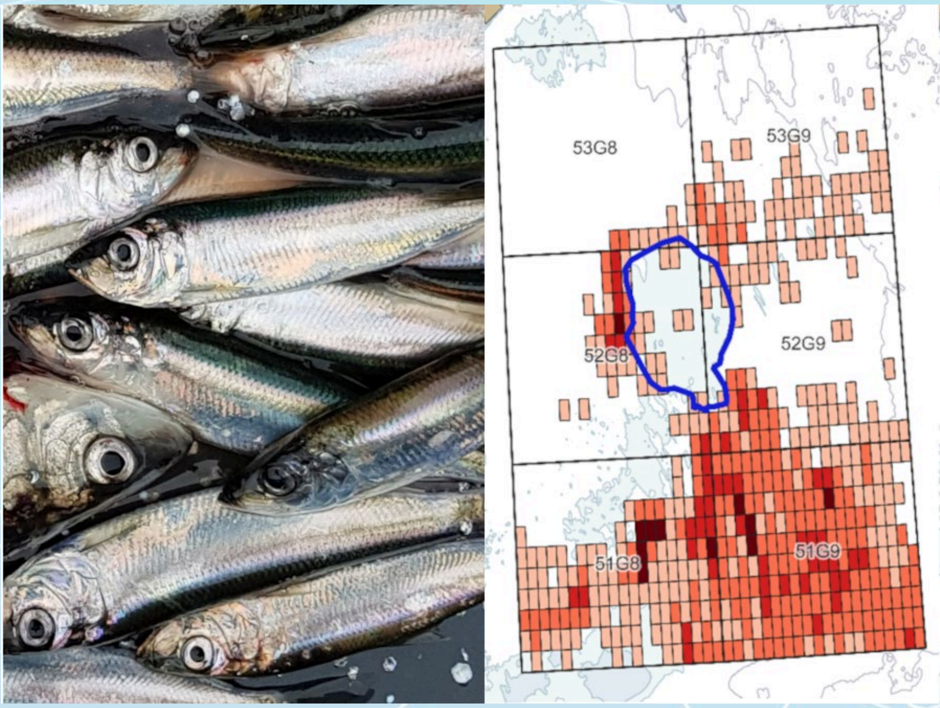

Eystrasalt Offshore wind farm - Commercial fishing catches and trawl locations using Vessel Monitoring System (VMS) data

Fish and Water Research Ltd

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Abstract

The commercial fishing activities in the planned Eystrasalt Offshore wind farm area and its surrounding areas were reported using catch statistics and Vessel Monitoring System (VMS) data. The planned location of Eystrasalt Offshore is in the Bothnian Sea, and the six nearest ICES statistical catch rectangles were used as the basis of the analysis.

The fishing in the Baltic Sea is regulated by the EU Common Fisheries Policy in cooperation with Russia. As such, different quotas are defined for different Baltic herring and sprat stocks. Each country receives a share of that quota every year and allocates that between their fishing operators. This report focuses mainly on the Gulf of Bothnia stock of Baltic herring (*Clupea harengus membras)* and the Baltic Sea stock of sprat (*Sprattus sprattus*).

Heat maps were produced showing the most used fishing areas and routes that the fishing vessels were using in 2017–2020. Fishing in these six ICES statistical rectangles was roughly divided into three areas of which two reached near to the Eystrasalt project area: one on the Northwest of the project area and one on the South from the project area.

There was very little (2.4 % of the whole dataset) fishing in the project area. For a closer look, six buffers were created every 5 km outside of the project area, and the fishing activities were compared between the buffers. Fishing was approximately equally (13.0–15.7 % per buffer in Finland and 14.7–19.4 % in Sweden) distributed between the six buffers. However, the first 5 km buffer closest to the project area showed slightly higher importance than others, mainly due to the fishing activities on the west of the project area.

January–April was the most important season for trawling in the Swedish data (73.8 %) and in the Finnish data (57.3 %). Autumn (September–October) had a higher importance in the Finnish data than in the Swedish data, and the autumn months were also more important near the study area (within 30 km) than in the rest of the dataset. Almost all of the trawl retrievals in the research area were between September and April (*e.g.*, 96.8 % in the Finnish data).

Almost all (97.7 %) of the catch in the Research Area of Interest (RAI) was herring, but also sprat, sticklebacks, fourhorn sculpin, and smelt were reported in the study area. The two southernmost rectangles in the RAI had the highest fishing pressure and largest catches in 2017–2020. The rectangle 52G8 west of the project area also showed importance in the catch data, mainly in the Finnish dataset. Additionally, the highest average length of herring in the Bothnian Sea was also found in that rectangle in fisheries surveys in 2013–2020.

When the catch statistics and VMS data were combined together to produce a summary map where the approximate catch proportions are divided between the fishing areas identified using the VMS data.

When the Finnish herring catches were compared over a longer (1980–2020) time period in the whole Gulf of Bothnia, it was shown that the importance of the northernmost rectangles (Bothnian Bay) in the total catch was much higher from 1980 to mid-1990's than in the 2000's. The southernmost rectangles have provided most of the herring and sprat catch in the last 20 years. The six ICES statistical rectangles (53G8, 53G9, 52G8, 52G9, 51G8 and 51G9) closest to the project area (*i.e.*, the RAI) provided 19–27 % of the Finnish herring and 12–21 % of the Finnish sprat catch.

Of the 46 rectangles in the Gulf of Bothnia, seven were identified where the percentage of the catch of the total herring catch varied more than in the other rectangles. These rectangles showed moderate and strong negative correlations between each other, *i.e.*, when catch in one rectangle was lower it was higher in the other. These seven rectangles also provided between 63.9 % and 78.4 % of the annual catch every year in the 2000's.

In conclusion, the fishing in and near the planned wind farm area is heavily focused on herring and most of the fishing occurs between the months of September and April, in the three areas that are identified in this report. The impact of the wind farm to fishing can be minimised by avoiding disturbances to fishing in these areas and months.

1. Introduction

Eystrasalt Offshore AB assigned Fish and Water Research Ltd. to document the commercial fishing activities in the planned Eystrasalt Offshore wind farm area and its surrounding areas. The planned location of Eystrasalt Offshore is in the Bothnian Sea, outside the Swedish territorial boundary, in the exclusive economic zone (EEZ) of Sweden.

This report is part of the EIA-process. The aim of this report is to document the fishing activities in the planned wind farm area and its surrounding areas using catch statistics and Vessel Monitoring System (VMS) data. Using the six nearest ICES catch statistic rectangles of the project area, the objectives of the study were to:

1) produce a heat map showing the most used fishing areas in 2017–2020,

2) produce a heat map showing routes that the fishing vessels are using when not fishing,

3) compare fishing activities between 5 km buffer zones from the project area,

4) compare fishing activities between the 12 months of a year,

5) compare fishing pressure and catches per species between the six statistical rectangles,

6) combine fishing location information and catch data,

7) compare the proportions of annual catches between the statistical rectangles (Figure 1) of the whole Gulf of Bothnia in 1980–2020, and

8) compare herring length in the different statistical rectangles in the Bothnian Sea.

1.1 Introduction to commercial fishing quotas in the Baltic sea; Baltic herring and sprat

Apart from Russia, all Baltic coastal states are members of the European Union and their fisheries' activities are being regulated by the EU Common Fisheries Policy (CFP; Helcom 2020A). EU and Russia have agreed on cooperation in fisheries and marine conservation in the Baltic sea (Agreement between the European Community and the Government of the Russian Federation on cooperation in fisheries and the conservation of the living marine resources in the Baltic Sea. —Official Journal of the European Union L129: 2-7).

The stock (*i.e.*, fish population) sizes are assessed and the exploitation levels are carried out by the International Council for the Exploration of the Sea (ICES) annually (Helcom 2020B) and the European Commission presents proposals for measures and instruments for resource conservation, such as the following years' catch limits in the Baltic Sea (Government.Se 2019, Helcom 2020B). The commission proposes total allowable catches (TAC) and quotas for commercially important fish stocks (cod, herring, sprat, salmon, and plaice stocks) (Government.Se 2019), and the proposals are commented in the process by stakeholders (Helcom 2020B). The agriculture, forestry, and fisheries ministers (the Council of the EU) then adopt the regulations with consultation of the European Parliament (Helcom 2020B).

The TAC is used to define the national quotas of each EU state; *i.e*, how much the fishing operators in each country are allowed to catch that year. Each member state receives a fixed percent of the TAC (Gov.Wales 2019). As an example, Finland's share of the herring TAC of the Gulf of Bothnia is 81.9858 percent (SAKL 2020). The fishing quotas may be exchanged between the countries (Europa. Eu 2021). A request for exchanging quotas with another member state can be made when the quota is likely to be exceeded before the year is over, (Havs- och Vattenmyndigheten 2014) and when the available quota for a species is exhausted the EU country must close the fishery (*i.e.*, stop fishing) (Europa.Eu 2021).

In the Baltic Sea, four different quotas (also: "management units" or "stocks") are defined for Baltic herring: Gulf of Bothnia (Figure 1), Gulf of Riga, Gulf of Finland and the rest of the Baltic Sea, and the western stock. The sprat quota is defined for the whole Baltic Sea (Valtioneuvosto 2017).

The Baltic coastal and inland fisheries are mainly regulated by each Baltic country through their national legislation and the fisheries control systems (*e.g.*, surveillance, inspections, data collection and enforcement) are controlled by the EU member states through their national authorities and inspectors (Helcom 2020B; ELY-keskus 2019A).

The shares of the national fishing quotas are allocated nationally by each member state (see below for Finland and Sweden). EU countries must use transparent and objective criteria when distributing national quotas among their fishing operators (Europa.Eu 2021).

National Quotas: Sweden and Finland

Previously, the distribution of fishing quota was concerned with equal access and fair competition between the operators, *i.e.*, all operators were fishing from the same quota (Hultman et al. 2018). In many instances, this leads to competition where volume-based operation, such as larger vessels that could go out in rough winter weather, would benefit over quality-oriented or otherwise slower operators (Hultman et al. 2018). Today, to solve the distribution of limited fishing opportunities, all Nordic countries have introduced quota distribution based on market mechanism; *i.e.*, the operators were granted an individual and transferable quota share based on their historical catches (Hultman et al. 2018). The scopes and manners, however, differ largely between the countries (Hultman et al. 2018). The quota markets were mainly introduced to improve the economic performance of the fishing sector, and the development has led to advanced innovations and economies(-of-scale) development. However, it has also resulted in challenges to small-scale fisheries and the quota markets have been opposed by large groups of fishing operators in all of these countries (Hultman et al. 2018).

Sweden introduced individual and transferable quotas in the large-scale pelagic fisheries in 2009, and individual quotas with annual leasing have been introduced in the demersal fisheries since (Hultman et al. 2018). The quota for herring and sprat is allocated between the vessels that use large seines or trawlers using fishing rights (Jonas Ericson, The Swedish Agency for Marine and Water Management, pers. Comm). In Gulf of Bothnia (ICES subareas 30 and 31; Figure 1), the trawlers should be at least 15 metres in length in this quota, and 12 metres in the rest of the Baltic Sea (Jonas Ericson, pers. Comm). The other fisheries share a common coastal quota (Jonas Ericson, pers. Comm). Since the implementation of the system, there have been a large number of transfers and many (53 by 2016) fishing operators had sold all of their pelagic fishing rights permanently, and many of them had moved to coastal fishing instead (Sveriges Riksdag 2016). Thus, the vessels in the pelagic fleet had been halved (Sveriges Riksdag 2016).

