North Sea mackerel daily egg production and spawning stock biomass estimation in 2021

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Introduction

The North Sea Mackerel Egg Survey (NSMEGS) is designed to estimate the spawning stock biomass (SSB) of mackerel of the North Sea spawning component of the Northeast-Atlantic stock on a triennial basis. Prior to 2017 this was done utilizing the annual egg production method (AEPM). This method estimates and combines total annual egg production (TAEP), realized fecundity per gram female, and sex (male to female) ratio to calculate SSB.

Spatial and temporal coverage in the North Sea was impaired when Norway withdrew from the survey in 2014 and Netherlands was left as the sole survey participant in 2015 and 2017. In 2021 Denmark was recruited as a new participant for the NSMEGS. However, the planned coverage in 2021 of the mackerel spawning in the North Sea, both temporally and spatially, was far from ideal for the Annual Egg Production Method (AEPM; ICES 2018).

Another issue for the NSMEGS is that since 1982 it has been impossible to collect and sample pre-spawning mackerel, which are necessary in order to estimate the potential fecundity. For SSB estimation using the AEPM, the realized fecundity value used was from the 1982 estimate (Iversen and Adoff, 1983).

Consequently, WGMEGS discussed utilizing the Daily Egg Production Method (DEPM) for the NSMEGS. The DEPM only requires one full sweep, in a short time period, of the entire mackerel spawning area, preferably at peak spawning time, in order to estimate the Daily Egg Production (DEP). A disadvantage of the DEPM is that it requires many more mackerel ovary samples to be collected to estimate batch fecundity and spawning fraction. Considering the pros and cons of the AEPM and DEPM for the NSMEGS, in 2018 WGMEGS decided to switch to the DEPM for the NSMEGS in 2021 (ICES 2018).

Originally the NSMEGS was planned for 2020, however, due to the pandemic and the implementation of Covid-19 measures it was not possible to complete the survey in 2020. After consultation with WGMEGS chairs and the mackerel assessor it was agreed to postpone the survey to 2021.

Survey

In 2021 Netherlands and Denmark conducted the North Sea mackerel egg survey (NSMEGS). Whilst completing an exploratory egg survey, similar to those in 2017 and 2018, along the Norwegian Sea, Scotland was also able to contribute several additional survey transects within the Northern North Sea that were then incorporated into the 2021 NSMEGS dataset.

During 2021 Covid 19 measures continued to pose significant challenges that impeded the execution of the survey plan. The Dutch vessel was not permitted to enter foreign harbours during survey breaks, instead being required to undertake the long steam back to a Dutch harbour. As a consequence the Netherlands was unable to sample the most northerly transect. However Scotland was able to complete this transect during their exploratory survey.

The samples were collected and analysed according to the WGMEGS manuals (ICES 2019a, 2019b). The Netherlands and Scotland sampled eggs with a Gulf VII plankton sampler while Denmark used a Nackthai sampler. The Netherlands and Denmark utilised a 500 µm plankton net whereas Scotland used a 250 µm plankton net. At each station a double oblique haul was performed from the surface to 5 m above the bottom, a maximum depth of 200 m, or 20 m below the thermocline in case of stratification of the water column. Temperature and salinity were measured during the haul with a CTD mounted on top of the plankton sampler. Electronic flowmeters were mounted on the plankton sampler to monitor flow.

The NSMEGS was carried out from 25th May to 12th June (Table 1). During this period the spawning area between 53ºN and 62ºN was surveyed once, receiving a single coverage (Fig. 1). The survey is designed to cover the entire spawning area with samples collected every half ICES statistical rectangle (ICES, 2014). In total 294 plankton stations were sampled. In 26 of the half rectangles more than one plankton sample was collected (Fig. 1a). These rectangles were used to estimate the CV and variance of the DEP. On each transect at least one pelagic trawl haul was performed for the collection of mackerel adult samples (Fig. 1b).

Following the WGMEGS manual temperature at 5m depth was used to estimate egg development (ICES 2019a). For the DEPM only the mackerel eggs in development stage 1A are used to estimate daily egg production.

Results

Mackerel daily egg production

During the survey the weather was fine. Denmark and Scotland managed to sample all their planned plankton stations. The Netherlands missed 4 plankton stations due to technical issues and limited sampling time.

The spatial egg distribution is shown in Fig. 2. The standard interpolation rules (ICES, 2019a) were applied where needed (see interpolated stations in Fig. 2). The interpolated egg production accounted for 7.3% of the DEP. The egg distribution is comparable to previous surveys in the same area and period, with the highest numbers of eggs found in the south western area. Previous surveys did not sample above 59ºN and no comparison with previous years is available for this area.

The DEP was calculated for the total investigated area (Table 2). For comparison with the previous survey, the DEP was also calculated for the area between 53.5 and 59ºN which was the area sampled in 2017 in the same period of the year (extended period 2 of 2017). DEP of 2021 was 11% higher compared to 2017 (Table 3), but the sampled area was also a bit larger in 2021 (11%).

Adult parameters

Denmark was unable to analyse their ovary samples before the WGWIDE 2021 meeting. The Netherlands screened all samples and analysed part of the ovary samples for batch fecundity and spawning fraction estimation. Denmark had finished the screening of the samples. The Dutch and Danish results will be combined for the final estimations in 2022.

The Netherlands sampled 524 mackerel during the survey and collected ovary samples of 164 females. Of these 164 ovaries 73 can be analysed for batch fecundity estimation, and 108 for POF analyses for spawning fraction estimation. For this working document 40 batch fecundity and 51 POF samples were analysed. Denmark sampled 817 mackerel during the survey and collected ovary samples of 119 females.

The adult parameters are still very preliminary, and are therefore not provided in this document. Without adult parameters the SSB cannot be estimated. When final adult parameter estimates are available and agreed by WGMEGS an estimate of SSB will be provided to WGWIDE.

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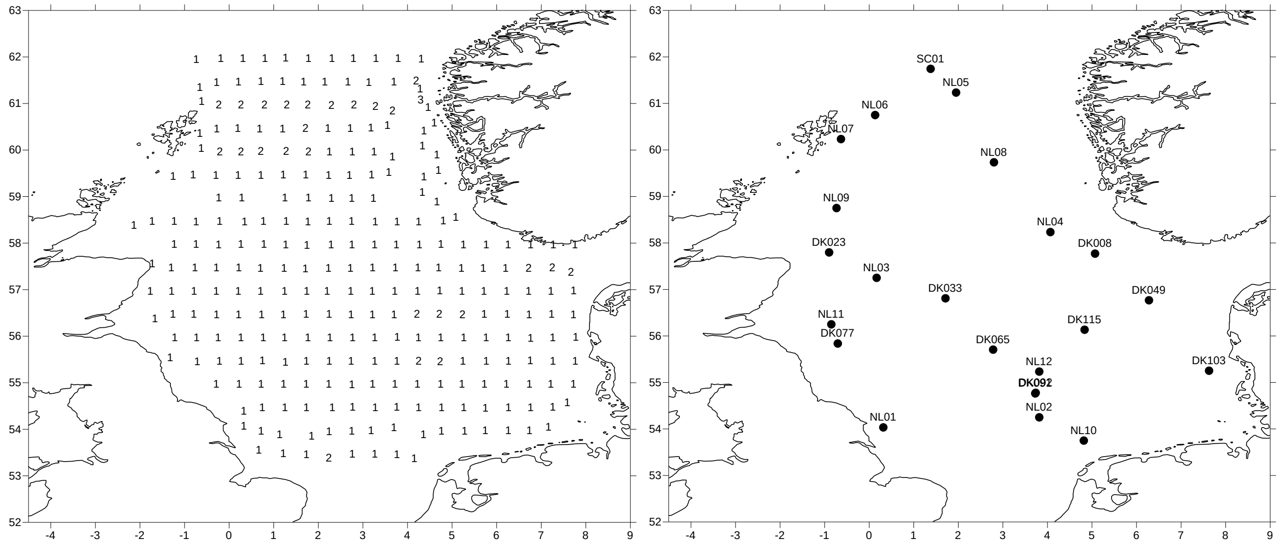

Figure 1. Number of samples for NSMEGS 2021; plankton samples per half ICES rectangle (left) and pelagic trawl hauls for mackerel adult samples (right; all hauls included).

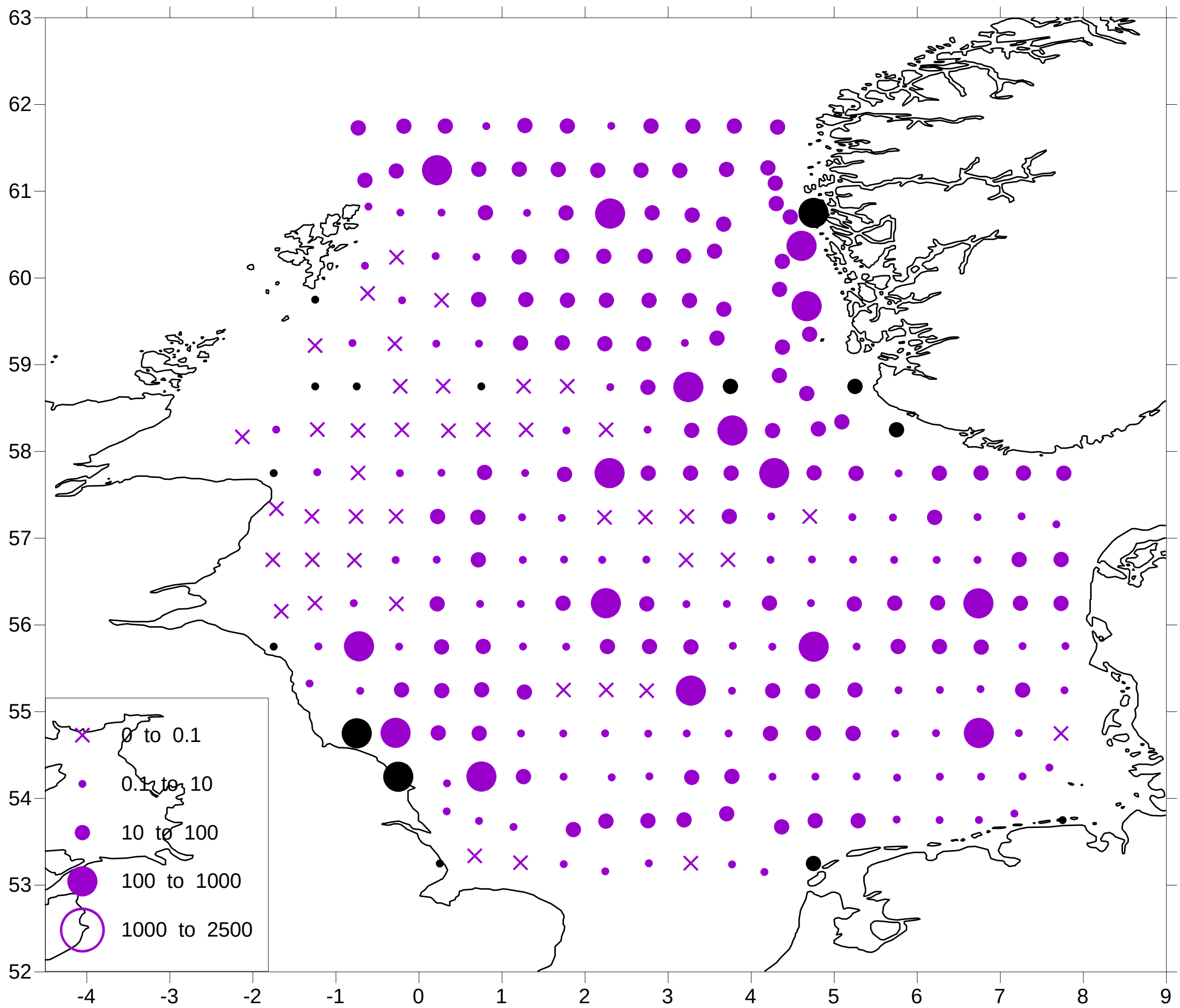

Figure 2. Stage 1A mackerel egg production (eggs/m^2/day) by half rectangle for NSMEGS 2021. Purple circles represent observed values, black circles represent interpolated values, and crosses represent observed zeros.

Table 1. NSMEGS surveys cruise dates in 2021 (For Scotland only stations used in the NSMEGS DEP calculation are shown.)

Country	**NL**	**DK**	**SCO**
Period	1	1	1
Dates	25.05-12.06	31.05-9.06	8.06-11.06
Plankton stations sampled	174	91	29
Pelagic trawl hauls	12	10	1

Table 2. Daily egg production estimate (stage 1A) in the North Sea.

Year	**DEP $*10^{13}$**	**CV DEP**
2021	1.28	16%

Table 3. Comparison of Daily Egg production (stage 1) between 2021 and 2017, in the area between 53.5 and 59ºN.

Year	**2021**	**2017 Extended period 2**
DEP $*10^{12}$	4.92	4.43
Area sampled ($* 10^{11}$ m^2)	2.24	1.97

PFA

PELAGIC FREEZER-TRAWLER ASSOCIATION

REPORT

PFA self-sampling report for WGWIDE 2021

M.A. Pastoors, F.J. Quirijns

WGWIDE 2021 WD02; PFA report 2021/08

24/8/2021

Pelagic Freezer-trawler Association (PFA)

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Front cover: measuring oxygen content in RSW tank with horse mackerel, December 2020

WGWIDE 2021 WD02, PFA report 2021_08

PFA self-sampling report for WGWIDE 2021

M.A. Pastoors, F.J. Quirijns

Executive summary

The Pelagic Freezer-trawler Association (PFA) is an association that has nine member companies that together operate 15 (in 2021) freezer trawlers in six European countries (www.pelagicfish.eu). In 2015, the PFA has initiated a self-sampling program that expands the ongoing monitoring programs on board of pelagic freezer-trawlers aimed at assessing the quality of fish. The expansion in the self-sampling program consists of recording of haul information, recording the species compositions by haul and regularly taking length measurements from the catch. The self-sampling is carried out by the vessel quality managers on board of the vessels, who have a long experience in assessing the quality of fish, and by the skippers/officers with respect to the haul information. The scientific coordination of the self-sampling program is carried out by Martin Pastoors (PFA chief science officer) with support of Floor Quirijns (contractor). The self-sampling program has been incrementally implemented in the fishery and by 2018 all vessels in the PFA fleet participated in the self-sampling.

This report for WGWIDE 2021 presents an overview of the results of the Pelagic Freezer-Trawler Association (PFA) self-sampling program for the fisheries for widely distributed pelagic stocks: Northeast Atlantic mackerel, Blue whiting, Horse mackerel and Atlanto-scandian herring (herring caught north of 62 degrees). The selection of hauls to be included in the analyses was based on first summing all catches by vessel, trip, species and week. For each vessel-trip-species-week combination, the proportion of the species in the catch were calculated. The following filter criteria have applied to the weekly data:

- for horse mackerel: latitude > 45, proportion in the catch > 10%, weekly catch > 10 tonnes
- for mackerel : latitude > 45, proportion in the catch > 10%, weekly catch > 10 tonnes
- for blue whiting : latitude > 50, proportion in the catch > 10%, weekly catch > 10 tonnes
- for herring : division = 27.2.a, proportion in the catch > 10%, weekly catch > 10 tonnes

Trips from 2017 up to 27/07/2021 have been processed for this overview. Pelagic fisheries within the Pelagic Freezer-trawler Association are carried out by vessels from different countries. Overall, around 48% of the catch volume of trips in this overview were taken by Dutch trawlers, 22% German trawlers, 14% UK trawlers and 16% other countries. Blue whiting constitutes the majority of the catch in those trips (54%), followed by mackerel (23%) and horse mackerel (12%). Atlanto-Scandian herring only constitutes around 3% of the volume in the PFA widely distributed fishery. Note that the North Sea herring fishery is not included in this overview.

The **Mackerel fishery** takes place from October through to March of the subsequent year. Minor by-catches of mackerel may also occur during other fisheries. Overall, the self-sampling activities for the mackerel fisheries during the years 2017 - 2021 (up to 27/07/2021) covered 357 fishing trips with 4940 hauls, a total catch of 287836 tonnes and 91096 individual length measurements. The main fishing areas are ICES division 27.4.a and division 27.6.a. Compared to the previous years, mackerel in the catch in 2021 have been relatively large with a median length of 36.4 cm compared to 33.6-36.2 in the preceding years. Also, the median weight has been somewhat higher with median weight of 435 gram compared to 385-422 gram in the preceding years.

The **horse mackerel fishery** takes place from October through to March of the subsequent year. Overall, the self-sampling activities for the horse mackerel fisheries during the years 2017 - 2021 (up to 27/07/2021) covered 243 fishing trips with 3446 hauls, a total catch of 141548 tonnes and 153307 individual length measurements. The main fishing areas are ICES division 27.6.a, division 27.7.b and division 27.7.d. Horse mackerel have a wide range in the length distributions in the catch. Median lengths in divisions 27.6.a, 27.7.b and 27.7.j have fluctuated between 26.2 and 31.3 cm (with one low median length of 23.3 cm in 27.6.a in 2018). In ICES divisions 27.7.d and 27.7.h, median lengths in the catch are smaller and fluctuated between 21.3 and 24.6 cm.

The **blue whiting** fishery takes place from February through to May although some minor fisheries for blue whiting may remain over the other months. Overall, the self-sampling activities for the horse mackerel fisheries during the years 2017 - 2021 (up to 27/07/2021) covered 240 fishing trips with 6560 hauls, a total catch of 650604 tonnes and 507481 individual length measurements. The main fishing areas are ICES division 27.6.a, division 27.7.c and division 27.7.k. Compared to the previous years, blue whiting in the catch in 2021 have been relatively large with a median length of 27.9 cm compared to 24.2-27.2 in the preceding years. Also, the median weight has been somewhat higher with median weight of 137 gram compared to 85-120 gram in the preceding years.

The fishery for **Atlanto-Scandian herring** (ASH) is a relatively smaller fishery for PFA and takes place mostly in October. Overall, the self-sampling activities for the horse mackerel fisheries during the years 2017 - 2021 (up to 27/07/2021) covered 27 fishing trips with 456 hauls, a total catch of 36003 tonnes and 10327 individual length measurements. Only the herring fishery in ICES division 27.2.a is considered for ASH. Note that there are herring catches in other divisions within the selected trips. These are trips where North Sea herring has been fished with some bycatches of mackerel for example. Atlanto-Scandian herring have a relatively narrow range in the length distributions in the catch. Median lengths have been between 31 and 36 cm.

1 Introduction

The Pelagic Freezer-trawler Association (PFA) is an association that has nine member companies that together operate 19 freezer trawlers in five European countries (www.pelagicfish.eu). In 2015, the PFA has initiated a self-sampling program that expands the ongoing monitoring programs on board of pelagic freezer-trawlers by the specialized crew of the vessels. The primary objective of that monitoring program is to assess the quality of fish. The expansion in the self-sampling program consists of recording of haul information, recording the species compositions per haul and regularly taking random length-samples from the catch. The self-sampling is carried out by the vessel quality managers on board of the vessels, who have a long experience in assessing the quality of fish, and by the skippers/officers with respect to the haul information. The scientific coordination of the self-sampling program is carried out by Martin Pastoors (PFA chief science officer) with support of Floor Quirijns (contractor).

2 Material and methods

The PFA self-sampling program has been implemented incrementally on many vessels that belong to the members of the PFA. The self-sampling program is designed in such a way that it follows as closely as possible the working practices on board of the different vessels and that it delivers relevant information for documenting the performance of the fishery and to assist stock assessments of the stocks involved. The following main elements can be distinguished in the self-sampling protocol:

- haul information (date, time, position, weather conditions, environmental conditions, gear attributed, estimated catch, optionally: species composition)
- batch information (total catch per batch=production unit, including variables like species, average size, average weight, fat content, gonads y/n and stomach fill)
- linking batch and haul information (essentially a key of how much of a batch is caught in which of the hauls)
- length information (length frequency measurements, either by batch or by haul)

The self-sampling information is collected using standardized Excel worksheets. Each participating vessel will send in the information collected during a trip by the end of the trip. The data will be checked and added to the database by Floor Quirijns and/or Martin Pastoors, who will also generate standardized trip reports (using RMarkdown) which will be sent back to the vessel within one or two days. The compiled data for all vessels is being used for specific purposes, e.g., reporting to expert groups, addressing specific fishery or biological questions and supporting detailed biological studies. The PFA publishes an annual report on the self-sampling program.

A major feature of the PFA self-sampling program is that it is tuned to the capacity of the vessel-crew to collect certain kinds of data. Depending on the number of crew and the space available on the vessel, certain types of measurements can or cannot be carried out. That is why the program is essentially tuned to each vessel separately. And that is also the reason that the totals presented in this report can be somewhat different dependent on which variable is used. For example, the estimate of total catch is different from the sum of the catch per species because not all vessels have supplied data on the species composition of the catch.

In order to supply relevant information to WGWIDE, the PFA self-sampling data has been filtered using the following approach. First, all catches per vessel, trip and species have been summed by week. For each vessel-trip-species-week combination, the proportion of the species in the catch were calculated. Then the following filter criteria have applied to the weekly data:

- for horse mackerel: latitude > 45, proportion in the catch > 10%, catch > 10 tonnes
- for mackerel : latitude > 45, proportion in the catch > 10%, catch > 10 tonnes

- for blue whiting : latitude > 50, proportion in the catch > 10%, catch > 10 tonnes
- for herring : division = 27.2.a, proportion in the catch > 10%, catch > 10 tonnes

For this report, data have been processed for 2017 - 2021 (up to 27/07/2021).

3 Results

3.1 General

An overview of all the selected self-sampling hauls is shown in Table 3.1.1.

year	nvessels	ntrips	ndays	nhauls	catch	catch/day	nlength
2017	12	64	887	1,886	184,973	208	95,190
2018	16	88	1,330	2,901	272,344	204	176,432
2019	16	101	1,426	3,113	253,326	177	151,187
2020	18	117	1,576	3,373	324,943	206	259,099
2021*	19	64	829	1,876	173,412	209	144,952
(all)		434	6,048	13,149	1,208,998		826,860

*Table 3.1.1: PFA fisheries for widely distributed species Self-sampling Summary of number of vessels, trips, days, hauls, catch (tonnes), catch per day and number of fish measured. * denotes incomplete year*

Catch and number of self-sampled hauls by year and division

division	2017	2018	2019	2020	2021*	all	perc
27.6.a	75,513	126,079	116,955	126,406	89,565	534,518	43.94959%
27.4.a	23,979	36,282	39,949	64,054	7,018	171,282	14.08329%
27.7.c	29,652	30,523	26,905	44,548	27,329	158,957	13.06990%
27.2.a	23,597	22,134	13,921	16,116	59	75,827	6.23471%
27.7.b	8,607	5,323	10,623	11,827	9,682	46,062	3.78735%
27.7.d	8,765	10,595	11,855	12,800	1,859	45,874	3.77189%
27.7.k	95	7,645	2,036	11,338	19,293	40,407	3.32238%
27.7.j	664	3,703	8,727	16,656	3,143	32,893	2.70456%
27.5.b	8,061	7,932	3,924	10,277	1,457	31,651	2.60244%
27.7.h	1,329	6,570	1,235	130	6,168	15,432	1.26886%
27.4.b	1,524	1,974	3,935	4,909	0	12,342	1.01479%
27.7.e	1,472	1,011	4,127	40	4,262	10,912	0.89722%
27.6.b	158	7,742	604	1,119	0	9,623	0.79123%
27.4.c	1,558	1,385	1,666	2,136	563	7,308	0.60088%
27.8.a	30	2,296	3,821	145	922	7,214	0.59316%
27.7.f	0	283	2,146	765	2,004	5,198	0.42739%
27.7.g	0	436	1,839	2,088	833	5,196	0.42723%
27.8.b	0	366	98	1,767	0	2,231	0.18344%
27.8.d	275	237	182	1,161	15	1,870	0.15376%
27.7.a	0	328	1,064	0	0	1,392	0.11445%
27.3.a	0	0	18	0	0	18	0.00148%
27.8.c	0	0	0	0	0	0	0.00000%
(all)	185,279	272,844	255,630	328,282	174,172	1,216,207	100.00000%

Table: catch

division	2017	2018	2019	2020	2021*	all	perc
27.6.a	668	1,268	1,281	1,210	792	5,219	39.691%
27.4.a	191	376	439	549	82	1,637	12.450%
27.7.c	256	243	252	328	241	1,320	10.039%
27.2.a	264	249	174	237	1	925	7.035%
27.7.d	157	190	206	213	35	801	6.092%
27.7.b	140	88	175	207	188	798	6.069%
27.7.j	20	60	138	209	112	539	4.099%
27.7.k	3	59	17	95	153	327	2.487%
27.5.b	66	82	38	87	11	284	2.160%
27.7.h	30	96	24	7	102	259	1.970%
27.7.e	45	32	79	11	73	240	1.825%
27.4.b	19	24	53	75	0	171	1.300%
27.8.a	1	41	101	9	14	166	1.262%
27.7.g	0	9	39	37	23	108	0.821%
27.4.c	22	16	25	30	12	105	0.799%
27.7.f	0	4	31	22	36	93	0.707%
27.6.b	2	50	10	7	0	69	0.525%
27.8.b	0	6	4	24	0	34	0.259%
27.8.d	2	2	13	16	1	34	0.259%
27.7.a	0	6	12	0	0	18	0.137%
27.3.a	0	0	1	0	0	1	0.008%
27.8.c	0	0	1	0	0	1	0.008%
(all)	1,886	2,901	3,113	3,373	1,876	13,149	100.000%

Table: nhauls

*Table 3.1.2: PFA fisheries for widely distributed species Self-sampling Summary of catch (top) and number of hauls (bottom) per year and division. * denotes incomplete year*

Catch and number of self-sampled hauls by year and month

month	2017	2018	2019	2020	2021*	all	perc
Jan	28,838	25,647	36,173	38,991	49,257	178,906	14.71%
Feb	19,420	32,985	34,946	28,442	39,045	154,838	12.73%
Mar	30,164	43,158	33,089	51,917	36,868	195,196	16.05%
Apr	28,506	58,665	28,857	66,444	29,582	212,054	17.44%
May	12,368	30,230	22,450	29,189	13,580	107,817	8.86%
Jun	0	6,866	1,498	4,241	2,271	14,876	1.22%
Jul	773	790	6,192	1,704	3,572	13,031	1.07%
Aug	6,762	4,551	3,960	5,083	0	20,356	1.67%
Sep	11,505	10,529	12,586	15,511	0	50,131	4.12%
Oct	21,362	28,098	34,110	35,940	0	119,510	9.83%
Nov	21,916	21,809	29,240	29,799	0	102,764	8.45%
Dec	3,666	9,521	12,535	21,024	0	46,746	3.84%
(all)	185,280	272,849	255,636	328,285	174,175	1,216,225	100.00%

Table: catch

month	2017	2018	2019	2020	2021*	all	perc
Jan	315	309	470	374	569	2,037	15.49%
Feb	208	333	413	290	465	1,709	13.00%
Mar	232	391	413	455	347	1,838	13.98%
Apr	201	494	289	580	248	1,812	13.78%
May	145	372	251	312	142	1,222	9.29%
Jun	0	77	23	103	32	235	1.79%
Jul	15	10	75	26	73	199	1.51%
Aug	68	39	42	70	0	219	1.67%
Sep	153	170	207	211	0	741	5.64%
Oct	247	301	410	424	0	1,382	10.51%
Nov	271	319	416	361	0	1,367	10.40%
Dec	31	86	104	167	0	388	2.95%
(all)	1,886	2,901	3,113	3,373	1,876	13,149	100.00%

Table: nhauls

*Table 3.1.3: PFA fisheries for widely distributed species Self-sampling summary of catch (top) and number of hauls (bottom) per year and month. * denotes incomplete year*

Catch and number of self-sampled hauls by year and country (flag)

flag	2017	2018	2019	2020	2021*	all	perc
NL	118,291	104,338	118,576	132,034	80,617	553,856	47.5%
DEU	29,214	57,340	49,764	72,173	42,113	250,604	21.5%
UK	37,780	32,276	32,124	39,468	21,572	163,220	14.0%
POL	0	17,042	31,602	55,192	12,421	116,257	10.0%
FR	0	13,483	22,157	15,216	6,325	57,181	4.9%
LIT	0	0	1,413	13,744	8,681	23,838	2.0%
(all)	185,285	224,479	255,636	327,827	171,729	1,164,956	100.0%

Table: catch

flag	2017	2018	2019	2020	2021*	all	perc
NL	1,243	1,138	1,491	1,591	969	6,432	50.6%
DEU	291	680	588	672	345	2,576	20.3%
UK	352	315	354	366	222	1,609	12.7%
FR	0	264	424	250	123	1,061	8.4%
POL	0	125	222	341	101	789	6.2%
LIT	0	0	34	142	62	238	1.9%
(all)	1,886	2,522	3,113	3,362	1,822	12,705	100.0%

Table: nhauls

*Table 3.1.4: PFA fisheries for widely distributed species Self-sampling summary of catch (top) and number of hauls (bottom) per year and month. * denotes incomplete year*

Catches by species and year (in tonnes).

species	english_name	scientific_name	2017	2018	2019	2020	2021*	all	perc
whb	blue whiting	Micromesistius poutassou	79,304	162,542	116,129	175,315	117,315	650,605	53.8%
mac	mackerel	Scomber scombrus	63,654	57,931	55,036	86,419	24,796	287,836	23.8%
hom	horse mackerel	Trachurus trachurus	21,278	30,250	40,822	27,987	21,211	141,549	11.7%
her	herring	Clupea harengus	8,621	11,135	23,540	14,834	4,450	62,580	5.2%
her_ash	herring	Clupea harengus	7,950	5,278	12,249	10,526	0	36,004	3.0%
arg	argentines	Argentina spp	2,596	4,097	4,566	7,036	4,646	22,940	1.9%
boc	boarfish	Capros aper	247	161	351	626	515	1,900	0.2%
pil	pilchard	Sardina pilchardus	818	514	170	232	40	1,773	0.1%
spr	sprat	Sprattus	257	7	32	1,271	0	1,567	0.1%
hke	hake	Merluccius merluccius	107	274	208	182	162	933	0.1%
oth	NA	NA	141	156	224	516	278	1,314	0.1%
(all)	(all)	(all)	184,974	272,344	253,326	324,944	173,412	1,209,000	100.0%

*Table 3.1.5: PFA fisheries for widely distributed species Self-sampling Summary of total catch (tonnes) by species. OTH refers to all other species that are not the main target species, * denotes incomplete year*

Haul positions

An overview of all self-sampled hauls in PFA fisheries for widely distributed species.

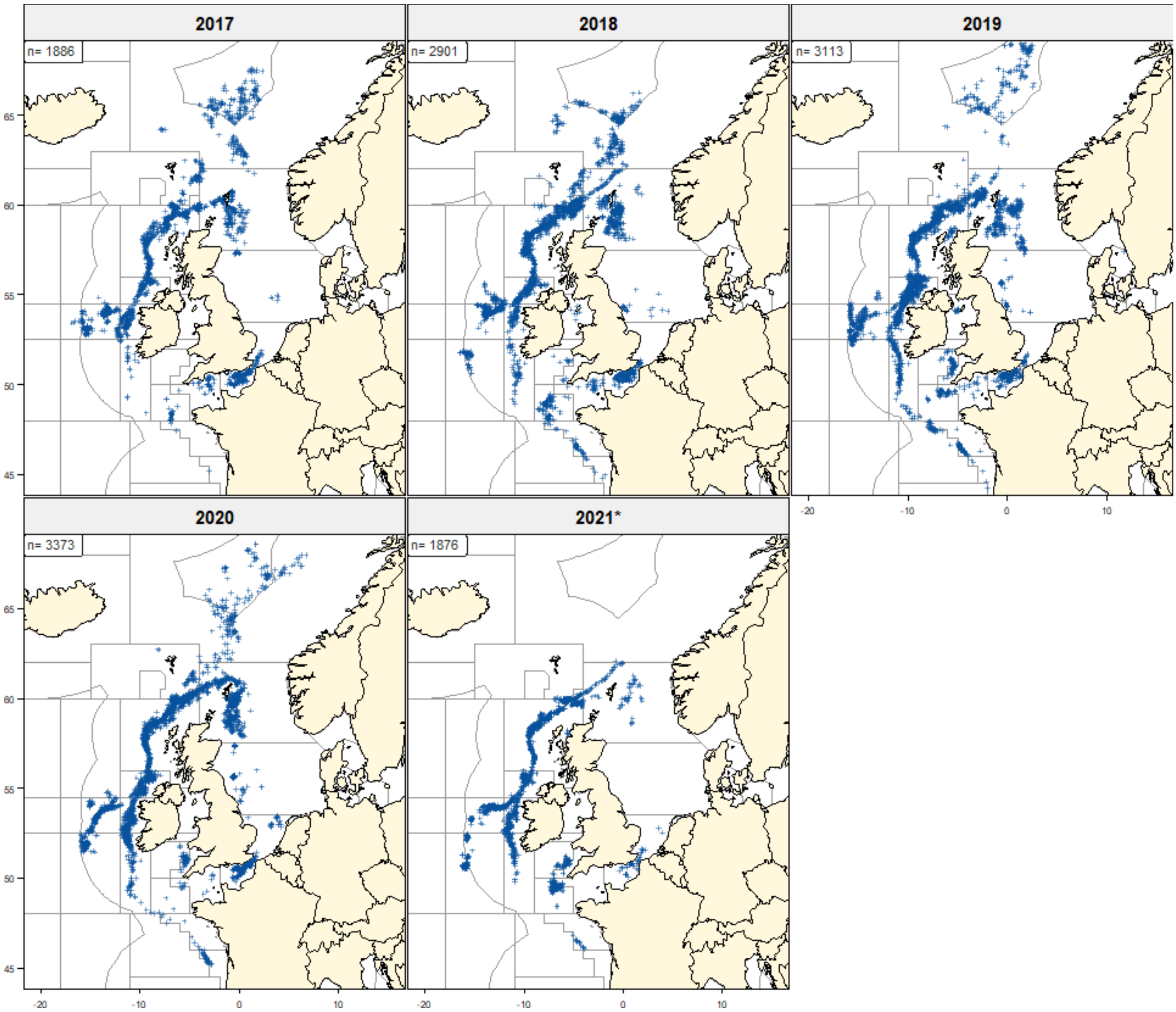

*Figure 3.1.1: PFA fisheries for widely distributed species Self-sampling haul positions. N indicates the number of hauls. * denotes incomplete year*

Catch of the main target species

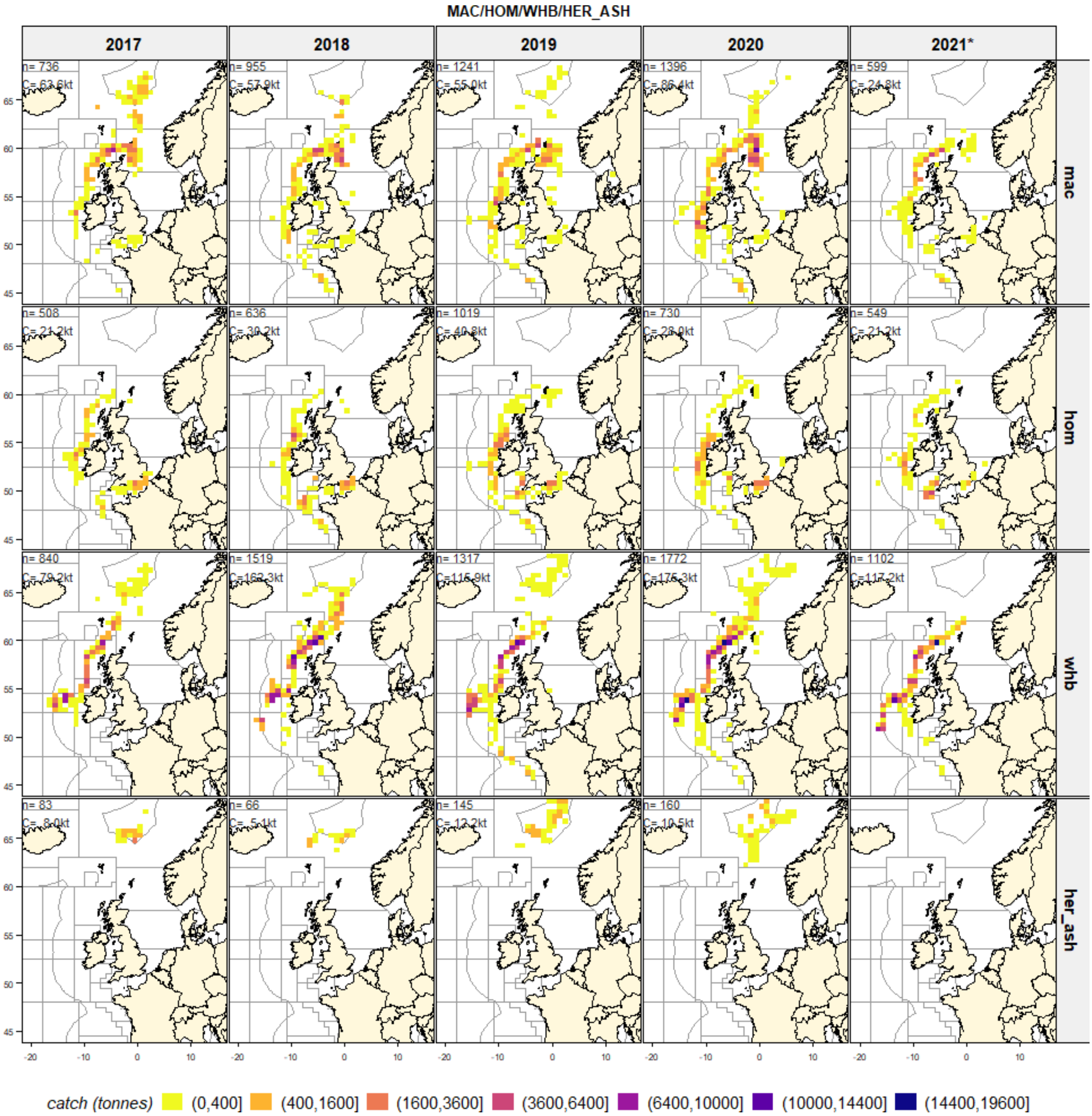

*Figure 3.1.2: PFA fisheries for widely distributed species Self-sampling catch per species and per rectangle. N indicates the number of hauls. Catch refers to the total catch per year. * denotes incomplete year*

Catch rates (catch/day) for the main target species

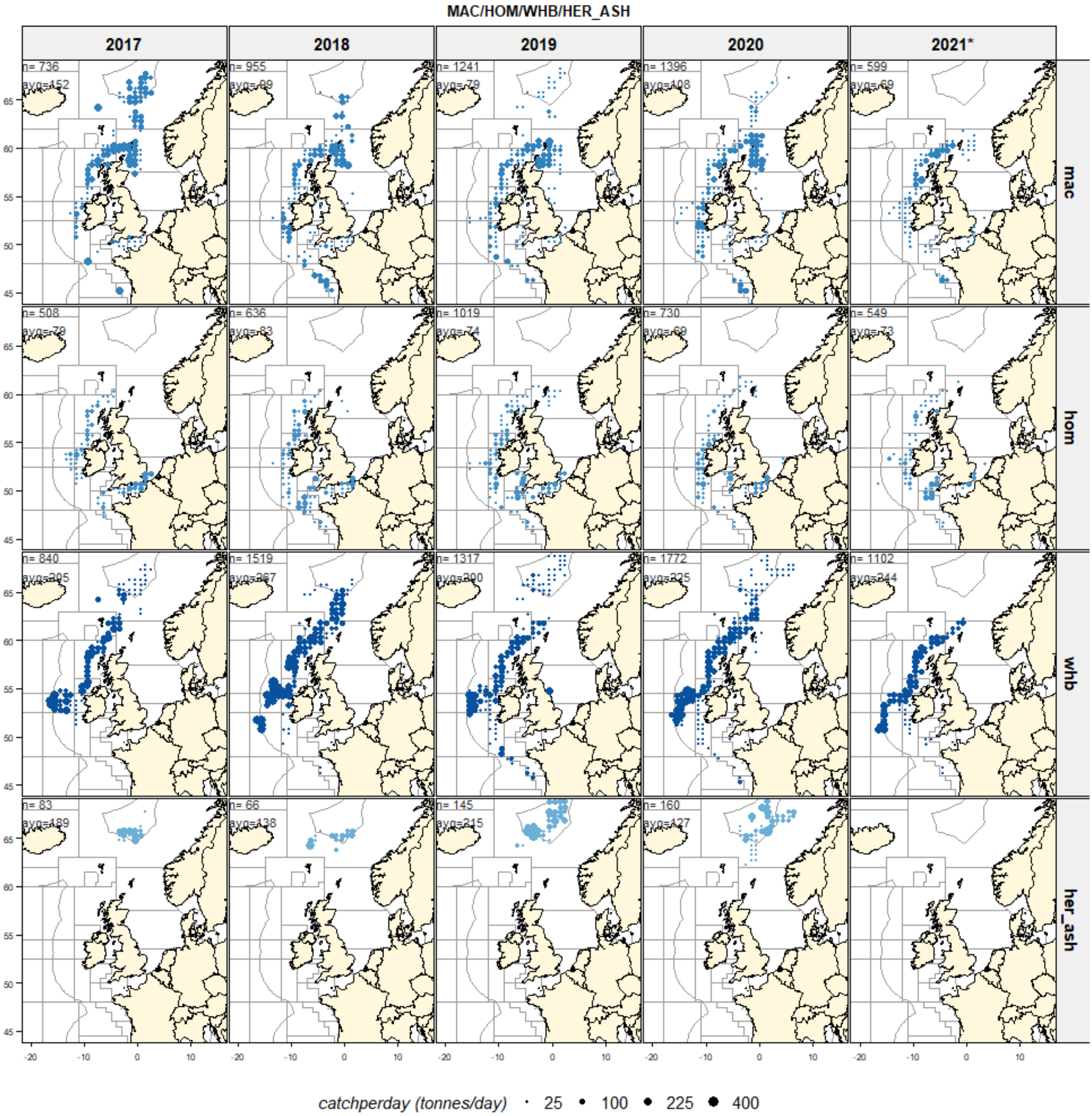

*Figure 3.1.3: PFA fisheries for widely distributed species Average catch per day, per species and per rectangle. N indicates the number of hauls; avg refers to the average catch per day; * denotes incomplete year*

Average fishing depth by rectangle

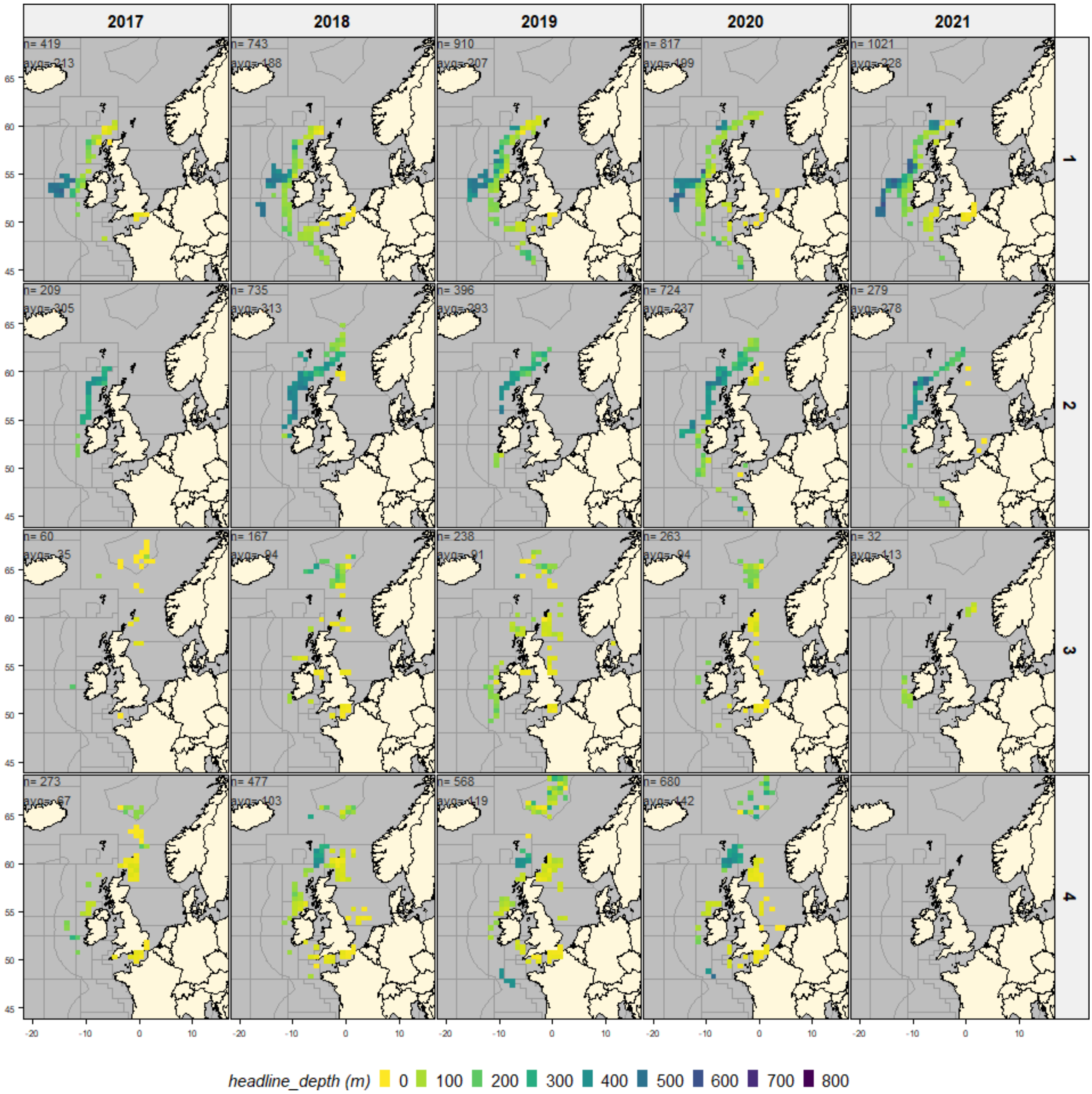

*Figure 3.1.4: PFA fisheries for widely distributed species Average fishing depth (m) by year and quarter. N indicates the number of hauls. Avg refers to the average fishing depth. * denotes incomplete year*