Finland was the last Nordic country to introduce individual quotas in the herring, sprat, and salmon fisheries (Hultman et al. 2018). Since 2017, for (Baltic) herring, (European) sprat, and Atlantic salmon, the quota is allocated between the fishing operators in Finland (SAKL 2020). The system is used for registered commercial fishing operators who have a vessel registered for commercial fishing (SAKL 2020). Of the fishing methods, the system is used for trawl and fyke net fishing of herring, trawl fishing of sprat, and Atlantic salmon fishing (SAKL 2020). Finland's national fishing quota is allocated between the fishing operators as an operator-specific fishing quota using the fishing rights that the Ministry of Agriculture and Forestry granted as transferable fishing rights for ten years for the commercial marine fishing operators based on the catches in 2011-2015 using the three best years. With this right at their disposal, a fishing operator is guaranteed a certain share of the annual national quota (Hultman et al. 2018). Each fishing operator may possess a maximum of 200 permilles of each herring or sprat quota and a maximum of 150 permilles of each salmon fishing quota (SAKL 2020). Because the rights are transferable, vessel owners can buy or lease more quota from other operators in order to increase catches (Hultman et al. 2018). A commercial operator is also allowed to catch up to 20 000 kg herring annual without a fishing right, and additional, non-transferable, fishing rights can be applied from the Centre for Economic Development, Transport and the Environment (ELY-Keskus 2019B).

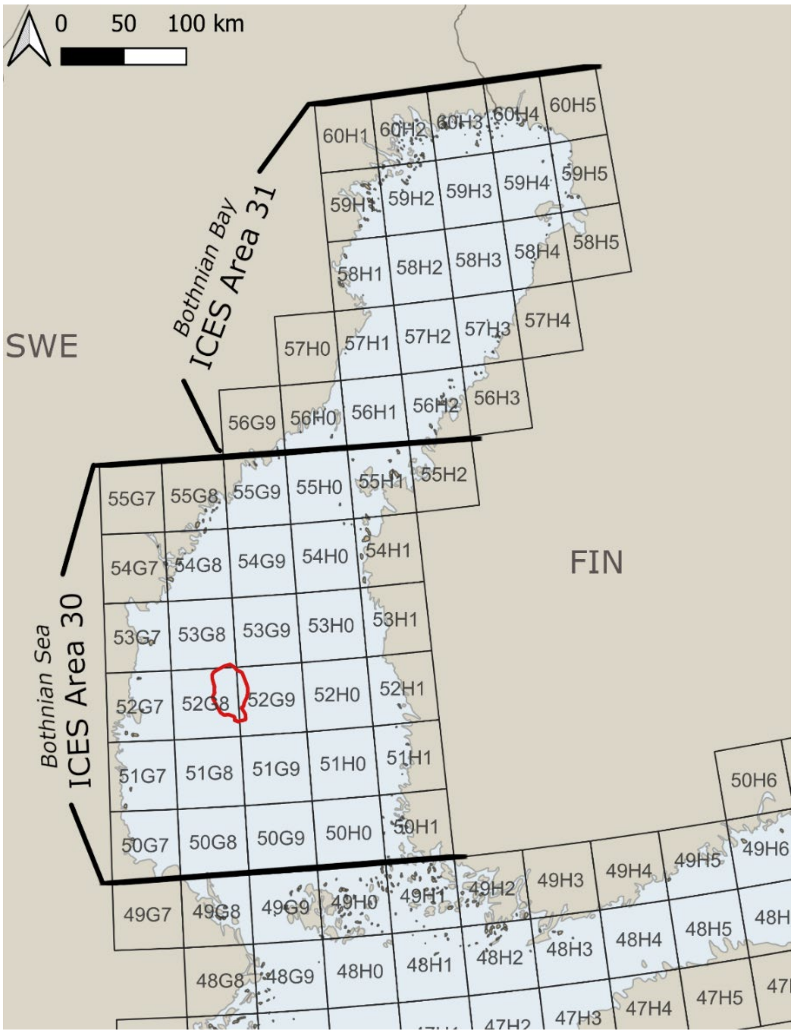

Figure 1. ICES statistical rectangles in the Northern Baltic Sea and ICES areas 30 (Bothnian Sea) and 31 (Bothnian Bay) in the Gulf of Bothnia. Eystrasalt project area marked in red.

2. Methods

2.1 Study area

The planned project area of Eystrasalt Offshore is in the Bothnian Sea, outside the Swedish territorial boundary, in the exclusive economic zone (EEZ) of Sweden (Figure 2). The Research Area of Interest (hereafter: RAI) was based on the ICES statistical rectangles that are used for reporting commercial fishing catches, and the six closest statistical rectangles (53G8, 53G9, 52G8, 52G9, 51G8 and 51G9) to the project area were used in this study (Figure 2). ICES statistical rectangles have been used since the 1970's and are used for gridding (fishing-)data to make analysis and visualization simpler (ICES 2021). The rectangles are created using 30´ (Lat) and 1° (Lon) intervals (ICES 2021), and in the Baltic Sea the size of one rectangle is therefore approximately 55 km x 55 km.

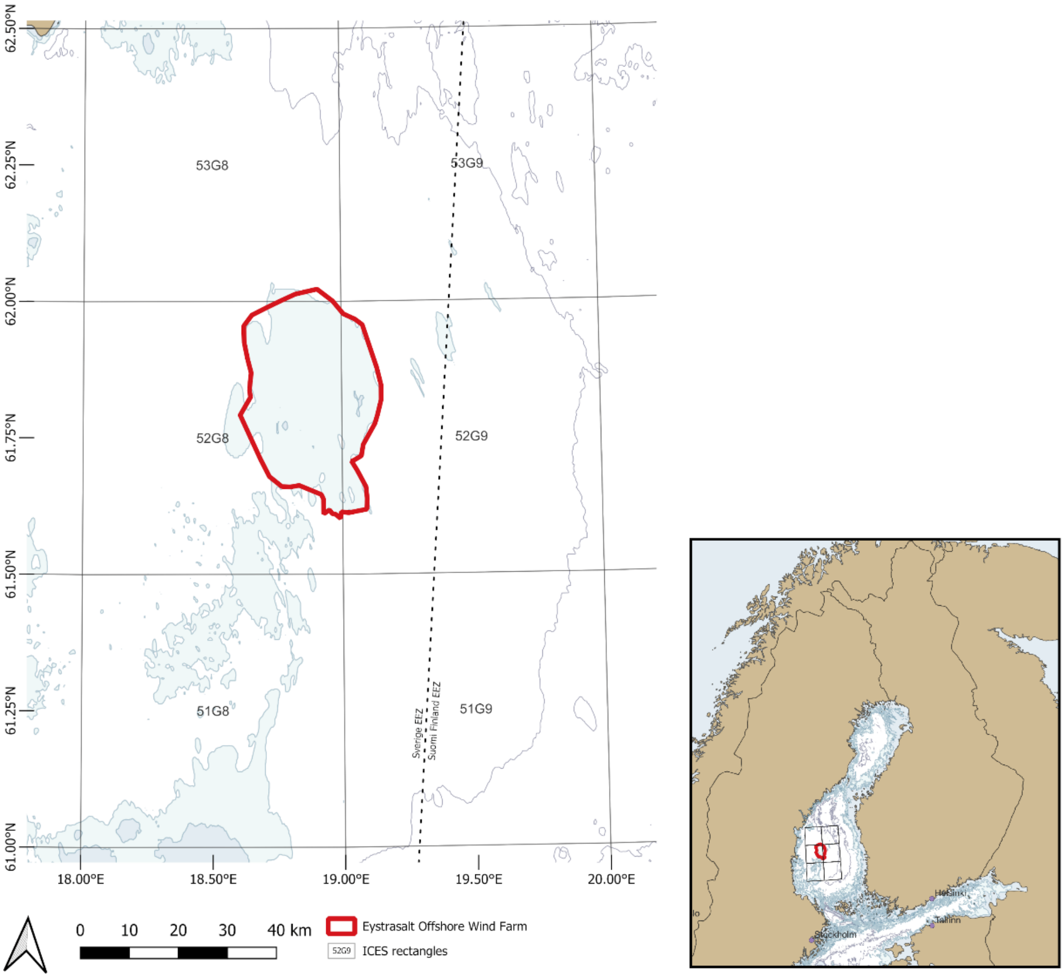

Figure 2. The planned project area in the Bothnian Sea and the six ICES statistical rectangles.

2.2 Data acquisition and data types

Fishing catch data and Vessel Monitoring System (VMS) data in the RAI were ordered from Swedish (Swedish Agency for Marine and Water Management) and Finnish (Centre for Economic Development, Transport and the Environment) authorities. Finnish historical catch data (1980–2020) were received from Natural Resources Institute. An inquiry was also sent to Estonian authority (Kalateave, Fisheries Information Centre) and a response was received that no Estonian vessels had reported catches in the RAI in 2017–2020. These four years were chosen because there was a change in Finnish quota system in 2017 (SAKL 2020), possibly resulting in changes in fishing operations.

The VMS data received from the Finnish authority included point data showing the locations of fishing vessels in 2017–2020, year, month, and vessel speed but the information of individual tracks or fishing vessels was hidden. Additionally, the trawl retrieval and deployment locations, month, and year, as point data, was included.

The VMS data received from the Swedish authority included line data showing individual tracks and their dates and hour-minute timestamps.

2.3 Data processing and GIS analysis

Heat Maps

The Finnish VMS data were divided to three groups using vessel speed: Fishing (1.5–5 knots), traveling (>5 knots), and trawl deployment/retrieval (<1.5 knots). These speeds were based on information from the Finnish authority (Minna Uusimäki, Centre for Economic Development, Transport and the Environment, Finland, personal communication) and similar speeds have been used for filtering VMS data before (*e.g.*, 2–4 knots as fishing speed; Ramboll 2017).

In the Finnish data, the locations were recorded approximately every hour (Minna Uusimäki, personal communication). For comparison of fishing intensity in the areas, the Swedish VMS lines were converted to point data using the average speed of Swedish vessels (typically ~3 knots, Minna Uusimäki, personal communication), *i.e.*, to create a point on the line that approximately represent the number of hours trawled. Therefore, a point was created on the line every 5.6 kilometers. This resulted into 8.4 points per line, on average, which is 3.2 times more than the average number of points per trawling in the Finnish data (2.6 points per line). This difference may have resulted from *e.g.*, difference in length (distance) of trawling or due to the variability in speeds while trawling.

For creating heat map data of the areas, each of the ICES statistical rectangles were divided into 200 smaller rectangles, resulting in rectangles approximately 5.6 km x 2.6 km. Due to the update frequency of the VMS data (location recorded approximately every hour) and the vessel speed, this grid size is most suitable for showing fishing (average vessel speed when fishing 2.5–3 knots or 4.6–5.6 km/h), and trawl deployment/retrieval (< 1.5 knots or < 2.8 km/h) when the vessel is North- or Southbound. When the vessel is moving perpendicular to the long edge of the rectangle (East-Westbound) or moving faster (travelling speeds), there is a possibility that the location is not updated within the limits of the rectangle, which may introduce some inaccuracies.