Average temperature at fishing depth by rectangle

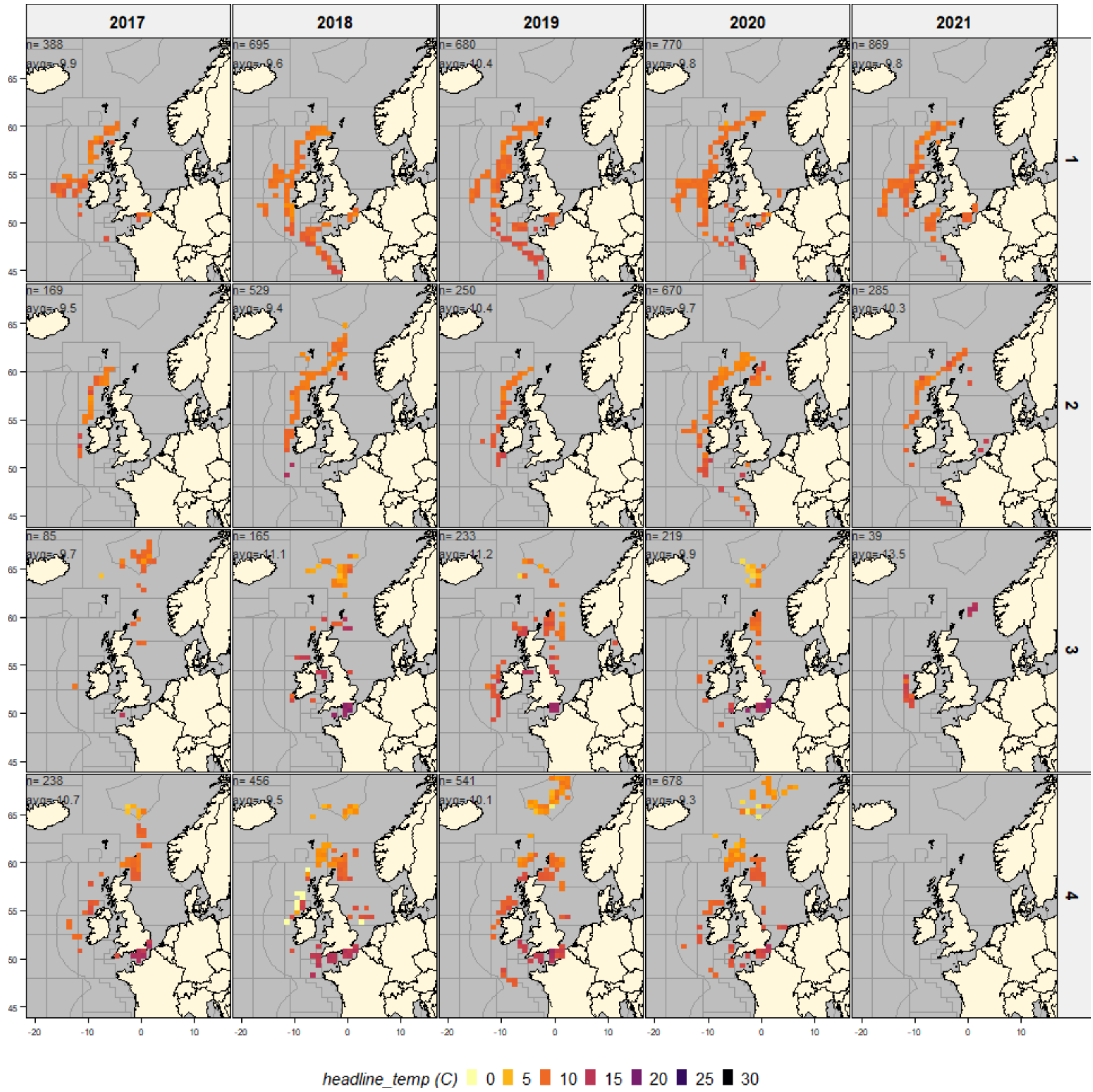

*Figure 3.1.5: PFA fisheries for widely distributed species Average temperature at fishing depth (C) by year and quarter. N indicates the number of hauls. Avg refers to the average temperature. * denotes incomplete year*

Average windspeed by rectangle

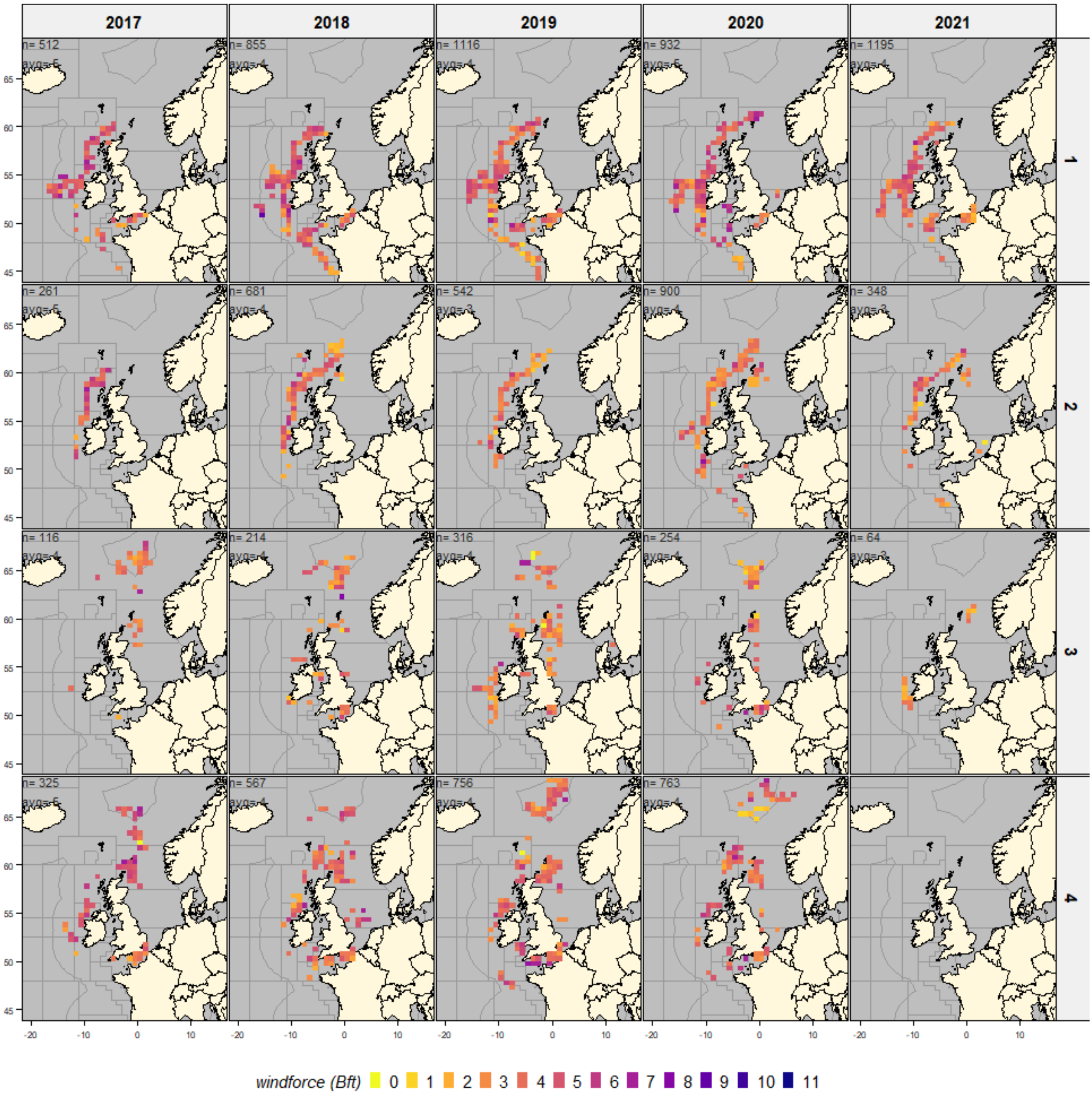

*Figure 3.1.6: PFA fisheries for widely distributed species Average wind speed (Bft) by year and quarter. N indicates the number of hauls. Avg refers to the average wind speed. * denotes incomplete year*

3.2 Mackerel (MAC, Scomber scombrus)

The main Mackerel fishery takes place during months 1, 2, 3, 10, 11. The self-sampling activities for the Mackerel fishery during the years 2017 - 2021 (processed up to 27/07/2021) covered 311 fishing trips with 4440 hauls, a total catch of 279029 tonnes and 85518 individual length measurements. The main fishing areas are 27.2.a, 27.4.a, 27.6.a, 27.7.b, 27.7.j.

species	division	year	nvessels	ntrips	ndays	nhauls	catch	catchperc	nlength	catchperday
mac	27.2.a	2017	6	9	81	164	13,020	21	1,948	161
mac	27.2.a	2018	5	7	39	66	4,805	9	9	123
mac	27.2.a	2019	4	4	26	45	205	0	291	8
mac	27.2.a	2020	6	7	29	34	634	1	290	22
mac	27.4.a	2017	8	17	93	155	17,325	28	4,475	186
mac	27.4.a	2018	13	24	170	296	28,511	52	5,651	168
mac	27.4.a	2019	14	27	182	341	24,300	45	7,016	134
mac	27.4.a	2020	16	46	272	475	50,545	60	24,971	186
mac	27.4.a	2021*	5	6	22	38	796	3	121	36
mac	27.6.a	2017	10	25	156	264	28,288	45	5,443	181
mac	27.6.a	2018	16	31	238	392	18,024	33	7,905	76
mac	27.6.a	2019	15	43	307	517	21,298	40	7,691	69
mac	27.6.a	2020	13	39	264	476	15,847	19	6,062	60
mac	27.6.a	2021*	14	39	200	329	21,783	91	3,608	109
mac	27.7.b	2017	6	9	51	98	3,640	6	276	71
mac	27.7.b	2018	6	9	33	51	1,111	2	14	34
mac	27.7.b	2019	12	22	73	124	5,386	10	1,849	74
mac	27.7.b	2020	12	22	85	140	6,044	7	2,913	71
mac	27.7.b	2021*	12	17	61	109	776	3	188	13
mac	27.7.j	2017	3	4	6	11	496	1	170	83
mac	27.7.j	2018	8	11	26	38	2,662	5	314	102
mac	27.7.j	2019	8	11	47	89	2,345	4	1,514	50
mac	27.7.j	2020	12	24	77	134	10,734	13	2,495	139
mac	27.7.j	2021*	8	15	40	54	457	2	302	11
mac	(all)	2017		64	387	692	62,769	101	12,312	162
mac	(all)	2018		82	506	843	55,113	101	13,893	109
mac	(all)	2019		107	635	1,116	53,534	99	18,361	84
mac	(all)	2020		138	727	1,259	83,804	100	36,731	115
mac	(all)	2021*		77	323	530	23,812	99	4,219	74
mac	(all)	(all)		468	2,578	4,440	279,032		85,516	108

*Table 3.2.1: Mackerel. Self-sampling summary with the number of days, hauls, trips, vessels, catch (tonnes), number of fish measured, catch rates (ton/effort). * denotes incomplete year*

Mackerel (MAC). Catch by month

species	month	2017	2018	2019	2020	2021*	all	perc
mac	Jan	18,594	11,592	18,766	20,750	14,862	84,564	29.382%
mac	Feb	8,198	7,613	11,872	19,408	5,706	52,797	18.344%
mac	Mar	4,724	3,307	5,507	7,115	2,782	23,435	8.142%
mac	Apr	1,025	1,225	1,325	797	1,114	5,486	1.906%
mac	May	296	191	488	1,239	94	2,308	0.802%
mac	Jun	0	60	96	175	41	372	0.129%
mac	Jul	88	0	306	83	194	671	0.233%
mac	Aug	247	59	431	242	0	979	0.340%
mac	Sep	9,388	4,822	3,063	6,365	0	23,638	8.213%
mac	Oct	7,972	19,465	11,559	20,400	0	59,396	20.637%
mac	Nov	11,653	9,229	1,618	9,490	0	31,990	11.115%
mac	Dec	1,463	362	0	350	0	2,175	0.756%
mac	(all)	63,648	57,925	55,031	86,414	24,793	287,811	100.000%

*Table 3.2.2: Mackerel. Self-sampling summary with the catch (tonnes) by year and month. * denotes incomplete year*

Mackerel (MAC). Catch by rectangle

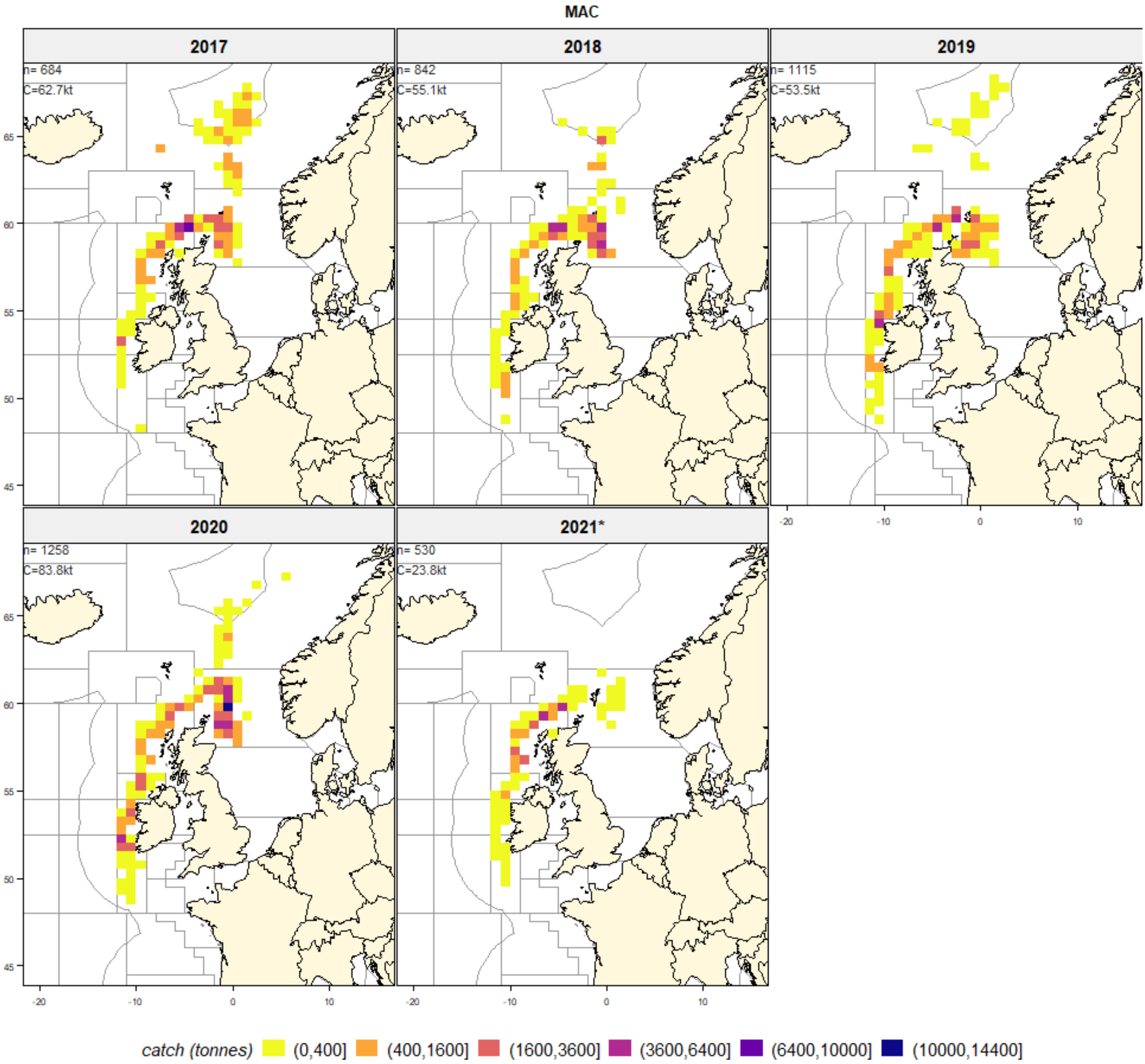

*Figure 3.2.1: Mackerel. Catch per rectangle. N indicates the number of hauls; Catch refers to the total catch per year. * denotes incomplete year*

Mackerel (MAC). Average catch per day

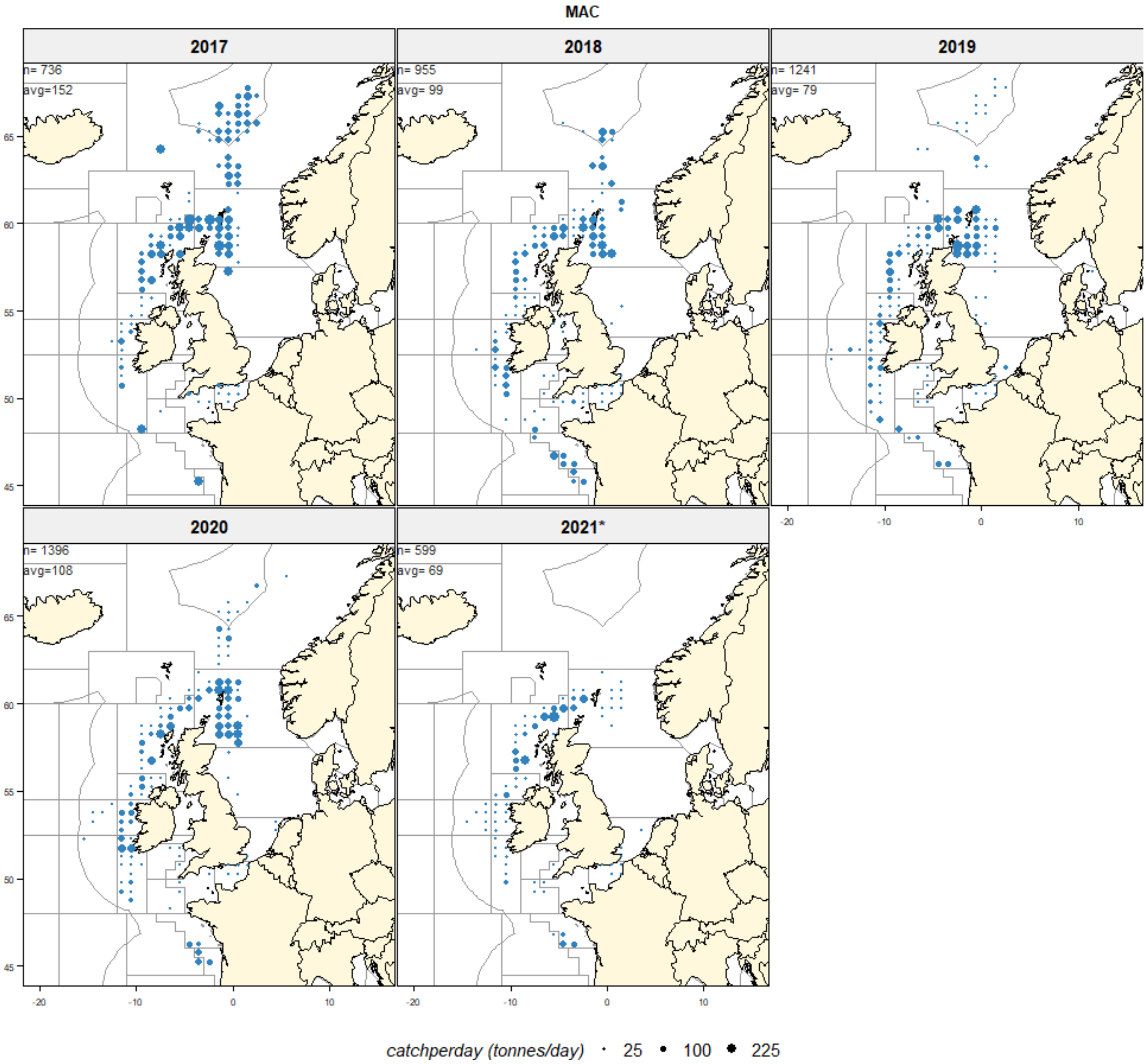

*Figure 3.2.2: Mackerel. Average catch per day per rectangle. N indicates the number of hauls; avg refers to the overall average catch per day. * denotes incomplete year*

Mackerel (MAC). Spatial-temporal evolution of the fishery

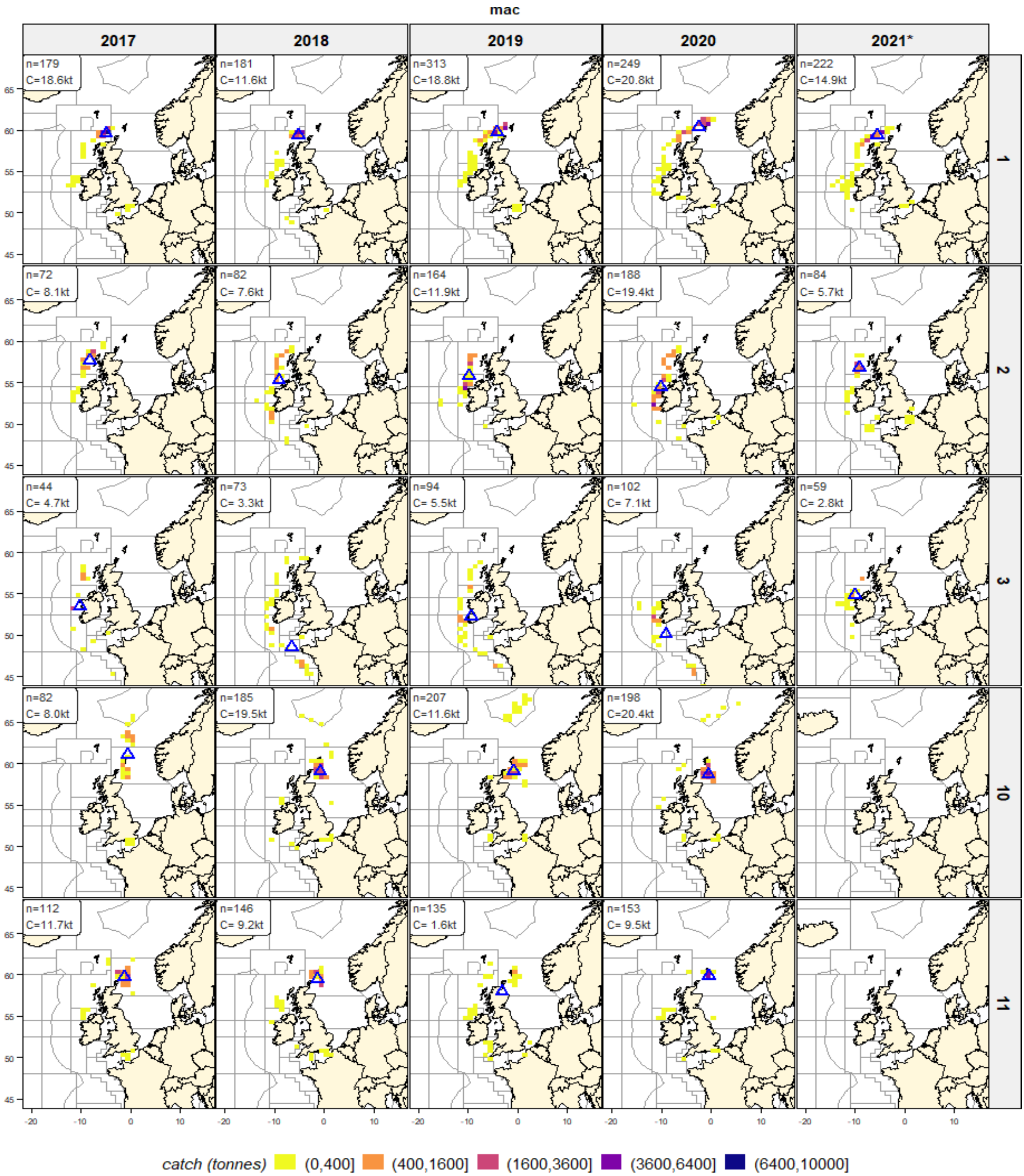

*Figure 3.2.3: Mackerel. Catch per rectangle and per month. N indicates the number of hauls; C refers to the overall catch. The midpoint of the distribution is indicated by the blue triangle. * denotes incomplete year*

Mackerel (MAC). Length distributions of the catch

Median length of Mackerel in the catch in 2021 is 36.4 cm compared to median lengths between 33.6 and 36.3 cm in the preceding years. Note that the data for 2021 is only up to 27/07/2021.

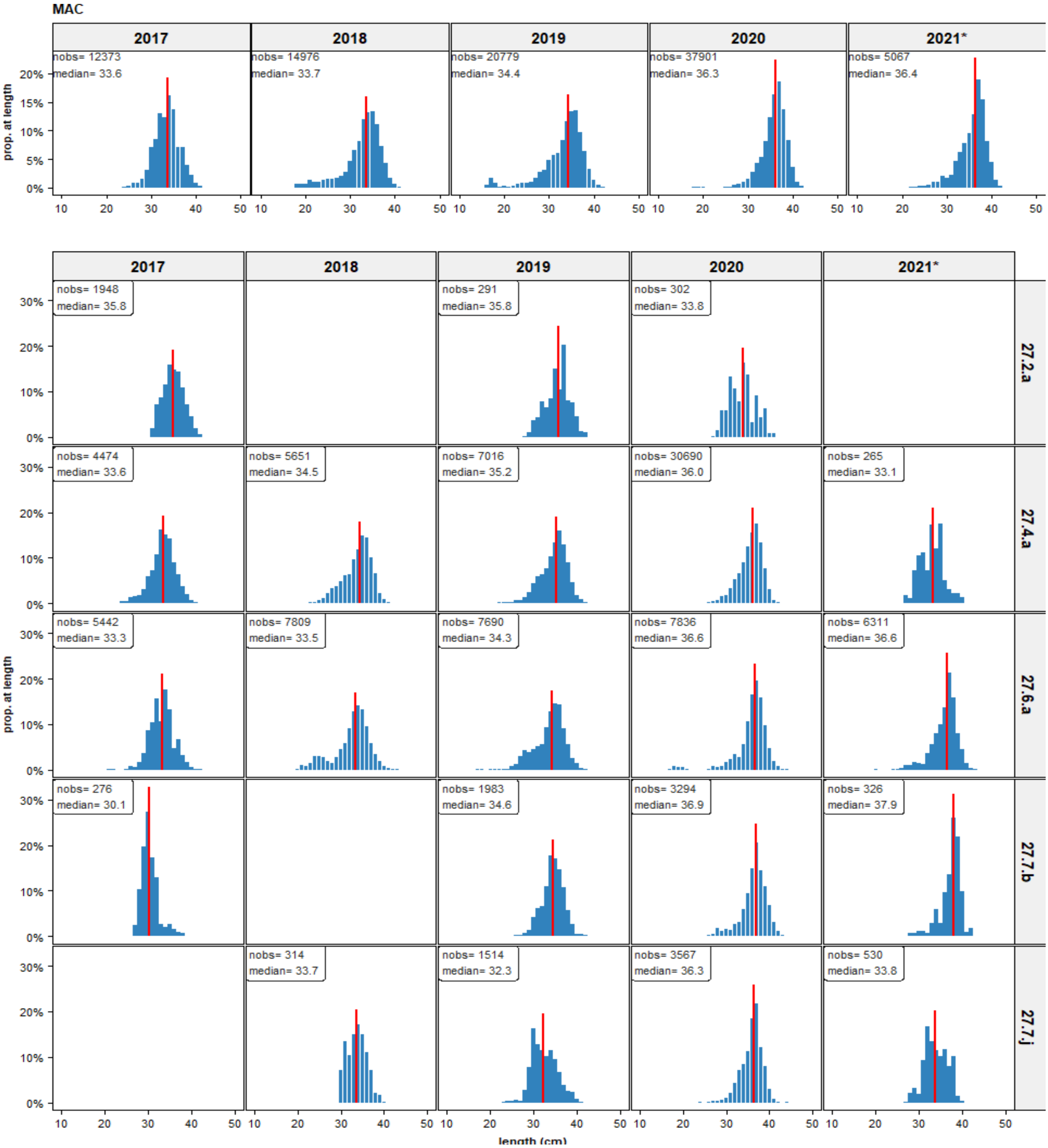

*Figure 3.2.4: Mackerel. Length distributions by year (top) and by year and division (bottom). Nobs refers to the number of observations; median denotes the median length. * denotes incomplete year*

Mackerel (MAC). Weight distributions by year

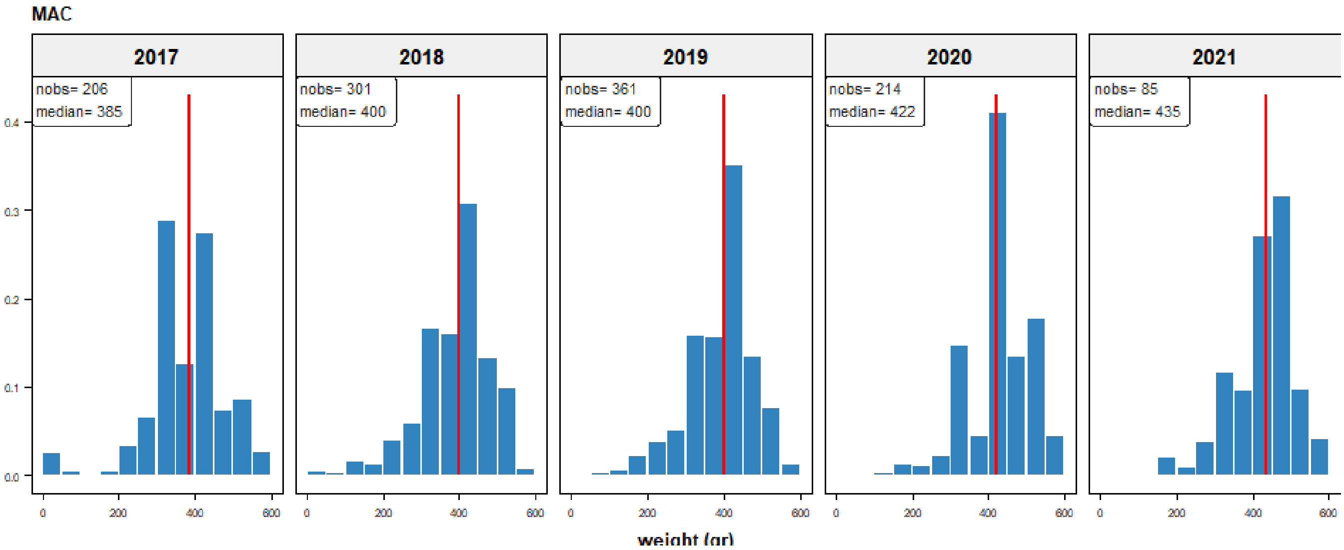

*Figure 3.2.5: Mackerel. Weight distributions (50-gram classes). Nobs refers to the number of batches where average weight was measured; median denotes the median length; * denotes incomplete year*

Mackerel (MAC). Fat percentages by week and year

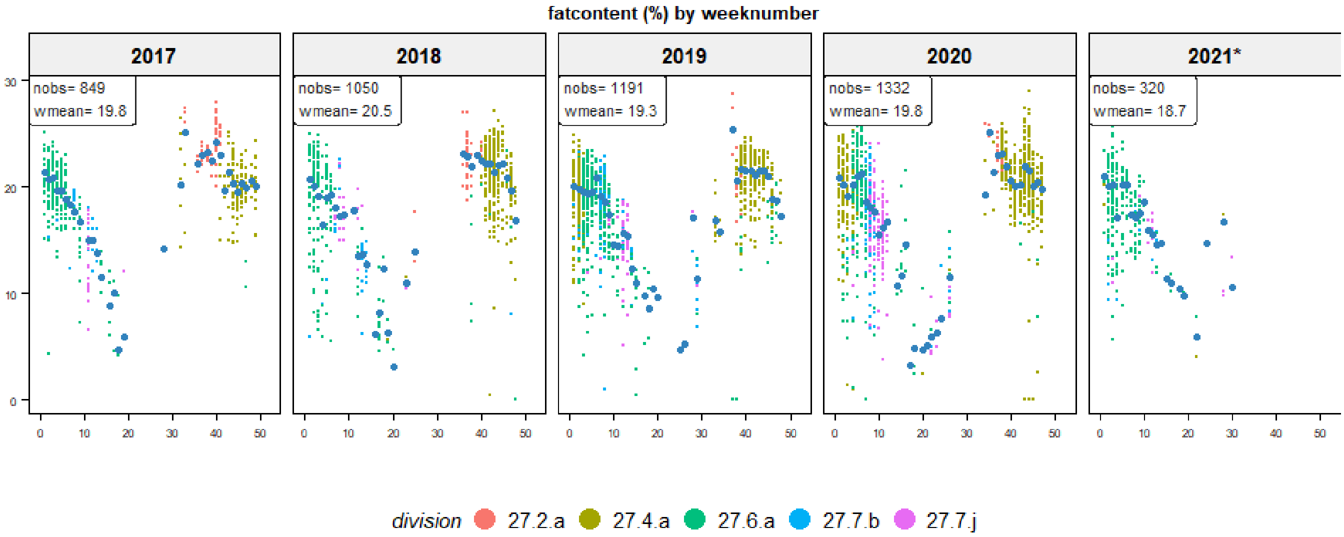

*Figure 3.2.6: Mackerel. Average fat percentage by week. Nobs refers to the number of batches where average fat was measured; black dots indicate the weekly averages; * denotes incomplete year*

Mackerel (MAC). Fishing depth distributions by year.

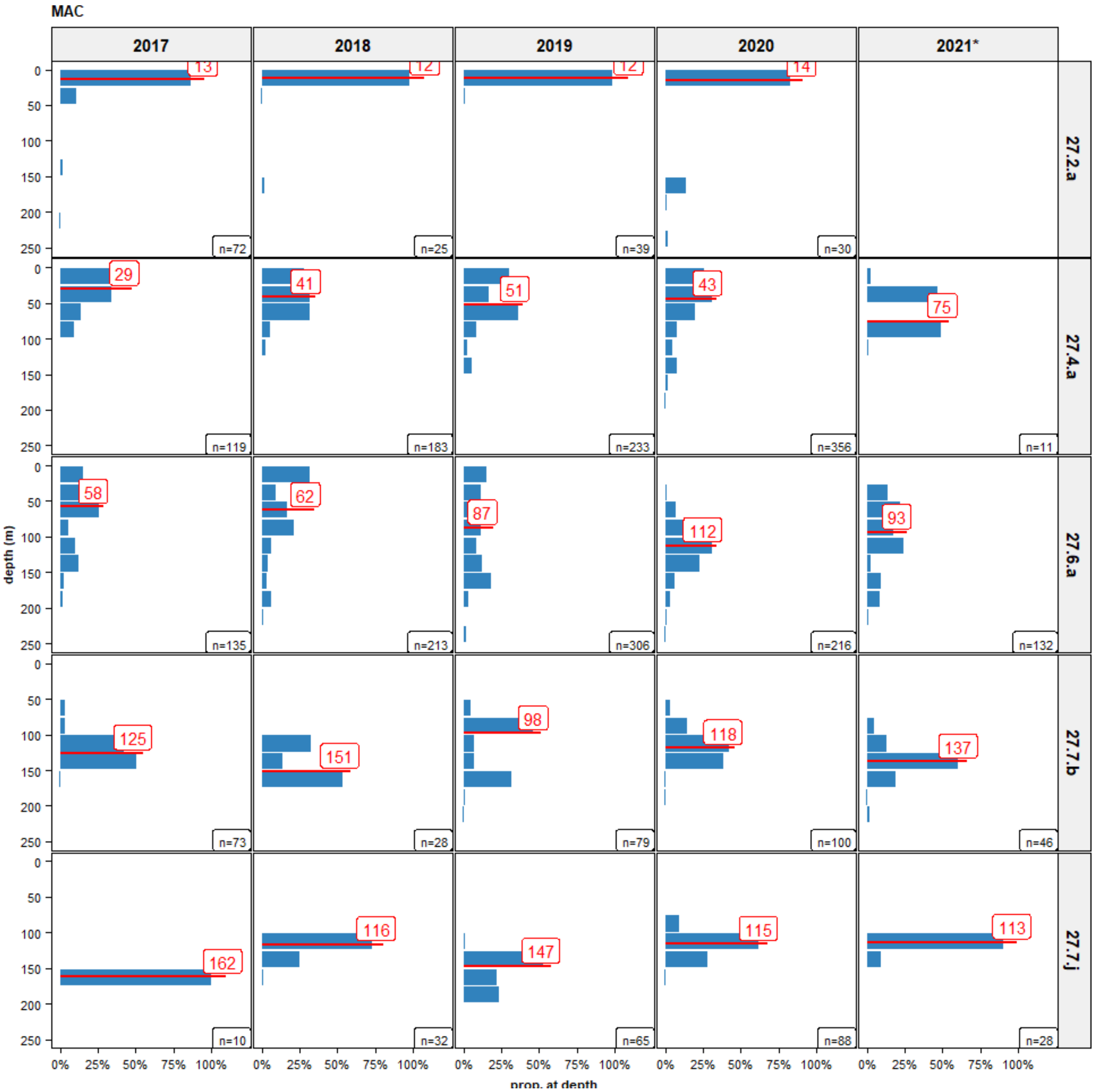

*Figure 3.2.7: Mackerel. Depth distributions by year and division. N is number of observations; median depth in red; * denotes incomplete year*

3.3 Horse mackerel (HOM, Trachurus trachurus)

The main Horse mackerel fishery takes place during months 1, 2, 3, 10, 11. The self-sampling activities for the Horse mackerel fishery during the years 2017 - 2021 (processed up to 27/07/2021) covered 221 fishing trips with 2844 hauls, a total catch of 115986 tonnes and 112735 individual length measurements. The main fishing areas are 27.6.a, 27.7.b, 27.7.d, 27.7.h, 27.7.j.

species	division	year	nvessels	ntrips	ndays	nhauls	catch	catchperc	nlength	catchperday
hom	27.6.a	2017	8	13	82	159	5,343	28	5,213	65
hom	27.6.a	2018	13	23	125	235	12,053	44	12,015	96
hom	27.6.a	2019	14	30	212	384	13,849	45	7,443	65
hom	27.6.a	2020	8	21	95	168	5,908	24	9,462	62
hom	27.6.a	2021*	10	15	58	80	1,564	11	1,600	27
hom	27.7.b	2017	6	12	57	104	4,741	25	3,459	83
hom	27.7.b	2018	9	11	39	60	2,250	8	1,663	58
hom	27.7.b	2019	12	24	78	129	4,176	13	2,678	54
hom	27.7.b	2020	12	23	84	147	5,226	21	5,478	62
hom	27.7.b	2021*	12	15	67	125	3,432	25	2,698	51
hom	27.7.d	2017	6	15	75	139	7,202	38	1,013	96
hom	27.7.d	2018	5	13	73	138	6,234	23	3,898	85
hom	27.7.d	2019	8	14	76	141	7,102	23	9,123	93
hom	27.7.d	2020	8	23	99	152	8,200	33	13,474	83
hom	27.7.d	2021*	3	3	8	14	688	5	143	86
hom	27.7.h	2017	2	5	18	30	1,329	7	0	74
hom	27.7.h	2018	9	13	50	89	6,282	23	7,804	126
hom	27.7.h	2019	6	6	13	21	984	3	2,663	76
hom	27.7.h	2020	2	2	2	2	55	0	0	28
hom	27.7.h	2021*	9	11	50	95	5,904	42	13,140	118
hom	27.7.j	2017	3	5	7	13	160	1	463	23
hom	27.7.j	2018	7	10	30	45	813	3	519	27
hom	27.7.j	2019	10	14	58	110	5,002	16	1,520	86
hom	27.7.j	2020	12	27	92	172	5,138	21	4,589	56
hom	27.7.j	2021*	11	20	63	92	2,352	17	2,674	37
hom	(all)	2017		50	239	445	18,775	99	10,148	79
hom	(all)	2018		70	317	567	27,632	101	25,899	87
hom	(all)	2019		88	437	785	31,113	100	23,427	71
hom	(all)	2020		96	372	641	24,527	99	33,003	66
hom	(all)	2021*		64	246	406	13,940	100	20,255	57
hom	(all)	(all)		368	1,611	2,844	115,987		112,732	72

*Table 3.3.1: Horse mackerel. Self-sampling summary with the number of days, hauls, trips, vessels, catch (tonnes), number of fish measured, catch rates (ton/effort). * denotes incomplete year*

Horse mackerel (HOM). Catch by month

species	month	2017	2018	2019	2020	2021*	all	perc
hom	Jan	9,613	11,518	11,547	7,178	6,285	46,141	32.603%
hom	Feb	3,124	5,961	5,304	4,799	12,679	31,867	22.517%
hom	Mar	227	3,581	4,083	1,263	584	9,738	6.881%
hom	Apr	0	31	45	0	48	124	0.088%
hom	May	155	6	41	529	2	733	0.518%
hom	Jun	0	226	1,357	649	25	2,257	1.595%
hom	Jul	186	15	5,467	419	1,586	7,673	5.422%
hom	Aug	58	0	8	0	0	66	0.047%
hom	Sep	134	1,910	2,343	3,911	0	8,298	5.863%
hom	Oct	4,620	1,954	3,555	4,062	0	14,191	10.027%
hom	Nov	3,027	3,925	6,076	3,228	0	16,256	11.486%
hom	Dec	129	1,117	990	1,943	0	4,179	2.953%
hom	(all)	21,273	30,244	40,816	27,981	21,209	141,523	100.000%

*Table 3.3.2: Horse mackerel. Self-sampling summary with the catch (tonnes) by year and month. * denotes incomplete year*

Horse mackerel (HOM). Catch by rectangle

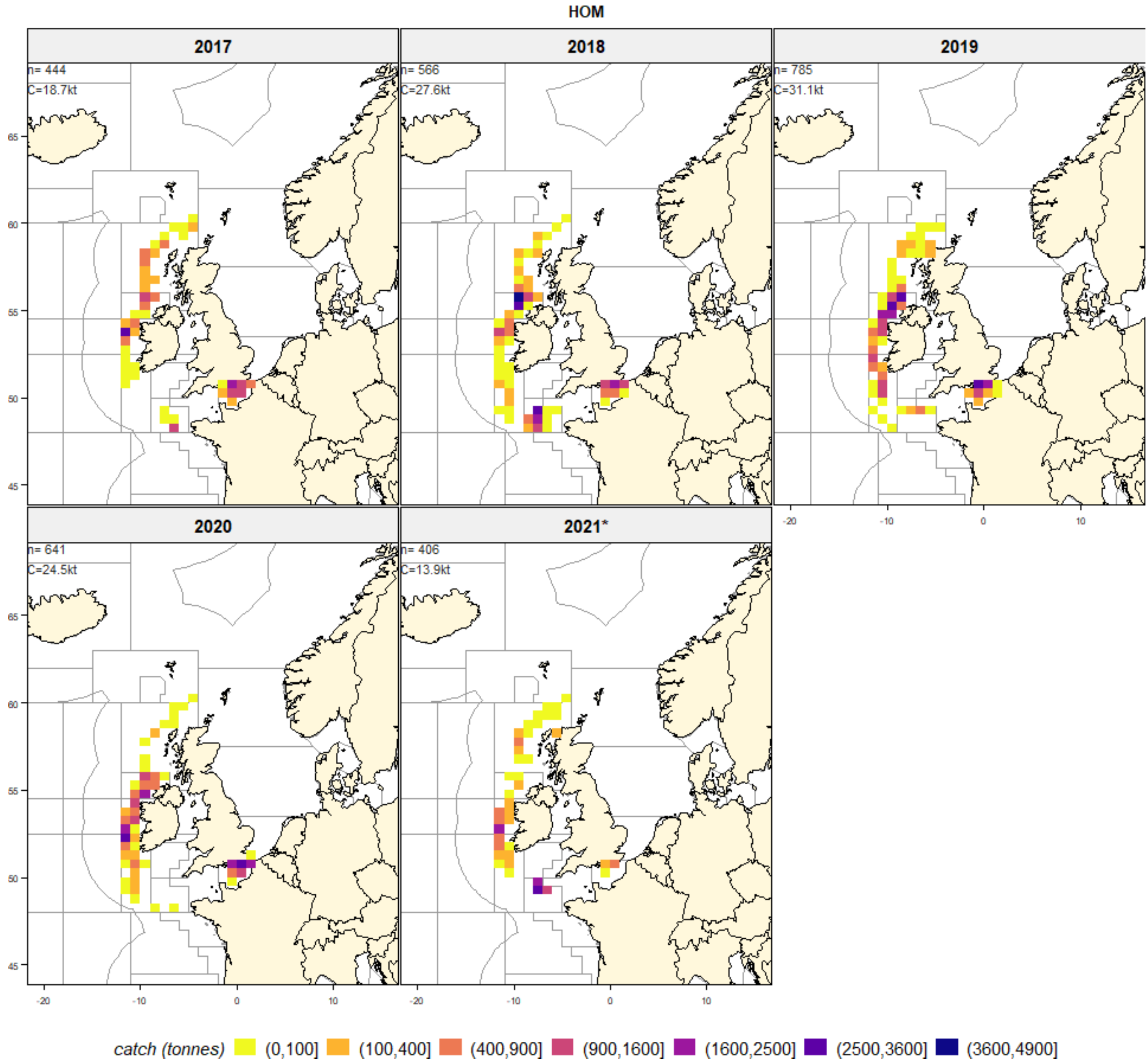

*Figure 3.3.1: Horse mackerel. Catch per rectangle. N indicates the number of hauls; Catch refers to the total catch per year. * denotes incomplete year*