Heat maps of fishing activity were created by counting VMS points in the small rectangles. Additionally, a Helcom 2013 (Helcom 2013) dataset was used to produce a comparable heatmap, to further understand how the fishing locations had changed over the years.

Heat maps were also created using trawl retrieval/deployment locations combined, expecting similar information as from the fishing activity heat maps, but also to understand possible differences between the datasets. The trawl retrieval/deployment locations in the Finnish data were used to create a heat map using the same grid as previously. From the Swedish data, the start and endpoints of the trawling lines were extracted and used as deployment and retrieval locations for creating the heat map. Additionally, from the Finnish VMS data, the slow speeds that were extracted in the earlier step were also used as a comparison, to represent trawl retrieval/deployment hours, although it is possible that the vessels may have been moving slowly or stationary for other reasons as well.

From the Finnish data, heat map was also created using the travel speed of the vessels. This heatmap indicates when the vessels were moving faster and not fishing, and therefore *e.g.*, travelling between fishing areas or fishing areas and (home) port. Further information will be collected in a questionnaire that will be reported in early 2022.

All heat maps were created using five groups. The smallest group was always zero and the other four were divided to groups first using Jenks natural breaks method that seeks to minimize each class' average deviation from the class mean (ArcGIS 2018), and then, based on the created groups but using individual assessment, matched to the other heat maps (of similar data) to create comparable outputs.

Buffer zones

To collect more understanding on the vessel locations within and near the project area, a 30 km buffer was created around the border of the project area. The buffer was then divided into six (5 km) buffers, and the number of points in these buffers and in the project area were calculated from the fishing activity data. This was done to understand how close to the project area the fishing has occurred and whether the fishing increases or decreases as the distance from the project area increases.

The 5 km buffer zones were used as they would allow a high accuracy using the VMS data, but also taking into account the update frequency of approximately 1 hour. The 30 km distance was the maximum possible distance in the RAI using 5 km buffers; 35 km buffer zone would have been partly outside of the RAI.

Seasonal distribution of fishing

The distance of each point from the project area was calculated. The data were divided to two groups depending on whether they were within a 30 km distance from the project area or outside of it. To understand the seasonal trends in fishing, the VMS data were further divided into different months.

The Swedish lines were divided into two datasets using a 30 km buffer. Therefore, some of the lines are cut into two lines and thus included in both outside and inside of the area.

Combining fishing locations and catches

Using visual assessment, areas were identified where most of the fishing had occurred in the VMS data. The catch data in the ICES rectangles was then combined to the identified fishing areas, to get a better understanding of the catch distribution between the areas that were mostly used for fishing.

Fishing intensity and catches in the ICES statistical rectangles

The number of hours in the statistical rectangles was calculated from the Finnish data using the fishing speeds only and from the Swedish data using the point data based on average speeds. The annual totals in each rectangle were compared.

The same approach was used for comparing herring (*Clupea harengus membras,* SWE: "strömming"("sill"), FIN: "silakka") catches and sprat (*Sprattus sprattus,* SWE: "skarpsill", FIN: "kilohaili") catches in the rectangles. The trawl lines cross the borders of the statistical rectangles and therefore, a catch reported in one rectangle may include fish from another rectangle and some retrievals may have occurred outside of the RAI and therefore not be included in the count. Due to the large number of trawl lines in the dataset, the reported catch retrieval locations (Finland) and endpoints of the trawl lines (Sweden) were used for comparing fishing intensity, as it was assumed that in the large dataset the probability that the catches where the trawl lines crossed multiple rectangles were equally distributed between the rectangles.

Historical herring catches in the Gulf of Bothnia

To understand the importance of the RAI on the overall trawl fishing in the Gulf of Bothnia, the statistical rectangles and years 1980–2020 were plotted using each rectangle's annual proportion of the annual total catch for analysing the overall trend in fishing over the years. The herring catches in all of the ICES areas of the Gulf of Bothnia were also compared using heat maps every five years between 2000 and 2020.

Years 2000–2020 were also used for understanding how much the percentage of the catch varies over the years in each rectangle. The percentage of each rectangle on the annual total catch was calculated, and the standard deviation (SD) of the 20-year dataset was then calculated for each rectangle. The rectangles that had an SD <2 % were first identified as rectangles with stable percentage, *i.e.*, in those rectangles the proportion did not change much over the years. The same procedure was repeated for the years 2010–2020.

Herring length in the Bothnian Sea

The fish lengths in the different ICES statistical rectangles in the Bothnian Sea was compared using biotic statistics from the Baltic Sea Information on the Acoustic Soundscape (ICES-BIAS) surveys in 2013–2020 (ICES 2022). The average lengths were calculated and compared for each year and for each statistical rectangle, and the length distributions were compared for 2018–2020.

3. Results and Discussion

3.1 Fishing in the area and trawl types

All reported fishing in the RAI in the Swedish data was trawling. Similarly, although not identified in the catch data, but because the catch data mainly consisted of herring and sprat in the Finnish data, the Finnish fishing operators were also likely only using trawling.

In the six ICES statistical rectangles of the RAI, 20 Finnish vessels and 8 Swedish vessels had reported catches in 2017–2020. Of the 20 Finnish vessels, 16 were still active in December 2021.

In the Swedish data, most of the trawlers were using pelagic mid-water trawls. Only one vessel had used bottom trawling within the studied area in (January–March) 2017, and no bottom trawling was used in 2018–2020. An earlier dataset existed from Helcom (Helcom 2013) that shows little bottom trawling in the southern part of the RAI (37 hours in 51G8 and 1 h in 51G9) in 2013. Most of the bottom trawling in the Helcom 2013 dataset is in the Southern Baltic Sea and in the Gulf of Bothnia in the fishing areas south of the RAI.

Table 1. Number of trawl retrievals in the Research Area of Interest (RAI) in each year. Because the trawl lines can cross multiple ICES statistical rectangles, some (approximately 6% in the Finnish dataset) trawl lines that occurred in the RAI but ended outside of the area are not included in these numbers.

Year	Finland	Sweden
2017	950	120
2018	700	126
2019	848	173
2020	678	191

3.2 Spatial distribution of fishing

Fishing intensity heat maps

Within the RAI, the Finnish and Swedish trawlers used similar locations for fishing (Figure 3 Left and Middle). The same locations can also be identified in the Helcom dataset from 2013 (Figure 3 Right). Although the distribution of fishing intensity is difficult to compare between the datasets, it is notable that the same locations were used in 2013 as 4–7 years later.

The Swedish trawlers were fishing in the 51G8 rectangle most intensively (Figure 3 Left), while the Finnish trawlers used the southeast (mostly in 51G9 rectangle) the most. There was also fishing (north)west of the project area, in rectangle 52G8, especially by the Finnish trawlers (Figure 3 Middle).

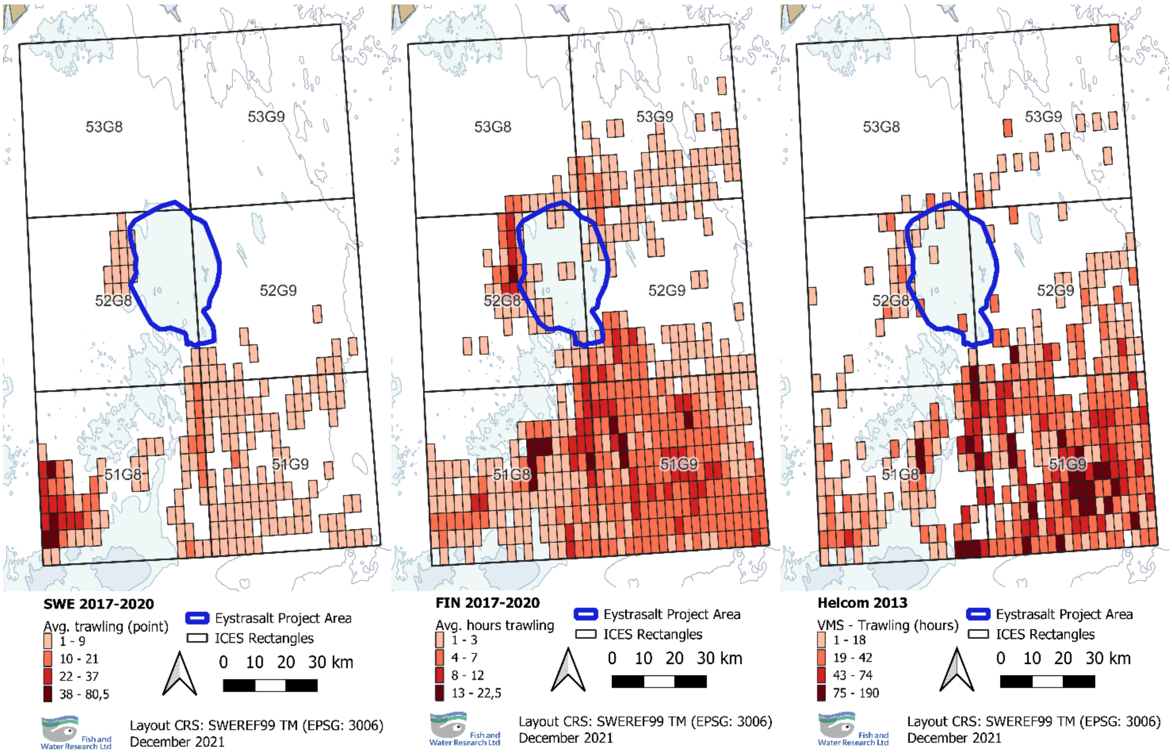

Figure 3. Heat maps showing the spatial distribution of trawling intensity in the Research Area of Interest (RAI) in Swedish data (Left), Finnish data (Middle), and in Helcom 2013 data (Right). Due to the difference in data collection methods the actual values are not directly compared between the maps; however, the groups (colours) were chosen so that the trends would be comparable.

Trawl deployment / retrieval heat maps

The trawl deployment/retrieval maps highlighted the same locations and the same differences between the two countries as the fishing data (Figure 4 Left and Middle). Additionally, the VMS data identified that vessels had moved slowly (<1,5 knots) or stayed in position, as expected, in the same locations where the trawls were deployed/retrieved (Figure 4 Right). Outside of those locations, the VMS data identified rectangles with a small (1–9) number of hours throughout most of the studied area (in 745 of 1 230 rectangles; Figure 4 Right).

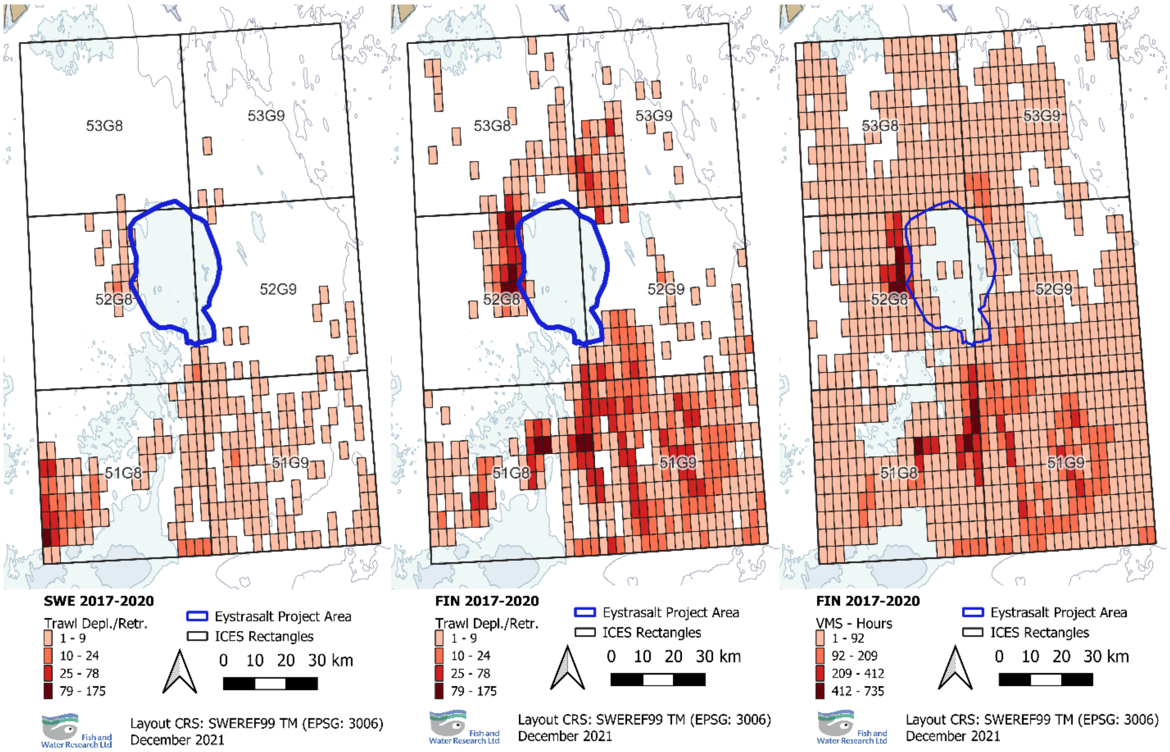

Figure 4. Heat maps showing the spatial distribution of trawl deployment and retrieval locations in the Research Area of Interest (RAI) in Swedish data using the start and endpoint of the lines (Left), Finnish data using the reported locations (Middle), and in the Finnish VMS data using the locations where the vessel speed was <1.5 knots (Right). Due to the difference in data collection methods the actual values are not directly compared between the VMS (Right) map and the trawl deployment/retrieval maps (Left and Middle); however, the groups (colours) were chosen so that the trends would be comparable.

Travelling to / from the area heat maps

There were 3 000 hours (6 % of all the Finnish VMS data) where the vessel speed was >5 knots. The routes identified most often in the southern parts of the RAI but also Northeast from the project area (Figure 5).

The (small) size of the grid may have introduced some inaccuracies because when the VMS is updated only once every hour, vessels moving >5 knots can travel through more than one rectangle before registering a location. However, because there were multiple points over four years, this still represents a trend showing that when the vessels where in the RAI area the vessels were moving using those speeds.

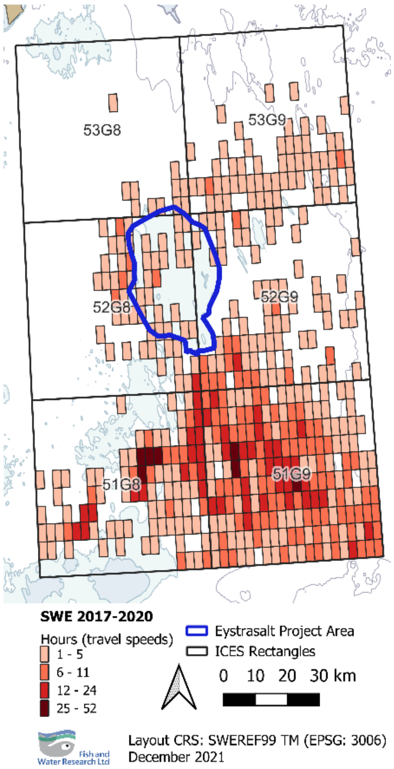

Figure 5. Heat map showing the spatial distribution of Finnish VMS data with where the vessel was using travel speeds (>5 knots) as average hours per year in the Research Area of Interest (RAI).

Buffer zones

To collect more understanding on the vessel locations within and near the project area, a 30 km buffer was created around the border of the project area.

Of all the data in the RAI, 34.6 % of the points in the Finnish data and 19.8 % of the points in the Swedish data were within the 30 km of the project area. There was variation in the annual share of data between the buffered 30 km zone and outside of it (in the whole RAI), especially in the Swedish dataset (Table 2).

Table 2. The proportion of the datapoints in the 30 km buffer zone of all the datapoints in the Research Area of Interest (RAI; i.e., the six ICES rectangles) in 2017–2020.

Year	2017	2018	2019	2020	All Years
Sweden	30.4 %	5.3 %	22.7 %	18.1 %	19.8 %
Finland	29.4 %	28.8 %	33.8 %	43.6 %	34.6 %

To understand how close to the project area the fishing has occurred and whether the fishing increases or decreases as the distance from the project area increases, the 30 km buffer zone was further divided into the project area and six 5 km buffers.

In the Finnish data, 7.4 % of the points (2.4 % of data in the whole RAI) were in the project area (Figure 6) and 20.6 % of the points in the first 5 km buffer. The percentage of fishing in the rest of the buffers was 13.0–15.7 %, and there were no large (*e.g.*, > 10 %) changes in the proportions in different years (Figure 6).

The number of points was low in the Swedish data (because most of the trawling was outside the 30 km buffer), which also caused variability in the proportions over the years. When the four years were combined, however, the proportion of the points in each of the

5 km buffer was similar, varying from 14.7 % to 19.4 % (Figure 7). There were not many points in the project area, and the proportion was 1.1 % of the points in the 30 km buffer (Figure 7) and 0.2 % of all the points in the whole RAI.

Therefore, in both countries, there was little fishing in the project area and fishing outside of the project area was mostly equally distributed between the 5km buffers; *i.e.*, there was as much fishing 20–25 km from the project area as 25–30 km from the project area (Figure 6 & Figure 7). The first buffer (0–5 km outside of the project area), was, however, the most used by both countries. Additionally, when the fishing intensities were proportioned by the size of the buffer, the first buffers near the project area would have even higher importance, because the buffers farther from the project area are larger.

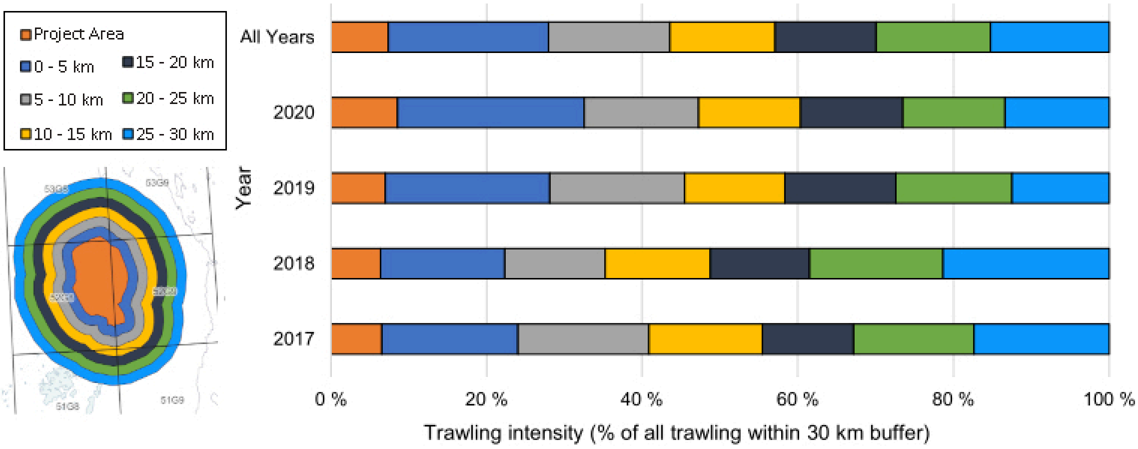

Figure 6. Finnish trawling intensity in the project area (orange) and outside of it, using 5 km buffers and up to 30 km distance from the project area (as shown on map on the left). The coloured bars on the right indicate the distribution of hours (when a vessel was moving at fishing speed) between the project area and six 5 km zones, proportional to all hours within 30 km from the project area, in 2017–2020 (and all years combined) in the Finnish VMS data. The map on the left shows the location of the project area and buffer zones, indicated using the same colours.

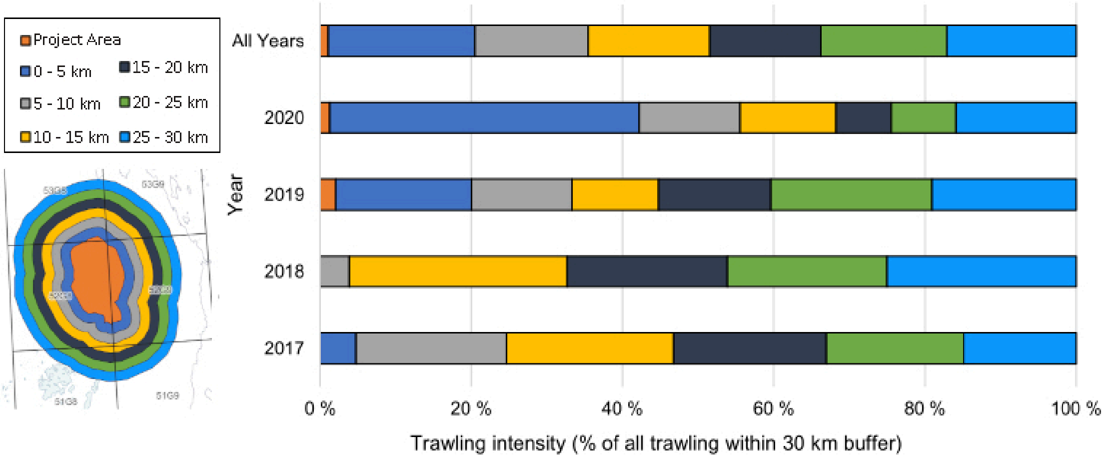

Figure 7. Swedish trawling intensity in the project area and outside of it, using 5 km buffers and up to 30 km distance from the project area (as shown on map on the left). The coloured bars on the right indicate the distribution of hours (VMS line data converted to points every 5.6 km) between the project area and six 5 km zones, proportional to all hours within 30 km from the project area, in 2017–2020 (and all years combined) in the Swedish VMS data. The map on the left shows the location of the project area and buffer zones, indicated using the same colours.

3.3 Seasonal distribution of fishing

Almost all (96.8 %) of the trawl retrievals in the RAI in the Finnish data were between September and April, and more than half (57.3 %) of Finnish trawl fishing was in the spring between January and April (Figure 8). The autumn months were also important, as 34.2 % of all the retrievals were between October and December (Figure 8). The importance of autumn was even more important in the area within the 30 km buffer, with 41.3 % of the retrievals from October–December (Figure 8). The variation of the proportion of the month was small (SD 0–5.3 %), *i.e.*, the monthly proportions were similar between the years (Figure 8).

Similar monthly distributions have been previously reported in the Baltic Sea, with most of the pelagic trawl fishery taking place from January–April, and to some extent, also October–December (Baltic Eye 2020). They state that the fishing is focused on herring that gather off the coast before spawning in the coastal zone or in shallower water, and that more of the Swedish trawling for herring has recently moved closer to the coast (Baltic Eye 2020).