Horse mackerel (HOM). Average catch per day

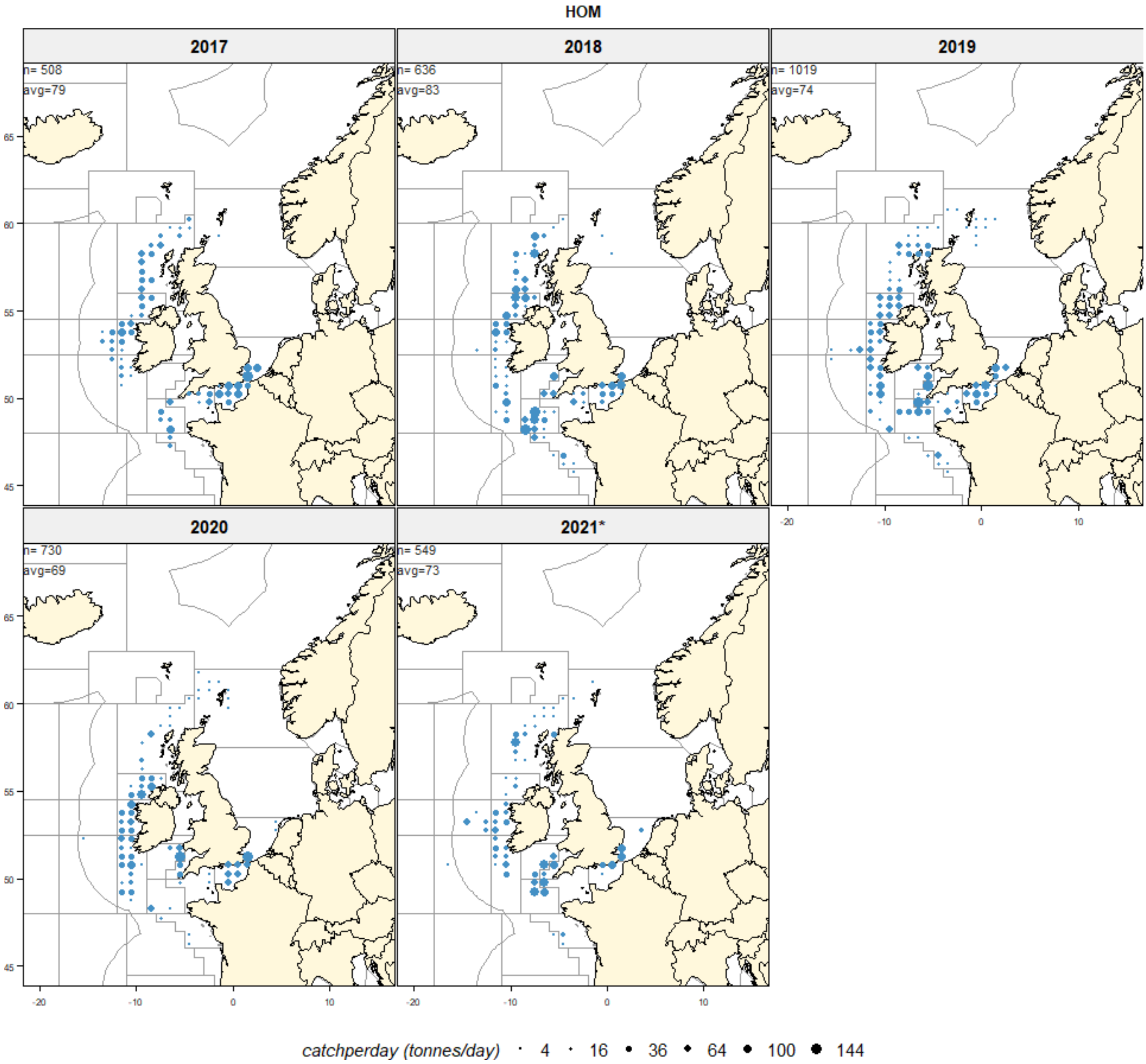

*Figure 3.3.2: Horse mackerel. Average catch per day per rectangle. N indicates the number of hauls; avg refers to the overall average catch per day. * denotes incomplete year*

Horse mackerel (HOM). Spatial-temporal evolution of the fishery

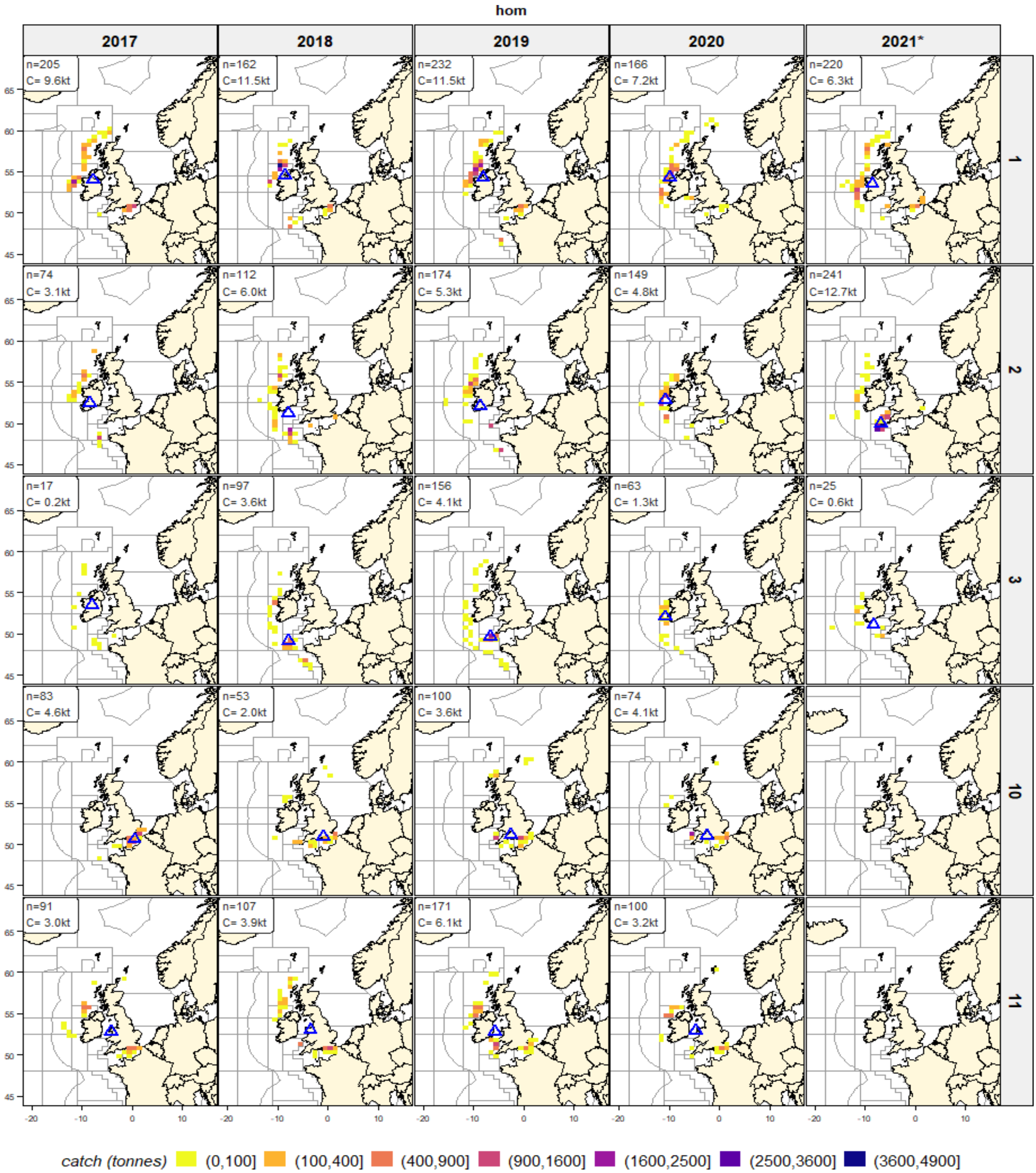

*Figure 3.3.3: Horse mackerel. Catch per rectangle and per month. N indicates the number of hauls; C refers to the overall catch. The midpoint of the distribution is indicated by the blue triangle. * denotes incomplete year*

Horse mackerel (HOM). Length distributions of the catch

Median length of Horse mackerel in the catch in 2021 is 22.0 cm compared to median lengths between 22.8 and 30.0 cm in the preceding years.

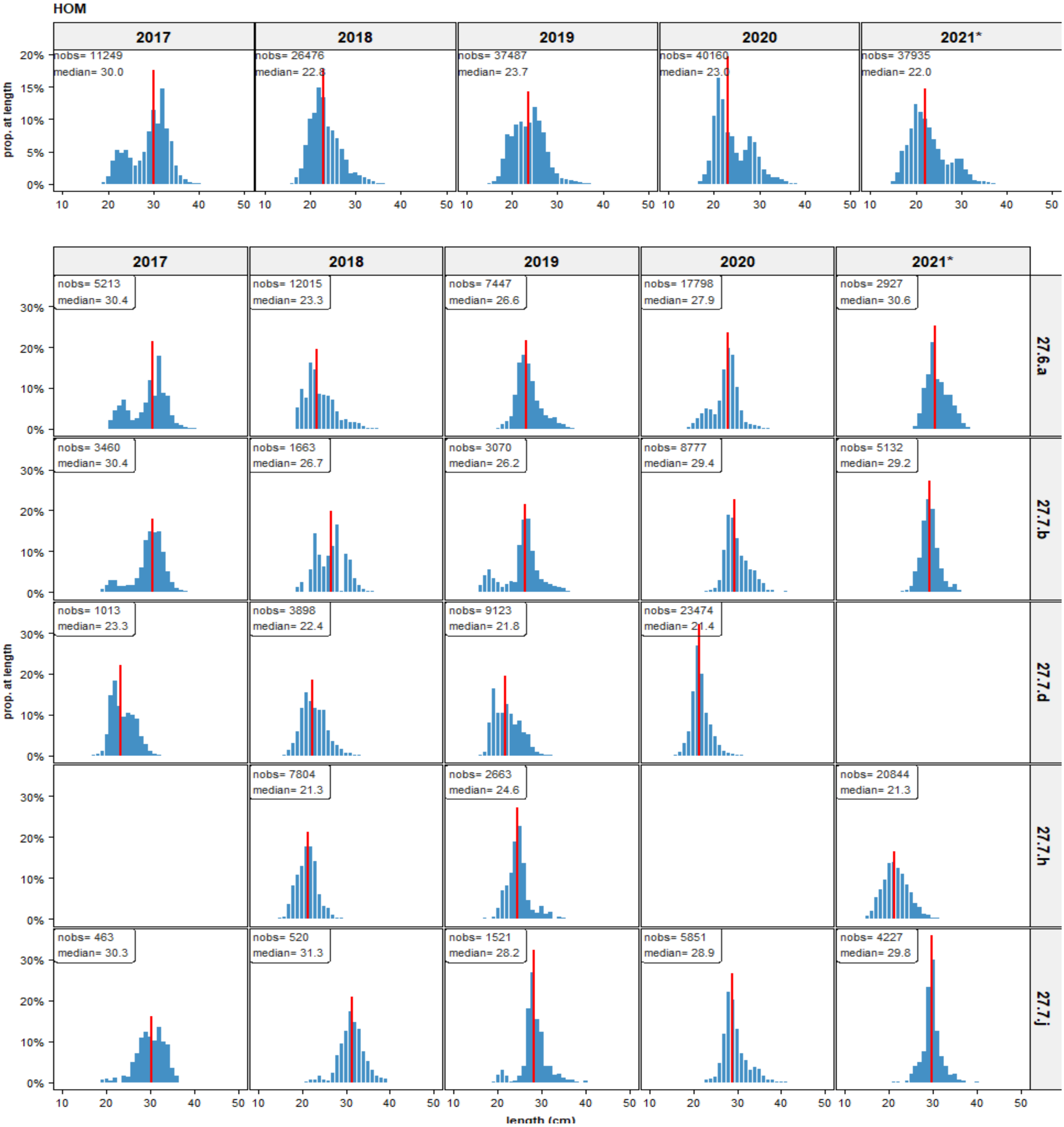

*Figure 3.3.4: Horse mackerel. Length distributions by year (top) and by year and division (bottom). Nobs refers to the number of observations; median denotes the median length. * denotes incomplete year*

Horse mackerel (HOM). Weight distributions by year

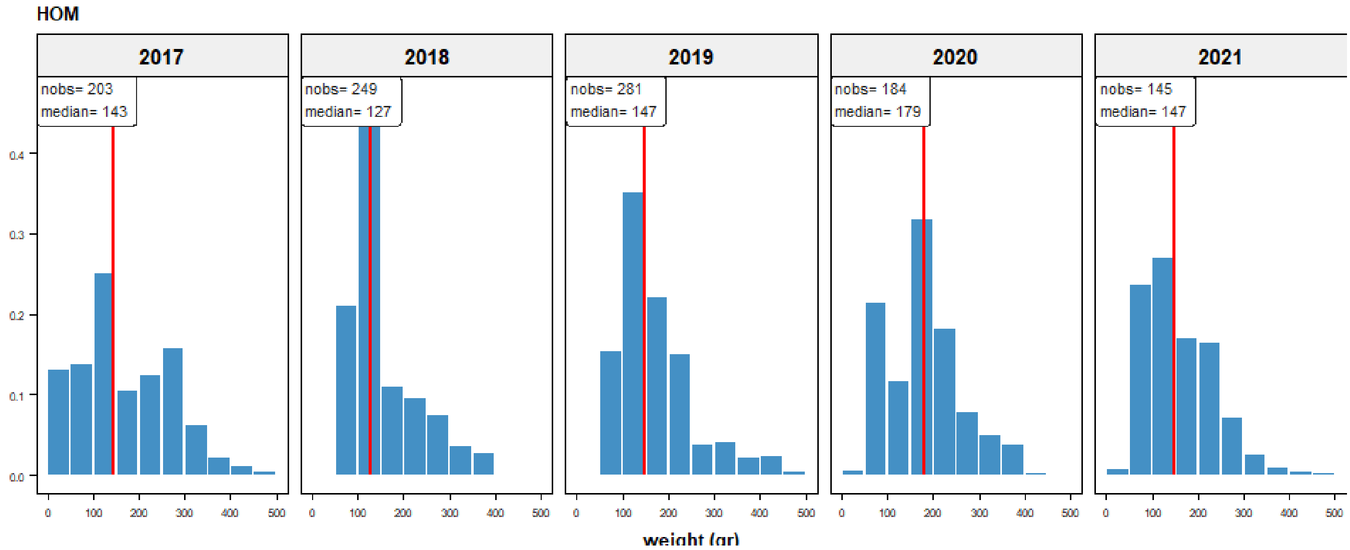

*Figure 3.3.5: Horse mackerel. Weight distributions (50-gram classes). Nobs refers to the number of batches where average weight was measured; median denotes the median length; * denotes incomplete year*

Horse mackerel (HOM). Fat percentages by week and year

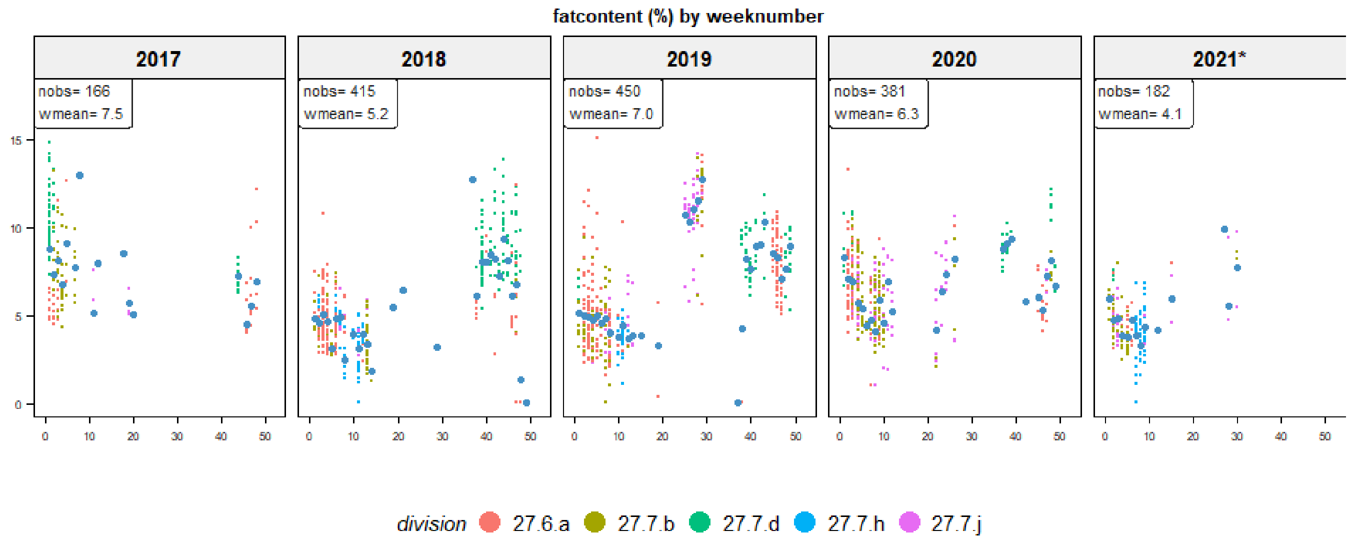

*Figure 3.3.6: Horse mackerel. Average fat percentage by week. Nobs refers to the number of batches where average fat was measured; black dots indicate the weekly averages; * denotes incomplete year*

Horse mackerel (HOM). Fishing depth distributions by year.

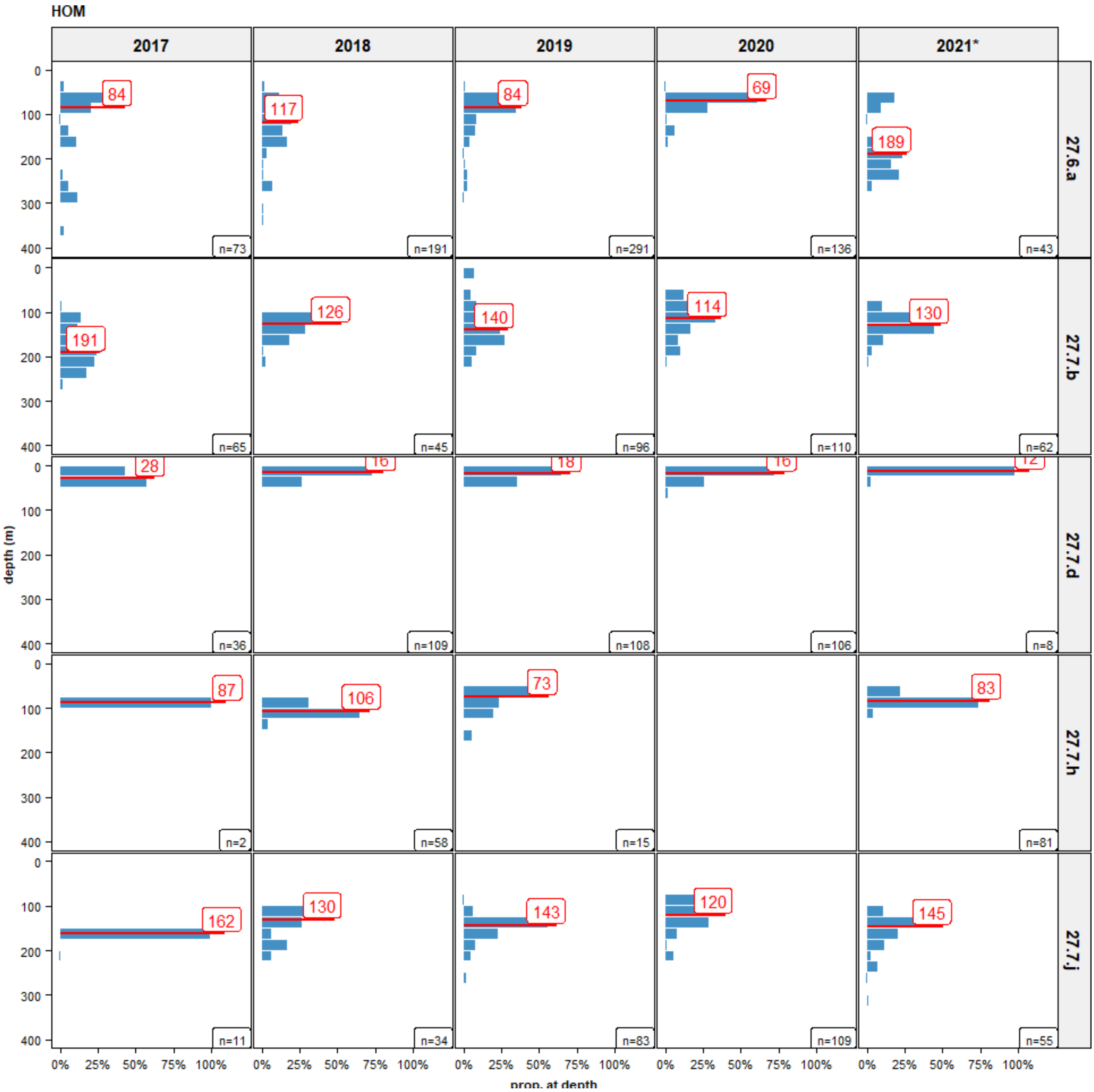

*Figure 3.3.7: Horse mackerel. Depth distributions by year and division. N is number of observations; median depth in red; * denotes incomplete year*

3.4 Blue whiting (WHB, Micromesistius poutassou)

The main Blue whiting fishery takes place during months 2, 3, 4, 5. The self-sampling activities for the Blue whiting fishery during the years 2017 - 2021 (processed up to 27/07/2021) covered 215 fishing trips with 5892 hauls, a total catch of 615193 tonnes and 463807 individual length measurements. The main fishing areas are 27.6.a, 27.7.c, 27.7.k, 27.5.b, 27.2.a.

species	division	year	nvessels	ntrips	ndays	nhauls	catch	catchperc	nlength	catchperday
whb	27.6.a	2017	7	16	163	378	39,085	50	36,456	240
whb	27.6.a	2018	12	29	340	860	91,738	61	74,164	270
whb	27.6.a	2019	14	35	310	724	75,707	69	37,899	244
whb	27.6.a	2020	13	42	388	949	97,232	58	74,590	251
whb	27.6.a	2021*	12	29	244	564	61,508	56	50,344	252
whb	27.7.c	2017	6	10	97	231	28,731	37	16,945	296
whb	27.7.c	2018	6	9	77	235	30,504	20	21,392	396
whb	27.7.c	2019	10	16	99	246	26,587	24	14,222	269
whb	27.7.c	2020	10	16	128	326	44,309	26	42,574	346
whb	27.7.c	2021*	9	15	102	235	27,074	25	15,081	265
whb	27.7.k	2018	3	3	20	59	7,646	5	3,077	382
whb	27.7.k	2019	4	4	11	17	2,036	2	401	185
whb	27.7.k	2020	5	6	36	93	11,307	7	10,757	314
whb	27.7.k	2021*	4	5	55	150	19,293	18	14,395	351
whb	27.5.b	2017	5	6	40	64	7,960	10	8,226	199
whb	27.5.b	2018	5	7	52	82	7,928	5	5,204	152
whb	27.5.b	2019	4	8	26	34	3,905	4	2,331	150
whb	27.5.b	2020	4	10	56	87	10,220	6	5,854	182
whb	27.5.b	2021*	4	4	10	11	1,440	1	910	144
whb	27.2.a	2017	5	9	56	92	2,587	3	2,597	46
whb	27.2.a	2018	6	8	90	158	12,032	8	12,352	134
whb	27.2.a	2019	4	7	61	130	1,417	1	1,640	23
whb	27.2.a	2020	7	9	103	166	4,902	3	12,185	48
whb	27.2.a	2021*	1	1	1	1	44	0	208	44
whb	(all)	2017		41	356	765	78,363	100	64,224	220
whb	(all)	2018		56	579	1,394	149,848	99	116,189	259
whb	(all)	2019		70	507	1,151	109,652	100	56,493	216
whb	(all)	2020		83	711	1,621	167,970	100	145,960	236
whb	(all)	2021*		54	412	961	109,359	100	80,938	265
whb	(all)	(all)		304	2,565	5,892	615,192		463,804	240

*Table 3.4.1: Blue whiting. Self-sampling summary with the number of days, hauls, trips, vessels, catch (tonnes), number of fish measured, catch rates (ton/effort). * denotes incomplete year*

Blue whiting (WHB). Catch by month

species	month	2017	2018	2019	2020	2021*	all	perc
whb	Jan	211	956	4,286	9,526	26,974	41,953	6.45%
whb	Feb	8,026	19,108	17,700	4,050	19,223	68,107	10.47%
whb	Mar	24,864	35,934	23,289	42,640	33,431	160,158	24.62%
whb	Apr	27,316	56,296	26,391	62,049	26,698	198,750	30.55%
whb	May	9,395	26,731	17,280	24,321	10,449	88,176	13.55%
whb	Jun	0	5,094	13	878	337	6,322	0.97%
whb	Jul	0	0	129	61	199	389	0.06%
whb	Aug	1,265	4,218	337	1,388	0	7,208	1.11%
whb	Sep	537	413	463	1,035	0	2,448	0.38%
whb	Oct	76	217	2,406	2,497	0	5,196	0.80%
whb	Nov	5,934	6,618	14,197	11,018	0	37,767	5.81%
whb	Dec	1,674	6,951	9,631	15,845	0	34,101	5.24%
whb	(all)	79,298	162,536	116,122	175,308	117,311	650,575	100.00%

*Table 3.4.2: Blue whiting. Self-sampling summary with the catch (tonnes) by year and month. * denotes incomplete year*

Blue whiting (WHB). Catch by rectangle

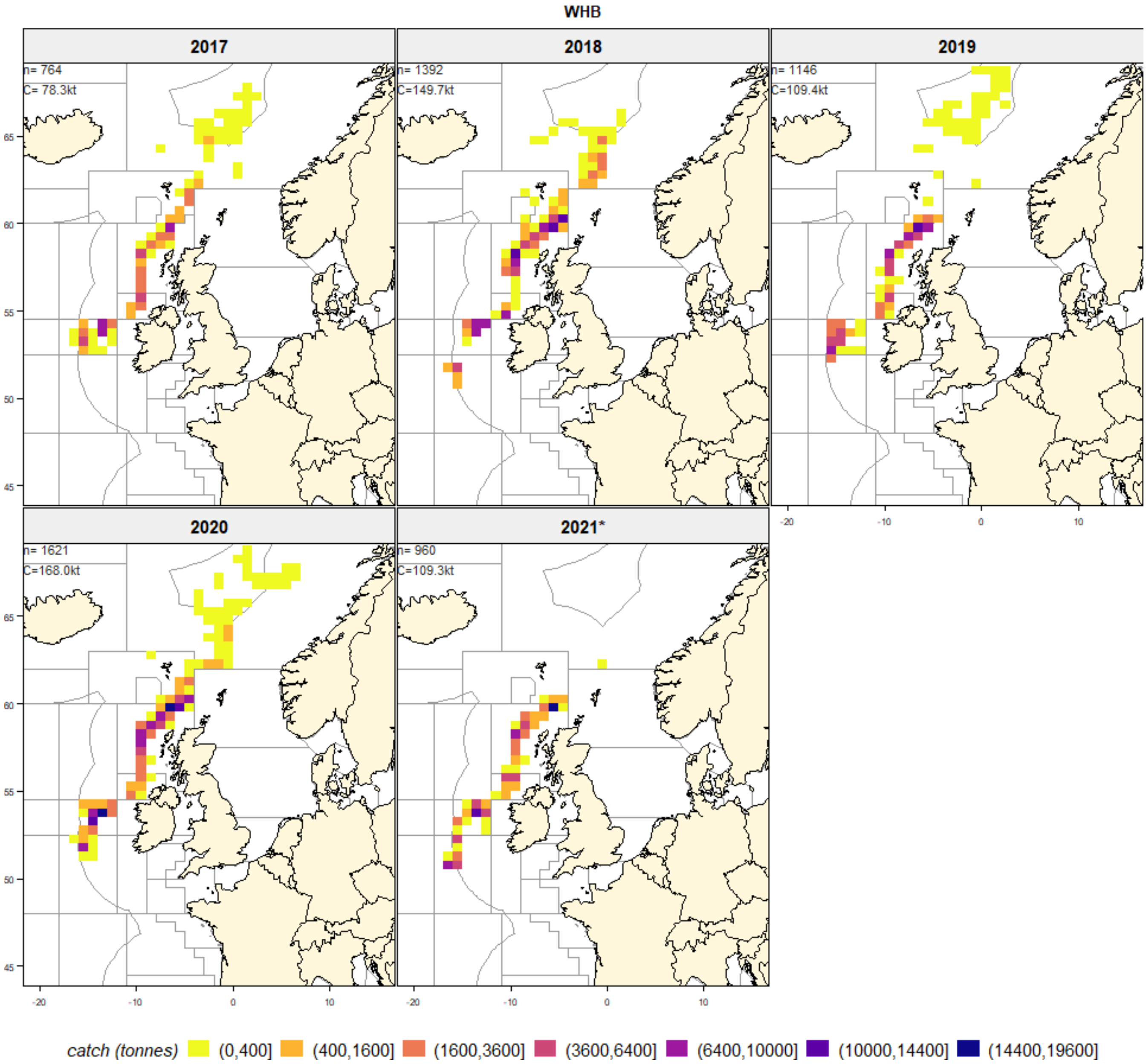

*Figure 3.4.1: Blue whiting. Catch per rectangle. N indicates the number of hauls; Catch refers to the total catch per year. * denotes incomplete year*

Blue whiting (WHB). Average catch per day

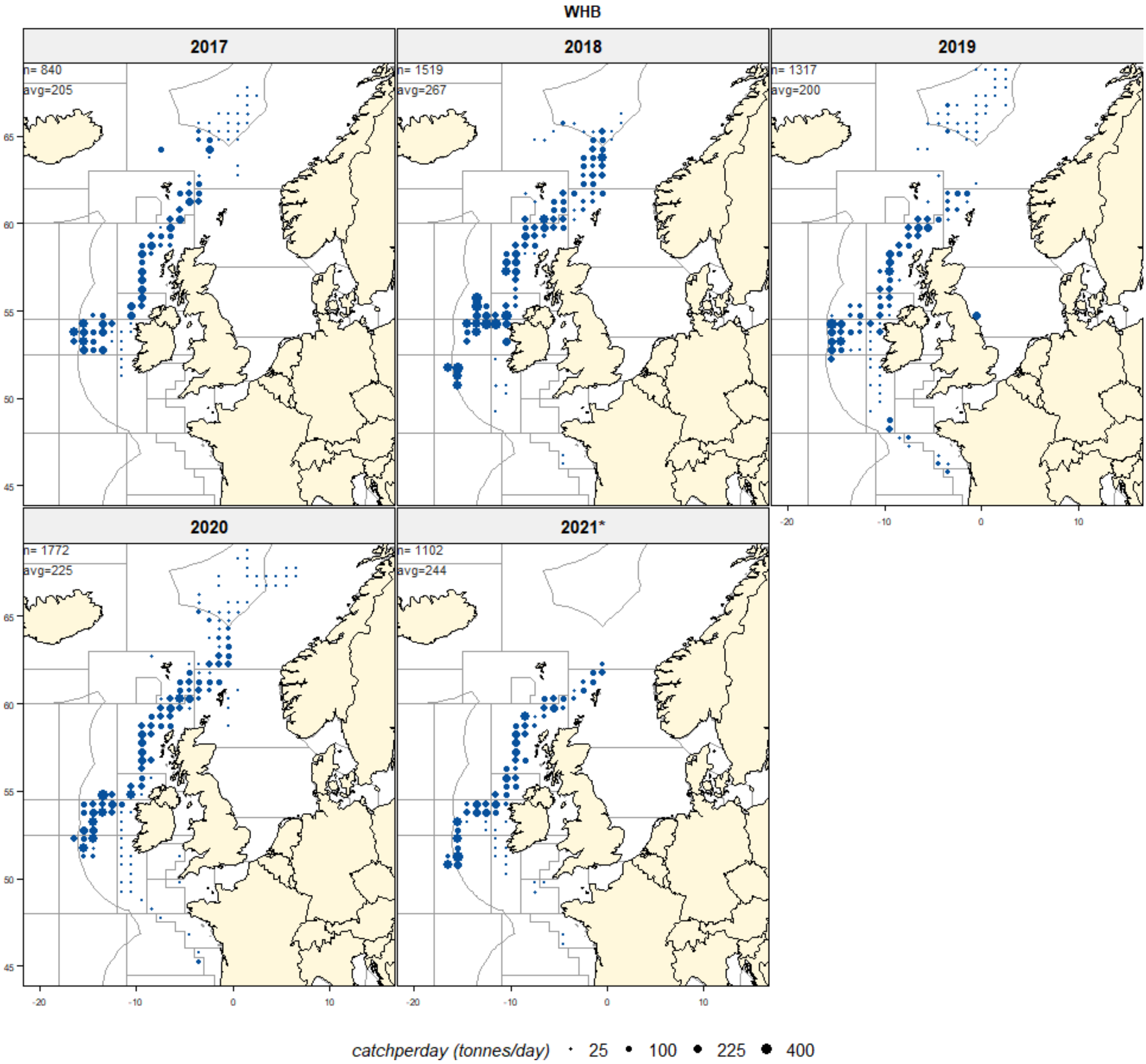

*Figure 3.4.2: Blue whiting. Average catch per day per rectangle. N indicates the number of hauls; avg refers to the overall average catch per day. * denotes incomplete year*

Blue whiting (WHB). Spatial-temporal evolution of the fishery

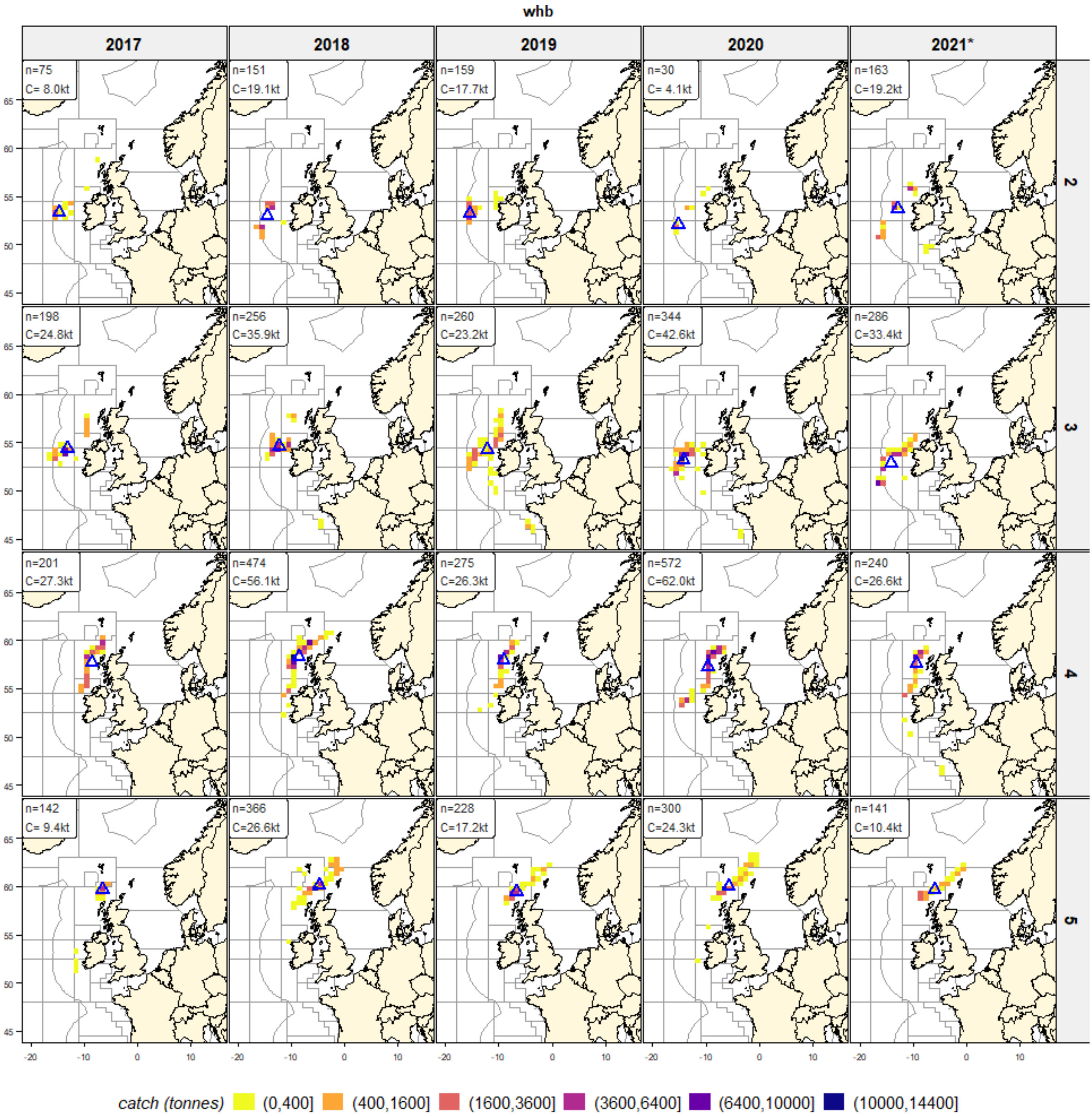

*Figure 3.4.3: Blue whiting. Catch per rectangle and per month. N indicates the number of hauls; C refers to the overall catch. The midpoint of the distribution is indicated by the blue triangle. * denotes incomplete year*

Blue whiting (WHB). Length distributions of the catch

Median length of Blue whiting in the catch in 2021 is 27.9 cm compared to median lengths between 24.2 and 27.7 cm in the preceding years. Note that the data for 2021 is only up to 27/07/2021.

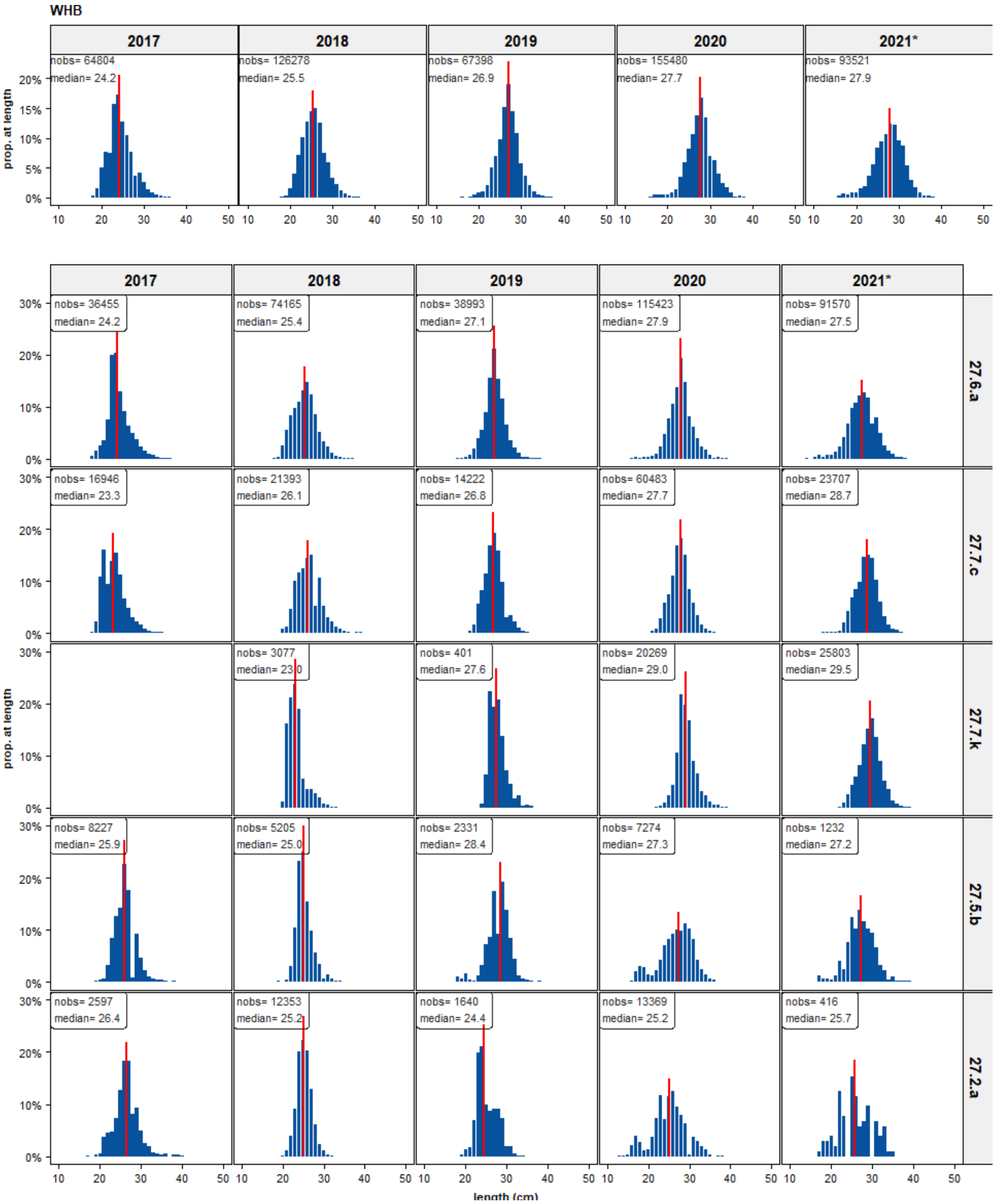

*Figure 3.4.4: Blue whiting. Length distributions by year (top) and by year and division (bottom). Nobs refers to the number of observations; median denotes the median length. * denotes incomplete year*

Blue whiting (WHB). Weight distributions by year

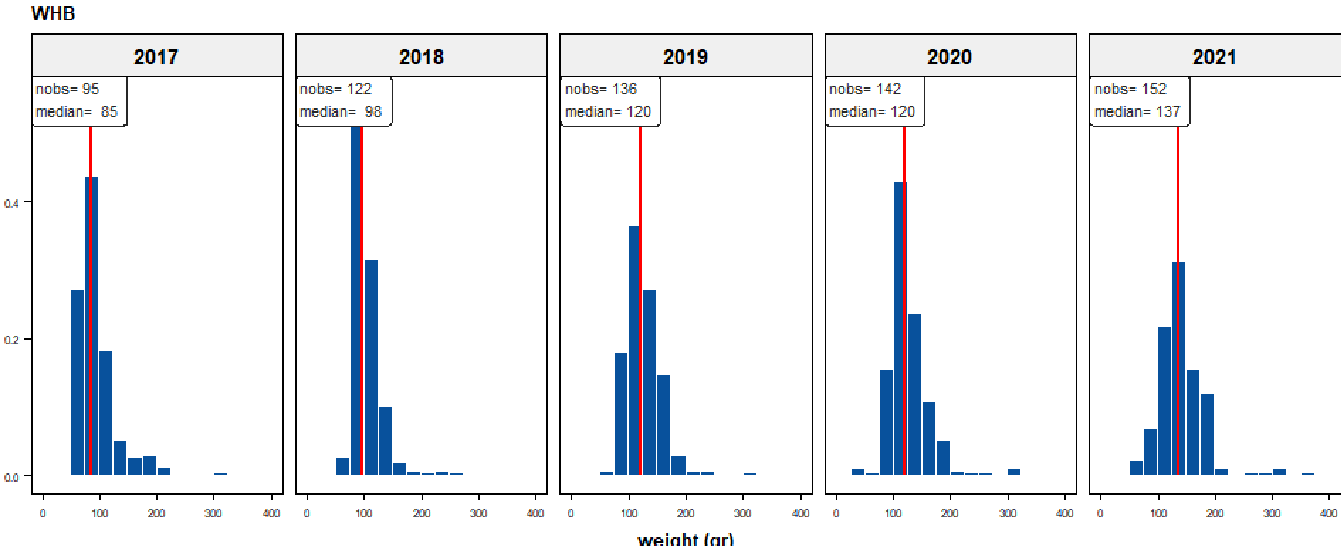

*Figure 3.4.5: Blue whiting. Weight distributions (25-gram classes). Nobs refers to the number of batches where average weight was measured; median denotes the median length; * denotes incomplete year*

Blue whiting (WHB). Fat percentages by week and year

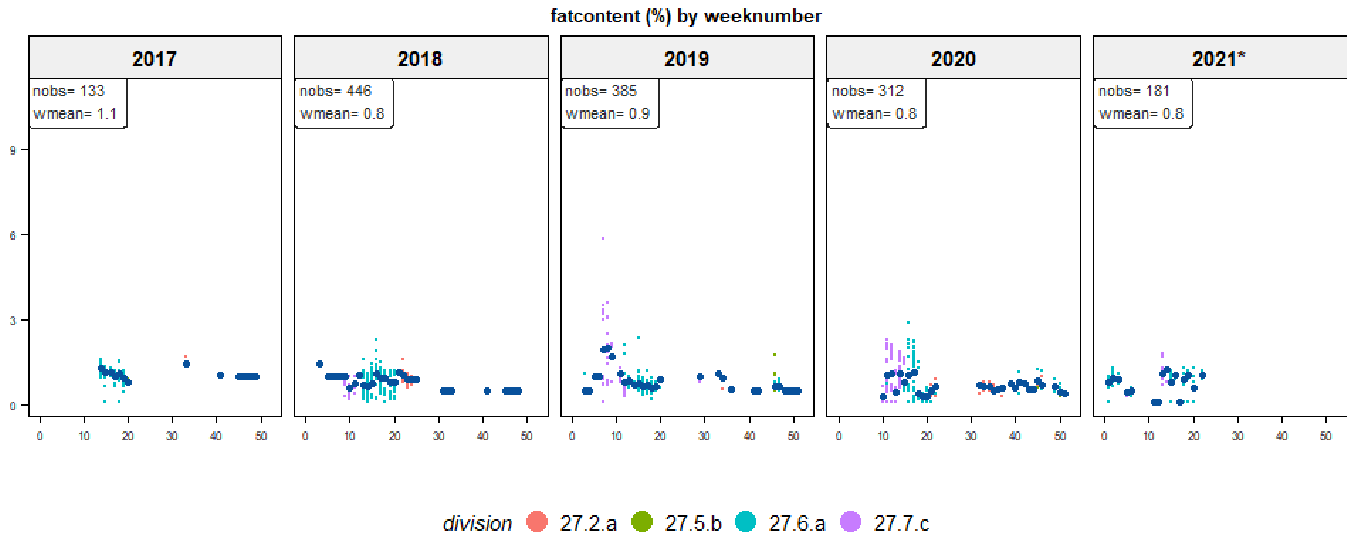

*Figure 3.4.6: Blue whiting. Average fat percentage by week. Nobs refers to the number of batches where average fat was measured; black dots indicate the weekly averages; * denotes incomplete year*

Blue whiting (WHB). Fishing depth distributions by year.