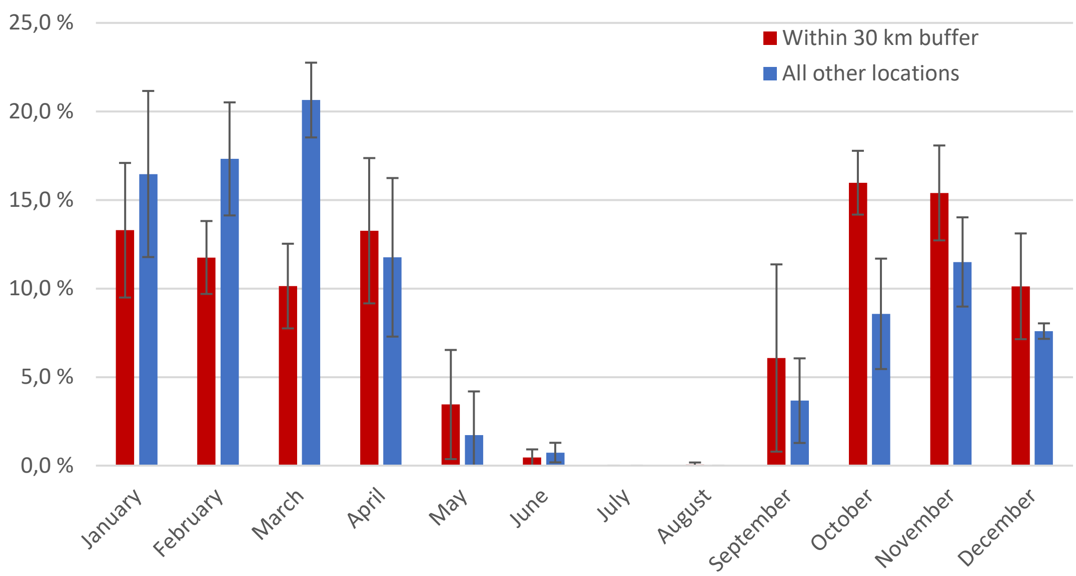

Figure 8. The mean ±1 SD proportion of fishing in each month of the year in the 2017–2020 Finnish dataset, using trawl deployment months only. The data were divided to trawling in the buffered zone (project area + 30 km buffer around it) and outside of the buffered area in the Research Area of Interest (RAI).

The Swedish data showed trawling in the same months as the Finnish data, however, most (73.8 %) of the trawling was in the spring between the months of January and April. As the Swedish data was more scarce than the Finnish data in the RAI and especially in the 30 km buffer zone, the variation was large (up to 23.5 %) in some of the months, *i.e.*, the proportion of the month varied between the years (Figure 9).

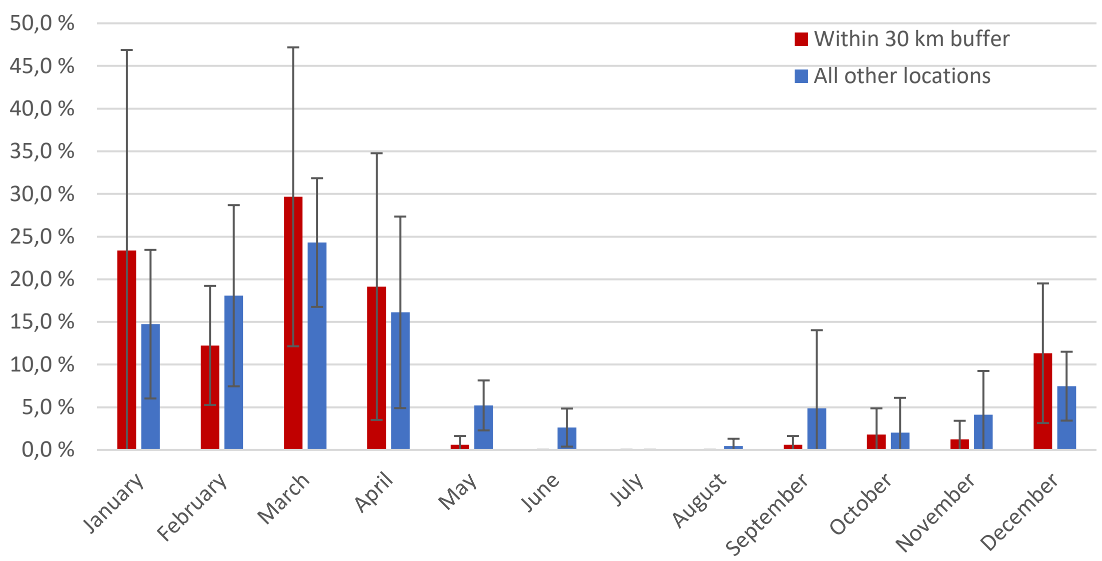

Figure 9. The mean ±1 SD proportion of fishing in each month of the year in the 2017–2020 Swedish data, using the trawl lines. The data were divided to trawling in the buffered zone (project area + 30 km buffer around it) and outside of the buffered area in the Research Area of Interest (RAI), and in case a line crossed the 30 km buffer, it was included in both of the areas.

3.4 Fishing intensity and catches in the six ICES statistical rectangles

Fishing intensity in 2017–2020

Of the six ICES statistical rectangles in the RAI, the trawling ended most often in the two southmost rectangles (51G8 and 51G9) in both Swedish (93 % of fishing) and Finnish (63 % of fishing) data (Figure 10). In the Finnish data, rectangle 52G8 was also common (Figure 10), resulting mainly from fishing in the Northwest outside of the project area (as identified in the heat maps: Figure 3). The importance of the other rectangles was lower but all the rectangles were still used by the trawlers (Figure 10).

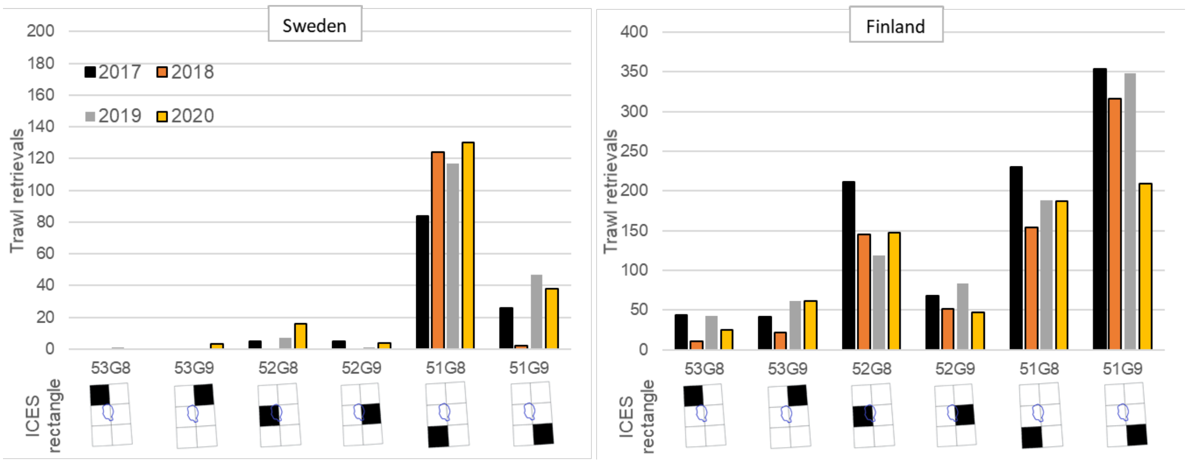

Figure 10. The number of trawl retrievals in each of the ICES statistical rectangle in the Research Area of Interest (RAI). Note: the maximum Y-axis value is 2x higher in the Finnish data.

Herring catches in 2017–2020

Of all the catch reported by the Finnish and Swedish fishing operators in the RAI in 2017–2020, 97.7 % was herring. This is similar to all of the Finnish commercial fishing, as herring's share of the total value of the catch in marine waters is 90 % (or 70 % when including inland waters; Natural Resources Institute Finland 2015).

The catch distribution between the six ICES statistical rectangles and years (Figure 11) was similar to the distribution of trawling effort (Figure 10) and there was a very strong positive correlation (r = 0.98) between the two (Appendix 1). The only exception was rectangle 53G8 with herring catches reported (Figure 11) but without any trawl lines in the Swedish data ending there. These catches were likely mostly from outside the RAI.

Due to the strong correlation between the fishing intensity and herring catches, and the fact that most of the catch in these rectangles was herring, it can be assumed that the VMS data identified in Figure 3 also represents the location of the herring catches.

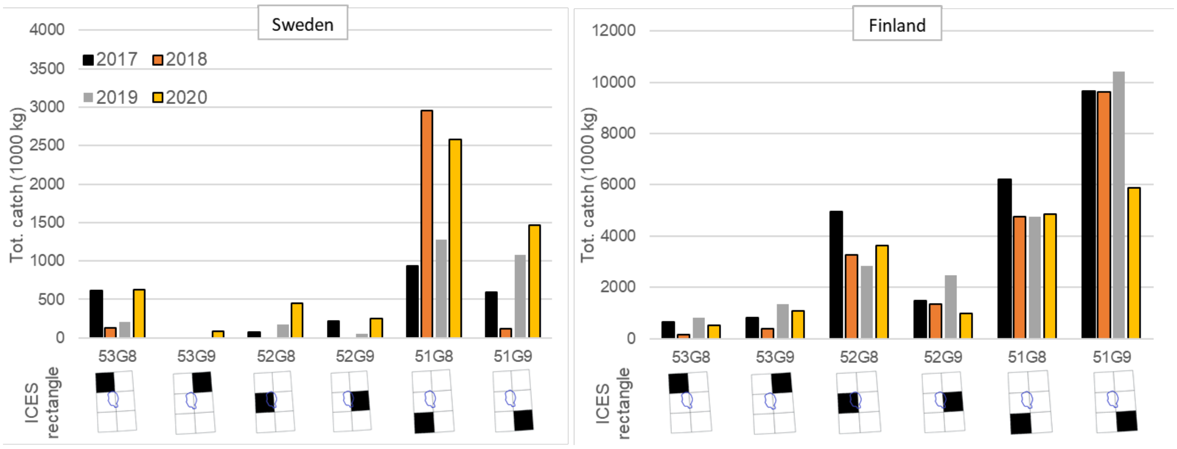

Figure 11. The total annual herring catch (1000 kg) in each of the ICES statistical rectangle in the Research Area of Interest (RAI). Note: the maximum Y-axis value is 3x higher in the Finnish data.

Sprat catches in 2017–2020

Sprat catches were small compared to herring catches, but there were sprat catches throughout the year in all of the ICES statistical rectangles in the RAI (Figure 12). Most (88.7 %) of the catch was from the two southernmost rectangles (Figure 12).