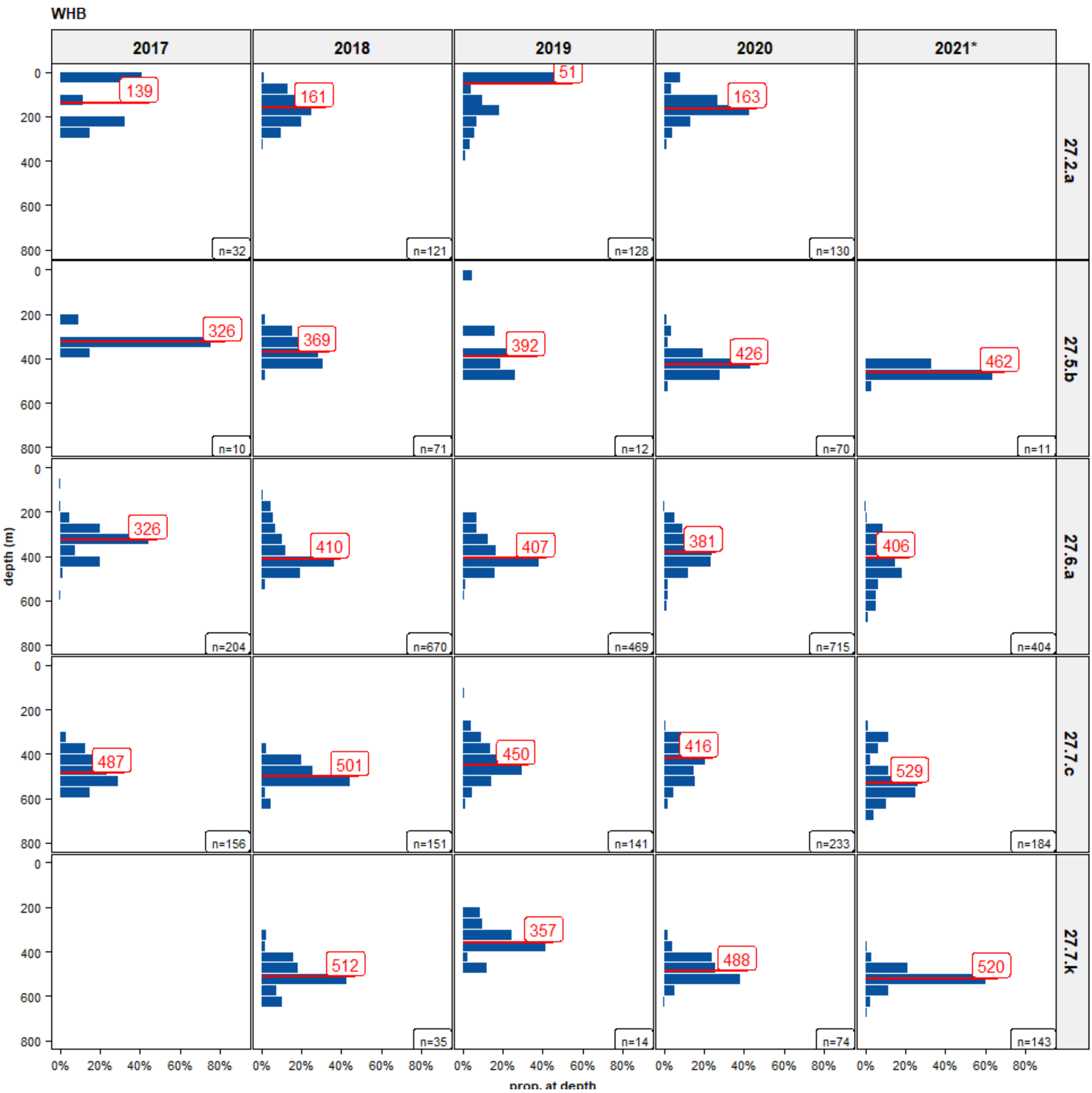

*Figure 3.4.7: Blue whiting. Depth distributions by year and division. N is number of observations; median depth in red; * denotes incomplete year*

3.5 Herring 'Atlanto-scandian' (HER_ASH, Clupea harengus)

The main Herring 'Atlanto-scandian' fishery takes place during months 9, 10, 11. The self-sampling activities for the Herring 'Atlanto-scandian' fishery during the years 2017 - 2021 (processed up to 27/07/2021) covered 27 fishing trips with 456 hauls, a total catch of 36003 tonnes and 10327 individual length measurements. The main fishing areas are 27.2.a.

species	division	year	nvessels	ntrips	ndays	nhauls	catch	catchperc	nlength	catchperday
her_ash	27.2.a	2017	4	7	42	83	7,950	100	2,210	189
her_ash	27.2.a	2018	4	5	37	68	5,278	100	490	143
her_ash	27.2.a	2019	4	5	57	145	12,249	100	3,714	215
her_ash	27.2.a	2020	8	10	83	160	10,526	100	3,913	127
her_ash	(all)	2017		7	42	83	7,950	100	2,210	189
her_ash	(all)	2018		5	37	68	5,278	100	490	143
her_ash	(all)	2019		5	57	145	12,249	100	3,714	215
her_ash	(all)	2020		10	83	160	10,526	100	3,913	127
her_ash	(all)	(all)		27	219	456	36,003		10,327	164

*Table 3.5.1: Herring 'Atlanto-scandian'. Self-sampling summary with the number of days, hauls, trips, vessels, catch (tonnes), number of fish measured, catch rates (ton/effort). * denotes incomplete year*

Herring 'Atlanto-scandian' (HER_ASH). Catch by month

species	month	2017	2018	2019	2020	all	perc
her_ash	May	0	0	0	26	26	0.07%
her_ash	Aug	118	51	0	41	210	0.58%
her_ash	Sep	6	405	361	65	837	2.33%
her_ash	Oct	7,825	4,820	8,066	7,514	28,225	78.41%
her_ash	Nov	0	0	3,821	2,878	6,699	18.61%
her_ash	(all)	7,949	5,276	12,248	10,524	35,997	100.00%

*Table 3.5.2: Herring 'Atlanto-scandian'. Self-sampling summary with the catch (tonnes) by year and month. * denotes incomplete year*

Herring 'Atlanto-scandian' (HER_ASH). Catch by rectangle

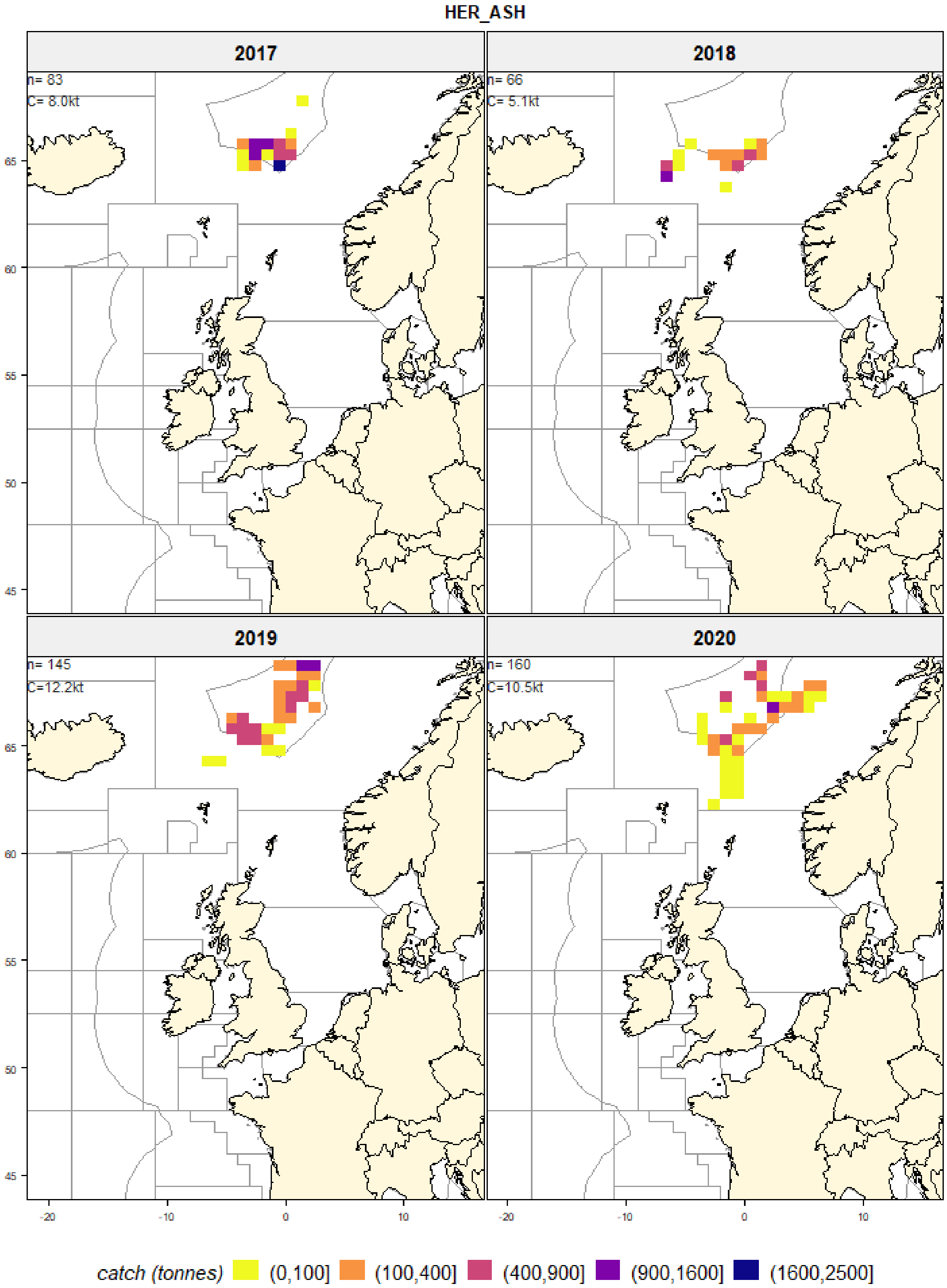

*Figure 3.5.1: Herring 'Atlanto-scandian'. Catch per rectangle. N indicates the number of hauls; Catch refers to the total catch per year. * denotes incomplete year*

Herring 'Atlanto-scandian' (HER_ASH). Average catch per day

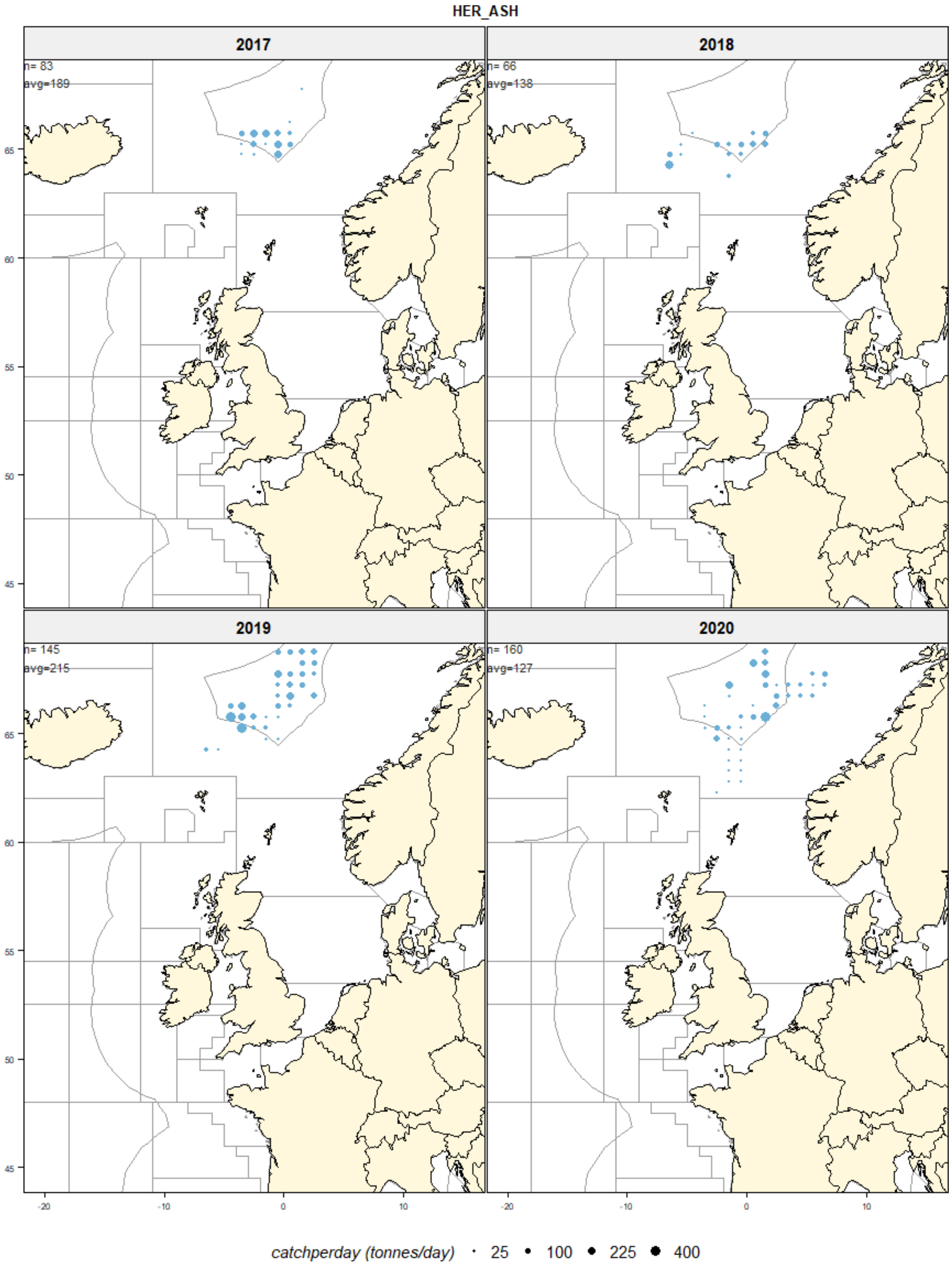

*Figure 3.5.2: Herring 'Atlanto-scandian'. Average catch per day per rectangle. N indicates the number of hauls; avg refers to the overall average catch per day. * denotes incomplete year*

Herring 'Atlanto-scandian' (HER_ASH). Spatial-temporal evolution of the fishery

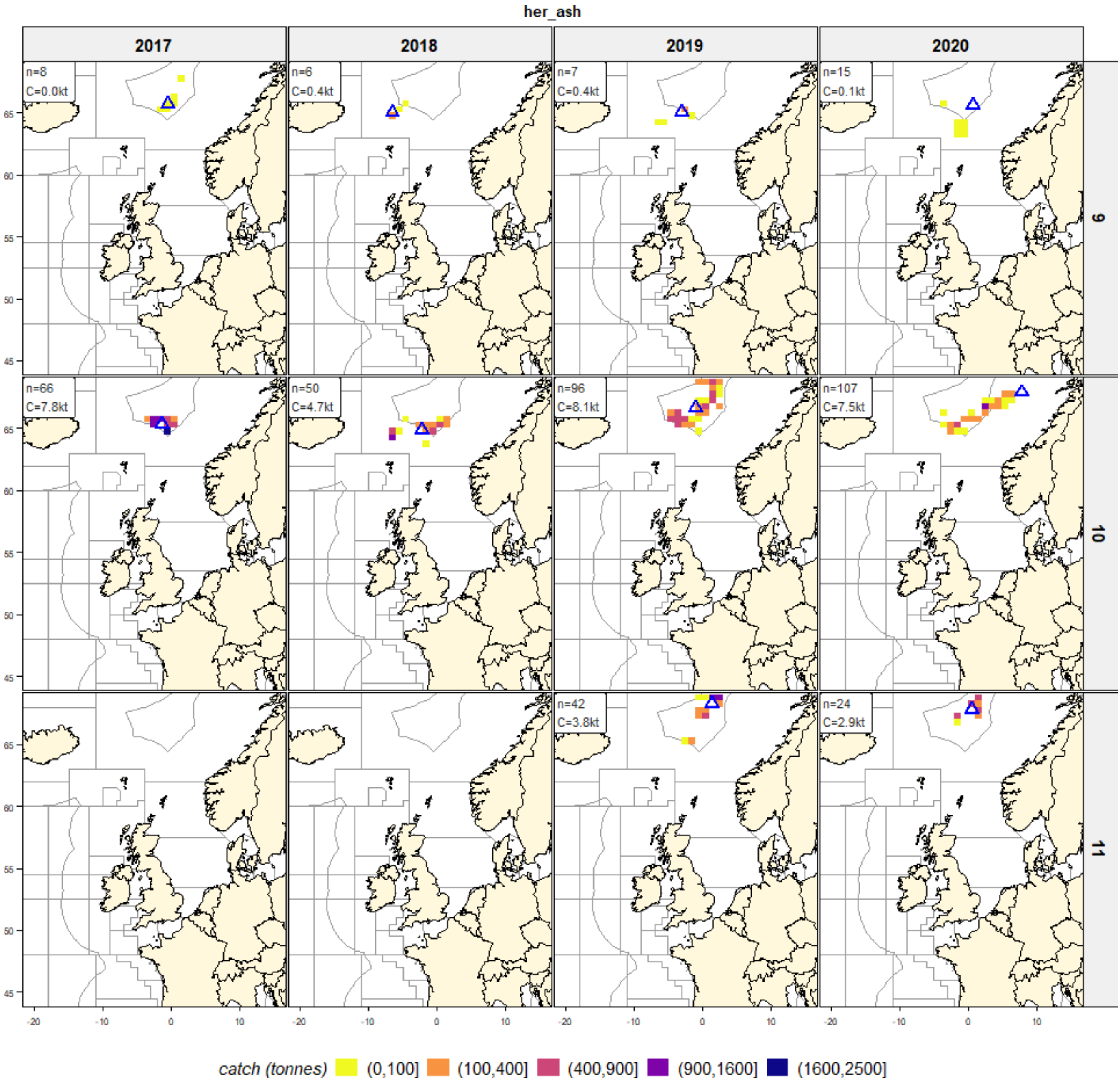

*Figure 3.5.3: Herring 'Atlanto-scandian'. Catch per rectangle and per month. N indicates the number of hauls; C refers to the overall catch. The midpoint of the distribution is indicated by the blue triangle. * denotes incomplete year*

Herring ‘Atlanto-scandian’ (HER_ASH). Length distributions of the catch

Median length of Herring ‘Atlanto-scandian’ in the catch in 2021 is NA cm compared to median lengths between 31.6 and 35.8` cm in the preceding years.

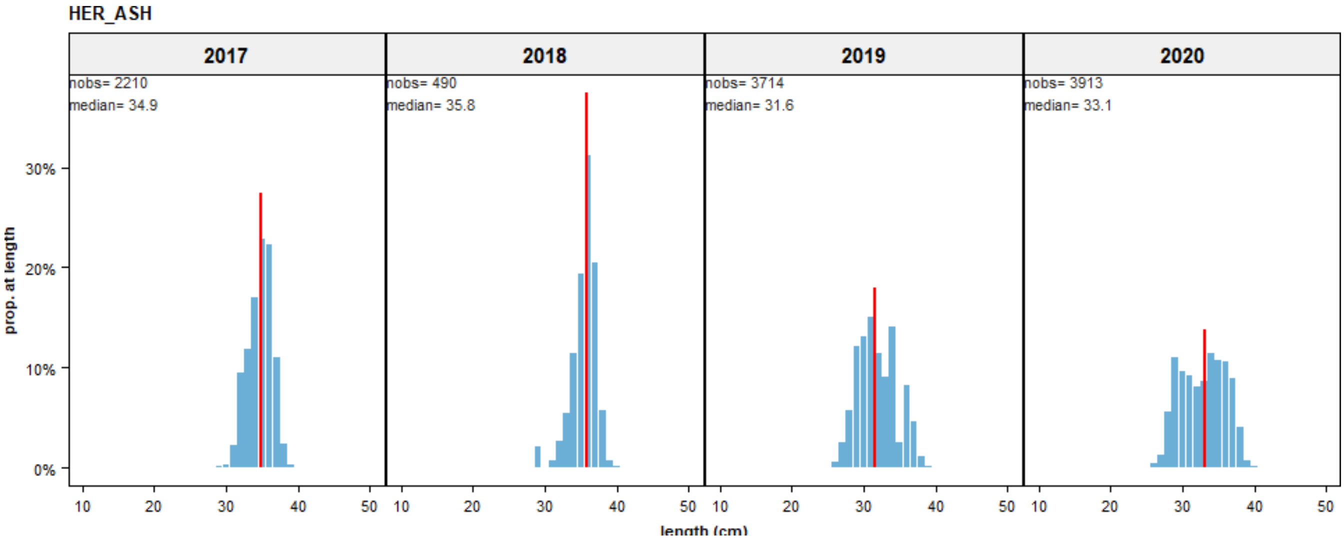

*Figure 3.5.4: Herring ‘Atlanto-scandian’. Length distributions by year (top) and by year and division (bottom). Nobs refers to the number of observations; median denotes the median length. * denotes incomplete year*

Herring ‘Atlanto-scandian’ (HER_ASH). Weight distributions by year

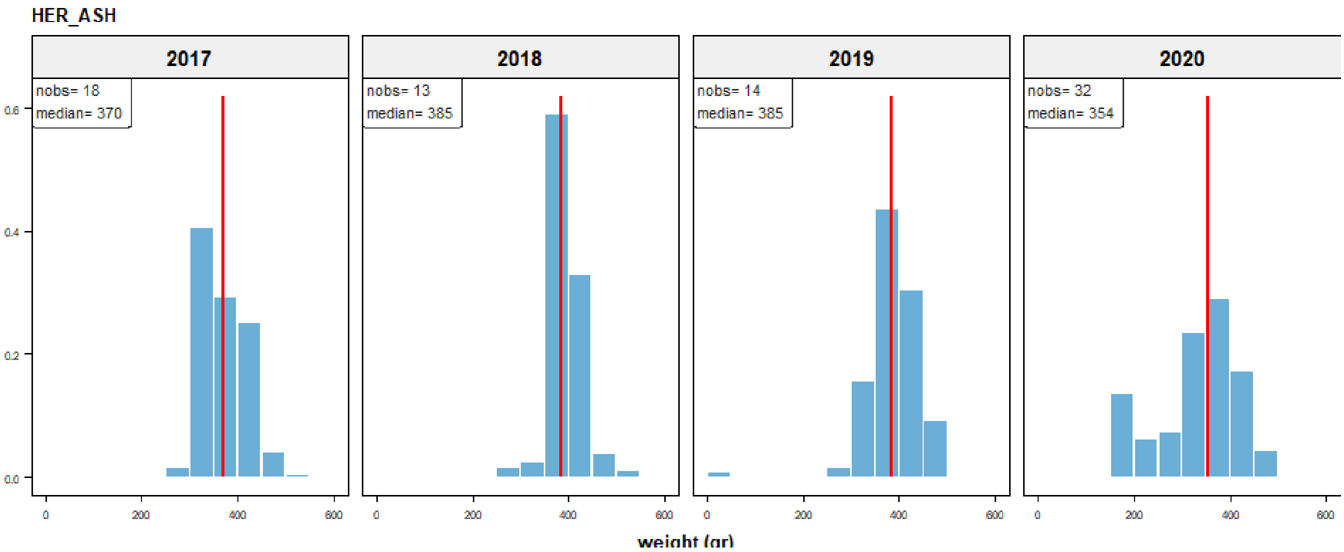

*Figure 3.5.5: Herring ‘Atlanto-scandian’. Weight distributions (50-gram classes). Nobs refers to the number of batches where average weight was measured; median denotes the median length; * denotes incomplete year*

Herring ‘Atlanto-scandian’ (HER_ASH). Fat percentages by week and year

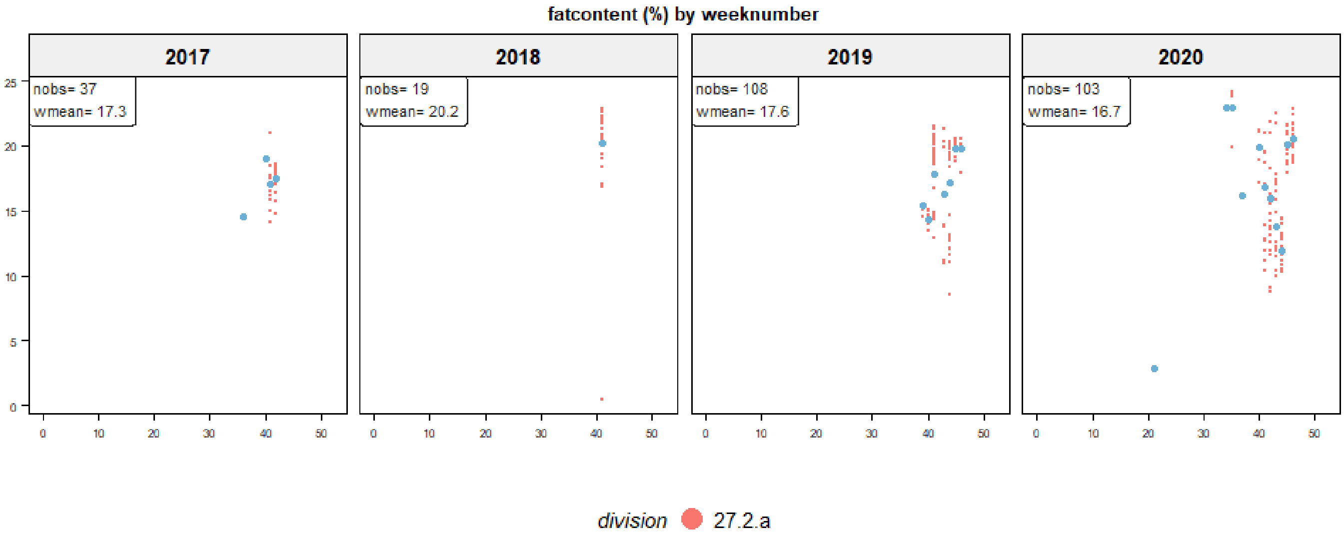

*Figure 3.5.6: Herring ‘Atlanto-scandian’. Average fat percentage by week. Nobs refers to the number of batches where average fat was measured; black dots indicate the weekly averages; * denotes incomplete year*

Herring 'Atlanto-scandian' (HER_ASH). Fishing depth distributions by year.

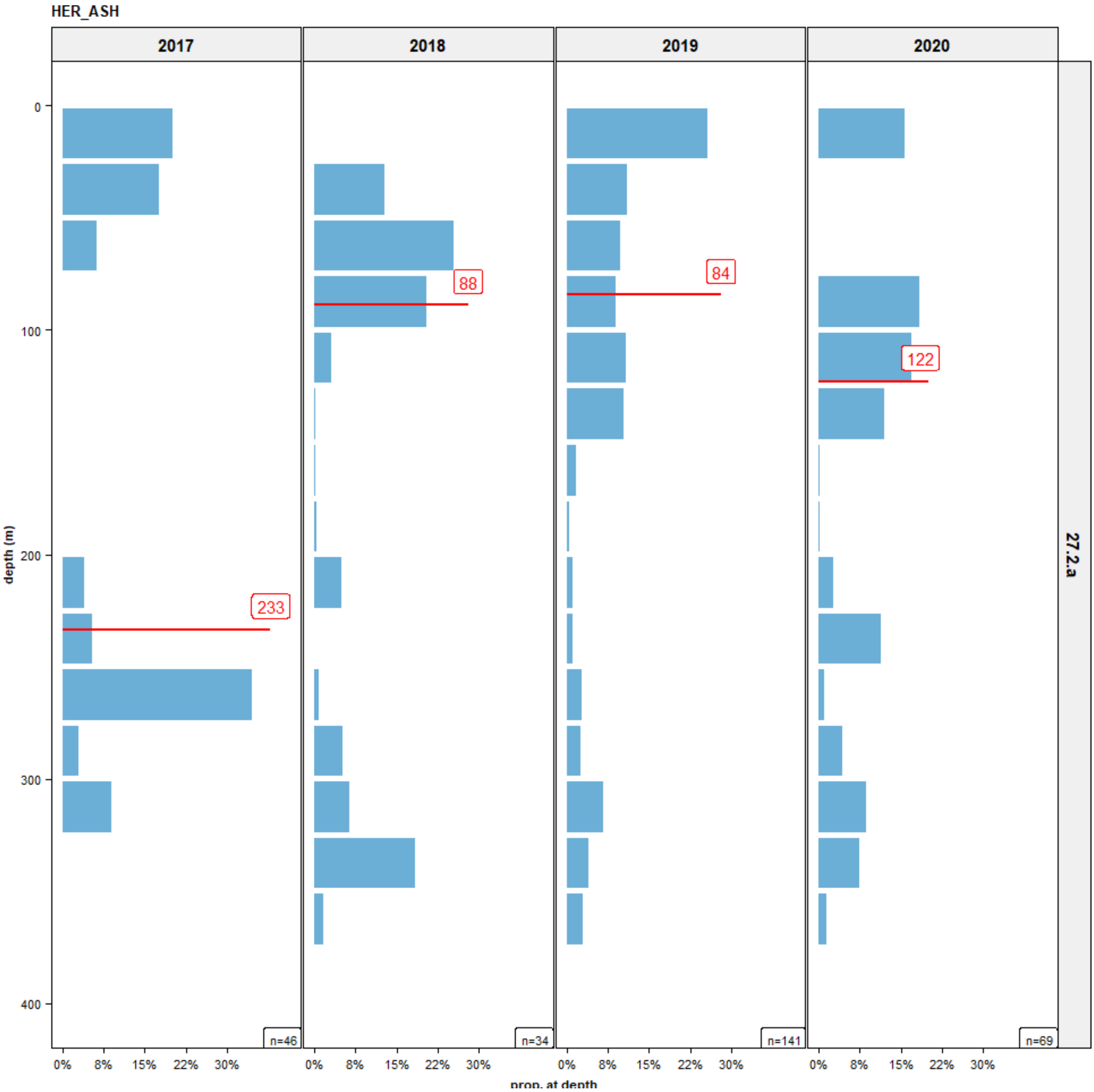

*Figure 3.5.7: Herring 'Atlanto-scandian'. Depth distributions by year and division. N is number of observations; median depth in red; * denotes incomplete year*

4 Discussion and conclusions

The PFA self-sampling program has been carried out for the seventh year in a row (2015-2021). Here, results have been presented for the years 2017-2021 in terms of meta-information on the sampling (number of vessels, trips, days and length measurements per area and/or season), in terms of the spatio-temporal distribution of catches and the length and weight compositions by area and/or season.

The definition of what constitutes the 'widely distributed fishery' has been approached by selecting all combination of vessel-trip-weeks where hauls were taken in a certain area and where the catch composition consisted of a minimum percentage of certain species (blue whiting, mackerel, horse mackerel, Atlanto-scandian herring) and a minimum weekly catch of 10 tons. Although for herring we aimed to select only trips for Atlanto-scandian herring (in division 27.2.a) some trips with North Sea herring have been included because they were combined with some fishing for mackerel. Trips from 2017 up to 27/07/2021 have been processed for this overview. Pelagic fisheries within the Pelagic Freezer-trawler Association are carried out by vessels from different countries. Overall, around 48% of the catch volume of trips in this overview were taken by Dutch trawlers, 22% German trawlers, 14% UK trawlers and 16% other countries. Blue whiting constitutes the majority of the catch in those trips (54%), followed by mackerel (23%) and horse mackerel (12%). Atlanto-scandian herring only constitutes around 3% of the volume in the PFA widely distributed fishery. Note that the North Sea herring fishery is not included in this overview.

The **Mackerel fishery** takes place from October through to March of the subsequent year. Minor by-catches of mackerel may also occur during other fisheries. Overall, the self-sampling activities for the mackerel fisheries during the years 2017 - 2021 (up to 27/07/2021) covered 357 fishing trips with 4940 hauls, a total catch of 287836 tonnes and 91096 individual length measurements. The main fishing areas are ICES division 27.4.a and division 27.6.a. Compared to the previous years, mackerel in the catch in 2021 have been relatively large with a median length of 36.4 cm compared to 33.6-36.2 in the preceding years. Also, the median weight has been somewhat higher with median weight of 435 gram compared to 385-422 gram in the preceding years.

The **horse mackerel fishery** takes place from October through to March of the subsequent year. Overall, the self-sampling activities for the horse mackerel fisheries during the years 2017 - 2021 (up to 27/07/2021) covered 243 fishing trips with 3446 hauls, a total catch of 141548 tonnes and 153307 individual length measurements. The main fishing areas are ICES division 27.6.a, division 27.7.b and division 27.7.d. Horse mackerel have a wide range in the length distributions in the catch. Median lengths in divisions 27.6.a, 27.7.b and 27.7.j have fluctuated between 26.2 and 31.3 cm (with one low median length of 23.3 cm in 27.6.a in 2018). In ICES divisions 27.7.d and 27.7.h, median lengths in the catch are smaller and fluctuated between 21.3 and 24.6 cm.

The **blue whiting** fishery takes place from February through to May although some minor fisheries for blue whiting may remain over the other months. Overall, the self-sampling activities for the horse mackerel fisheries during the years 2017 - 2021 (up to 27/07/2021) covered 240 fishing trips with 6560 hauls, a total catch of 650604 tonnes and 507481 individual length measurements. The main fishing areas are ICES division 27.6.a, division 27.7.c and division 27.7.k. Compared to the previous years, blue whiting in the catch in 2021 have been relatively large with a median length of 27.9 cm compared to 24.2-27.2 in the preceding years. Also, the median weight has been somewhat higher with median weight of 137 gram compared to 85-120 gram in the preceding years.

The fishery for **Atlanto-Scandian herring** (ASH) is a relatively smaller fishery for PFA and takes place mostly in October. Overall, the self-sampling activities for the horse mackerel fisheries during the years 2017 - 2021 (up to 27/07/2021) covered 27 fishing trips with 456 hauls, a total catch of 36003 tonnes and 10327 individual length measurements. Only the herring fishery in ICES division 27.2.a is considered for ASH. Note that there are herring catches in other divisions within the selected trips. These are trips where North Sea herring has been fished with some bycatches of mackerel for example. Atlanto-Scandian herring have a relatively narrow range in the length distributions in the catch. Median lengths have been between 31 and 36 cm.

5 Acknowledgements

The skippers, officers and the quality managers of the PFA vessels are putting in a lot of effort and dedication to make the PFA the self-sampling work. Without their efforts, there would be no self-sampling.

6 More information

Please contact Martin Pastoors (mpastoors@pelagicfish.eu) if have any questions on the PFA self-sampling program or the specific results presented here. Detailed length compositions (e.g., CSV files) can be made available on request.

Working Document WGWIDE 2021

Overview of the Scottish Pelagic Industry Self-Sampling Programme with potential data opportunities relevant to stock assessment

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1. Purpose

Data collected by industry has the potential to provide data to stock assessment and contribute to the quality of stock assessment and ICES advice. This working document provides:

- An overview of the Scottish pelagic industry self-sampling programme.
- A summary of the Scottish pelagic industry self-sampling data collected since 2018 for mackerel, herring and blue whiting.
- Example data: distribution maps of self-sampling / co-sampling and the biological data available for mackerel in 2021, alongside Marine Scotland Science (MSS) onshore sampling data for the same fishery/period.

This is a preliminary presentation of the work carried out by the Scottish Pelagic Industry Self-sampling Programme, to communicate its future data contribution to WGWIDE.

2. The Scottish Pelagic Industry Self-Sampling Programme

The Scottish Pelagic Industry Self-Sampling Programme[1] has been developed by the Scottish Pelagic Fishermen's Association (SPFA), Shetland UHI (SUHI)[2] and Marine Scotland Science (MSS) with the support of the EU H2020 project PANDORA.

Building on an initial feasibility study[3], the self-sampling programme began in 2018. Initial expectations for a limited pilot programme have been far exceeded, and by 2020 commitment to full voluntary participation by SPFA member vessels (representing 20 out of 21 Scottish pelagic vessels) was achieved, covering data collection from herring, mackerel and blue whiting fisheries. With routine procedures[4] now firmly established, the Scottish pelagic industry are committed to the continuation of the self-sampling programme beyond 2021.

The industry data collection programme comprises two parts. The first part, the self-sampling scheme, requires vessel crews to sample fish from every haul of every trip. Fish length (cm) and weight (g) data are

[1] The pelagic self-sampling is part of the SPFA Data Collection Strategy

[2] NAFC Marine Centre merged into the Shetland UHI organization on 1st August 2021

[3] Pelagic-self-sampling_FIS020-report_FINAL.pdf (scottishpelagic.co.uk)

[4] Methods and protocols manual for the Scottish pelagic self-sampling programme

collected as the fish are pumped onboard pelagic vessels, and haul information is recorded to connect the biological sample data to the location and date/time of the catch, and other operational and environmental parameters. The second part, the co-sampling scheme, added to the programme in 2020, requires samples of fish to be frozen and brought ashore for biological sampling on length, sex, maturity and age by scientists at SUHI and MSS laboratories. The procedure for collecting frozen samples is described in more detail below.

As part of the programme, vessel crews undertake training and are provided with all the necessary tools, including measuring boards, sampling protocols, data recording sheets and – more recently – electronic keypads for paperless data entry and standardised recording. Data quality checks are in place as part of the programme's Data Chain of Custody; and the quality of self-sampling data have been examined by comparing the data against landings that have been sampled through the current MSS onshore sampling (as carried out by MSS and the designated agent NAFC, now SUHI).

The SPFA Data Policy describes the conditions and procedures regarding data access and use by the scientific community. All Data Products are by default publicly available.

3. Summary of industry self-sampling data collection (2018-2021)

Industry are keen to engage in the self-sampling programme, with the participation of SPFA member vessels increasing each year from 35% in 2018 to 100% in 2020 (Table 1).

Table 1. Number of unique vessels/trips/hauls/fish sampled (length and weight), from a total of 20 SPFA member vessels.

	2018	2019	2020	2021
Herring				
No. unique vessels	7	5	15	n/a
No. trips	41	14	65	n/a
No. hauls	73	30	128	n/a
No. fish	7,882	3,640	15,396	n/a
Mackerel (Autumn, Oct/Nov)				
No. unique vessels	7	7	15	n/a
No. trips	29	20	67	n/a
No. hauls	53	39	133	n/a
No. fish	6,165	4,191	15,119	n/a
Mackerel (Winter, Jan/Feb)				
No. unique vessels	n/a	7	14	18
No. trips	n/a	23	45	67
No. hauls	n/a	42	82	138
No. fish	n/a	4,862	9,140	15,822
Blue whiting				
No. unique vessels	n/a	1	5	9
No. trips	n/a	4	20	40
No. hauls	n/a	16	69	125
No. fish	n/a	1,893	8,002	15,110

4. Results of industry self-sampling and Marine Scotland Science onshore sampling for mackerel 2021 (Winter Jan/Feb)

Industry data are shown below, alongside MSS onshore sampling data. Biological data collection from onshore sampling of pelagic landings in Scottish ports has been carried out by MSS since around 1970. These data are used to provide numbers-at-age for use in stock assessment. The sampling programme is overseen by MSS and is currently undertaken by MSS and SUHI (and Marine Institute, Ireland for blue whiting). The data comprise biological information such as length, maturity and age, collected from samples of landings obtained opportunistically from the vessels at Scottish ports. The sample can be allocated to a fishing trip and the statistical rectangles reported for that trip, but not to individual hauls and their associated locations. Typically, around 50% of trips are sampled each year under the MSS onshore sampling scheme.

4.1 Sample location

Participation in the self-sampling programme requires that all hauls from all trips are sampled. With full participation of the fleet, full spatial and temporal coverage of the fishery can be achieved. This census approach enables greater reach of the self-sampling data compared to the MSS onshore sampling programme (Fig. 1) and includes sampling of landings abroad. The self-sampling data can be further resolved with individual haul locations (not shown here).

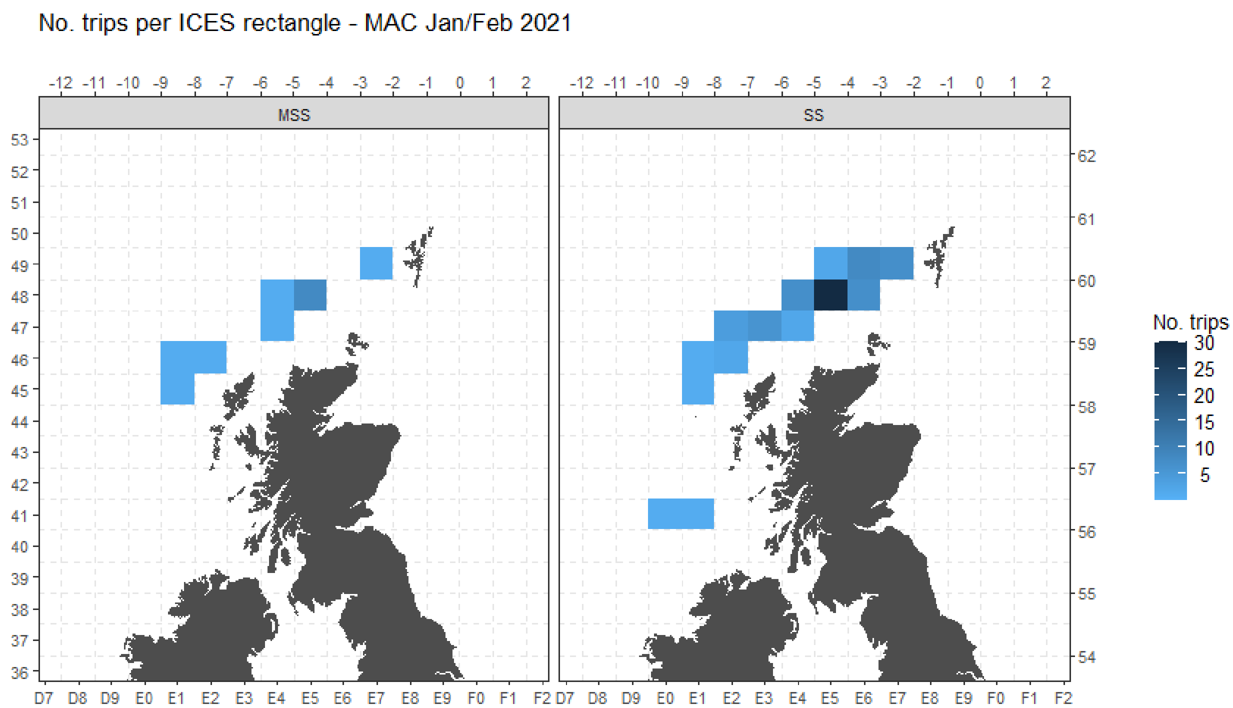

Figure 1. Sample locations from industry self-sampling and Marine Scotland Science sampling for mackerel 2021 (Winter, Jan/Feb). Number of trips per ICES rectangle, mapped by dataset, where MSS=onshore sampling overseen by MSS, and SS=self-sampling undertaken by SPFA vessels.

4.2 Sample length distribution

In 2021, 14 trips were sampled by both the self-sampling programme and the onshore sampling overseen by MSS (Fig. 2). The two datasets demonstrated similar length distributions for all but one trip.

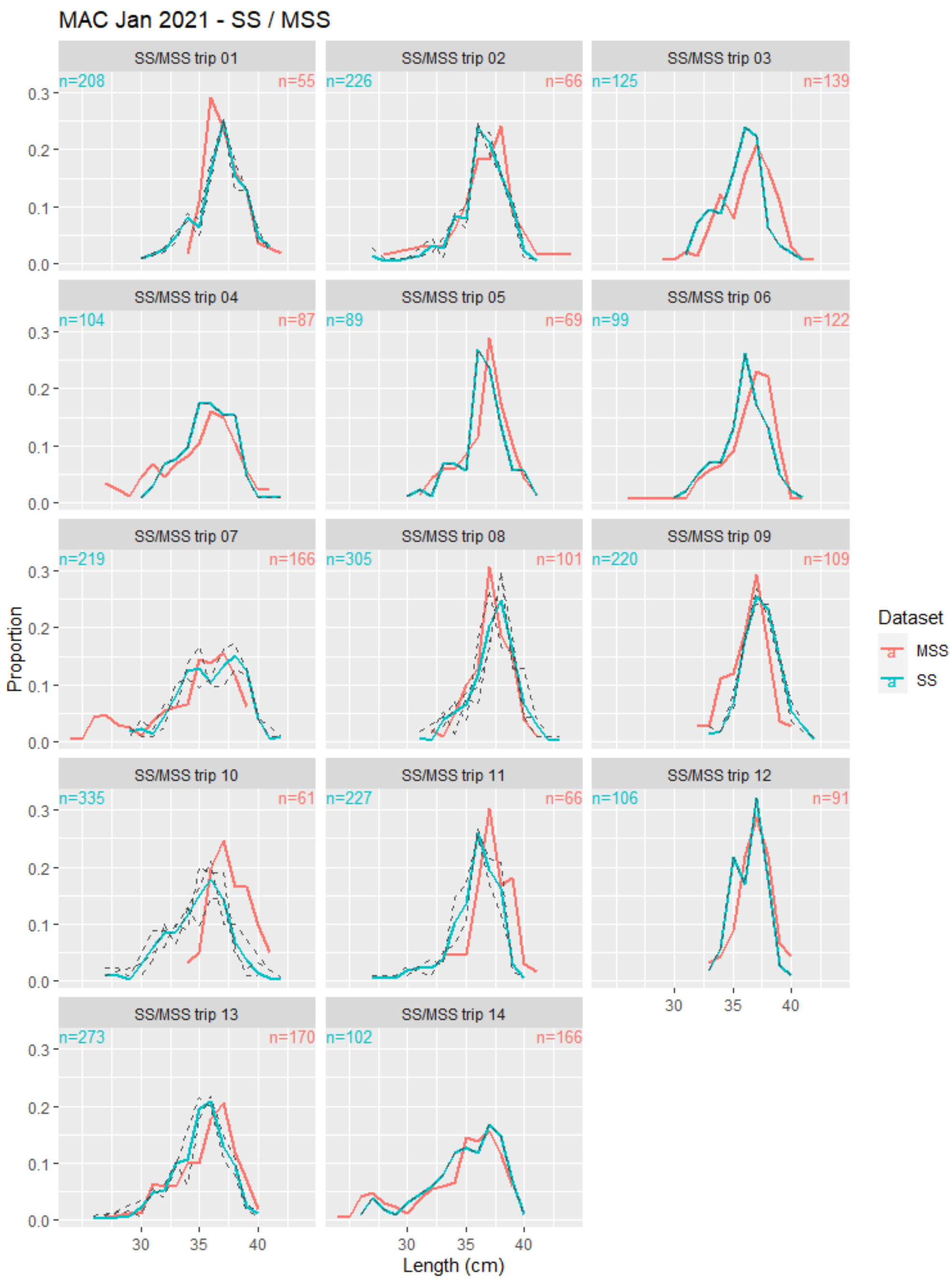

Figure 2. Length distribution from industry self-sampling and Marine Scotland Science sampling for mackerel 2021 (Winter, Jan/Feb). Length distribution of fish by trip where data coincides from each dataset. MSS=onshore sampling overseen by MSS, and SS=self-sampling undertaken by SPFA vessels. For the self-sampling data, the blue line shows the length distribution across all hauls in a single trip, while the dotted black line shows the length distribution for each haul within a trip. Trip codes have been anonymised for vessel confidentiality.

4.3 Sample length-weight relationship

The mean weights-at-length from the self-sampling data for mackerel in January and February in 2021 were compared with the monthly weight-length relationships currently used by MSS (Fig. 3). The observed self-sampling weight data indicate that the pooled mean weight of fish of intermediate lengths is greater than that predicted by the L-W relationships used by MSS, in spring 2021. Sampling both lengths and weights enables seasonal and inter-annual variations in growth patterns of cohorts to be captured and incorporated into stock assessments. It also provides valuable data for research on species ecology.

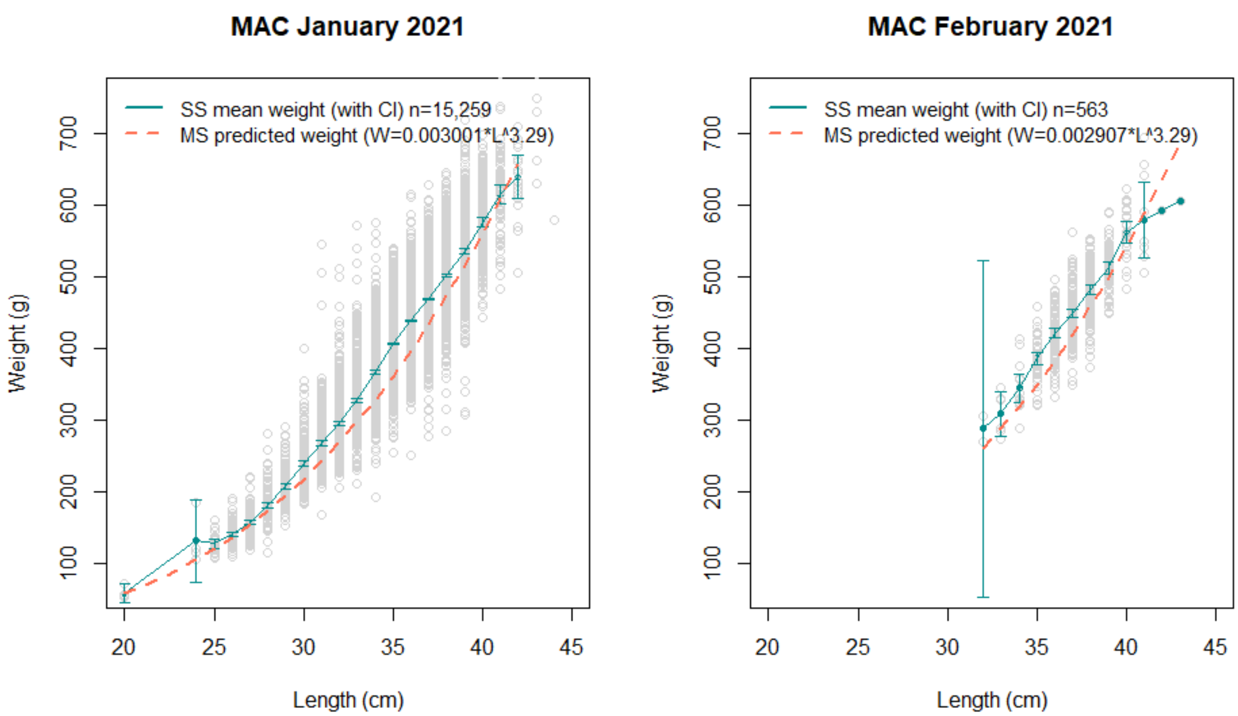

Figure 3. Fish length-weight relationship for mackerel 2021 (Winter, Jan/Feb). Fish length-weight relationship by month with SS weight-length dataset (grey circles). MSS=onshore sampling overseen by MSS (data plotted as predicted weight-at-length), and SS=self-sampling undertaken by SPFA vessels (data plotted as mean weight-at-length with confidence interval [CI]).

5. Co-sampling: age, length, sex and maturity data collection

Since 2020, fish samples are frozen and brought ashore for additional biological sampling on age, length, sex, and maturity by scientists at the SUHI and MSS laboratories. An electronic 'coin-toss' is used to randomly select the trips required to collect frozen samples. From each selected trip one box of fish is collected from each haul.

5.1 Sampling locations

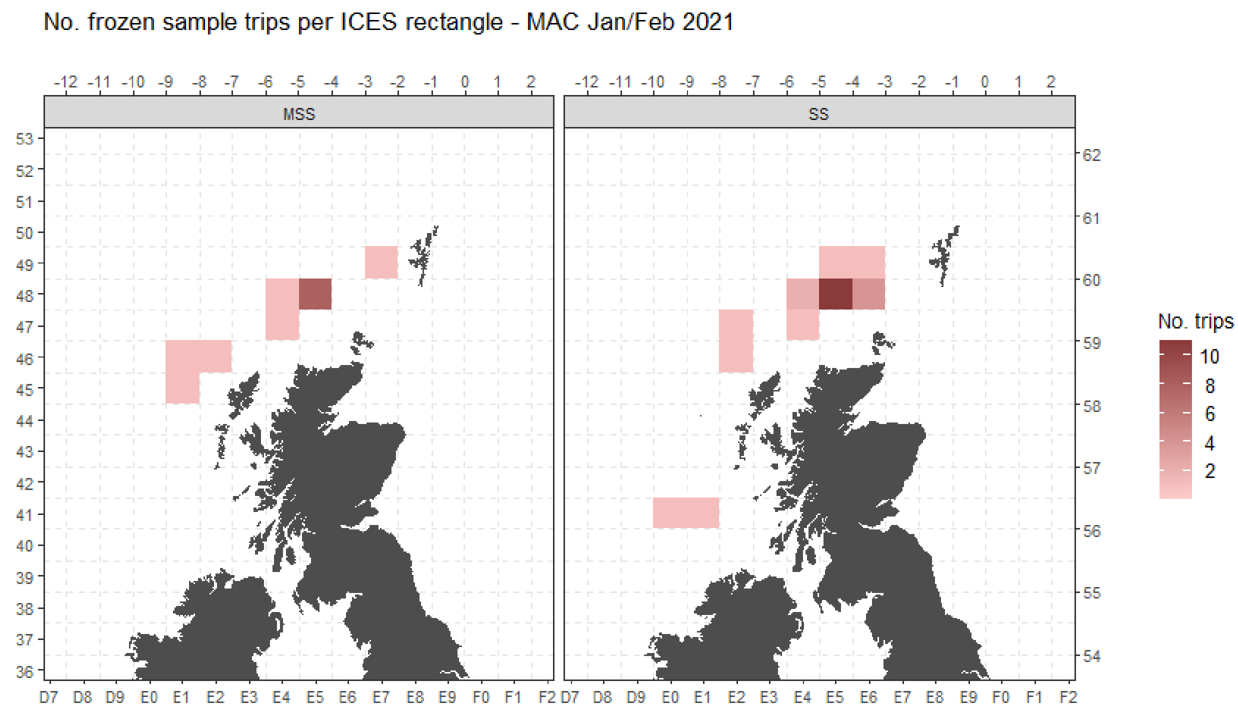

Figure 4. Sample locations of frozen samples collected via self-sampling and sample locations from MSS onshore sampling for mackerel 2021 (Winter, Jan/Feb). Number of trips per ICES rectangle, mapped by dataset, where MSS=onshore sampling overseen by MSS, and SS=self-sampling undertaken by SPFA vessels.

6. Conclusions

Industry self-sampling and co-sampling can be used to obtain biological data on commercial catches, provided that the sampling design and methods result in data that are representative of the catch composition.

The Scottish Pelagic Industry Self-sampling Programme offers several opportunities in efforts to ensure continuous improvements in the quality of stock assessment and ICES advice. In particular:

- Sample coverage can be representative of the fishing behaviour of the fleet as all but one vessel participate, and vessels that land catches overseas will also provide samples.
- Sample coverage can be representative of the spatial distribution of the fleet since every haul can be sampled.
- Samples include direct measurements of both the weight and length of fish, allowing monitoring of changes in fish growth.
- Co-sampling of frozen samples from randomly selected trips is an efficient and effective way to collect age, sex and maturity data.

Inclusion of new biological data into an existing time series has the potential to cause a shift in the data, which could be misinterpreted as a change in the structure of the stock. Therefore, prior to the introduction of any new data, examination of the resulting effects on estimates will be required. As more data are collected through the Scottish Pelagic Industry Self-sampling Programme, additional comparative work will be undertaken. Further assurances will also be made to ensure long-term access to the industry collected data.

The North Sea Mackerel Egg Survey: Changing from the Annual to Daily Egg Production Method.

Working Document for ICES WGWIDE, online meeting, 25 - 31 August 2021

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Introduction

The working group on mackerel and horse mackerel egg surveys (WGMEGS) coordinates the Mackerel and Horse Mackerel Egg Survey in the Northeast Atlantic and the Mackerel Egg Survey in the North Sea with the purpose of estimating the spawning stock biomass of the different NEA mackerel spawning components since 1977 (Lockwood et al. 1981). These surveys are carried out triennially, although the North Sea survey is normally completed one year after the western and southern area surveys. The survey for the western area mackerel was initiated in 1977. The southern area was later added in 1992 (ICES, 1993).

Egg production survey methods

Egg production surveys provide a method of estimating SSB, independent of any data on commercial catches, to be integrated in or used to inform the stock assessment process.

The underlying concept for egg production methods is very simple; if we know how many eggs have been spawned over a period of time (e.g. daily or annually) in the spawning area (egg production), and we know how many eggs an average individual mature female can produce over the same period (fecundity), then we can estimate the size of the spawning population (Bernal et al., 2012).

There are two primary methods (Gunderson 1993; Hunter and Lo 1993), namely the annual egg production method (AEPM) and the daily egg production method (DEPM). The first method is designed for species with a determinate fecundity, i.e. those in which all the eggs to be spawned during the year are present and identifiable in the ovary immediately prior to spawning (Potential fecundity). With the AEPM, estimated egg production is integrated over the whole annual spawning season, using data from a series of surveys, and how many eggs are produced on average per unit mass of spawning female in the year. Whereas the application of AEPM is suitable only for determinate annual spawners, the DEPM can in principle be applied to indeterminate and determinate spawners that release pelagic eggs in a series of batches and for which the daily spawning fraction and batch fecundity can be estimated with sufficient accuracy (Kraus et al., 2012).

The DEPM can be used for species with an indeterminate fecundity, in which the potential annual fecundity is not fixed before the onset of spawning (Stratoudakis et al., 2006) and previtellogenic oocytes are recruited over the spawning season. The DEPM requires a single ichthyoplankton survey covering the entire spawning area during a brief period of the spawning season to estimate the mean daily egg production and to have representative samples of spawning adults during the survey period in order to estimate the mean daily fecundity (batch fecundity, spawning fraction and sex ratio) per unit mass of adults, at or near the annual peak of spawning (Parker, 1980, Stratoudakis et al., 2006). Accordingly the DEPM provides a snapshot rather than an integrated view of the spawning season (Stratoudakis et al., 2006).

The main difference of the DEPM in relation to the AEPM method resides on the appropriate measure of fecundity, which in the case of indeterminate spawners has to be based on the number of oocytes released per fish in each spawning event (batch fecundity) and the proportion of females reproducing daily (spawning fraction) (Stratoudakis et al., 2006).

Mackerel egg survey

Since 1977 the AEPM has been used for estimation of NEA mackerel SSB (Lockwood et al. 1981; Lockwood 1988) under the assumption that mackerel has a determinate fecundity. However, Greer Walker et al. (1994) had shown that the assumption of mackerel having a determinate fecundity was not conclusive and concluded 'that for all practical purposes the mackerel should be considered as having a determinate fecundity". Priede and Watson (1993; 1997) compared the use of the Daily Egg Production Method (DEPM) and Annual Egg Production Method (AEPM) for the estimation of spawning-stock biomass (SSB) in mackerel during the 1989 and 1992 egg surveys. These estimations showed inconsistent results.

In 2012 WGMEGS coordinated the Workshop on Survey Design and Mackerel and Horse Mackerel Spawning Strategy (WKMSPA) (ICES, 2012b) to discuss spawning strategies of mackerel and horse mackerel and to make recommendations on the survey design. The reason for organising this workshop was that observations from egg surveys in 2007 and 2010 seemed to indicate that mackerel (and horse mackerel) have an indeterminate fecundity type. This workshop recommended that extra adult samples should be collected on surveys to investigate the estimation of DEPM adult parameters, and to attempt a contrast between AEPM and DEPM results and review fecundity samples collected in previous surveys for DEPM adult parameters

The North Sea Mackerel Egg Survey (NS-MEGS) is designed to estimate the spawning stock biomass (SSB) of the North Sea spawning component of Northeast-Atlantic mackerel. Up to 2017 this was done utilizing the annual egg production method (AEPM). This method estimates and combines total annual egg production (TAEP), realized fecundity per gram female, and sex (male to female) ratio to calculate SSB. TAEP of mackerel spawning in the North Sea is based on counts of freshly spawned (stage 1) eggs from plankton catches, which ideally cover the entire spawning area and season. Temporal coverage is achieved through several passes of the entire spawning area during the spawning season. Realized fecundity is estimated based on histological examinations of pre-spawning (for potential fecundity) and spawning ovaries (for atresia estimation) from caught mackerel. For details on methods see the respective WGMEGS survey manuals (ICES 2019 a, b).

The NS-MEGS was first carried out in 1980, and continued on an annual basis until 1984, before being conducted biennially until 1990. No NS-MEGS surveys were carried out between 1990 and 1996. The survey was restarted in 1996 and has been carried out triennially since, similar to the Northeast-Atlantic MEGS (NEA-MEGS), however it always takes place one year after the western and southern surveys. In the early years of the survey, prior to 1990, more than 90 ship days were allocated to the survey, however since the re-instatement of the survey in 1996 this effort was much reduced to approximately 30 days per year. The number of participating nations also declined, from at least three in the beginning to two after 1996 (at first Norway and Denmark, later Norway and The Netherlands). After the 2011 survey, and coinciding with the 2014 benchmark for mackerel stock assessment, Norway decided to withdraw from the NS-MEGS, leaving The Netherlands as the only participating nation (ICES 2014). In an effort to continue providing good quality data the Netherlands increased its survey time from 15 to 20 days after the withdrawal of Norway.

Spatial and temporal coverage had already been impacted when the survey was re-initiated in 1996, due to the reduction in available survey effort, and this became even more serious with the withdrawal of the Norwegian participation. Due to technical difficulties with the Dutch survey vessel the 2014 North Sea survey had to be postponed until 2015. In 2020 Covid-19 measures again prevented the survey being carried out, so it was postponed until 2021.

Prior to 2011 Norway was responsible for calculating TAEP and SSB for North Sea mackerel. After the withdrawal of Norway, discrepancies in the estimation of the TAEP were found compared to the current method described in the WGMEGS manual. This discrepancy rendered the 2015 and 2017 estimates inconsistent with the earlier estimations in the NS-MEGS time series. This became particularly noticeable for the 2015 NS-MEGS (Figure 1 and Table 1). The 2015 egg production curve is almost entirely below the curves of the 2008 and 2011 surveys, but still delivers a higher TAEP estimate. In addition, the 2017 egg production curve does not really suggest a higher TAEP than the one of 2005. However, the 2017 TAEP exceeds 2005 by almost a third.

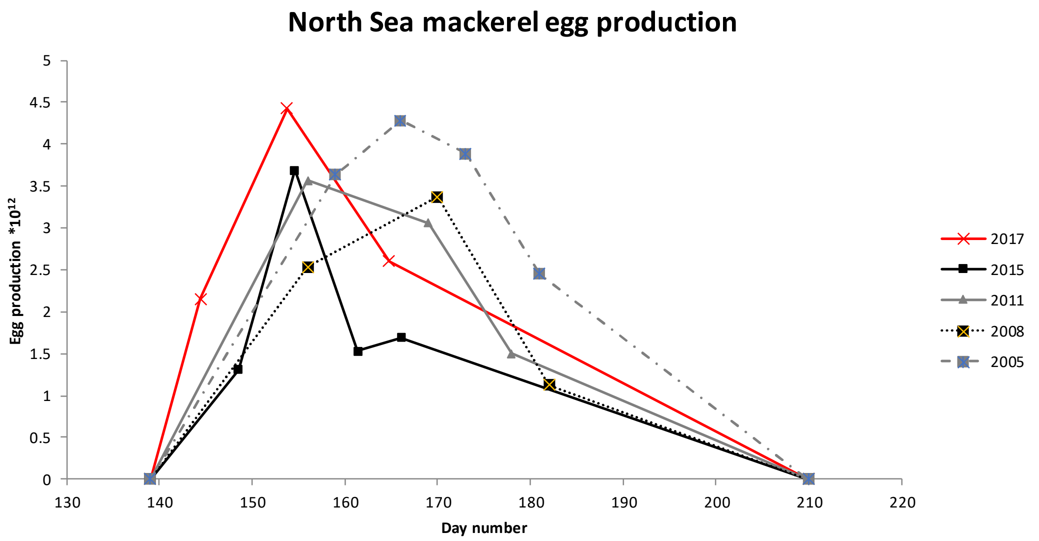

Figure 1: Annual egg production curves for North Sea mackerel (prior to 2015 the Lockwood egg development equation was used, since 2015 the Mendiola equation was used).

Table 1: Egg production estimates from egg surveys 2005 – 2017 in the North Sea and corresponding SSB based on a standard fecundity of 1401 eggs/g/female.

Year	Egg prod *10^{12}	SSB *10^{3} tons
2005	155	223
2008	108	154
2011	116	165
2015	119	170
2017	201	287

These inconsistencies in the time series have remained unexplained. Currently it is not known how TAEP was calculated by Norway before they withdrew from the survey, the methodology used was never described in the WGMEGS manual. However, two reasons may explain the discrepancies:

1. As documented in the survey manual (ICES 2019b) WGMEGS had decided in 2013 to replace the Lockwood development equation with one developed by Mendiola. As a result, in 2015, the Netherlands used the Mendiola equation for the first time in the North Sea convert egg abundance into daily production. Using the Mendiola equation leads to higher egg production compared to the Lockwood equation. The time series for the western and southern surveys has been recalculated using the Mendiola equation, this work still needs to be carried out for the North Sea.

2. For the recent egg surveys, and following the latest versions of the MEGS manual, TAEP was calculated as the area under the histogram, while according to the methodology for surveys prior to 2015, the area under the curve was utilized (ICES 1997, 2000, 2003, 2006, 2009, 2012), which may also contribute to a lower estimate in those years.

The North Sea time series data still awaits thorough quality assurance checks and re-analysis with respect to the above-mentioned inconsistencies.

Another problem for the NS-MEGS is that since 1982 it has been impossible to collect pre-spawning mackerel, which are necessary to estimate the potential fecundity. For North Sea SSB estimation MEGS have used the realized fecundity value from the 1982 estimate (Iversen and Adoff, 1983). Both in 1998 and 2001 the realized fecundity in the western area was re-estimated but considered to be rather low (ICES 2002) and WGMEGS decided to reject these estimations (ICES 2000, 2003).

In 2018 WGMEGS, (ICES 2018), after assessing the quality of the 2017 NS-MEGS results, decided that future North Sea surveys, starting in 2020, would use a DEPM sampling scheme rather than AEPM. Even with the inclusion of Denmark the limited ship time available would not be sufficient to provide adequate coverage of mackerel spawning in the North Sea either temporally or spatially using the AEPM approach (ICES 2018). The DEPM only requires one full coverage of the spawning area over a shorter time period, and preferably during peak spawning. Full coverage of the spawning area can, due to its spatial confinement, be much easier achieved in the North Sea than in the open Northeast-Atlantic. Sampling during peak spawning is preferred because of the increased chances of catching spawning mackerel for batch fecundity and spawning fraction estimations. However, this method also requires a large number of adult samples to be collected and analysed to estimate reliable batch fecundity and spawning fraction estimation. However because only one coverage of the spawning area is necessary for daily egg production, it was predicted that sufficient ship time would be available to collect the higher number of adult samples necessary. The application of DEPM would enable WGMEGS to deliver a more robust estimate of the SSB of the North Sea mackerel stock component compared to any of the previous years since 1996.

Because of the Covid-19 pandemic, the 2020 NS-MEGS had to be postponed to 2021, when it was carried out successfully in May-June. For the first time, the entire North Sea spawning area could be covered and enough adult female mackerel were caught for the necessary fecundity and spawning fraction estimations. It is, therefore, anticipated that for the first time a robust estimate of the SSB of the North Sea spawning component of mackerel will become available.

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The WESPAS Survey & Mackerel

WD to WGWIDE 2021

August 25-31, 2021

Andrew Campbell,

Marine Institute, Ireland

Introduction

The WESPAS (Western European Shelf Pelagic Acoustic Survey) is an annual survey conducted by the Fisheries Ecosystems Advisory Services division of the Irish Marine Institute. The survey is an amalgamation of the Irish component of the Malin Shelf herring acoustic survey which has been carried out annually since 2008 in ICES subareas 6a and 7bc and the boarfish acoustic survey which was first conducted in 2011 in 7hjk and the north of 8c on a commercial vessel. In 2016 the surveys were combined into the WESPAS survey and have been conducted by the RV Celtic Explorer since this time. The survey runs for 6 weeks in June and July over 2 legs covering the shelf waters from 47˚30’ N to 58˚30’ N. The 2021 survey track is shown in fig 1.

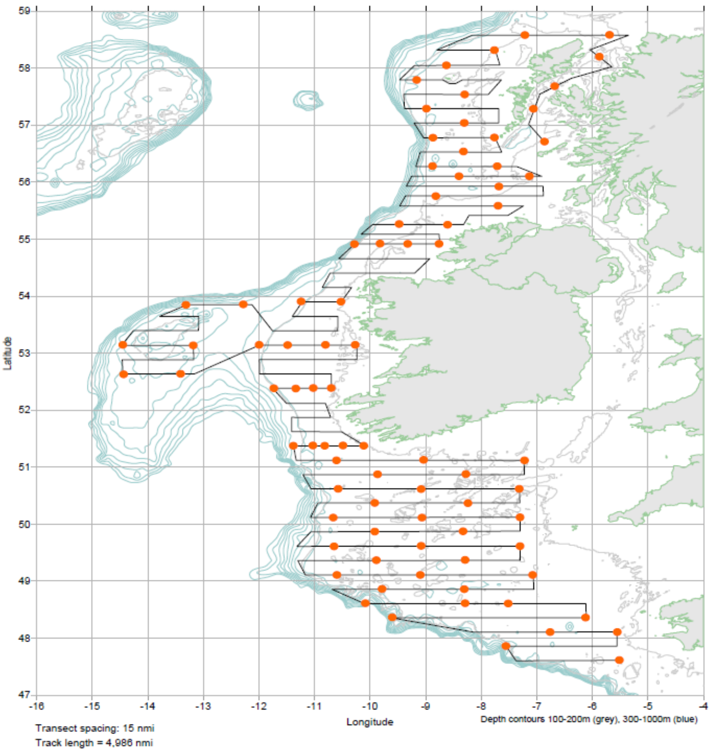

Fig 1: WESPAS 2021 survey track with CTD stations.

Since 2017 the survey has started in the south in north Biscay and worked in a northerly direction in a series of parallel transects spaced 10-15nm apart. The western extent of the transects coincides with the shelf break and depths of approximately 300m with the exception of the Porcupine bank (400m). The easterly extent of the transects generally coincides with the land mass (min. depth 50m) with the exception of Celtic Sea transects. Transects may extend further east or west than planned as they are usually only ended once a number of miles have been completed with no acoustic detections. The survey design consists of a number of strata (species specific) with a total transect length of approximately 5000nm (9250 km) and area coverage of 65,000 nm^2 (225,000 km^2).

Acoustic data is collected by a Simrad EK60 on 4 frequencies (18,38,120 and 200kHz). Echograms are scrutinised by experienced scientists with individual schools identified to species level where possible. Annual survey estimates of abundance at age at species level are generated using the StoX software package.

The RV Celtic Explorer is equipped with twin electric motor propulsion powered by a diesel engine and meets the ICES criteria for research vessel standards with respect to underwater radiated noise (CRR209).

Biological sampling is carried out in response to acoustic registrations using a single midwater pelagic trawl 85m in length with a fishing circle of 420m. Mesh size in the wings is 2.4m, reducing to 10cm in the cod end. The net is fished with a vertical opening of approximately 25m and monitored via a headline transducer and door sensors. On selected hauls, cameras and lighting are mounted in the net. Tow speed is approximately 4-4.5 knots with tow duration dependent on real time information on catch from the headline transducer. The net is weighted by a pair of chain clumps of 750 kg each, ensuring a rapid descent to the targeted fishing depth. During the shooting of the net, the vessel steams ahead at approximately 1-1.5 knots during which time the gear sinks rapidly. The warp length depends on fishing (target) depth and varies between 50 and 800m. Once the target has been sampled the gear is hauled. During the hauling of the gear, the vessels' speed is reduced to approximately 1-1.5 knots reducing the door spread and warps are winched at approximately 1.25 m/s such that a trawl with a fishing depth of 150m would typically have a warp length of 700m and require 10 minutes of hauling to retrieve the doors. The fishing power of the net during shooting and hauling is considered to be minimal.

Once on deck, all components of the catch are sorted and identified. Length frequency and length weight data recorded for each species component. Subsampling for age determination is carried out for Herring, Boarfish and Horse Mackerel. Haul level information is used by StoX in the estimate of abundance at age for each target species with hauls assigned to individual acoustic registrations within the StoX project.

A number of additional scientific programmes are carried out during the WESPAS survey including

- CTD monitoring of water column structure at approximately 80 predetermined stations on the survey track. Water samples are taken at a range of depths and further analysed for
  - Coloured Dissolved Organic Matter
  - Chlorophyll
- Zooplankton and jellyfish
- Seabird and marine mammal observations

Water column structure

Approximately 80 CTD casts are conducted each year at predetermined stations to record conductivity and temperature depth profiles and also to secure water samples at various depths for the ancillary science programs. CTD casts are also often accompanied by zooplankton sampling.

The survey takes place during summer when thermal stratification is established over much of the continental shelf. The local extent to which stratification is established in any one year depends on a number of factors including thermal heating, vertical mixing induced by wind and wave activity, proximity to shore and the effects of coastal runoff and the prevailing tidal conditions particular to the locality and the springs-neaps tidal cycle.

There is significant variability in both the depth and gradient of any thermocline over the survey area. The surface temperature (@10m) from the 2016-2021 surveys is shown in figure 2.

WESPAS 2016-2021, Temp @ 10m

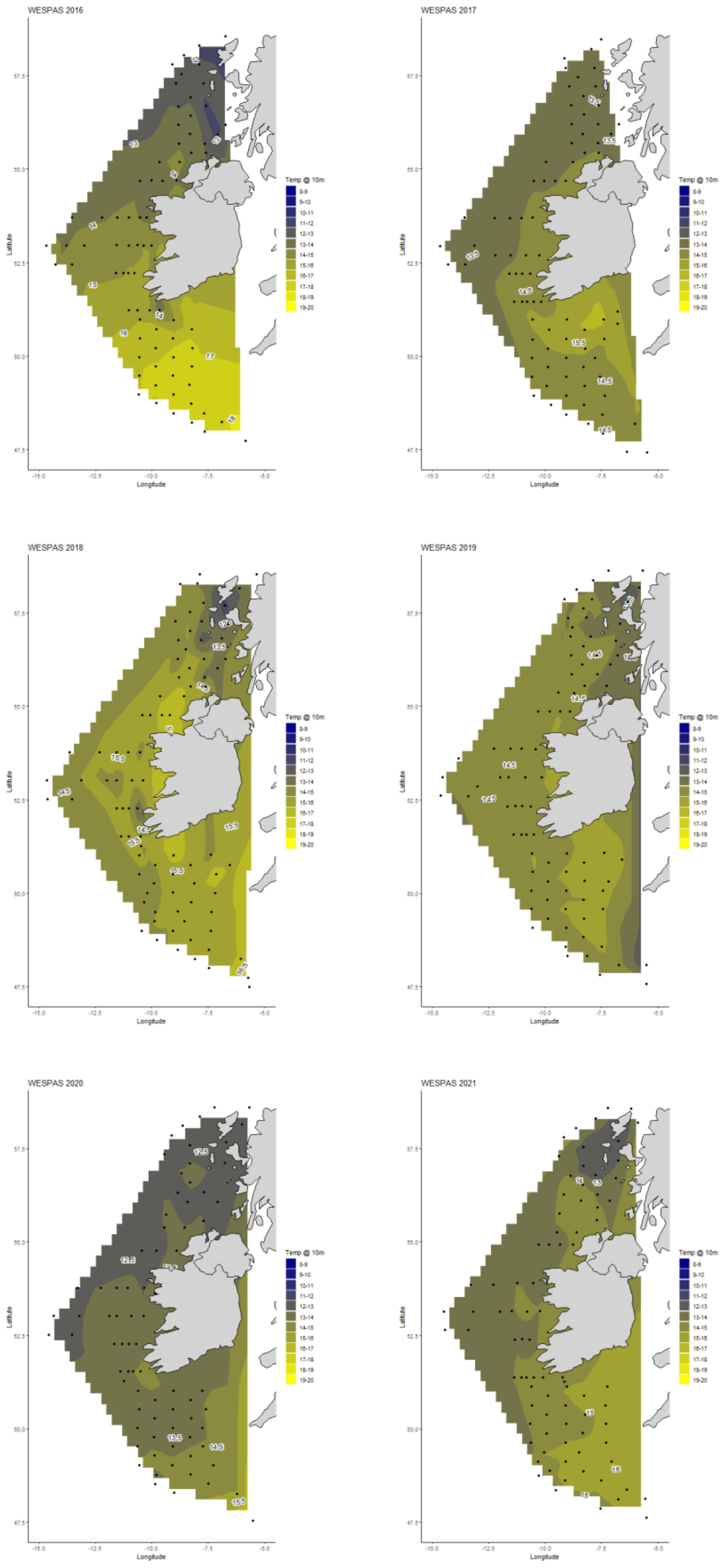

Fig. 2 Temperature at 10m depth from WESPAS surveys 2016-2021.

A wide range of surface temperatures have been recorded over the survey area. At the southern extremes, surface temperatures of 16 ˚C are common although 18 ˚C was recorded in the Celtic Sea and Northern Biscay in 2016, although it should be noted that in 2016, the survey ran north to south such that observations in the south in 2016 would be approximately 6 weeks later in the years since. At the most northern stations, temperatures are typically in the range 12-13 ˚C. 2016 appears to be a particularly warm year, particularly in the south whereas 2020 is the coolest overall. The corresponding temperatures at 25m and 50m are shown in figures 3 and 4 respectively.

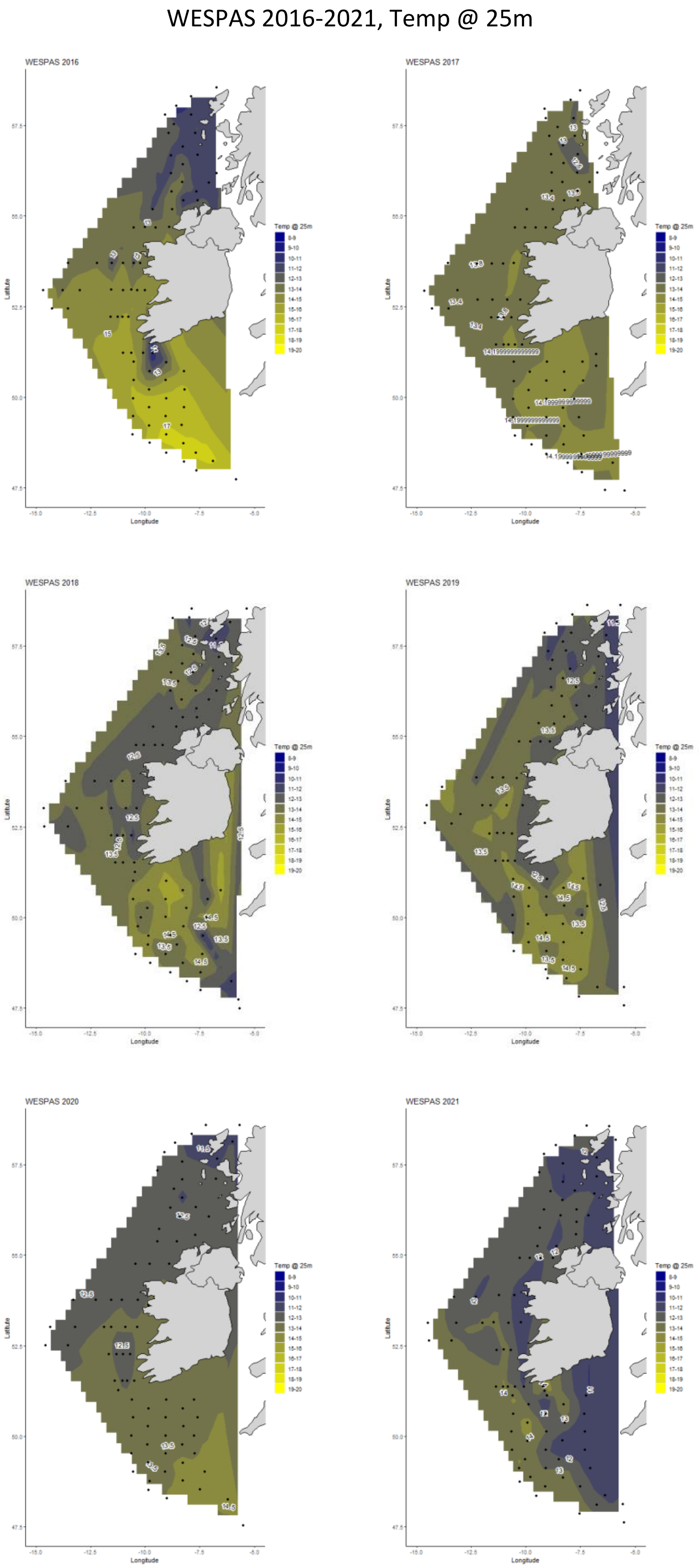

Fig. 3 Temperature at 25m depth from WESPAS surveys 2016-2021.

WESPAS 2016-2021, Temp @ 50m

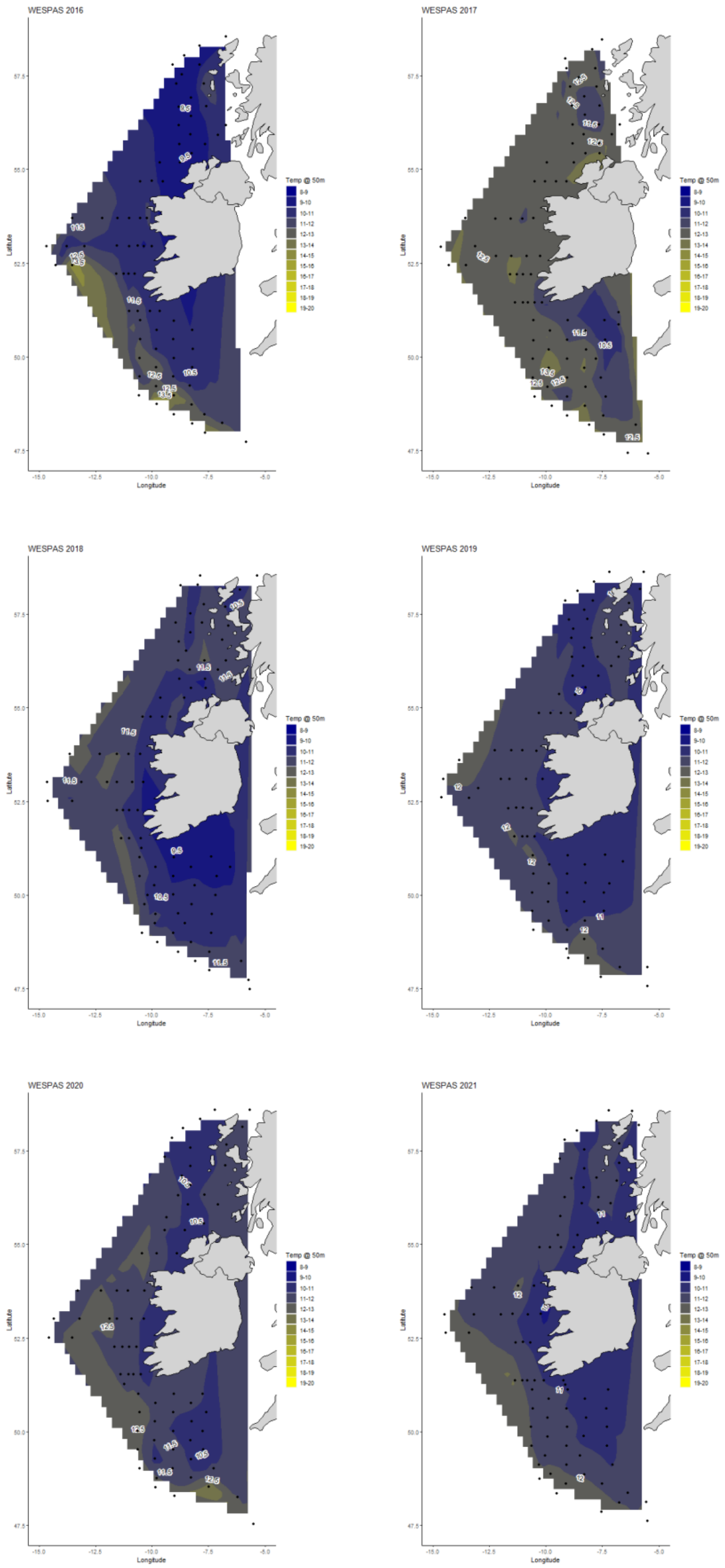

Fig. 4 Temperature at 50m depth from WESPAS surveys 2016-2021.

Temperatures at 25m vary between 12 and 17˚C indicating that the warm mixed surface layer frequently extends to depths greater than 25m. Temperatures at 50m tend to be more uniform across the survey area in any year, varying by a maximum of 2˚C between the most southerly and northerly stations and are rarely below 10˚C but indicate that the thermocline is usually at a depth of less than 50m.

Individual CTD profiles reveal the degree of stratification typically found over the geographic extent of the survey. CTD stations in the Celtic Sea tend to be associated with strong thermal stratification which is reduced somewhat closer to the shelf edge. Fig 5 shows the vertical profile from 6 Celtic Sea stations in 2017

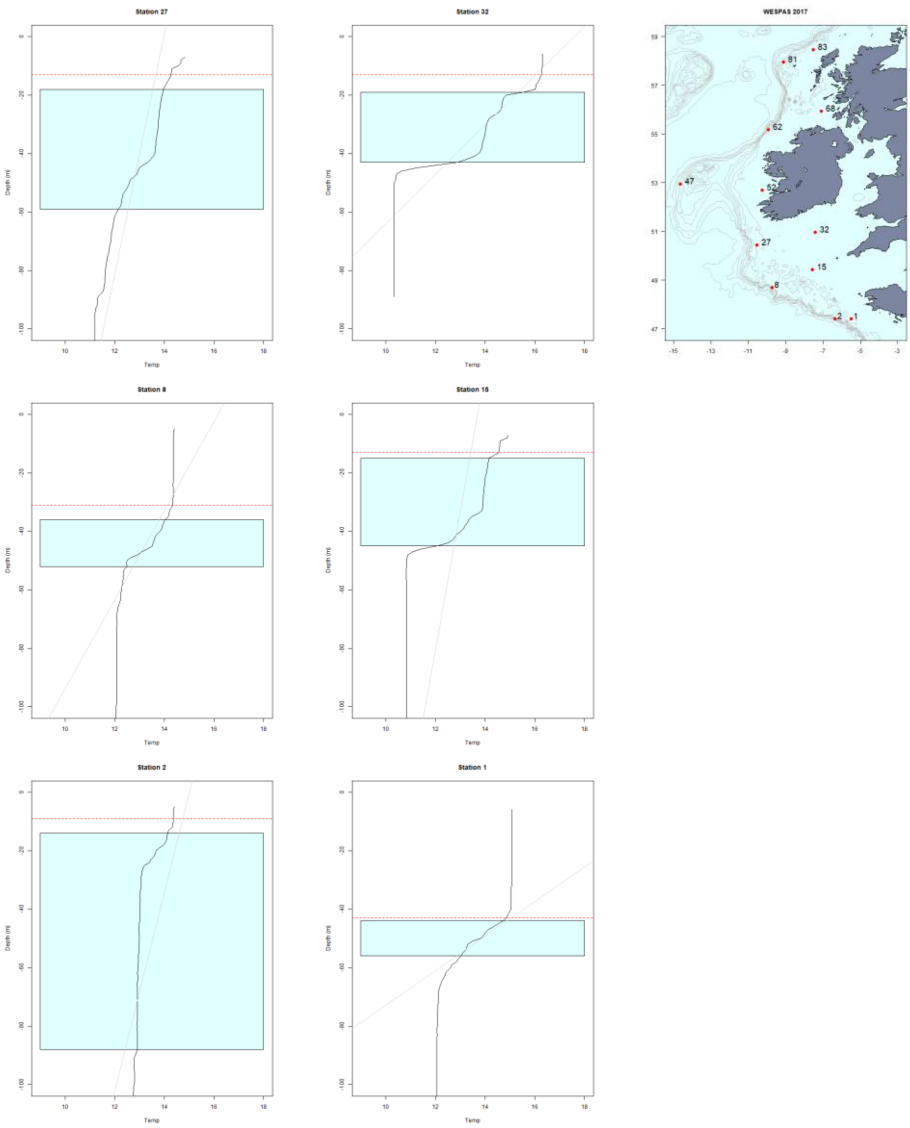

Fig. 5. Selected CTD temperature profiles, Celtic Sea & Northern Biscay, WESPAS 2017. Red dashed line indicates the mixed layer depth, blue shading the thermocline as calculated using the scheme of Chu and Fan (2016)

Stations on the Porcupine Bank where depths reach 400m typically show a more uniform temperature profile with stratification increasing closer to the Irish coast. Varying degrees of stratification are found to the North of Ireland and West of Scotland. Figure 6 shows a selection of profiles recorded during 2017. The position of the relevant CTD stations are indicated on the map.