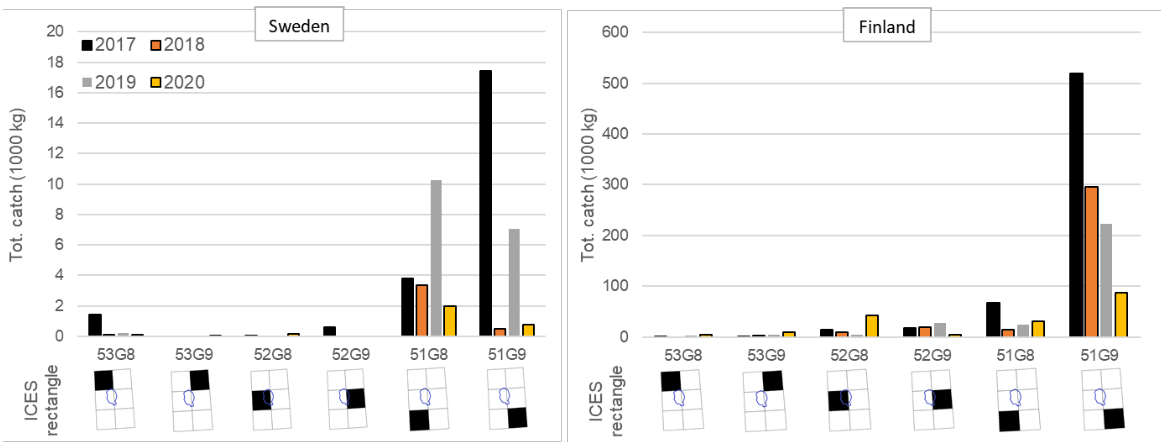

Figure 12. The total annual sprat catch (1000 kg) in each of the ICES statistical rectangle in the Research Area of Interest (RAI). Note: the maximum Y-axis value is 30x higher in the Finnish data.

Other species in 2017–2020

The other species reported in the RAI were three-spined stickleback (*Gasterosteus aculeatus*, SWE: “storspigg”, FIN: “kolmipiikki”) or other sticklebacks, fourhorn sculpin (*Myoxocephalus quadricornis*, SWE: “hornsimpa”, FIN: ”härkäsimppu”), and smelt (*Osmerus eperlanus*, SWE: “nors”, FIN: ”kuore”). In the Finnish data, 97 % of the catch of species other than herring and sprat was reported as “others” without specifying the species. Of the species that were reported for species in either of the dataset, 82 % were sticklebacks. In the Swedish data, most of these species were caught in the two southernmost rectangles (Figure 13), where the fishing intensity was also largest (Figure 10). On the contrary, in the Finnish data, the other rectangles had high catches, with 52B8 being the highest (Figure 13).

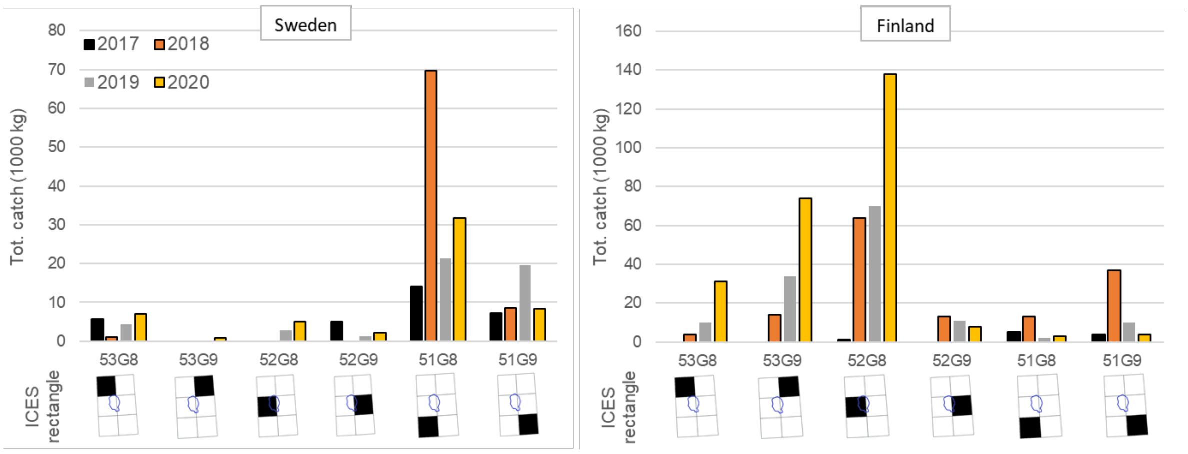

Figure 13. The total annual catch (1000 kg) of other species than herring and sprat in each of the ICES statistical rectangle in the Research Area of Interest (RAI). Note: the maximum Y-axis value is 2x higher in the Finnish data.

3.5 Combined catch data and fishing locations

By combining information from the VMS datasets, three areas where most of the fishing occurred can be approximated in the Research Area of Interest near the Eystrasalt Offshore project area (Figure 14). These areas are: 1) the 51G9 rectangle and southern parts of the 52G9 in the Southeast of the map area, 2) Southwest of the 51G8 rectangle North of Finngrunden, and 3) Northwest of the Eystrasalt project area in the other three rectangles (Figure 14). There was very little fishing outside of these areas.

Because the three fishing areas were approximately within different ICES statistical rectangles and included most if not all catches in the respective rectangles, the catch data in the rectangles can be assumed to represent the catch in these fishing areas (Figure 14).

There is some overlap between the areas, mainly between the Areas 1 and 2, and their reach to the south of statistical rectangle 52G8. Therefore, the true proportion of Area 3 is lower than shown and there is likely some variation between areas 1 and 2 (Figure 14). Area 1 and Area 2 also likely reach further outside the RAI into other ICES statistical rectangles (Figure 14). Hence, the borders in this presentation are artificial for Areas 1 and 2, while the whole Area 3 is within the RAI.

For Finnish trawlers, Area 1 was the most important herring (51 % of total catch) and sprat (84 %) location and most other species (80 %) were reported in the Area 3 (Figure 14). For

Swedish trawlers, Area 2 was the most important location for herring (56 %) and other species (63 %) while Area 1 was the most important location for catching sprat (55 %) (Figure 14). The catch from the Area 3 was low (17 % of herring catch) for Swedish trawlers (Figure 14) while for Finnish trawlers it was approximately the same as Area 2 (Figure 14).

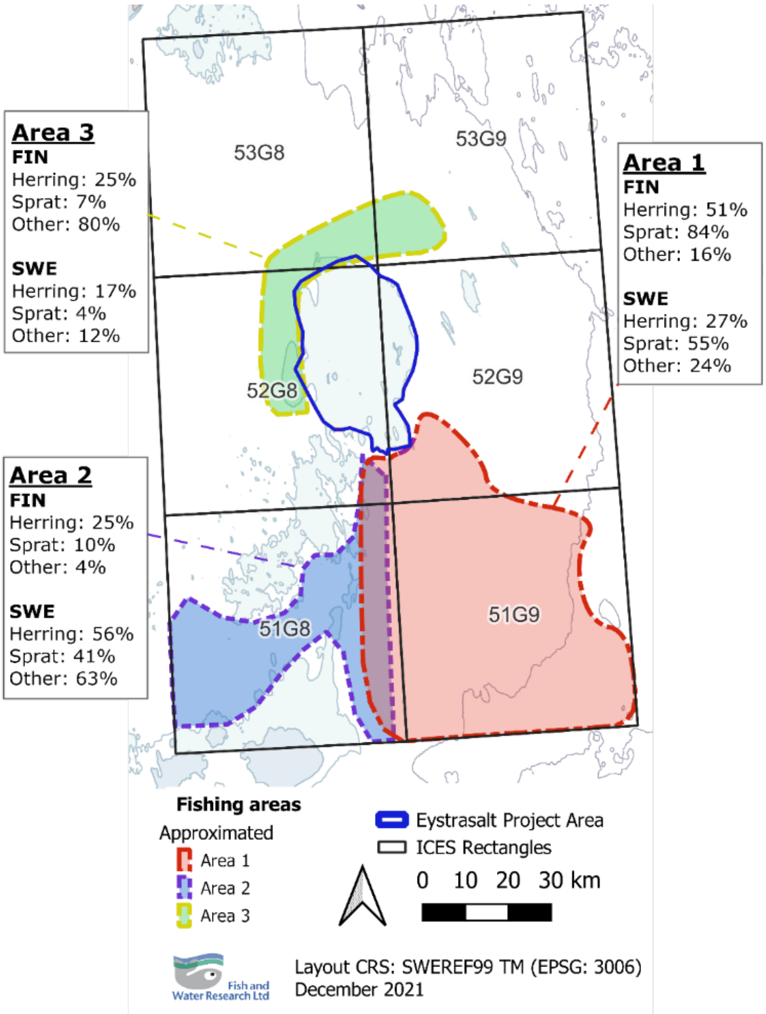

Figure 14. Approximated fishing areas and their proportion of the total catch (per species per country) in the Research Area of Interest (RAI) in 2017–2020.

3.6 Historical herring and sprat catches in the Gulf of Bothnia by Finnish fishing operators

Much larger percentage of the herring catch of the Gulf of Bothnia was caught in the northern parts of the Gulf of Bothnia (Bothnian Bay: ICES statistical rectangles 56–60) from 1980 to mid-1990’s than in the 2000’s (Figure 15). Recently, the southernmost rectangles (ICES 50–52) have provided most of the herring catch (Figure 15, Figure 16). Today, nearly a third of the herring catch is caught in the Bothnian sea and a small number of fishing vessels bring in most of the catch (Natural Resources Institute Finland 2015).

Similarly for sprat, the proportion of catch in the northern areas has decreased from 2001–2005 to 2016–2020 (Figure 17). Almost all of the sprat catch was caught in the five rectangles in the Southern part of the Gulf of Bothnia (Figure 17).

Of the total herring catch, 22 % (2001–2005), 23 % (2006–2010), 19 % (2011–2015), and 27 % (2016–2020) were caught in the six ICES statistical rectangles in the RAI (Figure 16). The same numbers for sprat were 16 % (2001–2005), 13 % (2006–2010), 12 % (2011–2015), and 21 % (2016–2020) (Figure 17).

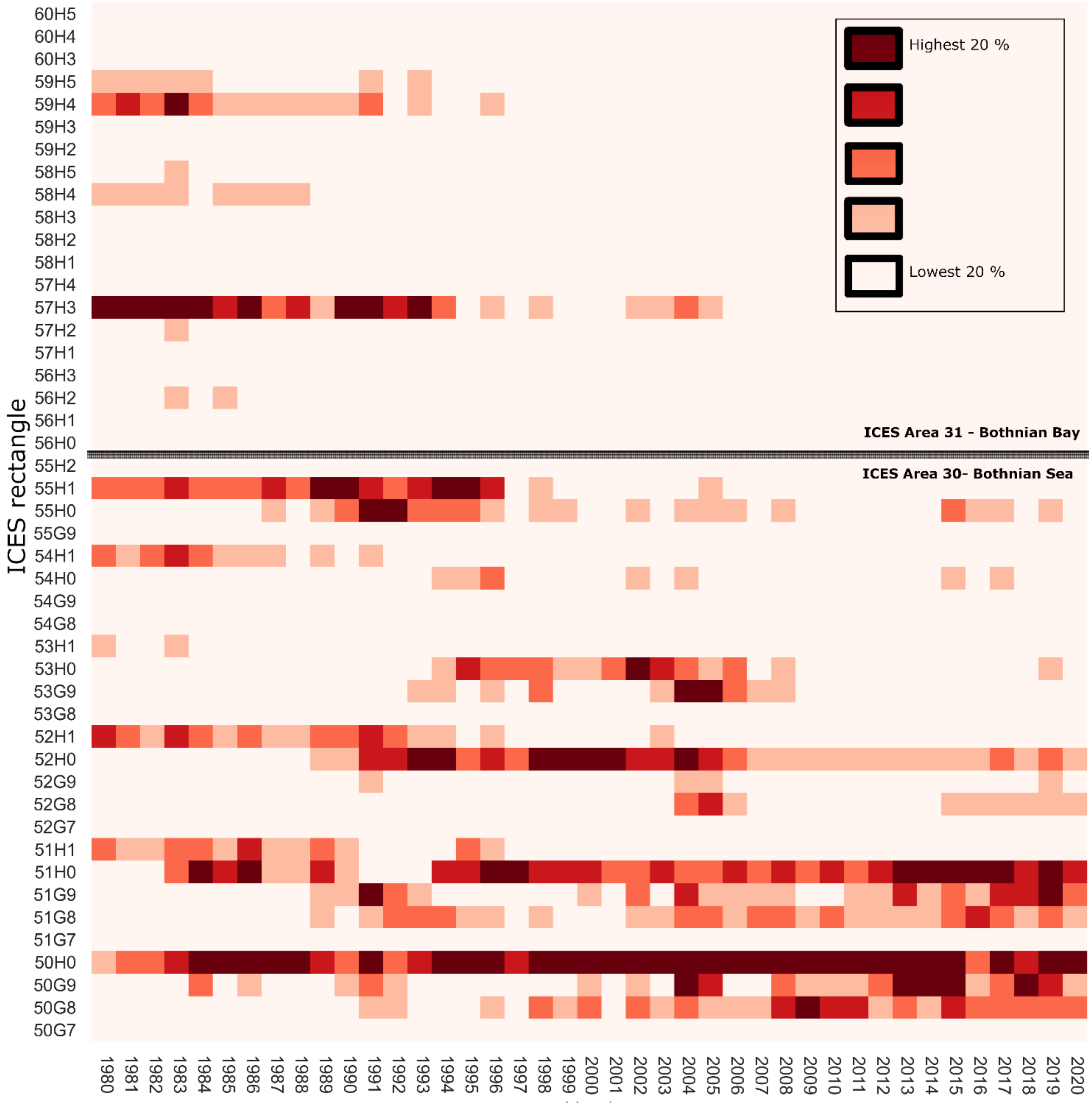

Figure 15. The annual proportion of total catch in each of the ICES statistical rectangle in 1980–2020. The colours in the heat map represent five equal-width bins based on the data (minimum value: 0% and maximum value 25 %).

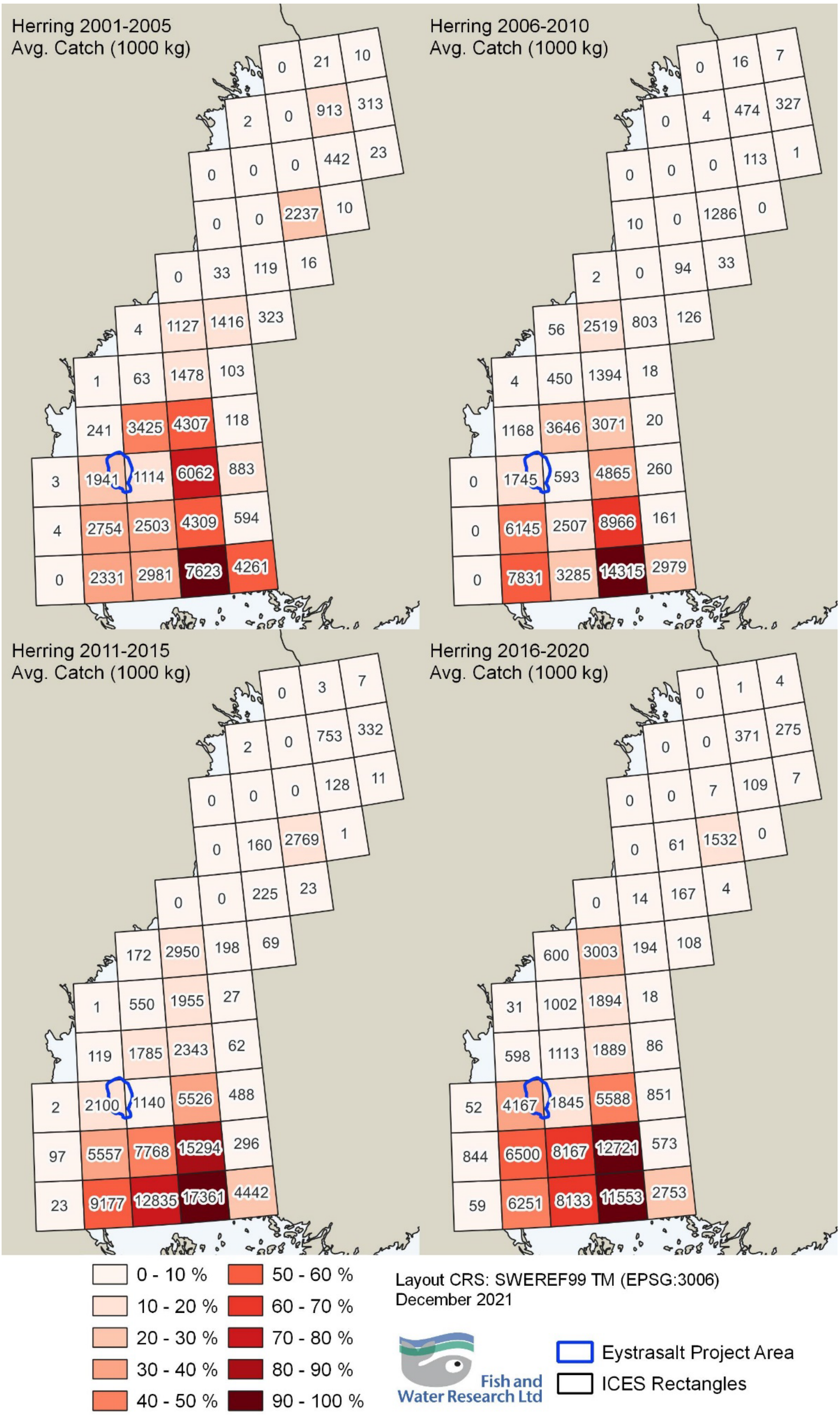

Figure 16. Herring catches in the ICES statistical rectangles in the Gulf of Bothnia by Finnish trawlers in 2001–2020 as yearly averages.

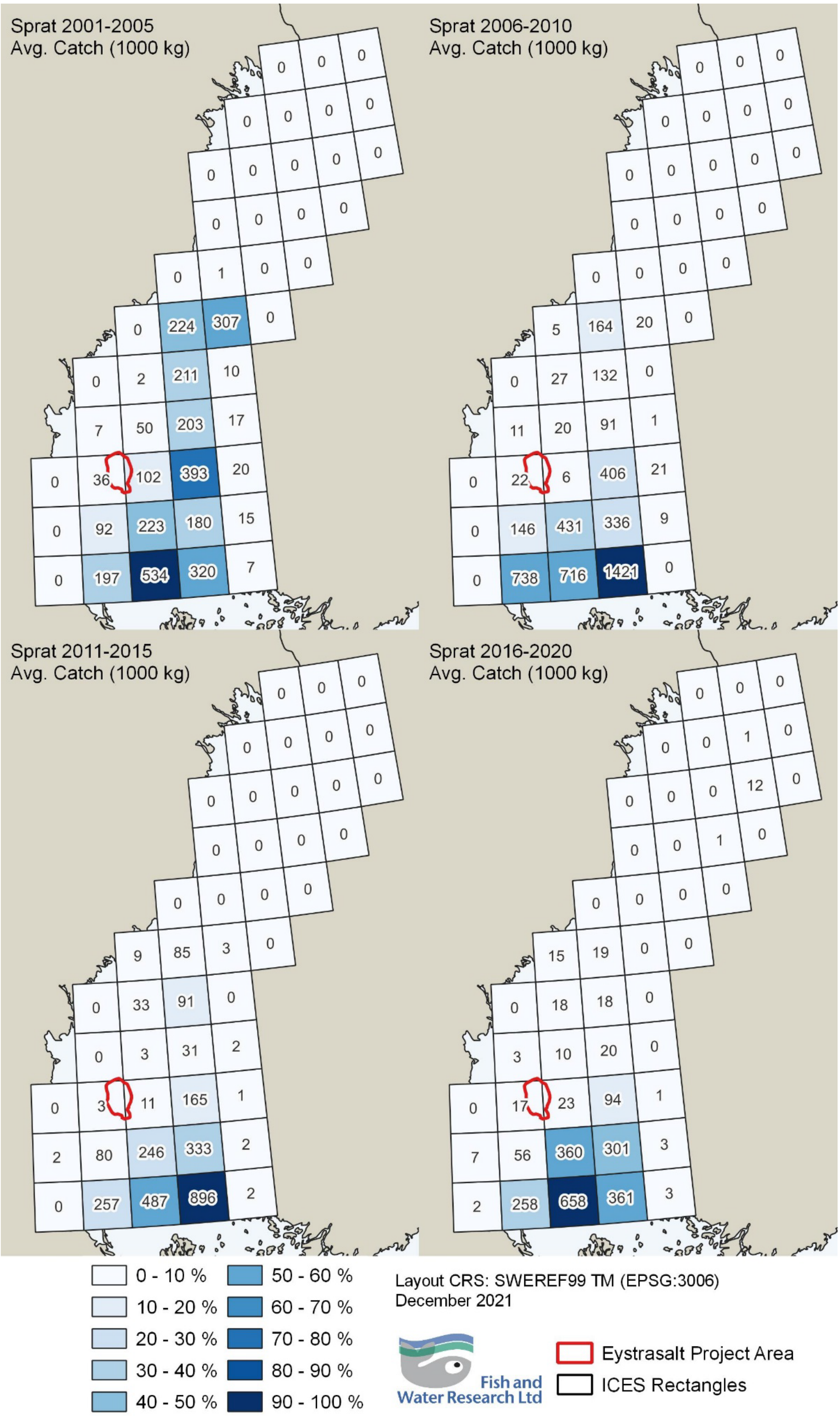

Figure 17. Sprat catches in the ICES statistical rectangles in the Gulf of Bothnia by Finnish trawlers in 2001–2020 as yearly averages.

Of the 46 ICES statistical rectangles, seven had a SD >2 % when calculated from the annual catch proportion between 2010–2020 in the Finnish data, *i.e.*, in these rectangles the percentage of the catch of the total herring catch varied more than in the other rectangles. These rectangles together provided from 63.9 % (in 2006) to 78.4 % (2012) of the annual catch every year.

The correlations were calculated between those rectangles, and six of the seven rectangles showed moderate (0.5–0.75) and strong (>0.75) negative correlations with at least one other rectangle (Figure 18, Table 3). This indicates pairs of rectangles that have opposing trends, *i.e.*, when one rectangle has a smaller portion of the catch the other has a higher portion in the same year (Figure 18). As an example, there was a moderate (-0.6) negative correlation between the two southernmost rectangles in the RAI (51G8 and 51G9; Figure 18, Table 3).

Table 3. Correlations between the seven ICES statistical rectangles.