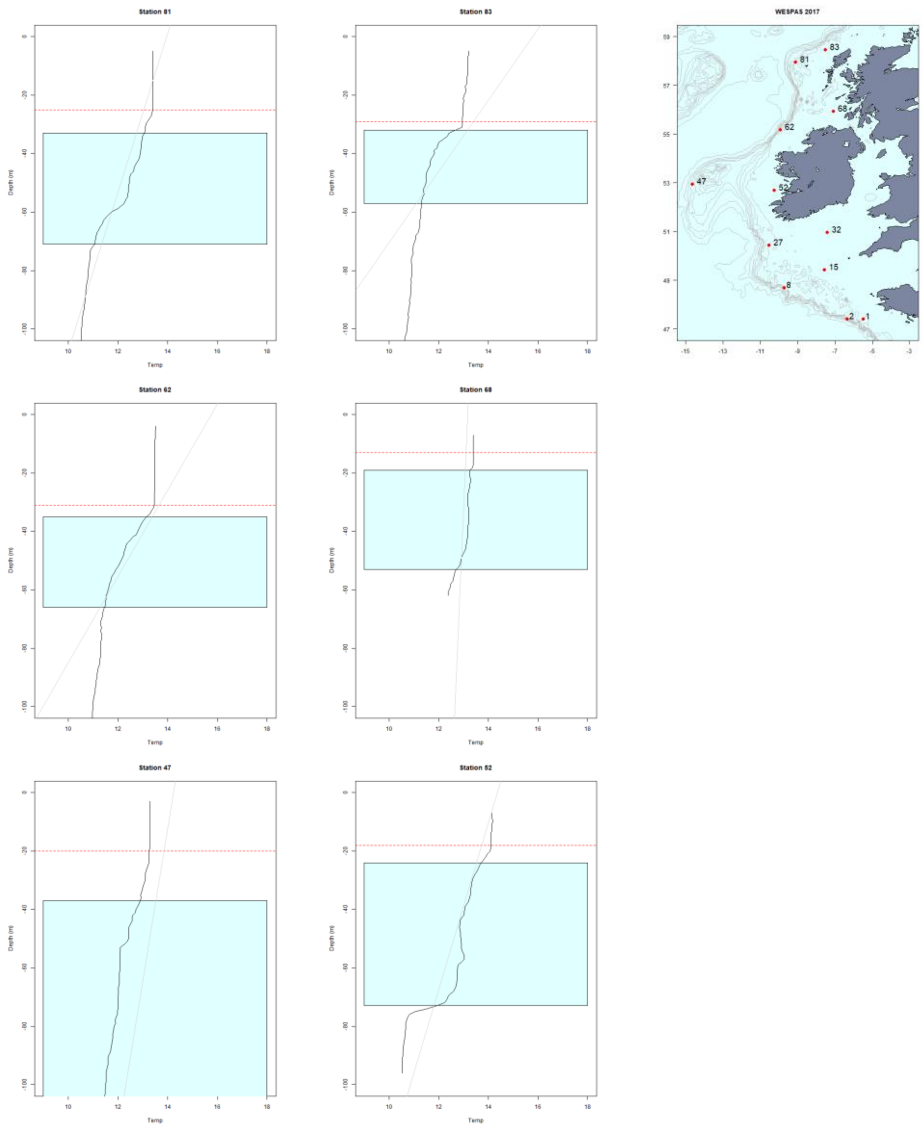

Fig. 6. Selected CTD temperature profiles, Porcupine Bank, West of Ireland and Scotland, WESPAS 2017. Red dashed line indicates mixed layer depth, blue shading the thermocline as calculated using the scheme of Chu and Fan (2016)

Across the survey area, mixed layer depth is variable – generally between 20 and 30m but extending to 50m in deeper waters to the west where the thermal gradient is also weaker. Surface to bottom temperature differences vary from close to zero to 6˚C with a median of approximately 3.5˚C. The minimum bottom temperature is rarely below 9 ˚C. Figure 7 shows the distribution of temperature difference values between the surface and bottom for each survey year.

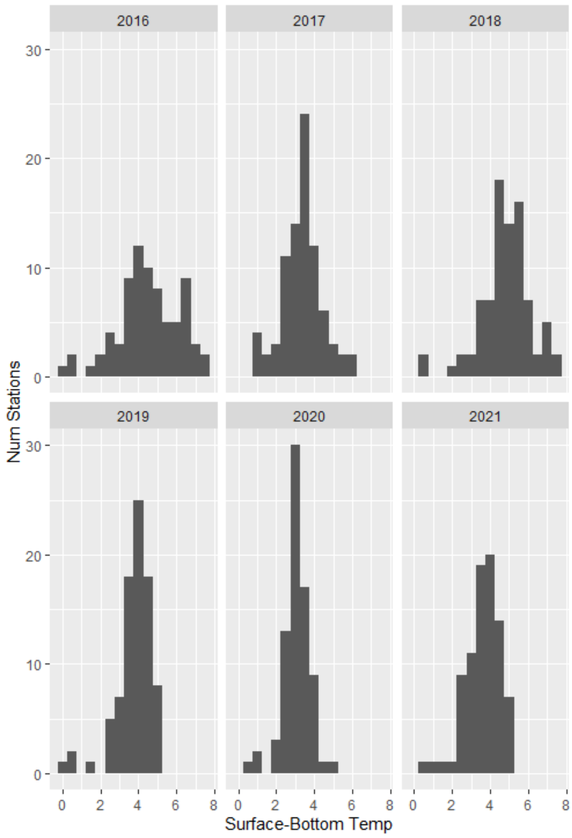

Fig.7. Distribution of Surface-Seabed temperature differences by survey year

Chu and Fan (2017) Exponential leap-forward gradient scheme for determining the isothermal layer depth from profile data. Journal of Oceanography, 73, 503-526

Fishing Haul Samples

A number of hauls are undertaken each year (35-65) in order to provide biological samples for the verification and quantification of acoustic registrations. The majority of hauls are conducted for the purposes of sampling the survey target species (Herring, Boarfish and Horse Mackerel) but are also carried out to validate acoustic marks or layers of unknown or non-target species. The complete catch from each haul is separated by species and sampled for length and weight and further subsampling for age, sex, maturity and genetics (herring only) for the target species. Also recorded during fishing operations are a number of metrics associated with the fishing tow including tow speed, door spread, tow duration, warp length, headline depth and temperature at the headline. Tow depth varies according to the position of the target, duration is generally between 30 and 60 minutes but occasionally shorter if the headline transducer indicates a potentially large catch.

Figure 8 shows the location of the hauls from each of the surveys between 2016 and 2021. Hauls with no Mackerel, those with Mackerel present and those with 20kg or more of Mackerel are indicated.

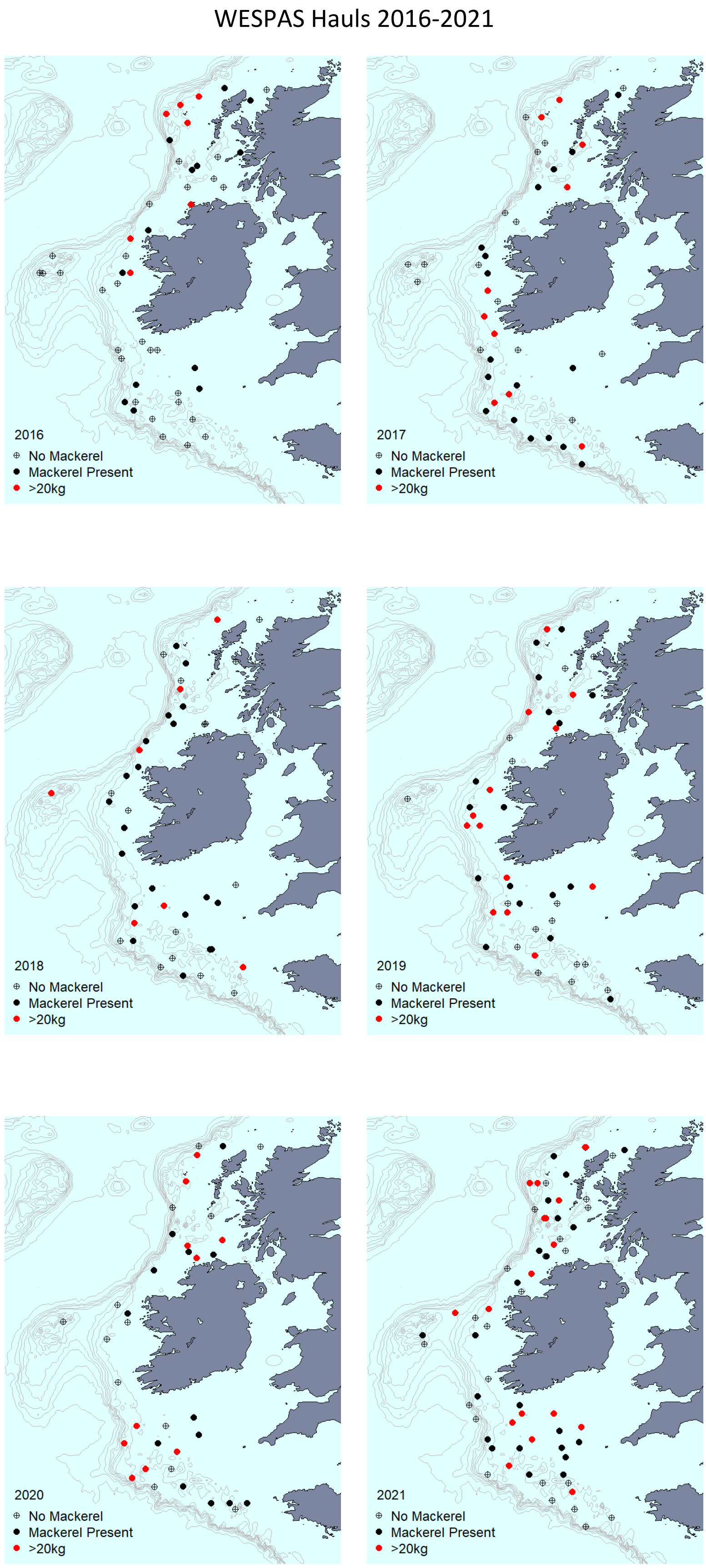

Figure 8. WESPAS survey hauls indicating those with no mackerel, those with mackerel (filled circles) and those with greater than 20kg of mackerel (red).

Mackerel has been caught in over 60% of the survey hauls in each year with the exception of 2016 when most of the hauls carried out in the Celtic Sea and SW or Ireland did not contain any mackerel. Surface temperatures in this area in 2016 were the highest in the time series, in excess of 17˚C south of 50˚N although it should also be noted that the survey was conducted from north to south in this year such that the sampling in southern waters will be several weeks later than that in surveys since 2017. The highest proportion of hauls containing mackerel (2/3) is recorded in 2020 (a relatively cool year).

Aside from the distribution noted for 2016, there appears to be little geographical variation in the distribution of hauls containing or devoid of mackerel. Hauls containing over 20kg of Mackerel are also widely distributed over the survey area. The table below details the proportion of hauls containing mackerel for the survey time series.

Year	Hauls	With Mackerel	>20kg Mackerel	Catch Rate (kg/km2) (CR >0)		
				25^{th}	Median	75^{th}
2016	47	20 (43%)	7 (15%)	25	48	274
2017	42	27 (64%)	10 (23%)	23	85	237
2018	42	27 (64%)	7 (15%)	15	46	162
2019	45	30 (60%)	13 (28%)	14	62	289
2020	35	23 (66%)	10 (29%)	30	70	247
2021	65	40 (62%)	18 (28%)	24	85	210
All	276	167 (61%)	65 (24%)	18	70	225

The catch rate per haul is calculated on the basis of an estimated swept area. The net is designed to have a wingspread of 42m. Combined with the fishing time (the time spent (min) at the target depth *i.e.* excluding shooting and haul period) and tow speed (knots) recorded during the fishing operation, the swept area in square km is calculated as

Swept area = (fishingtime*60) * (wingspread/1000) * (towspeed*0.514/1000)

The catch rate per station for each of the surveys is shown in figure 9.

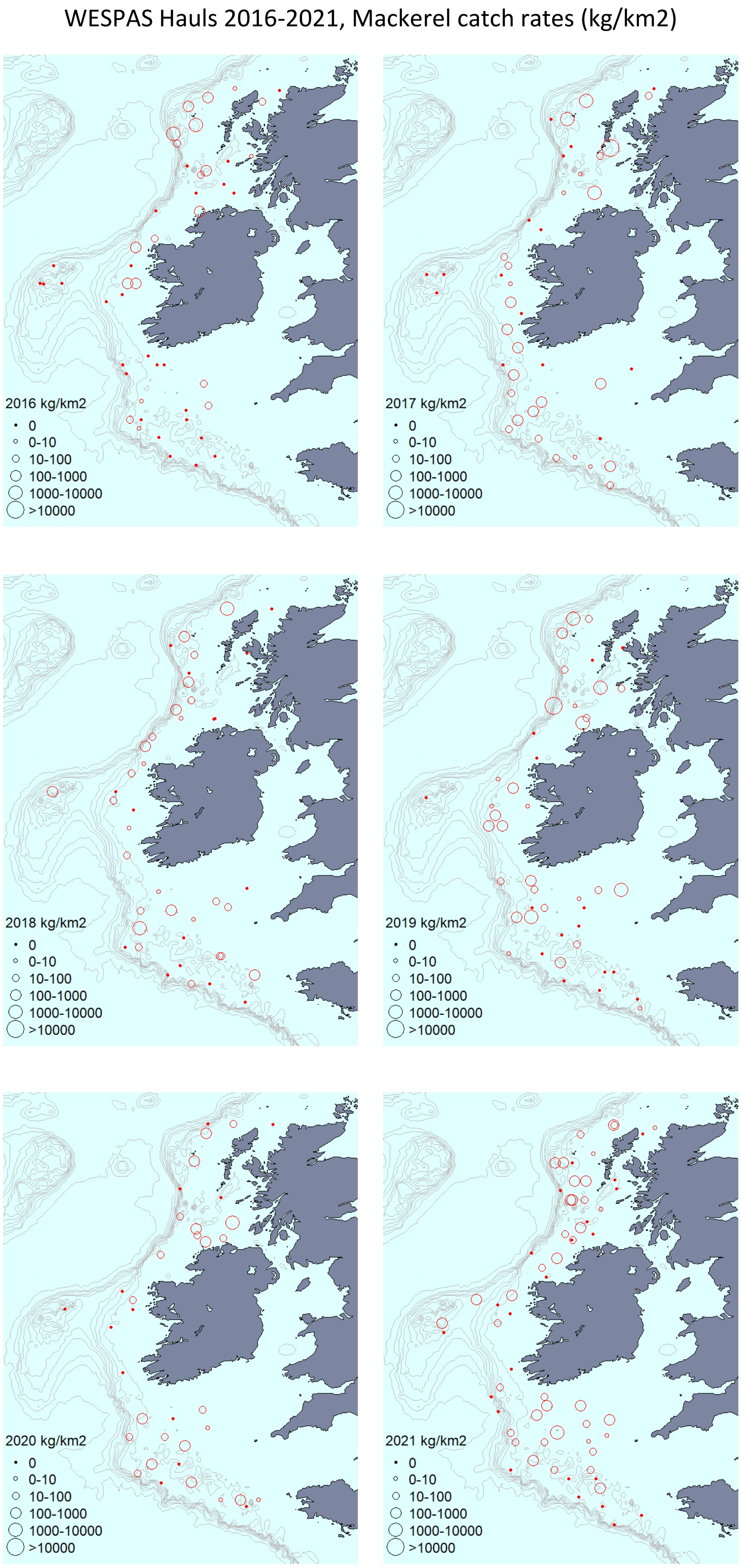

Figure 9. WESPAS surveys 2016-2021. Mackerel catch rates

Catch by depth

Hauls are carried out at various depths, depending on the acoustic data with targets situated both above and below the thermocline although the majority (approximately ¾) are below 50m (median fishing depth 92m, 276 observations). Most hauls take place within 50m of the seabed as determined by the height of the footrope (bottom depth - headline depth - net opening)

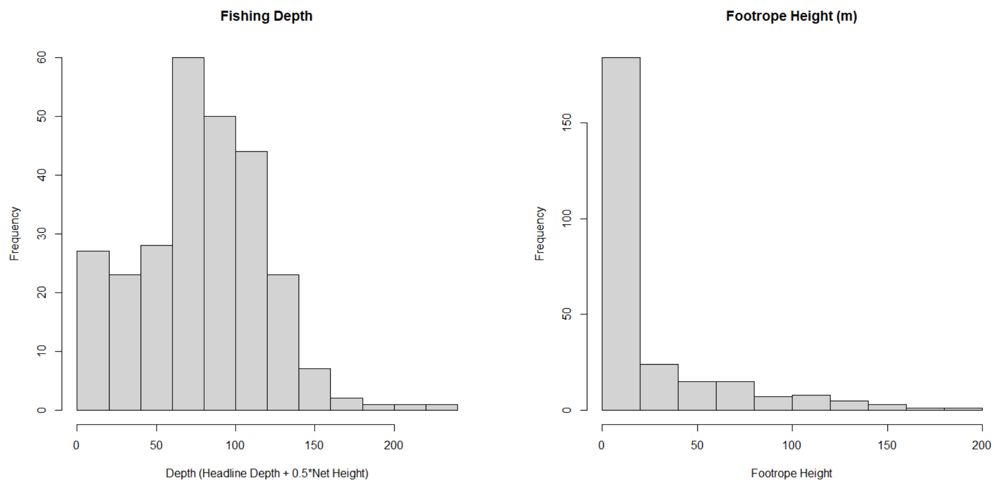

Figure 10: Distribution of fishing depth and footrope height, all hauls 2016-2021.

For all hauls containing mackerel, the relation between catch rate and fishing depth is shown in figure 11.

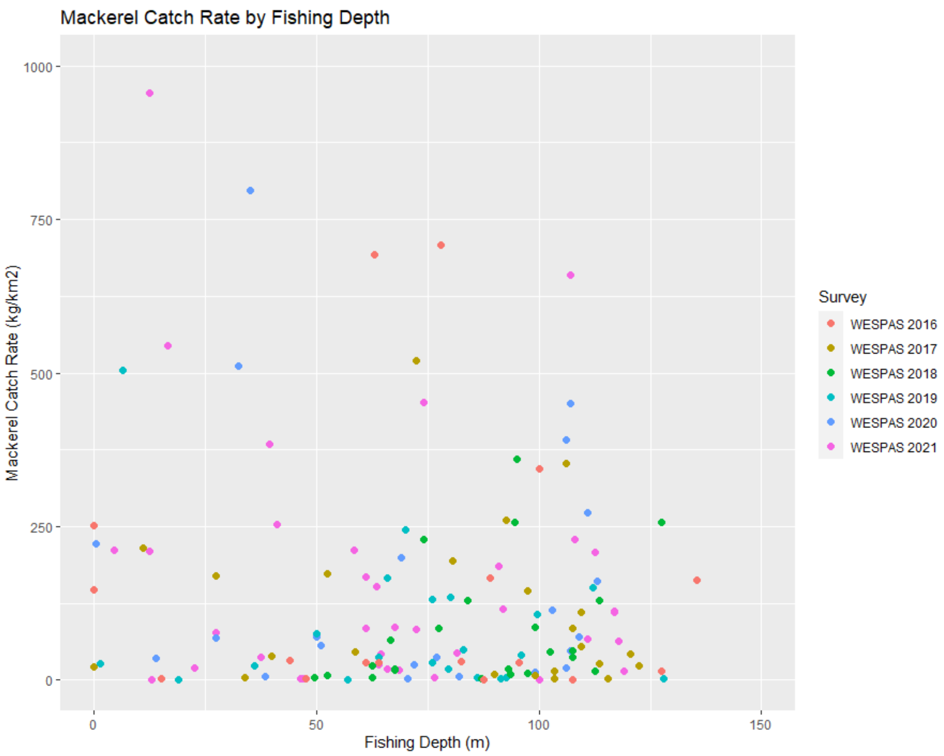

Figure 11. Mackerel catch rate (kg/km^2) by fishing depth (depth of midpoint of vertical net opening)

The majority of hauls contain less than 20kg mackerel. However, a total of 65 hauls have 20kg or more. The fishing depth of this subset of hauls is shown in figure 12.

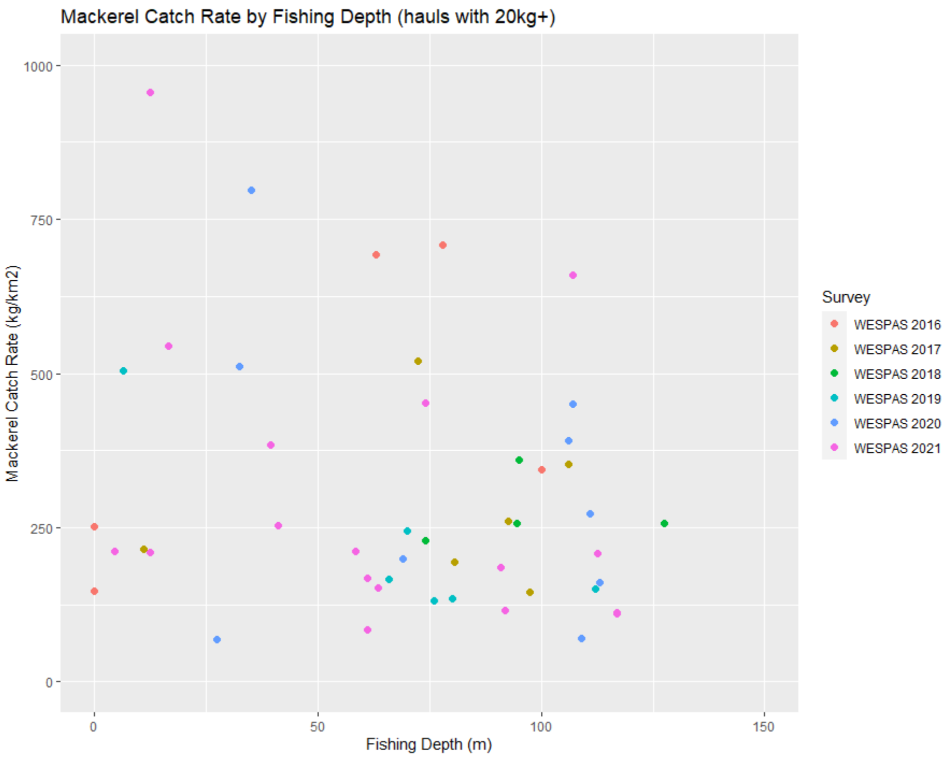

Figure 12. Mackerel catch rate (kg/km^2) by fishing depth (depth of midpoint of vertical net opening) for hauls with over 20kg of mackerel.

Length Structure

As mackerel is not a target species for the WESPAS survey, samples are not collected for ageing. However, a length frequency is recorded for each species caught during the survey. The aggregated mackerel length frequency for each survey is shown in figure 13.

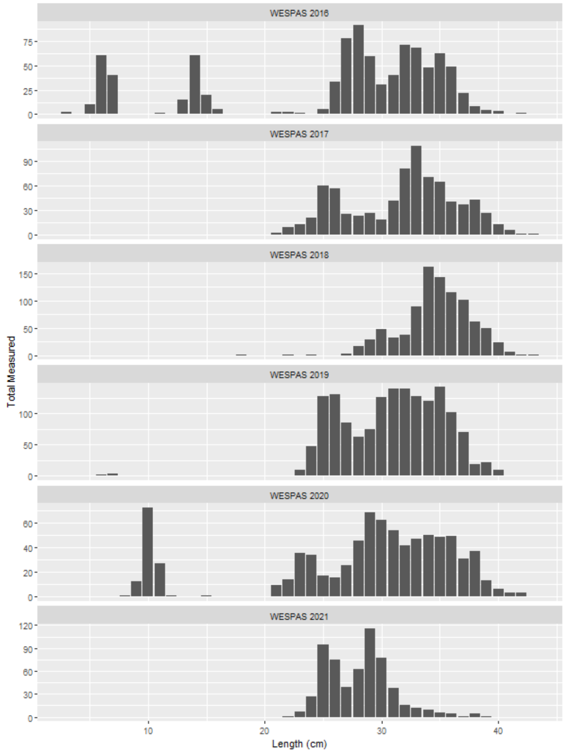

Figure 13. Mackerel length frequency from all samples by survey year (5566 specimens, average 75 per haul)

Although variable with occasional hauls of juvenile fish (in 2016 and 2020), figure 13 indicates that both immature and mature mackerel are to be found over the survey area during June and July. There is some degree of cohort tracking, particularly from 2016-2020 with a peak from 32-36cm (age 3-7). 2021 samples consist primarily of specimens under 30cm (mean length at age 2 = 30.7 cm from 2019 commercial catch sampling).

Acoustic Registrations

Due to its lack of a swim bladder, mackerel is more difficult to detect acoustically and do not show up reliably on the 38kHz echosounder, the frequency used to estimate abundance and biomass of herring, boarfish and horse mackerel on this survey. However, occasionally aggregations can be detected at the higher frequencies available on this survey (in particular 120 and 200kHz). Scientists scrutinising the survey echotraces will identify a mark to species level based on a number of factors including the density, size, shape, depth and location of a mark but also based on the relative response at each frequency. Mackerel marks are usually not selected for sampling as this is not a target species on this survey. Moreover, the design of this survey including the net specifications mean that mackerel is difficult to catch, experience shows it is very capable of avoiding the gear, in particular by diving under the footrope. They are also fast swimmers, easily capable of swimming faster than the gear. Each year however, a number of acoustic marks are designated to be mackerel. These marks can be found close to the surface (Figure 14), close to the bottom (Figure 15) and in midwater (Figure 16), with no apparent trend in their distribution from year to year. It is unclear why mackerel tend to be visible on the echosounder in some areas and years and not in others. Generally during this survey mackerel are caught in hauls where there is little evidence of them appearing on the echosounder. An acoustic estimation of mackerel abundance and biomass from this survey is unreliable at this stage.

Mackerel Marks

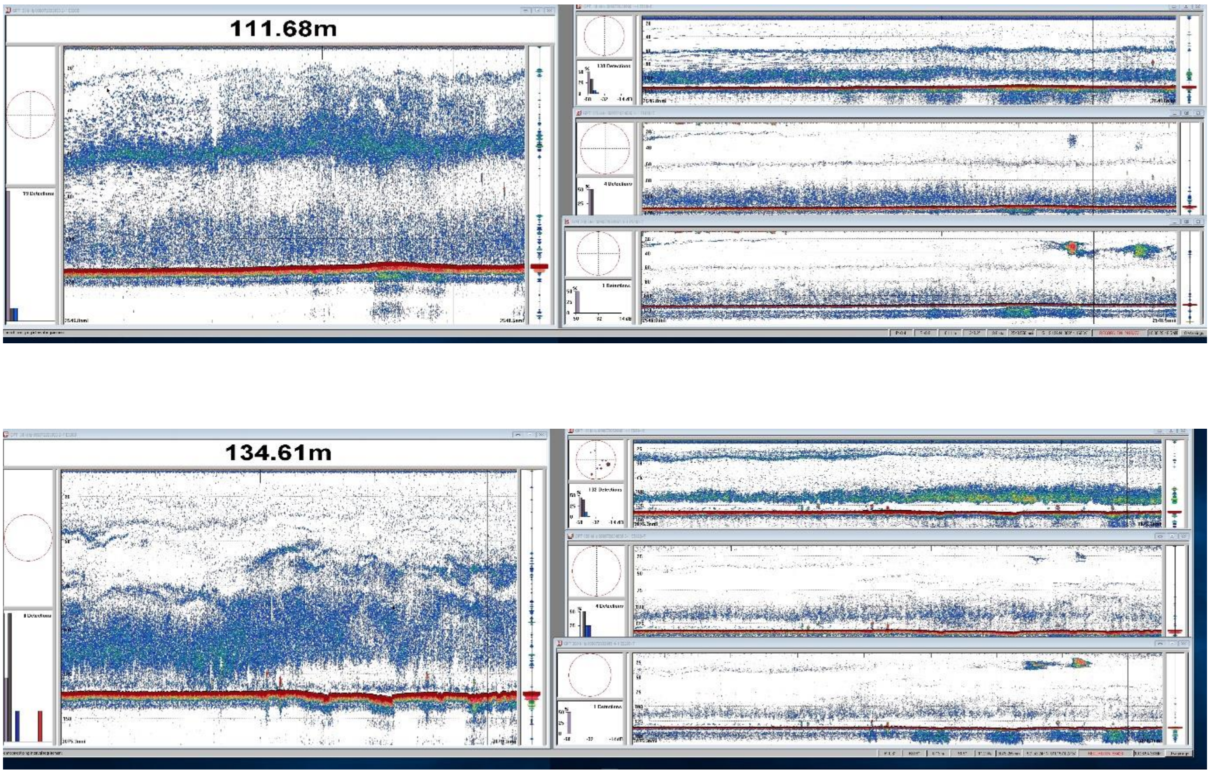

Figure 14. WESPAS 2021 surface marks showing stronger on the higher frequencies (120 and 200kHz)

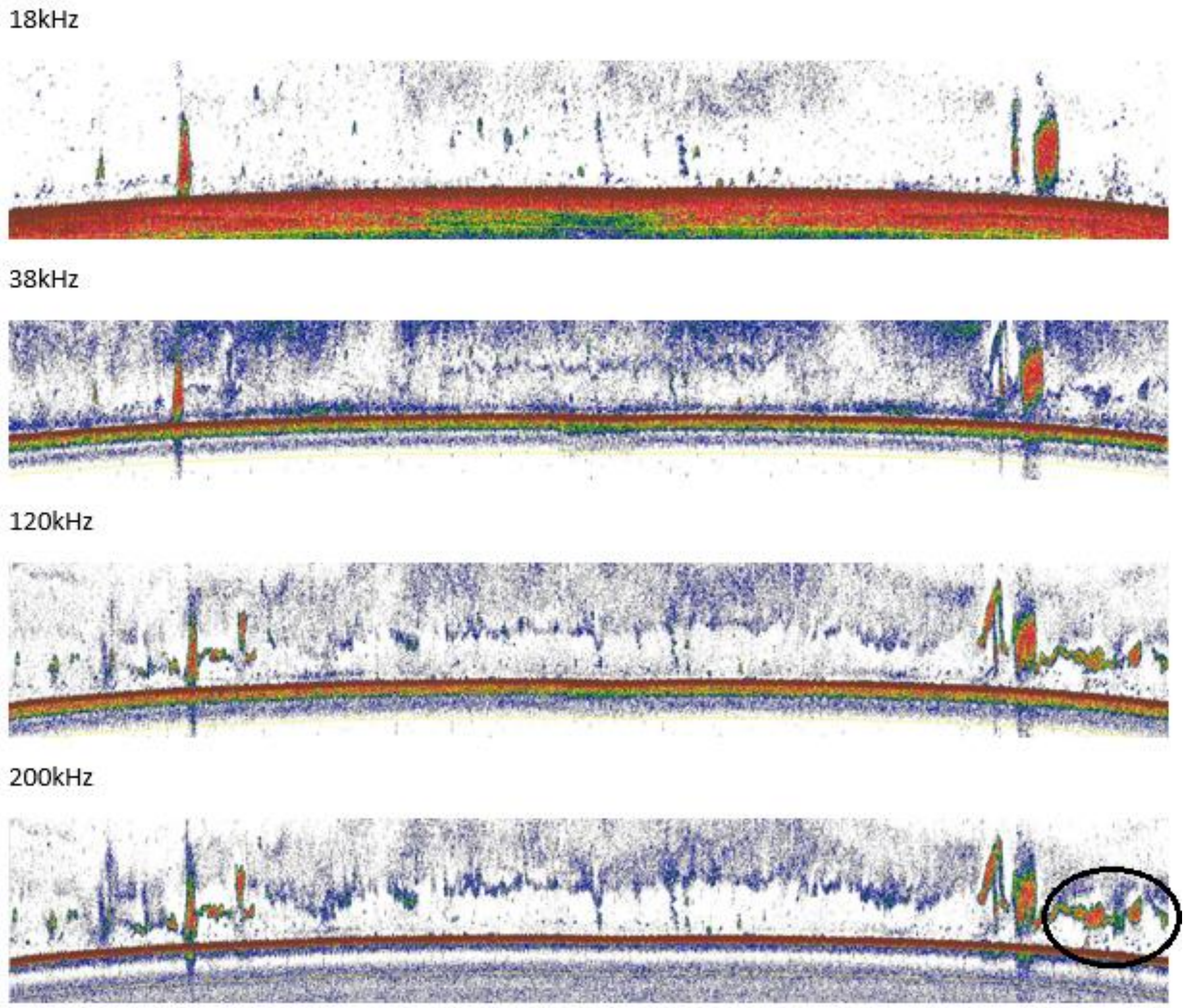

Figure 15. WESPAS 2019 (haul number 38 at 56˚ 36N and 7˚ 53W). Example of mackerel caught at ~160m depth. The target for sampling was the tall echotrace marking on all 4 frequencies on the right hand side of all panels above. This mark has all the attributes of a swim-bladdered fish, and turned out to be blue whiting. The black oval shape shows mackerel marking on the 120 and 200kHz, and very little showing on the lower frequencies (18 and 38 kHz) in this area. The catch for this haul was 104 kg blue whiting and 92 kg mackerel. There is some evidence of mackerel marking on the left hand side of the panels above also, however these marks were not fished on.

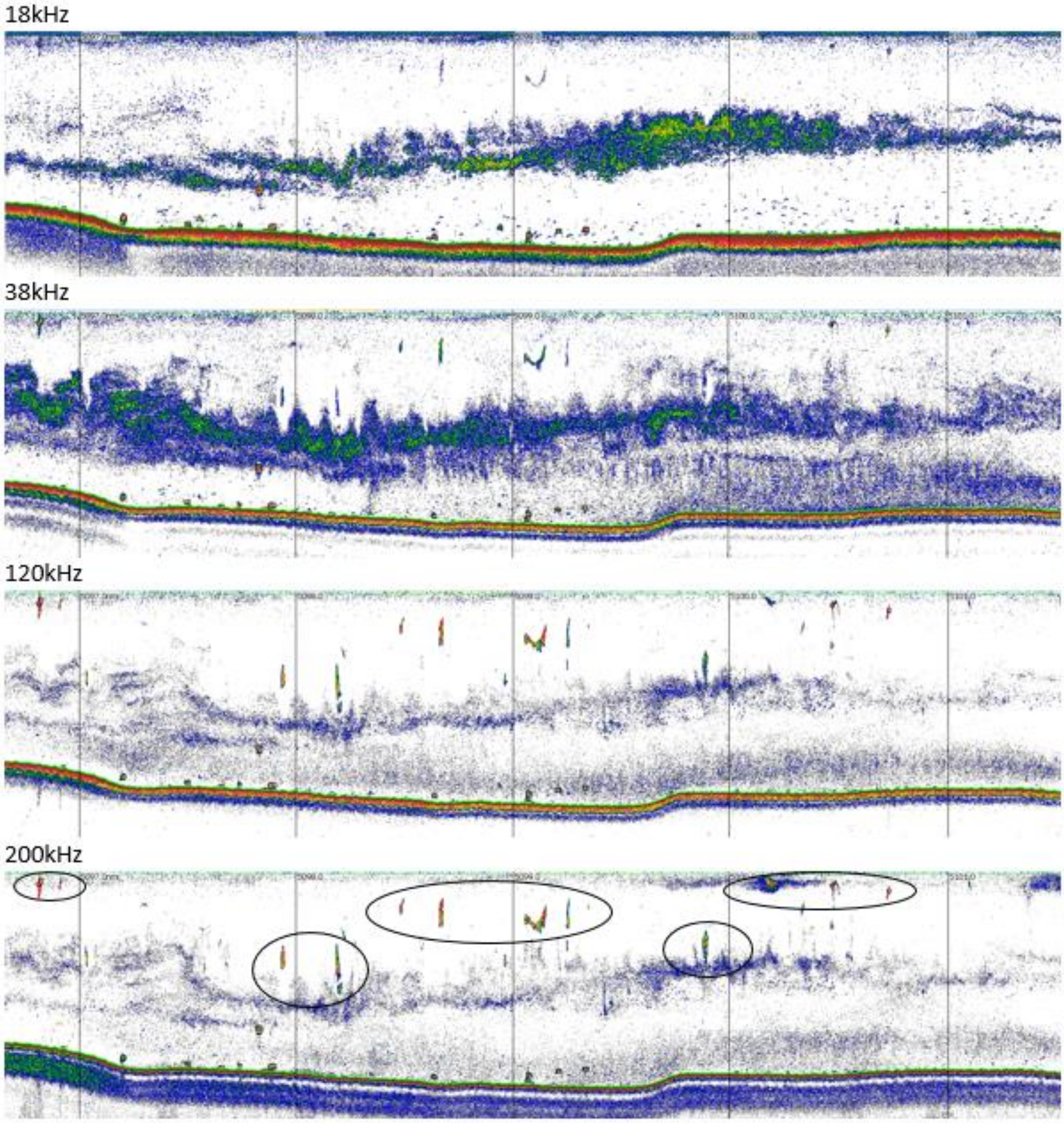

Figure 16. WESPAS 2021 (transect 45 at 56˚ 31N and 7˚ 43W). The black oval shapes show suspected mackerel marks in surface and midwater (surface down to 100m). On the occasions when mackerel show on the echosounder during the survey, the marks tend to show stronger on the 120 and 200kHz. Water depth ~ 190m.

WD ICES WGWIDE 20201

The 2021 updated RFID tag-recapture data on NEA mackerel – Trends in abundance with different filtering

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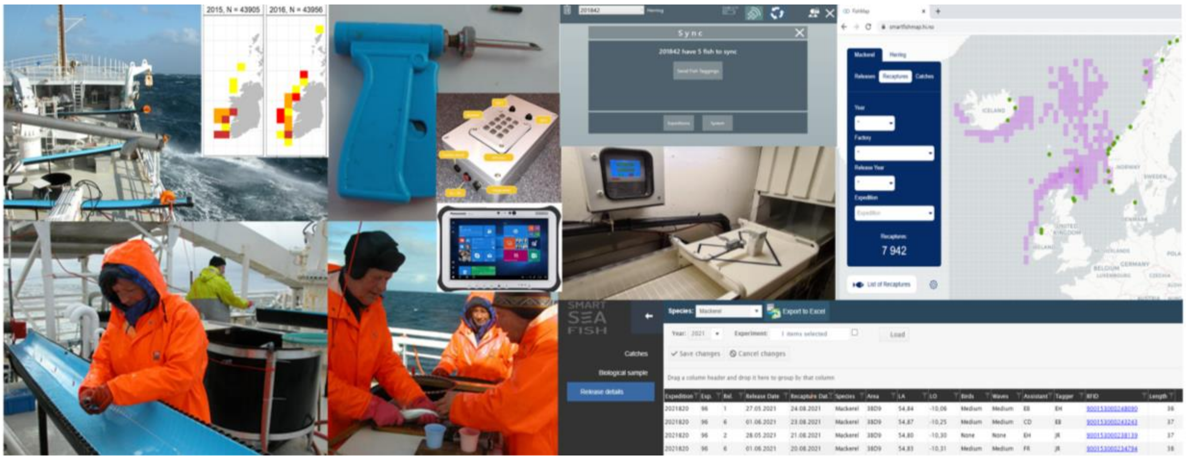

Summary

A full overview and update of the RFID tagging experiments of mackerel 2011-2021, as well as the recaptures and scanned fish 2012-2020 is given. Since the benchmarking process during ICES IBPNEAMac 2019 and decisions therein, the data included in the SAM stock assessment has been filtered to only include mackerel tagged at ages 5-11, release years 2013 an later and recaptures limited to year 1 and 2 after release. The RFID data set used as input to the SAM stock assessment is a complex one with numbers released per age in a release year, and the numbers scanned and recaptured of these year classes annually in all the years after release; i.e not typical abundance indices per age per year as normally included in age based assessments. Hence, the overview does not only focus on the input data themselves and quality assurance of these, but the actual trends they show for both the different year classes and biomass. Special effort in put on demonstrating trends in actual data included in assessment compared with other ways of filtering the data, such as including more age groups and more years with recaptures after release then the current assessment. Finally, the year class trends, mortality trends in the RFID data are compared with the other age-based input data from commercial catches and the international trawl survey in the Norwegian Sea (IESSNS).

Background

The Institute of Marine Research in Bergen (IMR) has conducted tagging experiments on mackerel on annual basis since 1968, both in the North Sea and to the west of Ireland during the spawning season May–June. Information from steel-tagged mackerel tagged west of Ireland and British Isles was introduced in the mackerel assessment during ICES WKPELA 2014 (ICES, 2014), and data from release years 1980-2004, and recapture years 1986-2006 has been used in the update assessments after this. The steel tag experiments continued to 2009, with recaptures to 2010, but this part of the data was at the time considered less representative and was excluded.

What is used in the SAM stock assessment is a table of data showing numbers of steel tagged fish per year class in each release year, and the corresponding numbers scanned and recaptured of the same year classes in all years after release. The steel tag data and the corresponding trends in the data in terms of index of total biomass and year class abundance by year is described in (Tenningen et al., 2011).

The steel tag methodology involved a whole lot of manual processes, demanding a lot of effort and reducing the possibility to scan larger proportions of the landings. The tags were recovered at metal detector/deflector gate systems installed at plants processing mackerel for human consumption. This system demanded external personnel to stay at the plants supervising the systems during processing. Among the typical 50 fish deflected, the hired personnel had to find the tagged fish with a hand-hold detector and send the fish to IMR for further analysis. It was decided in the end to go for a change in methodology to radio-frequency identification (RFID), which would allow for more automatic processes and increased proportion of scanned landings.

RFID tag recapture methodology and data quality assurance

The RFID tagging project on NEA mackerel was initiated in 2011 by IMR, and the data were used in update assessments after the ICES WKWIDE2017 benchmark meeting (ICES, 2017b). The data format was the same as for steel tags, but the time series were treated with a different scaling parameter in the assessment.

RFID is a technology that uses radio waves to transfer data from an electronic tag, called an RFID tag, through a reader for the purpose of identifying and tracking the object. The tags used for mackerel are passive, commonly called PIT-tags, specifically developed for tagging fish and animals. They are made of biocompatible glass (specific type used for mackerel is ISO FDX-B 134,3 kHz, 3.85x23mm glass tags) which are equipped with a one-time programmable microchip with a unique ID. Information to the reader is released as it passes an electric field in the antenna system, and information is automatically updated in an IMR database over internet. When tagging and releasing the fish, information is also synced to the IMR database regularly over internet.

There is a web-based software solution (SmartSeaFish) and database that is used to track the different scanning systems at the factories, import data on catch information, and biological sampling data of released fish and screened catches. Based on this information the software is used to allocate the biological data to releases and catches, and to further estimate numbers released every year, and the concurrent numbers screened and recaptured over the next years (by year class).

The development of the tagging data time series is dependent on the work from each country's research institutes, fisheries authorities or the industry it selves to provide additional data about catches screened through the RFID systems, such as total catch weight, position of catch (ICES rectangle), mean weight in catch, etc. Regular biological sampling of the catches landed at these factories is also needed. Altogether, these data are essential for the estimation of numbers screened per year class. Responsible scientists in Norway, Iceland, Faroes and Scotland has been following up the factories, and delivering the catch data and biological data. Currently the responsibilities are as below:

Iceland: Anna Olavsdottir (HAFRO) responsible scientist

- uploading catch data and biological data to SmartSeaFish database
- allocating recaptures and biological samples to the different landings
- testing the 3 Icelandic factories for efficiency, 10 test tags in 10 different landings every year.
- initiates servicing of RFID-antenna systems if needed
-

Scotland: Steve Mackingson (Scottish Pelagic Fishermen's Association) responsible scientist

- uploading catch data to SmartSeaFish database (we still use Norwegian biological data from same period/ICES area)
- allocating recaptures to the different landings
- testing the 5 Scottish factories for efficiency, 10 test tags in 10 different landings every year/season.
- initiates servicing of RFID-antenna systems if needed
-

Norway: Aril Slotte (IMR) responsible scientist for the Norwegian RFID tagging program for mackerel and herring, main responsible for final estimations needed to procuce the data table delivered to ICES WGWIDE

- uploading catch data and biological data to SmartSeaFish database
- allocating recaptures and biological samples to the different landings (including biological data to Scottish landings)
- Norway now has 15 factories with RFID antenna systems for scanning mackerel and herring. All factories are serviced 1 time per year and when there are apparent issues to be solved
- A new monitoring system has been developed (Figure 1). which is now placed at all 15 Norwegian factories. This monitoring system is continuously overviewing that RFID antennas and readers are functioning. Voltage variations are measured and every 15 min the reading capabilities are tested automatically with a status tag, and these tests are also stored in the SmartFish database for further analyses of efficiency. This monitoring system has replaced the manual testing with 10 test tags in 10 different landings every year/season. The plan is that same systems are

Based on the manual test off recapture efficiencies or the online monitoring, responsible scientists decides if data from a factory has to be excluded from final estimation and data input to ICES WGWIDE assessment. Factories that does not function properly are put in an 'out of order' list (Figure 2), where catch data and recapture data from these 'out of order' periods are excluded during estimation. To conclude with regard to quality assurance we have made progress and current monitoring of efficiencies at factories that has been raised as a main issue is now at an acceptable level. Still, there is need for more quality control of both all raw tag-recapture data, biological data and allocations of these to landings, as well as the final estimations of data included in the ICES WGWIDE stock assessment. In the future we need to develop annual workshops prior to the assessment, where more scientists go through the new data being updated from new tagging experiments, as well as recaptures from all previous experiments, undertake quality assurance of the data and other analyses of the trends in the data outside of the assessment model. The idea is that this should work similarly as post-cruise meetings where all involved scientists take part in final report.

Status of updated RFID tag recapture data

The RFID tagging technology is clearly a more cost-effective than the old steel tag technology. We are now scanning about 10 times more biomass than during the period with steel tags. An overview of the RFID tagging data in terms of numbers tagged, biomass scanned, and numbers recaptured is given in Tables 1-3, and geographical distributions of data in Figures 3-6.

During the period 2011— 20th Aug 2021 as many as 506465 mackerel have been tagged with RFID (Table 1). This includes an experiment off the Norwegian Coast on young mackerel in September 2011 as well as five experiments carried out in August in Iceland 2015-2019, none of which are included as input data in the assessment. Data from the releases at the spawning grounds in May-June of Ireland and the Hebrides are the only data included in the assessment.

The 6663 RFID-tagged mackerel recaptured up to 31. December 2020 came from landing scanned at 23 European factories processing mackerel for human consumption (Table 2- 3). The project started with RFID antenna reader systems connected to conveyor belt systems at 8 Norwegian factories in 2012. Now there are 5 operational systems at 4 factories in UK (Denholm has 2 RFID systems) and 3 in Iceland. Norway has installed RFID systems at 8 more factories in 2017-2018, most of which with the purpose of scanning Norwegian spring spawning herring catches (IMR started tagging herring in 2016), but some also processing mackerel. Recently one factory, Pelagia Austevoll is terminated, so currently 15 factories are scanning for RFID tags in Norway. More systems are also bought by Ireland (3), which up to now has been non-operational.

During ICES WGWIDE 2018 (ICES, 2018d) meeting bias issues were described for RFID tag data, in addition to potential weighting issues of the tag data inside the model. After the intermediate benchmark meeting ICES IBPNEAMac 2019 (ICES, 2019a), these issues were overcome by using a subset of data for release years (exclude 2011-2012), recapture years (only use recaptures from year 1 and 2 after release) and age groups (exclude youngest fish ages 2-4, use ages 5-11). This is now the subset of data to be used in update assessments.

The exclusion of release years 2011-2012, and recapture years 2012-2013 is mainly based in lack of distributional coverage of scanned fishery, which changed significantly when more countries joined the program and scanned landings from 2014 onwards (Figures 4-5).

The exclusion of recaptures in year 3 or longer after the release year was because data indicated tag loss over time, and that the large majority was recaptured prior to year 3 after release. In year recaptures are not used. However, following recaptures from in year (years out=0) and further through year 1-3+ after tagging, it is apparent that tagged fish are quite quickly distributed in the fishery, and the distributional patterns of recaptures are maintained over time (Figure 6). Hence, potentially more recapture years could be included it one overcame how to adjust for potential tag loss.

The exclusion of ages 1-4, was mainly based in noisy data from these age groups, and the fact that in the early tagging years fish in these age groups were relatively few compared with the scanned fish year 1 and 2 after release. Fish from these ages were not considered representative for the behaviour of the year classes. However, over time this picture has changed considerable. The age structure of tagged and scanned fish year 1-2 after release are now overlapping, and high proportions of tagged mackerel are now at ages 2-4 (Figure 7). This means that given current filtering we will exclude large proportions of the RFID tag recapture data in coming years, so this is a decision that will have to be revised. Hence, in the following focus is on the actual trends and consistency in the RFID tag data, having in mind that the current filtering may have to be revised in near future.

Status of RFID tag recapture data trends and consistency for use in stock assessment

Estimates of year class abundance for unfiltered RFID tag-recapture data show trends over time that seems informative for stock assessment (Figure 8), and this is also supported by the tests of consistency in the data (Figure 9), implying a potential for including younger age groups in future assessments.

However, the information coming the RFID tag data is easier to interpret when comparing age aggregated biomass indices estimated from the RFID data (based on year 1-2 with scanning and recaptures) with SSB from the stock assessment, as shown in Figure 10. The decision to exclude release years 2011-2012 is supported by this plot, showing noisy estimates above the confidence intervals of the assessment. However, by including only release years 2013 onwards as in current assessments, the biomass trend in the RFID tag data are more in line with the SSB of the assessment, especially the decrease in SSB from 2017-2019 is also very evident regardless of ages aggregated from RFID data. This again signifies that over time, and in a future benchmark process, information of tag recaptures from younger age groups may be included again should the bias issues tend to disappear and trends are informative for the assessment.

In recent years we have seen a trend that the information from RFID tag recapture data about abundance in a release year increase when adding one more year with recaptures and scanned data. Figures 11-12 illustrates this issue for single year classes as well as various age aggregated abundance estimates. This support the decision to stick to only using recapture and scanned data for year 1 and 2 after release. Moreover, it also implies the last year included in the stock assessment always based on s will be revised in next update assessment, with a recent clear tendency that adding the second year with data lifts the perception of abundance in a release year.

One more way of looking at the information from RFID tag recapture data relative to the other sources of input data and the stock assessment itself, is to compare signals of total mortality rate (Z) by estimating slope of decrease in abundance of year classes 2003-2014 of fully mature fish aged 4-12 (Figure 13). Here it is apparent that mortality signals from RFID data seem informative following a steady decrease as the catch data, whereas IESSNS data sticks out as a bit noisier trends. When looking at the estimated Z for each data source, it is evident that the RFID data show signals of higher mortality rate than the catch data and WGWIDE2021 assessment, whereas Z estimates for the IESSNS data are even lower. Note that RFID data shows more uncertain estimates of Z for recent year classes with very few years, fewer than the other sources, which means the estimates may change over time. The overall conclusion is still that the RFID data seems quite informative, and that the current filtering and exclusion of data for use in stock assessment should be revised in near future.

Figure 14 demonstrates that recaptures from very young fish tagged in the North Sea at the western Norwegian coast (Bømlo Island) over the year adapted the same migration pattern as the fish tagged at older ages along Ireland-Hebrides. This support the hypothesis that mackerel growing up in the North Sea do not belong to a North Sea component, but to a large dynamic mackerel population changing migration pattern and spawning areas as the stock fluctuates in abundance and age structure.

Link to official publication of all raw data needed to produce input data set to the assessment is: Aril Slotte (IMR), Anna Ólafsdóttir (MFRI), Sigurður Þór Jónsson (MFRI), Jan Arge Jacobsen (FAMRI) and Steve Mackinson (SPFA) (2021) PIT-tag time series for studying migrations and use in stock assessment of North East Atlantic mackerel (Scomber Scombrus) http://metadata.nmdc.no/metadata-api/landingpage/f9e8b1cff4261cf6575e70e56c4c3b3e This is the correct citation when using the data. The data are available through this link as various APIs that are updated daily. There is also an R-package https://github.com/IMRpelagic/taggart can be used to download data from the APIs.

Tables

Table 1. Overview of numbers released in the different RFID tagging experiments, and numbers recaptured per year. Recaptures from experiments and recapture years used in 2021 stock assessment, based on decisions in the ICES IBPNEAMac 2019 (ICES 2019) are outlined and marked grey. However, note that these numbers also include recaptures from some factories excluded in the final estimation of tag table used in the stock assessment 2021 (see Tables 2-3), due to low efficiency or misfunctions. Recaptures in 2021 are not included in table until ICES WGWIDE 2022.

Survey	N-Released	2012	2013	2014	2015	2016	2017	2018	2019	2020	All years
Iceland 2015	806	0	0	0	6	2	3	0	0	0	11
Iceland 2016	4884	0	0	0	0	59	48	28	19	13	167
Iceland 2017	3890	0	0	0	0	0	28	27	9	13	77
Iceland 2018	1872	0	0	0	0	0	0	5	16	13	34
Iceland 2019	3614	0	0	0	0	0	0	0	5	25	30
Norway2011	31253	9	31	24	32	26	16	20	7	13	178
Ireland-Hebrides 2011	18645	27	24	29	24	17	5	9	7	3	145
Ireland-Hebrides 2012	32135	31	57	60	64	34	21	12	5	6	290
Ireland-Hebrides 2013	22792	0	26	**89**	**104**	61	30	21	10	8	349
Ireland-Hebrides 2014	55184	0	0	112	**311**	**277**	139	91	44	45	1019
Ireland-Hebrides 2015	43905	0	0	0	115	**217**	**177**	93	49	41	692
Ireland-Hebrides 2016	43956	0	0	0	0	124	**324**	**183**	121	92	844
Ireland-Hebrides 2017	56073	0	0	0	0	0	134	**344**	**174**	146	798
Ireland-Hebrides 2018	33475	0	0	0	0	0	0	180	**221**	**206**	607
Ireland-Hebrides 2018-2	4661	0	0	0	0	0	0	24	27	**23**	74
Ireland-Hebrides 2019	51179	0	0	0	0	0	0	0	290	**541**	831
Ireland-Hebrides 2020	48968	0	0	0	0	0	0	0	0	517	517
Ireland-Hebrides 2021	49173	0	0	0	0	0	0	0	0	0	0
All surveys	506465	67	138	314	656	817	925	1037	1004	1705	6663
All Ireland-Hebrides	410973	58	107	290	618	730	830	957	948	1628	6166

Table 2. Overview of numbers of tonnes scanned for RFID tags per factory per year. Data from years used in 2021 stock assessment (2014 and onwards), based on decisions in the ICES IBPNEAMac 2019 (ICES 2019), are outlined and marked grey. Based on an evaluation of efficiency of the scanners, data from some factories are excluded as they were not functioning or having poor data quality, and these are not marked grey.

Factory	2012	2013	2014	2015	2016	2017	2018	2019	2020	All years
FO01 Vardin Pelagic	0	0	**10460**	**11565**	**7895**	**4844**	**0**	**0**		34763
GB01 Denholm Coldstore	0	0	0	**4377**	**4710**	**5365**	**7806**	**5191**	**8809**	36258
GB01 Denholm Factory	0	0	**14939**	**17509**	**18840**	**17913**	**13609**	**12018**	**13951**	108780
GB02 Lunar Freezing Peterhead	0	0	**22586**	**17830**	**16473**	**9745**	**9857**	**14300**	**24382**	115173
GB03 Lunar Freezing Fraserburgh	0	0	0	8797	14282	12684	**9452**	**5729**		50943
GB04 Pelagia Shetland	0	0	**21436**	**41117**	**40200**	**26935**	**25350**	**15128**	**22573**	192739
GB05 Northbay Pelagic	0	0	0	0	0	0	**15353**	**12667**	**15478**	43498
IC01 Vopnafjord	0	0	**18577**	**18772**	**21716**	**22935**	**18869**	**18547**	**21191**	140607
IC02 Neskaupstad	0	0	0	**6288**	**21887**	**19558**	**16757**	**26633**	**28180**	119303
IC03 Höfn	0	0	0	0	0	0	0	**10592**	**13488**	24080
NO01 Pelagia Egersund Seafood	20930	21442	36724	14375	15905	0	**48373**	**25404**	**51013**	234165
NO02 Skude Fryseri	7546	8250	**16719**	**14172**	**8671**	**16760**	3108	1285	17661	94172
NO03 Pelagia Austevoll	6405	6134	10314	4203	2216	0	**7293**	**3533**	**8351**	48449
NO04 Pelagia Florø	9986	12838	**17379**	**12592**	**7749**	0	0	0		60544
NO05 Pelagia Måløy	13344	14632	**13942**	**21051**	**15762**	**22405**	**13341**	8591	**21287**	144355
NO06 Pelagia Selje	17731	26878	**39525**	**41209**	**29897**	**35416**	**28972**	**32047**	**31678**	283354
NO07 Pelagia Liavågen	9442	10968	**22395**	**18144**	**13911**	**19989**	**12398**	**11888**	**17487**	136623
NO08 Brødrene Sperre	14425	15048	**20182**	**34307**	**36736**	**18814**	34280	8515	32333	214641
NO09 Lofoten Viking	0	0	0	0	0	0	3380	2457	**3823**	9660
NO11 Nergård Sild	0	0	0	0	0	0	0	0	**2**	2
NO12 Pelagia Lødingen	0	0	0	0	0	0	0	0	**950**	950
NO14 Nils Sperre	0	0	0	0	0	0	**28304**	**26272**	**30265**	84841
NO15 Grøntvedt Pelagic	0	0	0	0	0	0	6411	0	0	6411
NO16 Vikomar	0	0	0	0	0	0	12512	**6480**	**15679**	34671
All factories	99808	116190	265178	286310	276850	233363	315426	247277	378582	2218984
All factories (data used)			**218140**	**258935**	**244448**	**220679**	**255734**	**217148**	**328588**	**1743672**

Table 3. Overview of numbers of RFID tagged mackerel recaptured per factory per year. Only recaptures from Ireland surveys (Table 1) that are used as basis stock assessment are shown. Recaptures from years used in 2021 stock assessment from 2014 and onwards, based on decisions in the ICES IBPNEAMac 2019 (ICES 2019), are outlined and marked grey. Based on an evaluation of efficiency of the scanners, data from some factories are excluded as they were not functioning or having poor data quality, and these are not marked grey. See Table 2 for biomass scanned.

Factory	2012	2013	2014	2015	2016	2017	2018	2019	2020	All years
FO01 Vardin Pelagic	0	0	**13**	**35**	**20**	**11**	0	0	0	79
GB01 Denholm Coldstore	0	0	0	**10**	**10**	**24**	**36**	**19**	**46**	145
GB01 Denholm Factory	0	0	**25**	**62**	**77**	**113**	**54**	**53**	**92**	476
GB02 Lunar Freezing Peterhead	0	0	**32**	**49**	**60**	**38**	**41**	**54**	**123**	397
GB03 Lunar Freezing Fraserburgh	0	0	0	9	14	7	**25**	**34**	0	89
GB04 Pelagia Shetland	0	0	**21**	**124**	**148**	**137**	**98**	**82**	**134**	744
GB05 Northbay Pelagic	0	0	0	0	0	0	**57**	**59**	**81**	197
IC01 Vopnafjord	0	0	**22**	**55**	**65**	**59**	**62**	**54**	**146**	463
IC02 Neskaupstad	0	0	0	**19**	**65**	**54**	**35**	**114**	**127**	414
IC03 Höfn	0	0	0	0	0	0	0	**44**	**65**	109
NO01 Pelagia Egersund Seafood	10	22	18	7	1	0	**137**	**80**	**184**	459
NO02 Skude Fryseri	5	6	**21**	**17**	**25**	**51**	13	3	34	175
NO03 Pelagia Austevoll	1	1	7	4	0	0	**28**	**17**	**48**	106
NO04 Pelagia Florø	5	12	**27**	**21**	**16**	0	0	0	0	81
NO05 Pelagia Måløy	5	13	**18**	**43**	**37**	**77**	**36**	**28**	**97**	354
NO06 Pelagia Selje	15	27	**37**	**76**	**59**	**85**	**87**	**153**	**172**	711
NO07 Pelagia Liavågen	10	11	**29**	**31**	**26**	**97**	**48**	**51**	**111**	414
NO08 Brødrene Sperre	7	15	**20**	**56**	**107**	**77**	52	12	0	346
NO09 Lofoten Viking	0	0	0	0	0	0	10	3	**5**	18
NO12 Pelagia Lødingen	0	0	0	0	0	0	0	0	**1**	1
NO14 Nils Sperre	0	0	0	0	0	0	**109**	**68**	**73**	250
NO15 Grøntvedt Pelagic	0	0	0	0	0	0	11	0	0	11
NO16 Vikomar	0	0	0	0	0	0	18	**20**	**89**	127
All factories	58	107	290	618	730	830	957	948	1628	6166
All factories (accept)			**265**	**598**	**715**	**823**	**866**	**898**	1594	**5759**

Figures

Figure 1. Example of how the new monitoring systems looks like. It follows the traffic light systems, where red implies that we currently may have issues with either voltage variations or reduced efficiency of RFID tags.

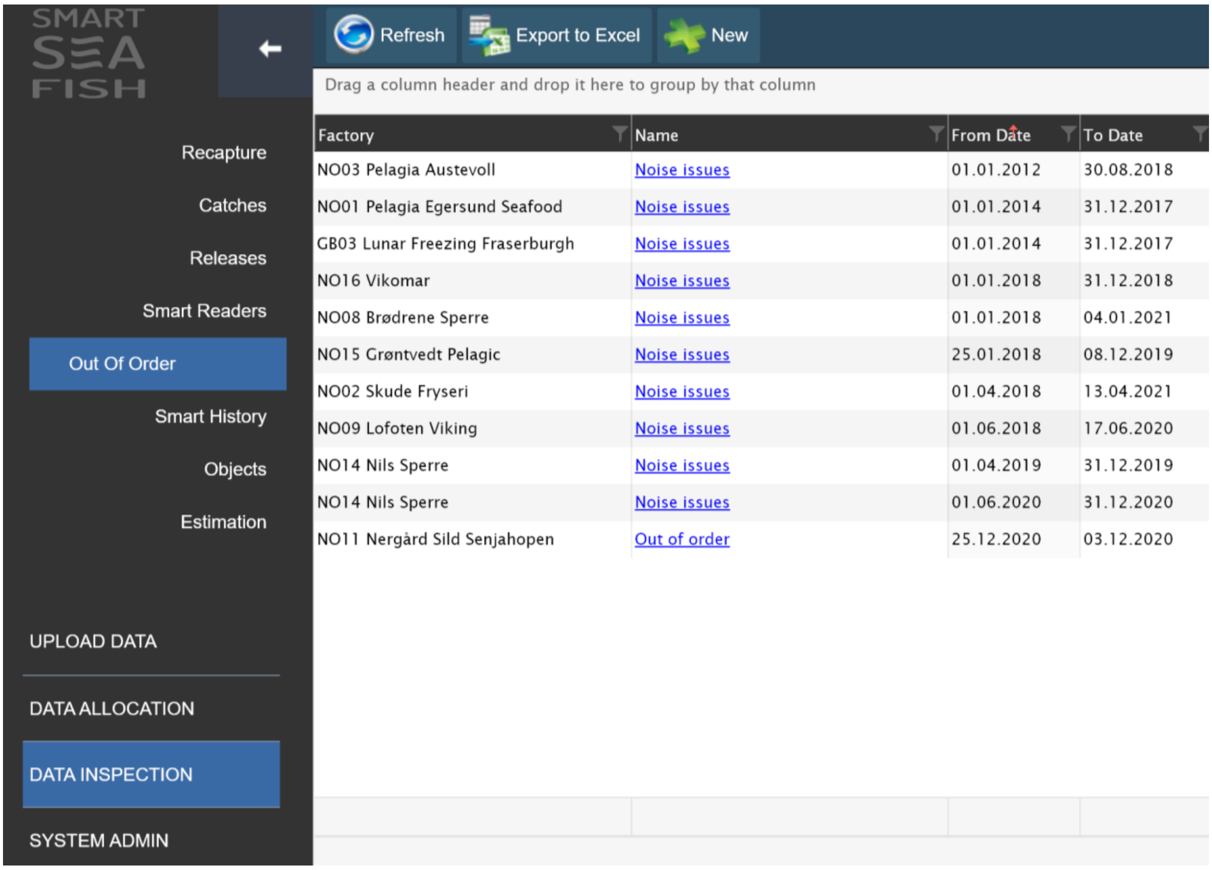

Figure 2. Example of how it looks like in the SmartSeaFish web-based software where factories having issues with recapture efficiency are put in an 'Out of order' list. Catch data and recapture data from these factories and periods are excluded in final estimation of data table being included in the ICES WGWIDE stock assessment.

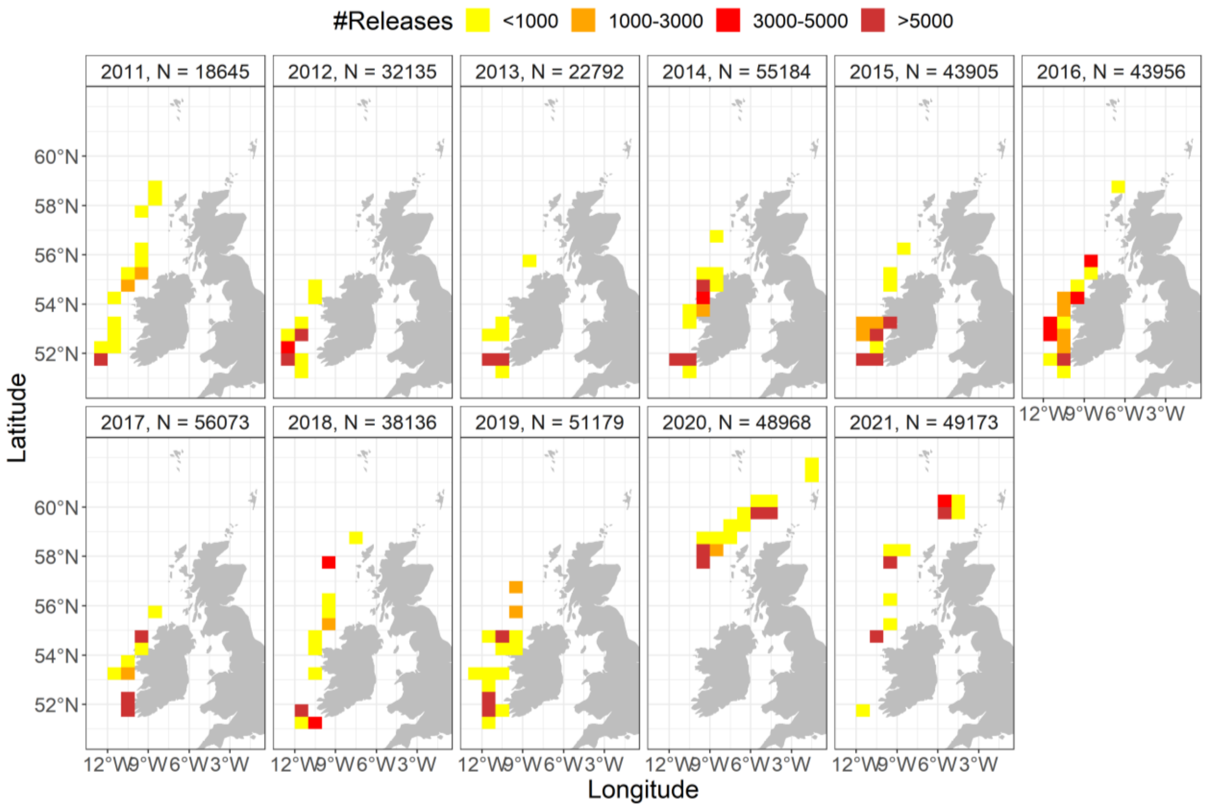

Figure 3. Distribution of RFID tagged mackerel from experiments west of Ireland-Hebrides during 2011-2021. Number of released fish is summed per ICES rectangle. See Table 1 for details on numbers released. Note that data from releases 2011-2012 are not used in the stock assessment, based on decisions in the ICES IBPNEAMac 2019 meeting (ICES 2019), and data from experiments in 2020-2021 are not included as there are no full years with recaptures yet.

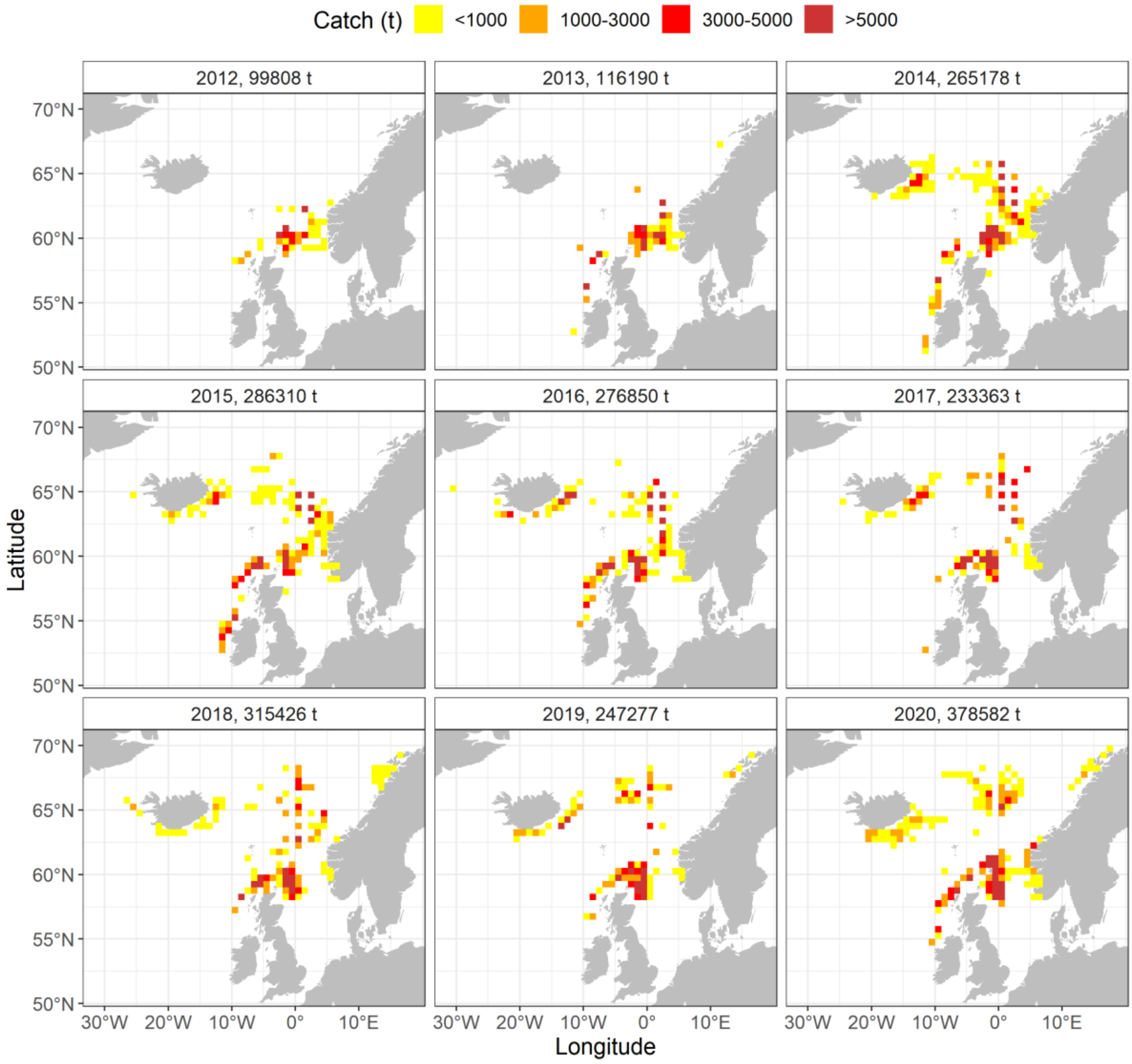

Figure 4. Distribution (summed per ICES rectangle) of catches scanned for RFID tagged mackerel during 2012-2020. Note that data on scanned catches in 2012-2013 are not used in the stock assessment based on decisions in the ICES IBPNEAMac 2019 meeting (ICES 2019). Detailed data on scanned biomass per factory and year are given in Table 2.

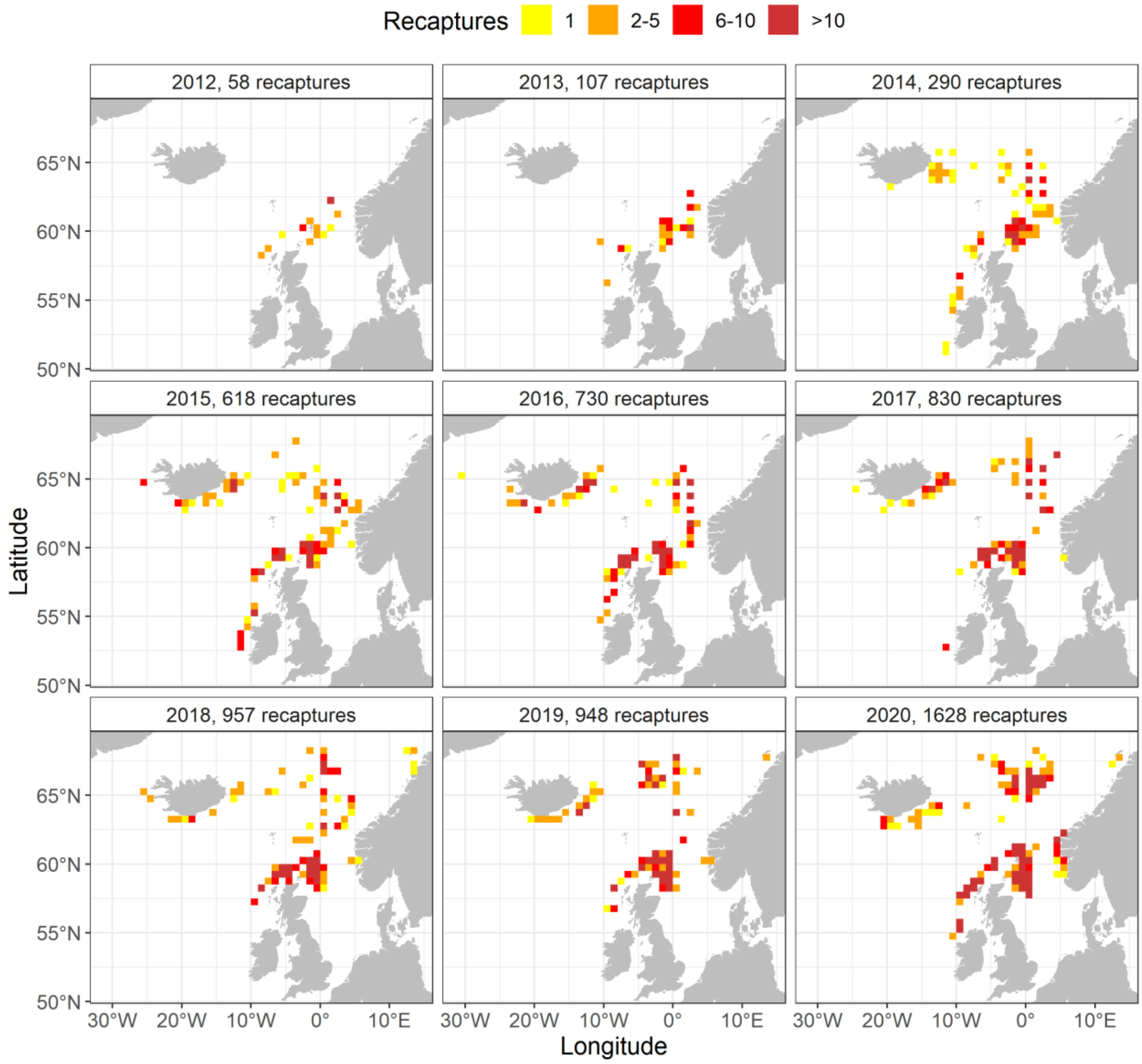

Figure 5. Distribution (summed per ICES rectangle) of recaptures of RFID tagged mackerel during 2012-2020. Note that data on recaptures in 2012-2013 are not used in the stock assessment based on decisions in the ICES IBPNEAMac 2019 meeting (ICES 2019). Detailed data on recaptures per factory and year are given in Table 3.

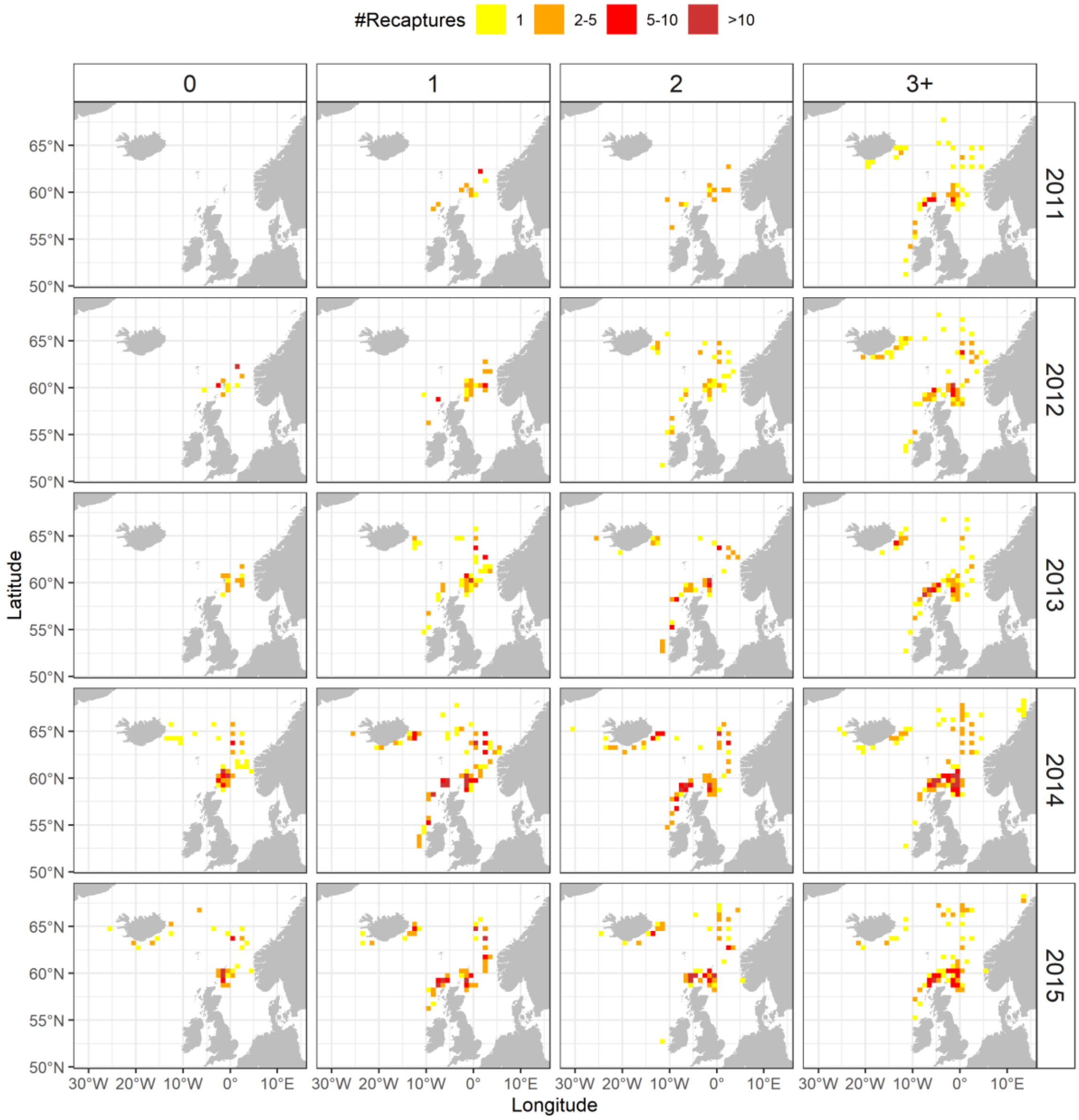

Figure 6. Distribution (summed per ICES rectangle) of recaptures of RFID tagged mackerel related to release years 2011-2015 and years after release (0=same year as tagging, 1= year after tagging etc.). Note that data on recaptures from 2011-2012 release years and from year 0 and 3+ after tagging are not used in the stock assessment based on decisions in the ICES IBPNEAMac 2019 meeting (ICES 2019). Note also tha t in 2011 scanning had not started (Figure 4), so no in year recaptures.

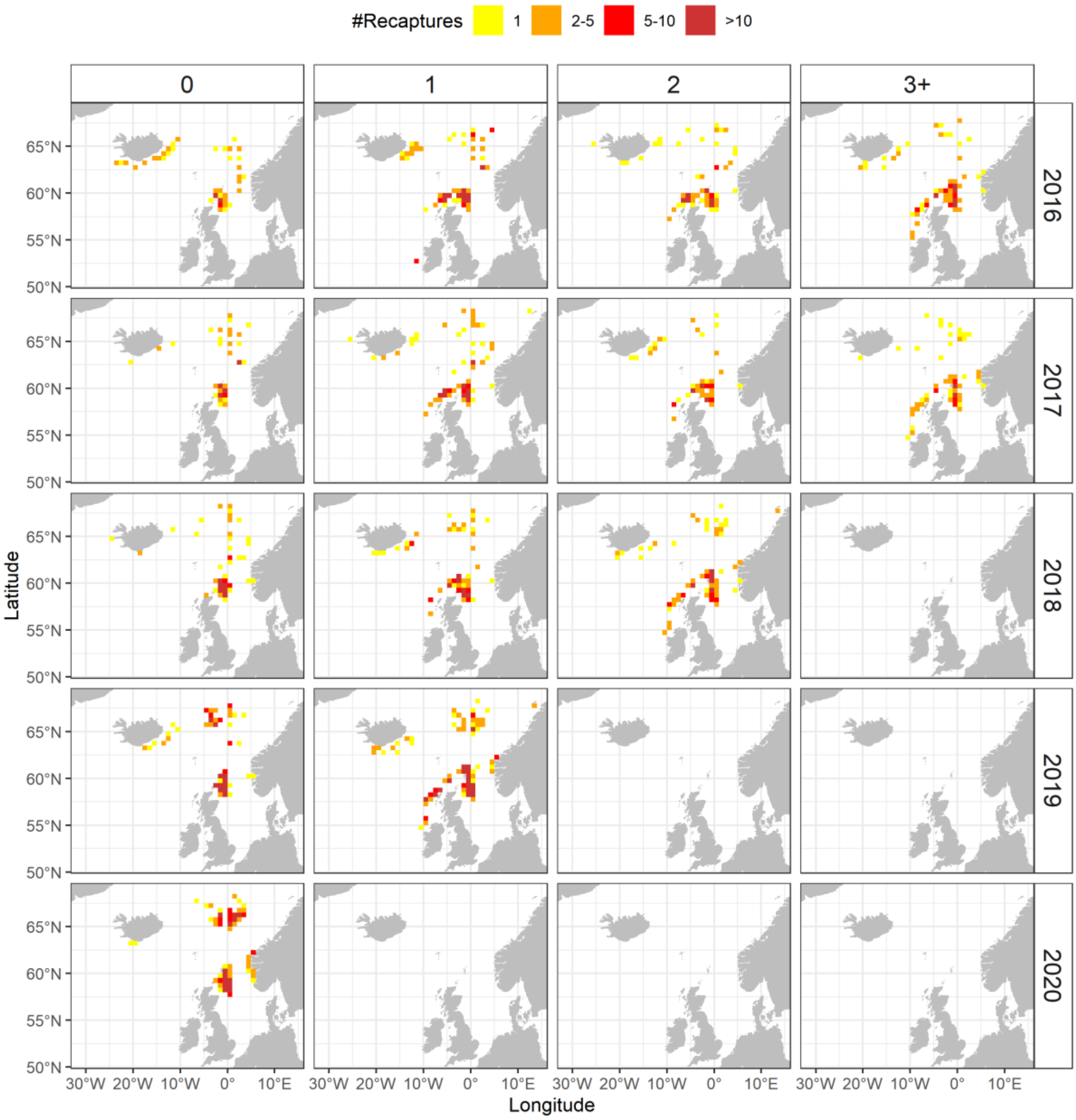

Figure 6 continued for release years 2016-2020. Preliminary recaptures in 2021 are not included as allocations to catches are not completed.

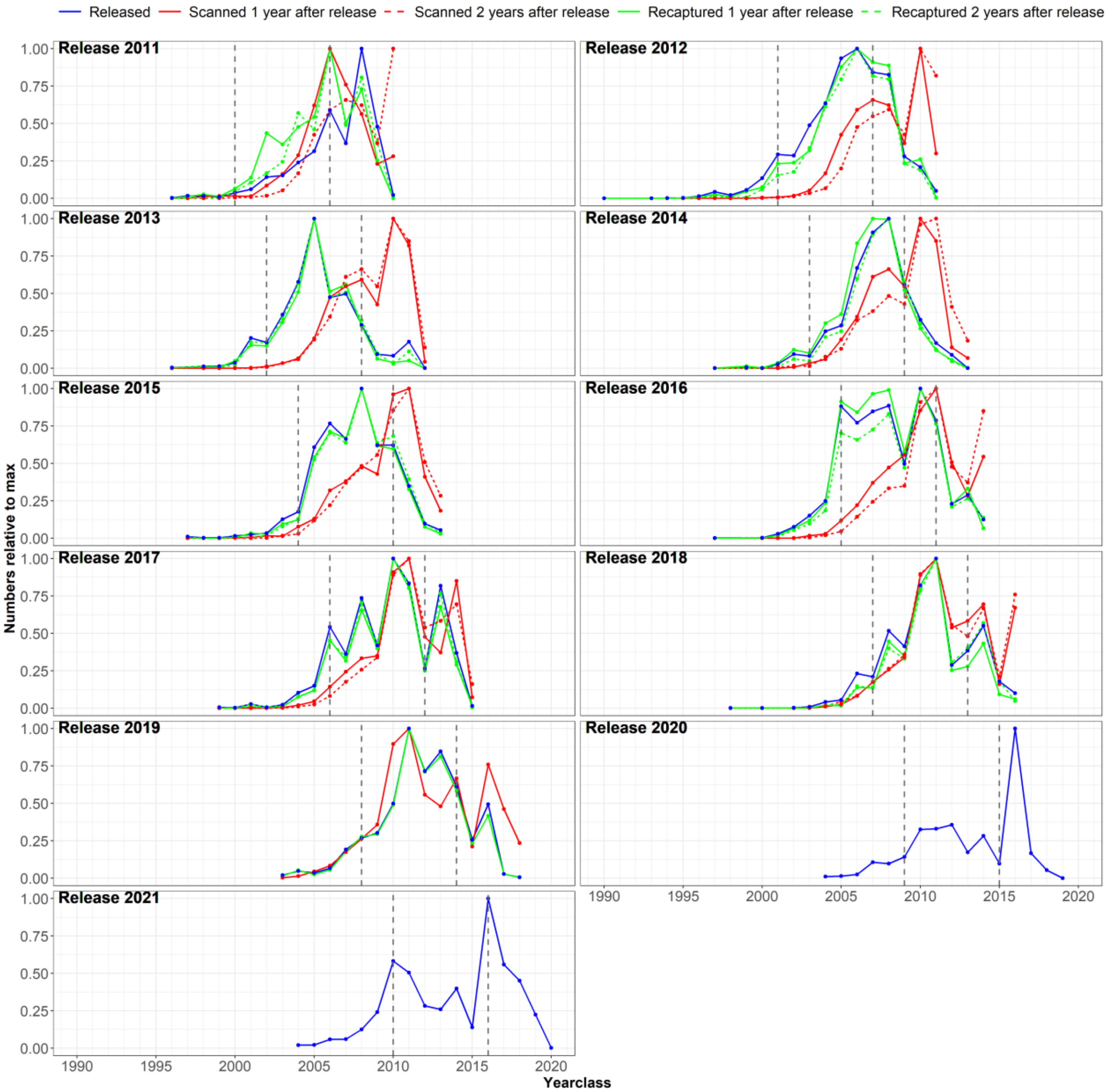

Figure 7. Overview of the relative year class distribution among RFID tagged mackerel per release year from experiments west of Ireland-Hebrides in May-June, compared with the number scanned and recaptured in year 1 and 2 after release of the same year classes. See Figure 3 for distribution of the tagged fish and the respective distribution of recaptures in year 1 and 2 after release in Figures 4-5. Note that data from releases in 2011-2012 are not used in the stock assessment based on decisions in the ICES IBPNEAMac 2019 meeting (ICES 2019). Note also that it was decided to only use ages 5-11 in updated assessments, and limits for this age span is marked (vertical grey dotted lines) for each release year. Details on actual numbers released and recaptured are given in Table 1 and 3, also for other tagging experiments not included in the stock assessment.

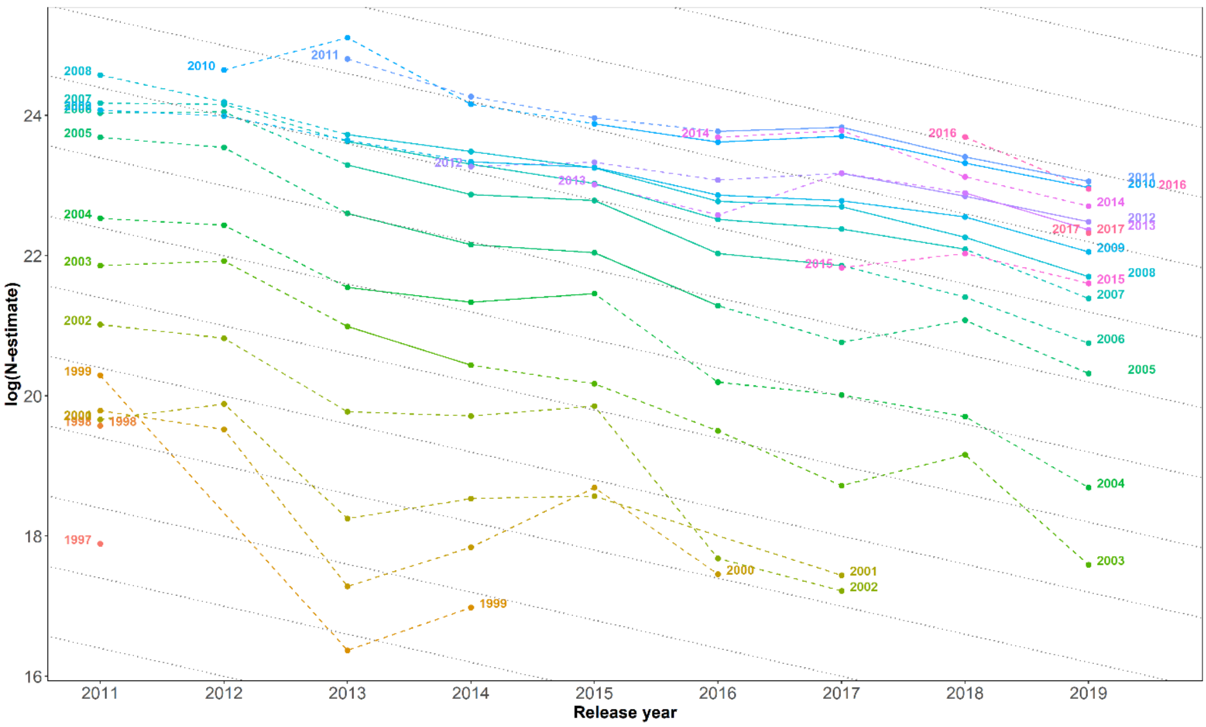

Figure 8. Trends in year class abundance (N=numbers released/numbers recaptured*numbers scanned) from RFID tag-recapture data based on aggregated data on recaptures and scanned numbers in year 1 and 2 after each release year. Data excluded in the stock assessment based on decisions in the ICES IBPNEAMac 2019 meeting (ICES 2019), release years 2011-2012 and ages 2-4 and 12+, are marked with dotted lines in year class trends. Note that dotted grey lines are showing a total mortality Z=0.4 for comparison with year class trends.