ICES rectangle	50G8	50G9	50H0	51G8	51G9	51H0
50G8						
50G9	-0.3					
50H0	**0.6**	-0.3				
51G8	0.4	**-0.8**	0.2			
51G9	**-0.7**	0.4	-0.4	**-0.6**		
51H0	-0.3	0.0	0.0	0.0	-0.4	
55H0	-0.1	0.0	**-0.7**	0.1	-0.1	-0.1

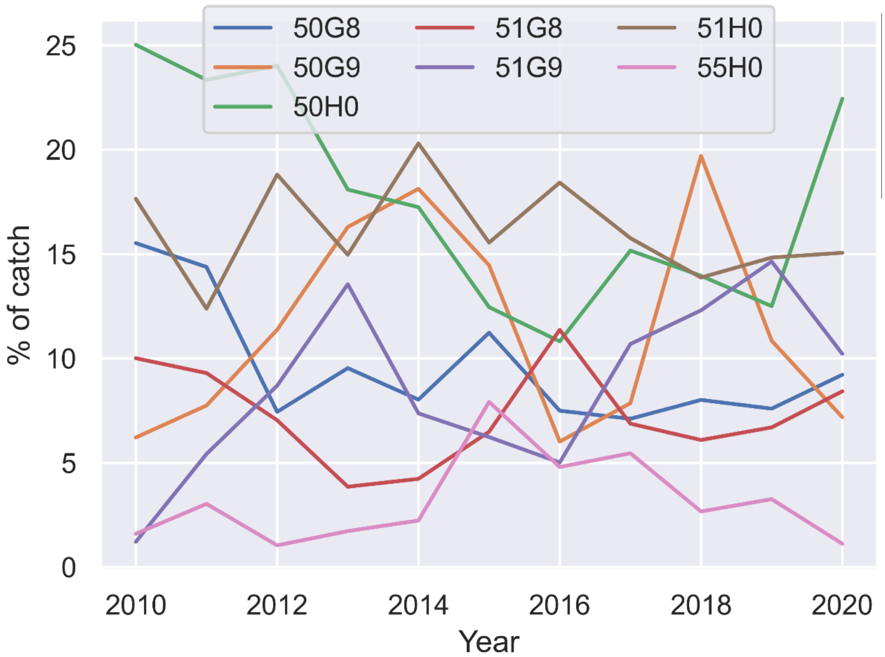

Figure 18. Annual percentage of the total catch in the seven ICES statistical rectangles.

3.7 Herring length

The herring length in the dataset varied between 40 mm and 275 mm, and the average length (all years combined) varied between 11.9 cm and 16.6 cm in the ICES statistical rectangles in the Bothnian Sea (Figure 19).

The length distribution in 2018–2020 was often normally distributed around 125–225 mm but some catches (e.g., 53G9 in 2020, 51G9 in 2018, and 25G9 in 2018) included another size class at around 60–100 mm (Figure 19 B). In 2018 and 2020 that smaller size class was more common on the east side of the project area than on the west side (Figure 19 B).

The bimodal length distribution also influenced the average length calculated for the rectangles, lowering the average length in the rectangle (and years) where the smaller size class was present (Figure 19 A). Therefore, a smaller average length does not necessarily mean that all adult fish in that rectangle are smaller than in other rectangle, but it can also indicate a presence of the smaller size class in the catch.

However, the highest average length was in the 52G8 rectangle (Figure 19 A) where there were also more ~175 mm herring caught than from other rectangles in 2019 and 2020 (Figure 19 B).

Because the fish catch data presented herein was caught for research purposes it represents the distribution of fish in the area. A commercial fishing catch in the same rectangle could differ drastically from these catches, as, for example, a commercial fishing boat can target schools of larger fish using their available technology and different (larger mesh size) fishing gear.

The research fishing trip is conducted in the autumn, typically starting at the end of September, and thus around the same time when the Finnish trawlers also fish in the area in the autumn (Figure 8).

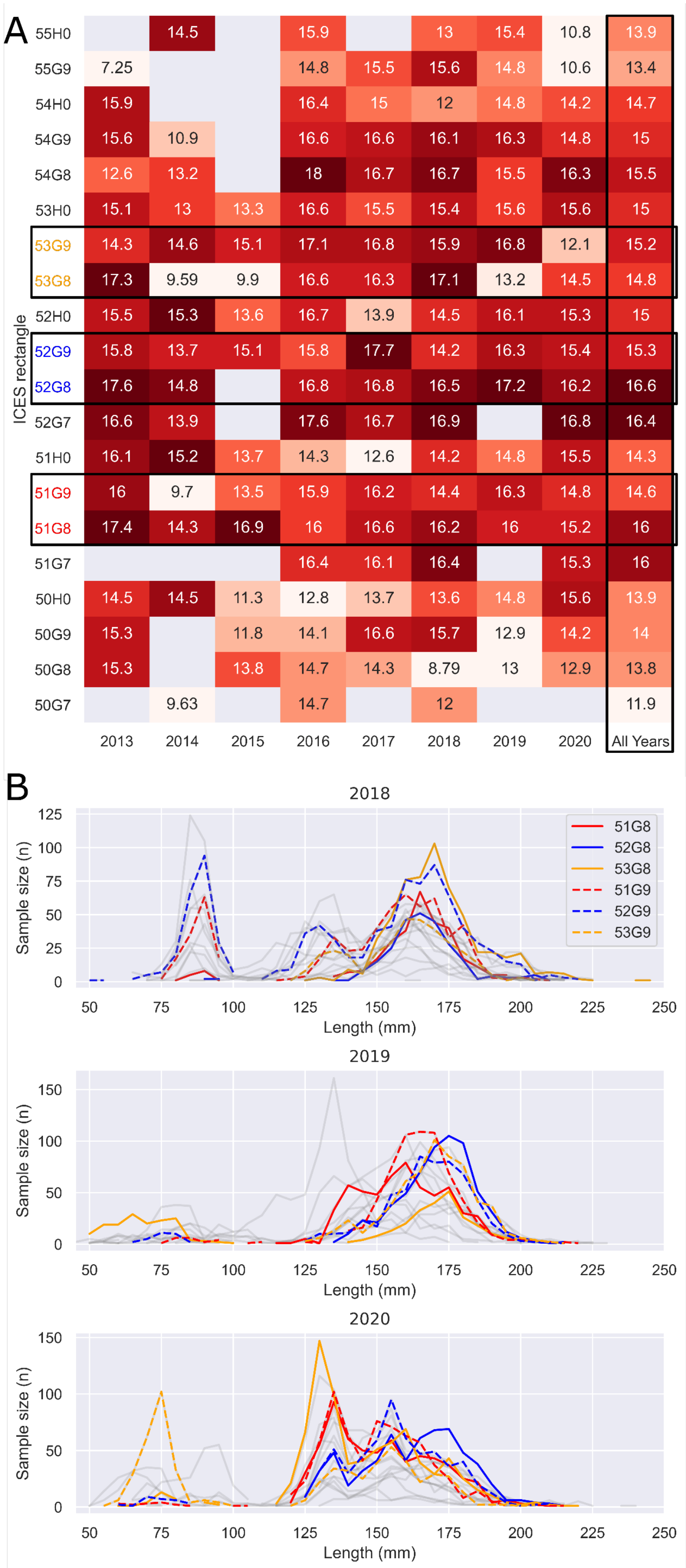

Figure 19. Herring length in the Bothnian Sea. The average length of herring in samples in the different ICES statistical rectangles in 2013–2020 and all years together (A) and the length distributions in 2018–2020 (B). The Research Area of Interest (RAI) rectangles highlighted in colours.

4. Conclusions

In this report, the commercial fishing activities and catches in the planned Eystrasalt Offshore wind farm area and its surrounding areas are documented.

Six ICES rectangles closest to the Eystrasalt project area were used as the Research Area of Interest (RAI). In the six rectangles the most important species was herring (97.7 % of the catch), but sprat was also an important catch, while other fish species were caught mainly in small quantities. Between 19 % and 27 % of the annual Finnish herring catch and between 12 % and 21 % of the annual Finnish sprat catch in the Gulf of Bothnia was caught from these six rectangles in the 2000’s.

In the 2000’s, most of the herring and sprat catch in the Gulf of Bothnia has been caught in the southern parts of the gulf. Similarly, most of the catch in the RAI was from the two southernmost rectangles (*e.g.*, 79 % of Swedish herring catch and 68 % of Finnish herring catch in the RAI), where also the fishing effort was highest. The rectangle 52G8 in which the largest proportion of the project area is located, was also important in the dataset, mainly for the Finnish trawlers (*e.g.*, 18 % of the Finnish herring catch and 5 % of the Swedish catch in the RAI). The highest average herring length (16.6 cm) was also found in the same rectangle 52G8.

To understand how the proportion of the catch between the different ICES rectangles in the Gulf of Bothnia varies over the years, seven rectangles were identified in which the annual percentage of the total herring catch varied more than in others. The two southernmost rectangles in the RAI were within these seven identified rectangles. These two rectangles had a moderate negative correlation between each other and a moderate/high negative correlation with another ICES rectangle (outside of the RAI), indicating that when a catch is small in one rectangle it is typically higher in the other rectangle.

Fishing locations

Based on VMS data, three areas can be identified where the fishing was most intensive and there was very little or no fishing outside of these areas. All of the identified three areas were used by both Finnish and Swedish trawlers. However, the intensity varied between the countries; the Swedish trawlers fished locations southwest of the project area most intensely and the Finnish trawlers mostly used areas southeast and northwest of the project area. The same fishing areas were used by trawlers in an older dataset from 2013, indicating that the same fishing areas are used throughout the years.

There was very little (2.4 % of the whole dataset) fishing in the planned Eystrasalt project area and most (65 % in the Finnish data and 80 % in the Swedish data) of the fishing in the RAI was farther than 30 km from the project area.

To understand fishing activities near the project area, the fishing within the first 30 km from the project area was examined using 5 km buffers, and was found to be mostly equally distributed between the buffers; *i.e.*, there was as much fishing 20–25 km from the project area as 25–30 km from the project area. The first 5 km from the project area, however, was used more than the other buffer zones. The first 5 km was especially used on the west side of the project area, but also on the south side of the project area.

The Eystrasalt Offshore wind farm is planned to be built in an area where there has been very little fishing in the previous years. Because the areas that are used for fishing in the RAI have remained the same throughout the previous years it is not expected, based on previous years, that the importance of the project area for fishing would suddenly increase.

There is, however, a fishing area just west of the project area where most of the fishing is within the first 5 km from the project area. The continuation of fishing in that fishing area in the future is dependent on the impact of the wind farm outside of the planned project area. Such impacts can include but are not limited to *e.g.*, legal or physical access to these areas, possible changes in physical environment (*e.g.*, ice formation), and possible changes in fish behaviour (*e.g.*, due to changes in spawning habitat).

Timing of fishing

Almost all (96.8 %) of the trawl retrievals in the RAI in the Finnish data were between September and April, and more than half (57.3 %) of Finnish trawl fishing was in the spring between January and April. The Swedish data showed trawling in the same months as the Finnish data, however, most (73.8 %) of the trawling was in the spring between the months of January and April.

Based on the timing of fishing in previous years and in order to avoid direct impact to fishing during building phase, it is recommended to focus the building operation and any additional ship traffic to the summer months, when there is no fishing. However, this is also dependent on indirect impact to fishing via ecosystem processes, *e.g.*, whether any operations in the summer impact herring spawning success.

Because winter is an important season for fishing, the impact of the wind farm to fishing depends especially on the wintertime access and fish behaviour, related to *e.g.*, ice formation and hydrology.

5. Literature

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Appendix 1.

When comparing annual total of trawl retrievals in the ICES statistical rectangles to total Herring catches per year in the rectangles, there was a very strong (r=0.98) positive correlation (or linear regression, R^2=0.96). The dataset included years 2017–2020 in the six ICES statistical rectangles in the Research Area of Interest (RAI) and both countries were separated in the dataset, therefore, n=48.