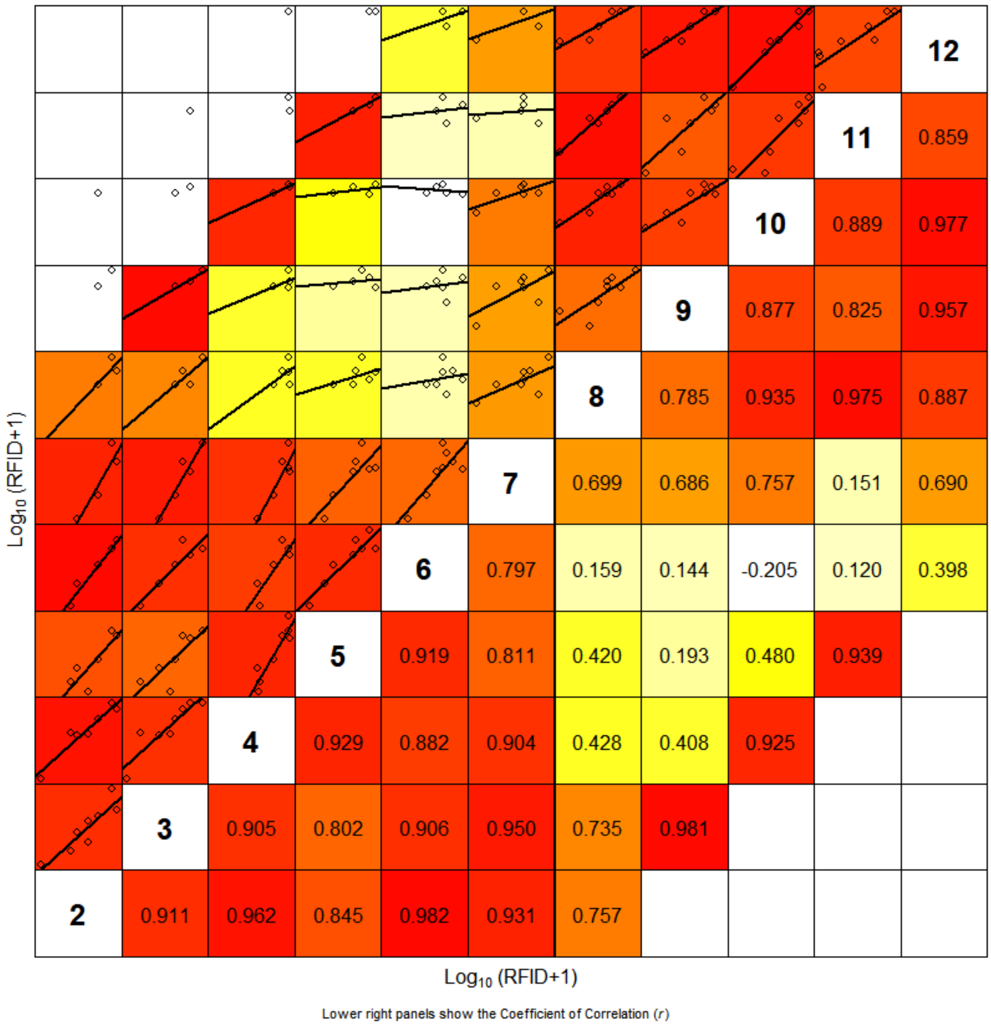

Figure 9. Internal consistency of the of mackerel RFID abundance index from release years 2011 to 2019, based on indices from Figure 8. Ages indicated by white numbers in grey diagonal cells. Statistically significant positive correlations (*p<0.05*) are indicated by regression lines and red cells in upper left half. Correlation coefficients (r) are given in the lower right half.

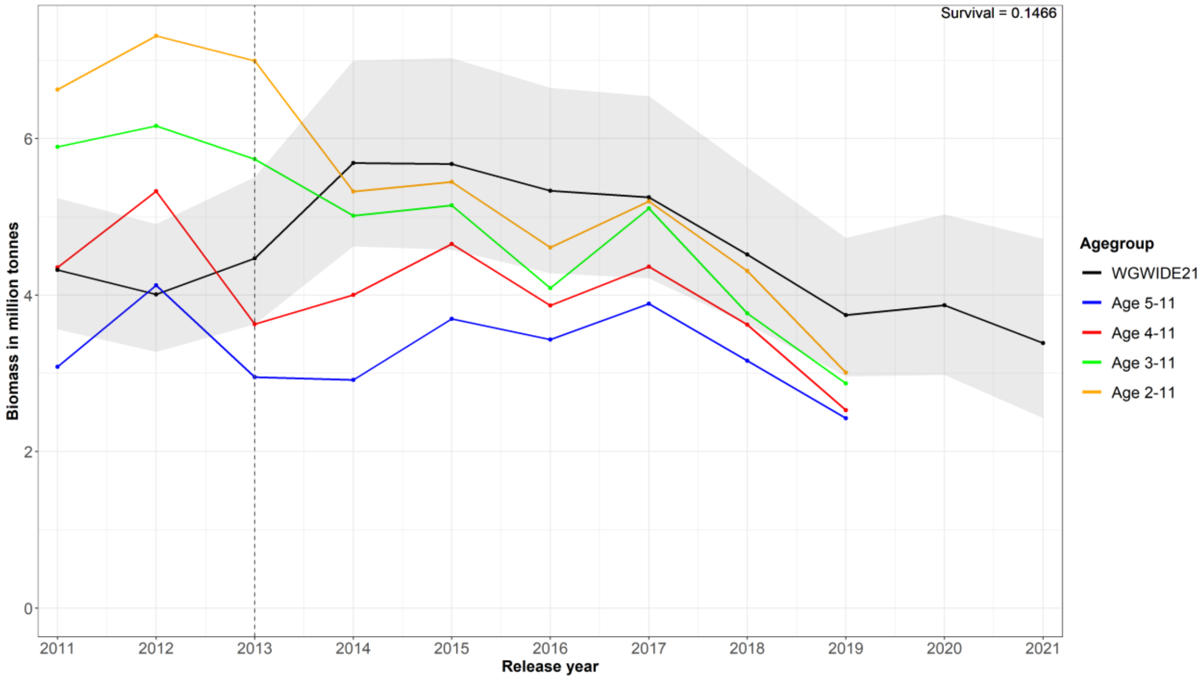

Figure 10. Trends in various age aggregated biomass indices from RFID tag-recapture data compared with the SSB (±95 confidence intervals) from the WGWIDE 2021 stock assessment. Data are based on a combination of estimated numbers by year class from Figure 8 scaled by the preliminary survival parameter estimated by SAM in WGWIDE 2021 (0.1466) and weight at age in stock form same assessment. Vertical dotted line marks the starting year where RFID tagging experiments are used in the stock assessment based on decisions in the ICES IBPNEAMac 2019. meeting (ICES 2019), and the trend of ages 5-11 is representing the subset of ages used in updated assessments. Note that final year with data 2019 is only based on recapture year 1 after release, whereas the other years are based on recapture year 1-2 after release, i.e. completed. In recent years (2016-2018) the estimates have tended to increase when adding the second recapture year (See Figures 11-12).

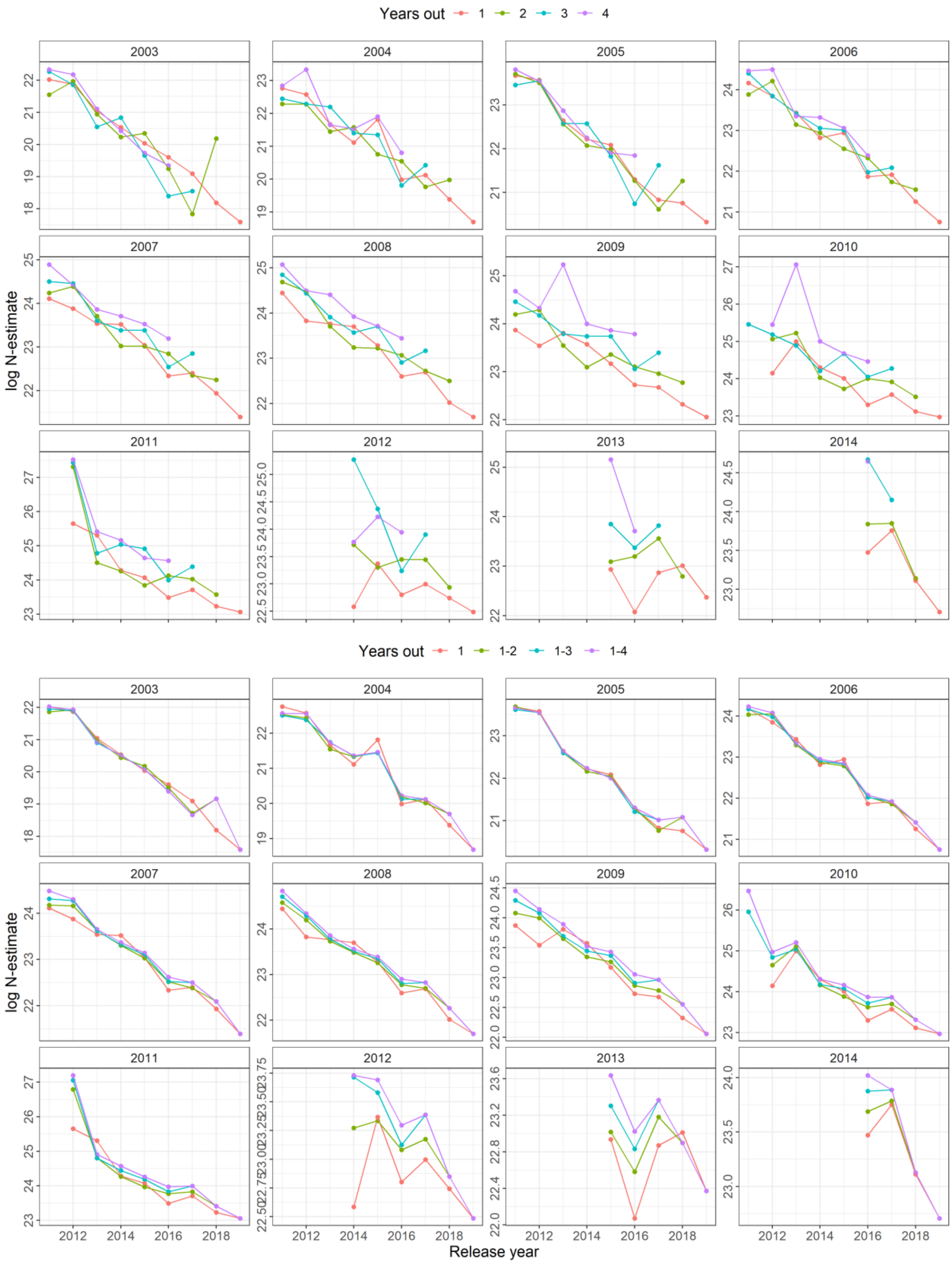

Figure 11. Trends in year class abundance (N=numbers released/numbers recaptured*numbers scanned) from RFID tag-recapture data based on different filtering of recapture year included. Upper panels show the difference between basing the estimate on either year 1, 2, 3, or 4 after release, whereas bottom panels show the difference between using year 1 after release versus various intervals of years after release. Note that data are shown for all ages (1-max 16) with data.

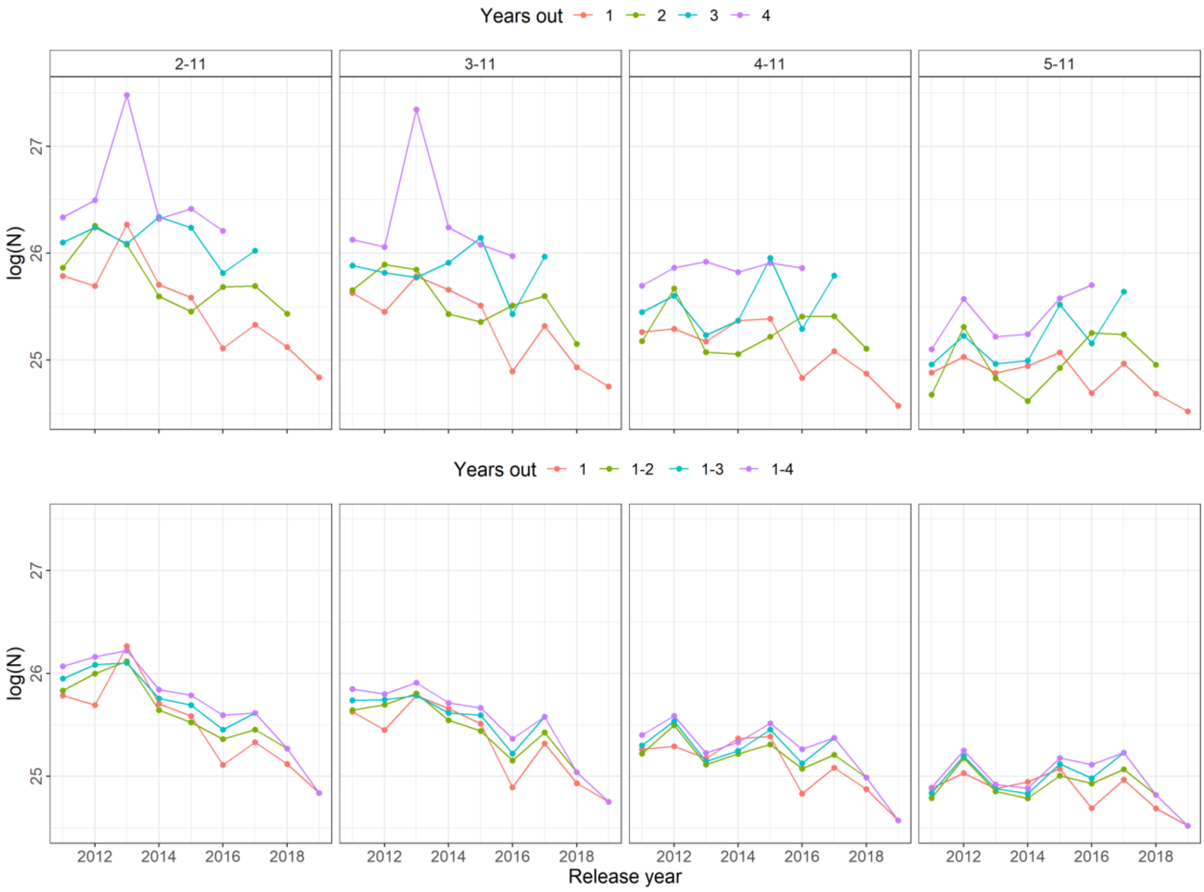

Figure 12. Trends in various age aggregated biomass indices from RFID tag-recapture data based on different filtering of recapture year included. Upper panels show the difference between basing the estimate on either year 1, 2, 3, or 4 after release, whereas bottom panels show the difference between using year 1 after release versus various intervals of years after release.

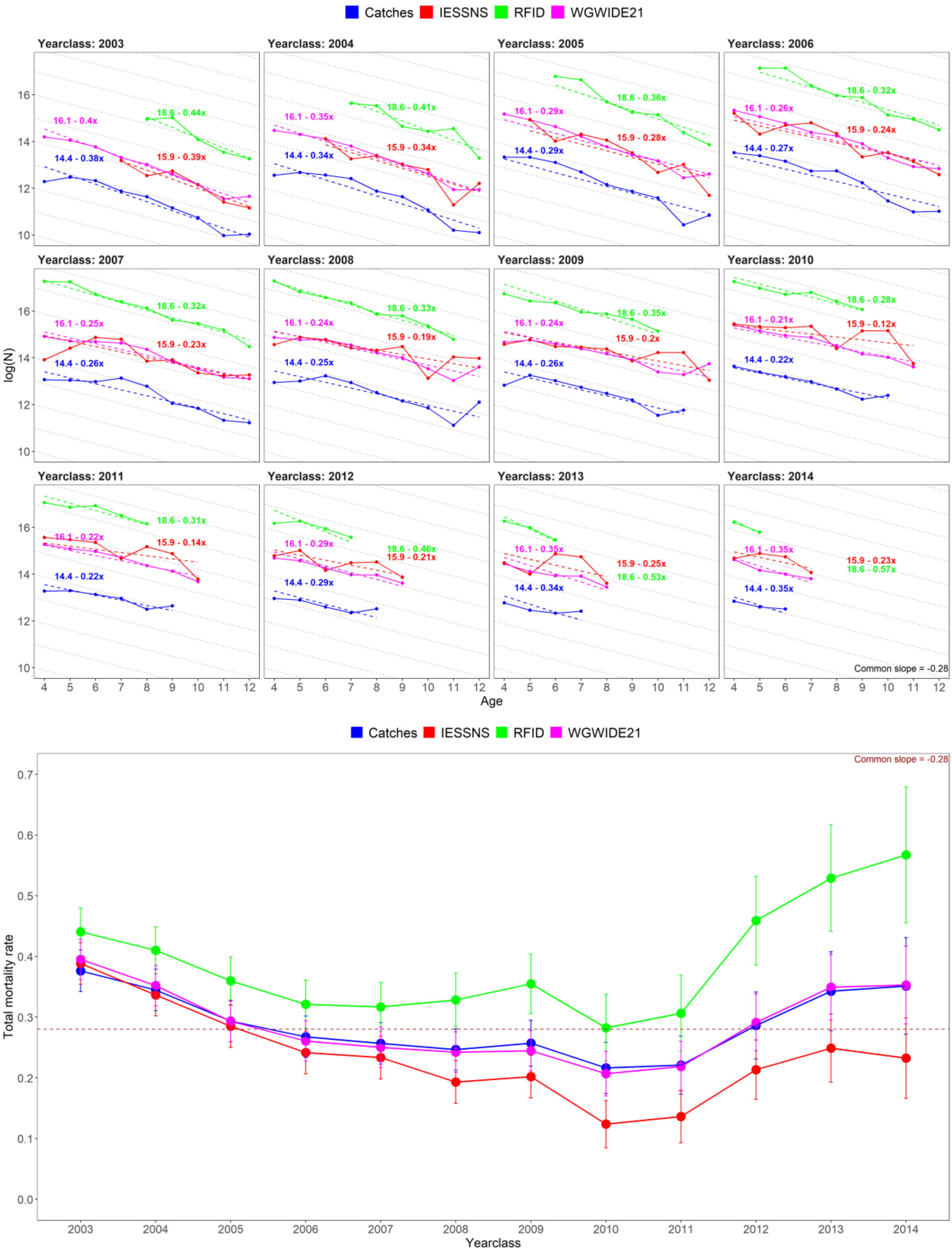

Figure 13. Signals of total mortality rate in input data to the mackerel stock assessment. Upper panels show the trends in year class abundance and estimated slope of decrease from the age 4 when it is fully recruited to the spawning stock until age 12 (interpreted as signal of total mortality), of various sources of unscaled input data to the mackerel stock assessment (RFID, IESSNS and catch data) compared with the final trend estimated in the stock assessment (WGWIDE 2021). Bottom panels summarize the year class differences in estimated total mortality rate (with 95% confidence intervals), and differences between the various data sources.

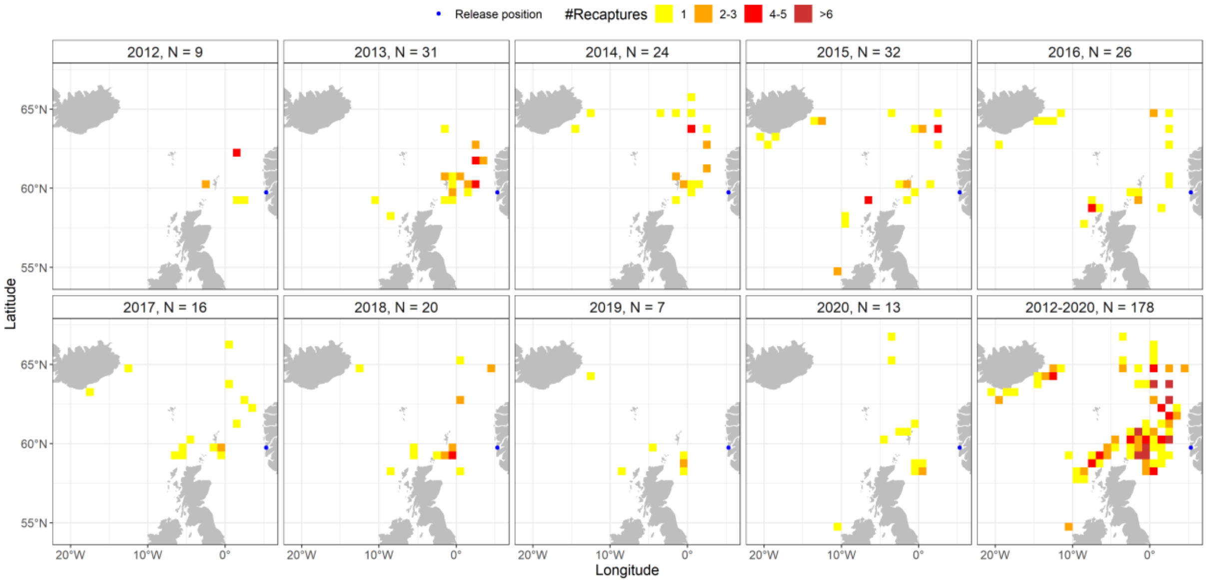

Figure 14. Distribution (summed per ICES rectangle) of recaptures 2012-2020 from an RFID tagging experiment on mackerel in the North Sea at the Norwegian West coast (blue dot) in 2011. This was mainly young mackerel tagged, where 88% were 1 year olds and 6.5% 2 year olds, using the North Sea/Norwegian coast as nursery.

WGWIDE 2021 WD…

Norwegian Spring Spawning Herring stock assessment by means of TISVPA

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The TISVPA (Triple Instantaneous Separable VPA) model (Vasilyev, 2005; 2006) represents fishing mortality coefficients (more precisely – exploitation rates) as a product of three parameters: f(year)*s(age)*g(cohort). The generation - dependent parameters, which are estimated within the model, are intended to adapt traditional separable representation of fishing mortality to situations when several year classes may have peculiarities in their interaction with fishing fleets caused by different spatial distribution, higher attractiveness of more abundant schools to fishermen, or by some other reasons.

The TISVPA model was first presented and tested at the ICES Working Group on Methods of Fish Stock Assessments (WGMG 2006) and was used for data exploration and stock assessment for several ICES stocks, including North - East Atlantic mackerel, blue whiting, NEA cod and haddock and Norwegian spring spawning herring. With respect to NSS herring stock the TISVPA model was used for data exploration for several years, last time - at WGWIDE 2019.

The TISVPA model is applied to NSS herring using the data, kindly presented by Stenevik Erling Kåre. 3 sets of age - structured tuning data were included into analysis: the survey on spawning grounds along the Norwegian coast (survey 1); of young herring in the Barents Sea in May (survey 4); in feeding areas in the Norwegian Sea in May (survey 5).

In order to produce more clear and less controversial signal from all sources of the data the settings of the model were somewhat changed in comparison to those used at WGWIDE 2019: so called “mixed” version, assuming errors both in catch-at-age and in separable approximation; additional restriction on the solution was the unbiased model approximation of logarithmic catch-at-age. The generation - dependent factors in triple - separable representation of fishing mortality coefficients were estimated for the age groups from 5 to 12. For surveys 1 the measure of closeness of fit was the traditional sums of logarithmic squared residuals in abundances assuming lognormal errors. For survey 4 the measure of fit was the absolute median deviation (AMD) of the distribution of logarithmic residuals in abundances. For survey 5 the absolute median deviation was applied to logarithmic residuals in age proportions. For catch-at-age data the measure of fit was the absolute median deviation of the distribution of logarithmic residuals in catch-at-age.

Profiles of the components of the TISVPA loss function with respect to SSB in 2021 are shown in Figure 1. The minima are clear for catch-at-age and all surveys.

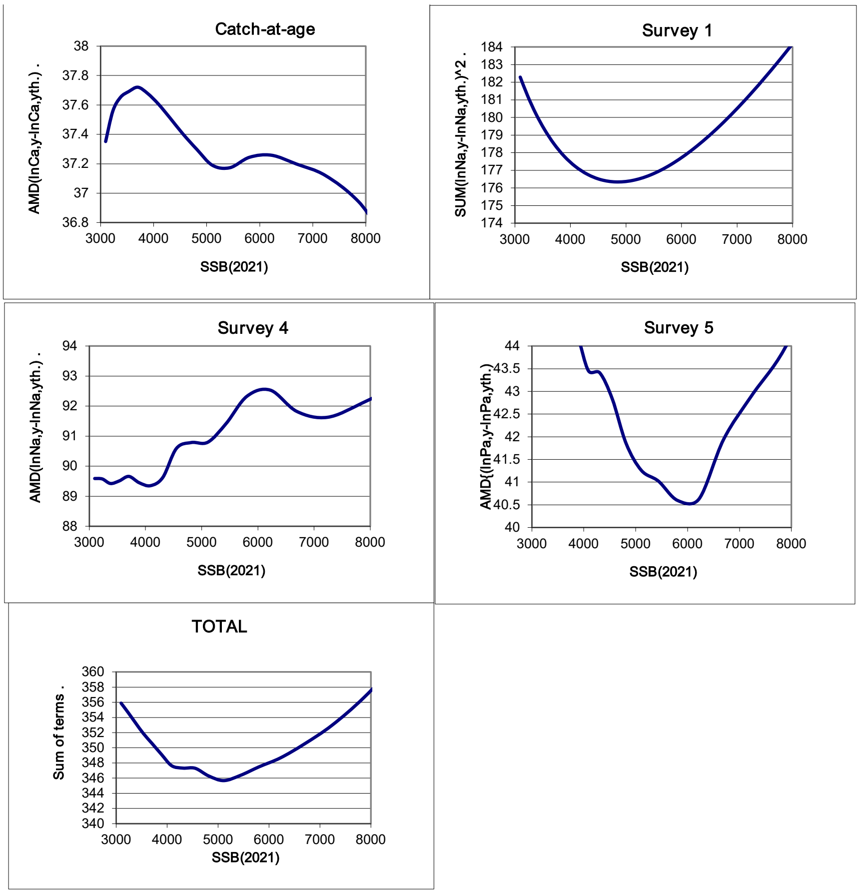

Figure 1. Profiles of the components of the TISVPA objective function.

The estimated selection pattern is given in Figure 2 (selection-at-age in the TISVPA model is normalized to SUM=1 for each year).

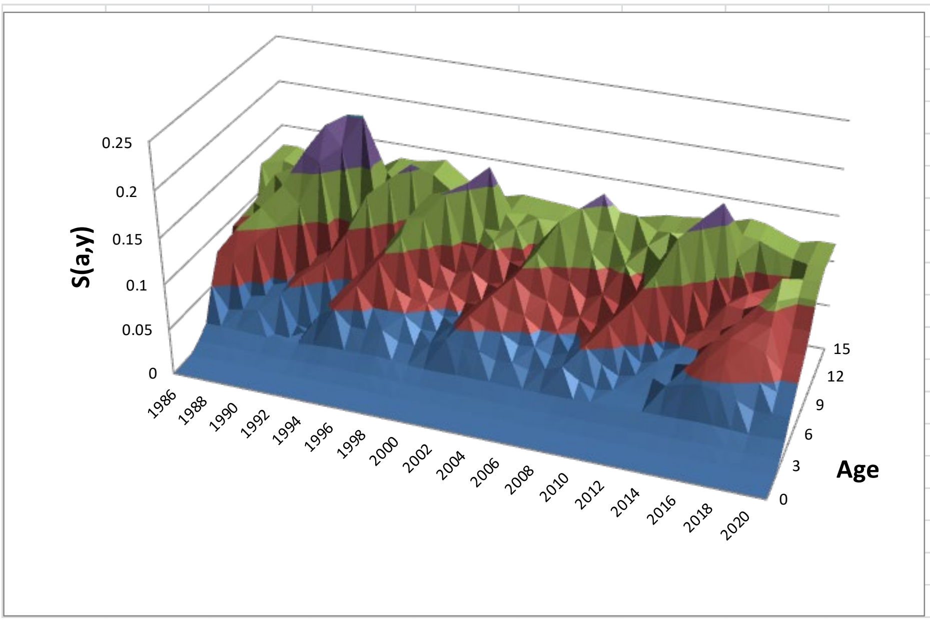

Figure 2. TISVPA – derived selection pattern.

Figure 3 represents the results of retrospective runs.

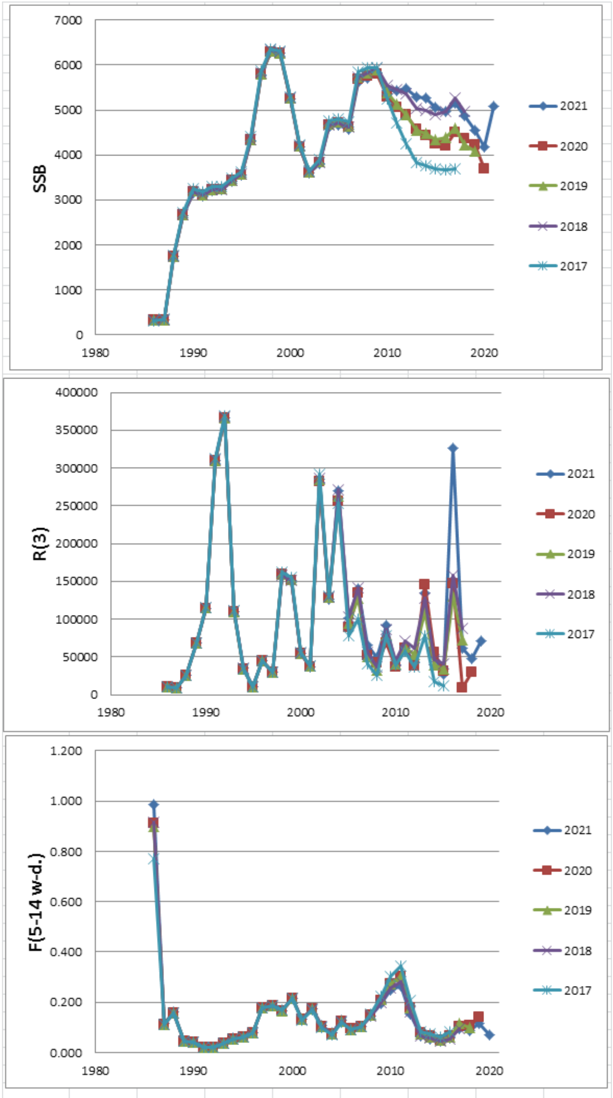

Figure 3. TISVPA retrospective runs

The residuals of the model approximation of the data are presented below.

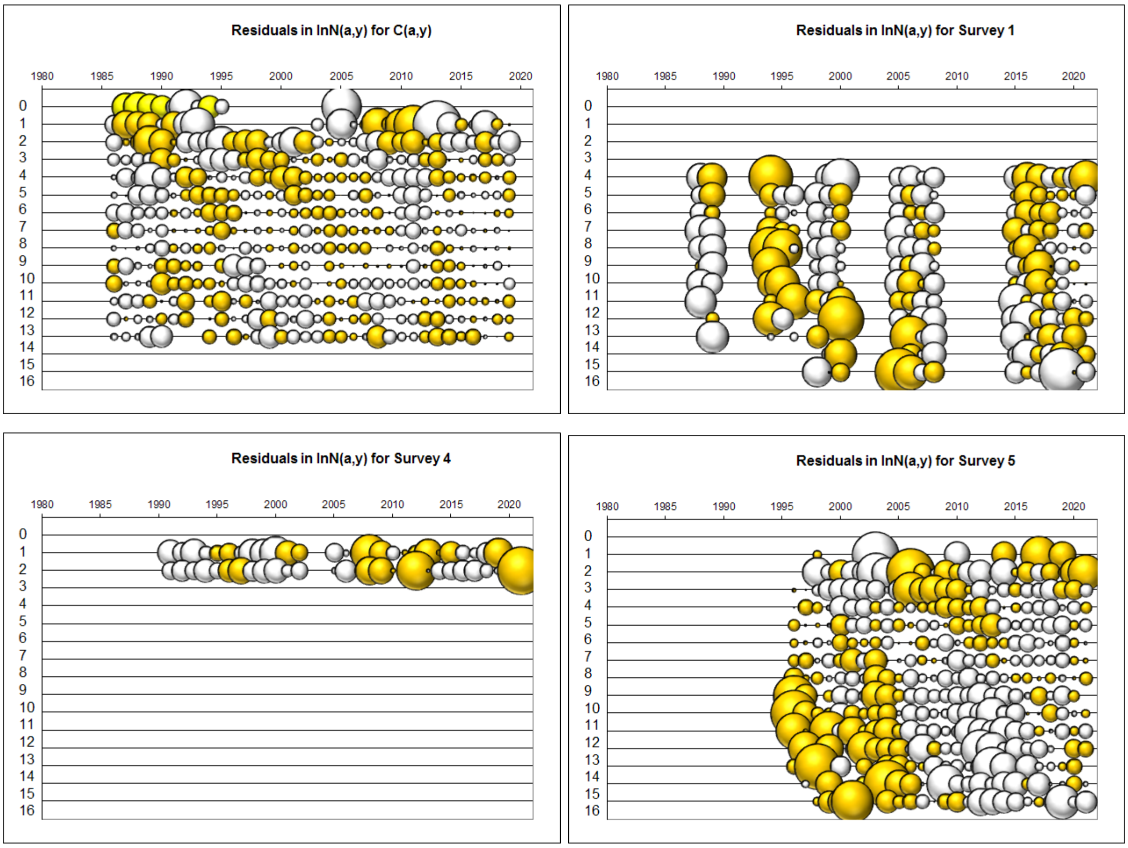

Figure 4. Residuals of the TISVPA data approximation.

The estimates of uncertainty in the results (parametric conditional bootstrap with respect to catch-at-age; "fleet" data were noised by lognormal noise with sigma=0.3) are presented on Figure 5.

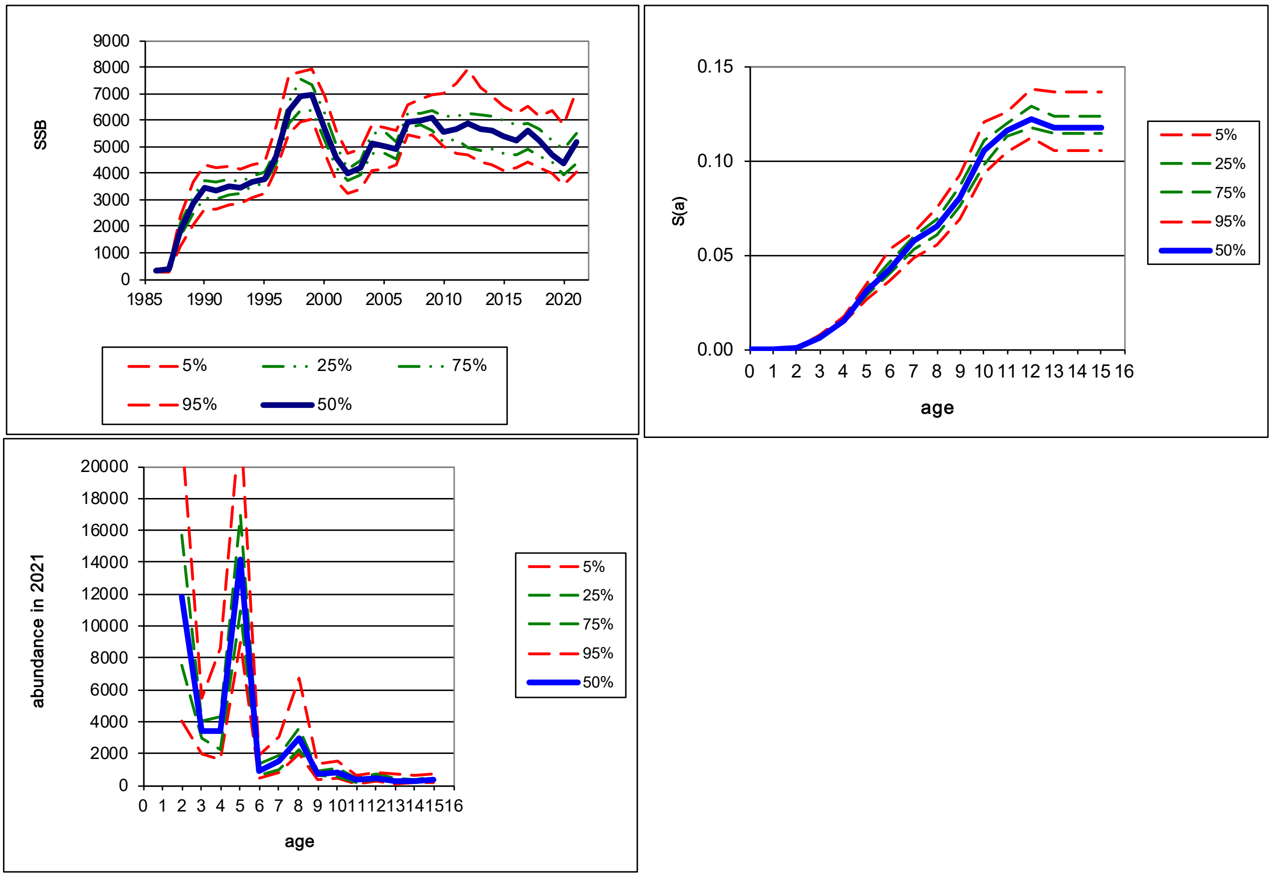

Figure 5. Bootstrap- estimates of uncertainty in the results.

Tables 1-3 represent the results of NSS herring stock assessment by means of TISVPA.

	B(0+)	SSB	R(0)	F(5-14)w-
1986	1691	331	9992	0.988
1987	2845	332	9091	0.116
1988	3010	1733	25603	0.160
1989	3462	2656	68208	0.047
1990	3932	3166	114264	0.041
1991	4599	3086	309952	0.022
1992	5674	3206	366528	0.022
1993	6819	3218	110224	0.038
1994	7950	3413	34621	0.056
1995	8866	3548	10384	0.064
1996	9156	4325	45026	0.080
1997	9218	5783	29971	0.180
1998	7840	6294	157828	0.188
1999	8177	6254	150571	0.168
2000	7677	5253	54194	0.216
2001	6290	4179	36714	0.132
2002	6284	3602	280801	0.176
2003	7320	3815	126349	0.108
2004	8696	4629	269488	0.079
2005	9312	4661	101257	0.128
2006	10251	4563	140306	0.095
2007	9905	5625	65356	0.104
2008	10233	5712	48510	0.146
2009	9785	5817	91935	0.196
2010	9093	5441	39000	0.250
2011	7881	5419	60828	0.267
2012	7329	5465	42109	0.155
2013	7144	5292	135058	0.066
2014	7228	5267	50014	0.056
2015	7151	5067	26718	0.046
2016	6872	4966	325706	0.060
2017	8149	5152	61479	0.095
2018	8840	4884	47697	0.088
2019	7868	4545	70669	0.116
2020	7888	4175		0.071
2021		5093		

Table 1. NSS herring stock assessments results by means of TISVPA

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1986	9992	21453	1672	18029	166	47	62	209	133	63	78	40	133	110	0	3
1987	9091	4058	8721	677	14882	126	26	27	113	41	28	22	14	12	10	1
1988	25603	3692	1648	3528	562	11916	92	15	11	72	15	15	12	6	3	1
1989	68208	10405	1500	666	2958	453	9214	68	8	4	48	4	9	7	2	0
1990	114264	27729	4230	603	570	2518	378	7570	55	6	3	38	3	7	5	5
1991	309952	46455	11273	1715	509	486	2152	313	6245	45	4	1	30	2	6	10
1992	366528	126016	18886	4582	1470	435	417	1840	262	5199	37	3	1	25	0	0
1993	110224	149018	51234	7677	3933	1246	371	357	1573	219	4300	31	2	1	0	0
1994	34621	44812	60585	20823	6579	3317	1018	312	304	1330	174	3383	26	2	1	16
1995	10384	14075	18219	24620	17839	5561	2618	775	256	256	1111	124	2440	20	1	2
1996	45026	4222	5723	7402	21039	14977	4375	1846	524	205	209	897	60	1491	0	0
1997	29971	18306	1716	2317	6305	17437	11724	3156	1251	357	163	171	709	35	755	1
1998	157828	12185	7443	691	1907	5116	13138	8273	2046	678	196	109	125	520	14	271
1999	150571	64168	4954	3000	557	1488	4030	9605	5862	1376	381	102	71	100	292	211
2000	54194	61217	26089	2011	2498	453	1172	3104	6911	4092	921	206	61	38	67	207
2001	36714	22034	24889	10591	1676	1850	352	898	2294	4726	2626	559	94	31	17	114
2002	280801	14927	8958	10112	9019	1351	1344	272	696	1746	3395	1834	398	57	22	32
2003	126349	114165	6069	3622	8535	7302	988	911	198	505	1232	2144	1159	252	35	27
2004	269488	51370	46414	2464	3063	7081	5723	726	644	146	368	864	1366	774	172	73
2005	101257	109564	20884	18849	2100	2565	5770	4426	545	456	105	271	616	895	519	64
2006	140306	41168	44544	8479	15908	1734	2054	4452	3129	373	286	61	178	408	524	181
2007	65356	57044	16736	18083	7207	13105	1406	1594	3261	2099	242	163	31	107	243	219
2008	48510	26572	23190	6797	15343	5922	10032	1086	1171	2273	1370	152	97	16	68	171
2009	91935	19723	10792	9415	5770	12612	4453	6962	770	778	1435	749	81	39	2	162
2010	39000	37378	8017	4352	7915	4745	9765	2998	4442	520	443	783	342	29	21	90
2011	60828	15856	15175	3237	3640	6447	3805	7138	1767	2492	287	190	322	95	11	20
2012	42109	24731	6412	6092	2712	2955	5122	2949	5001	906	1298	140	61	120	35	10
2013	135058	17120	10054	2601	5095	2252	2400	4065	2284	3578	507	743	78	24	58	14
2014	50014	54911	6960	4080	2200	4210	1875	1968	3270	1798	2657	318	514	51	15	61
2015	26718	20334	22325	2828	3486	1852	3436	1564	1625	2655	1440	2006	215	384	35	66
2016	325706	10863	8267	9073	2420	2955	1542	2824	1308	1341	2158	1159	1564	161	292	75
2017	61479	132422	4416	3359	7763	2047	2439	1250	2277	1076	1087	1710	919	1196	114	251
2018	47697	24995	53837	1790	2846	6453	1648	1878	934	1695	834	814	1244	691	824	237
2019	70669	19392	10162	21871	1522	2394	5284	1292	1444	702	1271	640	614	910	492	65
2020	0	28732	7884	4128	18656	1264	1927	4106	980	1050	495	901	455	444	610	475
2021	0	0	11681	3201	3509	15568	1024	1522	3162	737	763	341	606	301	295	405

Table 2. NSS herring. TISVPA. Estimates of abundance-at-age

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1986	0.000	0.000	0.005	0.051	0.130	0.471	0.862	0.301	1.063	0.453	0.649	0.960	2.605	2.398	0.000	2.398
1987	0.000	0.000	0.005	0.042	0.106	0.171	0.571	0.948	0.298	1.107	0.488	0.565	0.775	1.392	1.392	1.392
1988	0.000	0.000	0.004	0.033	0.083	0.159	0.191	0.581	0.868	0.290	1.137	0.406	0.447	0.900	0.900	0.900
1989	0.000	0.000	0.001	0.009	0.021	0.046	0.055	0.060	0.148	0.206	0.088	0.214	0.096	0.167	0.167	0.000
1990	0.000	0.000	0.001	0.006	0.016	0.009	0.048	0.053	0.053	0.136	0.197	0.071	0.165	0.122	0.122	0.122
1991	0.000	0.000	0.000	0.003	0.007	0.003	0.006	0.029	0.029	0.031	0.080	0.096	0.035	0.056	0.056	0.056
1992	0.000	0.000	0.000	0.003	0.007	0.008	0.004	0.007	0.032	0.033	0.036	0.080	0.093	0.051	0.000	0.000
1993	0.000	0.000	0.001	0.005	0.012	0.029	0.020	0.010	0.015	0.069	0.076	0.000	0.000	0.000	0.000	0.000
1994	0.000	0.000	0.001	0.008	0.019	0.055	0.068	0.041	0.019	0.030	0.149	0.138	0.122	0.149	0.149	0.149
1995	0.000	0.000	0.001	0.012	0.029	0.058	0.122	0.139	0.078	0.036	0.060	0.266	0.236	0.241	0.241	0.241
1996	0.000	0.000	0.002	0.016	0.039	0.076	0.112	0.222	0.234	0.133	0.062	0.090	0.403	0.339	0.000	0.000
1997	0.000	0.000	0.003	0.029	0.071	0.150	0.201	0.277	0.554	0.618	0.336	0.126	0.176	0.720	0.720	0.720
1998	0.000	0.000	0.003	0.023	0.058	0.098	0.174	0.211	0.271	0.562	0.660	0.294	0.107	0.543	0.543	0.543
1999	0.000	0.000	0.002	0.018	0.044	0.079	0.105	0.168	0.190	0.252	0.543	0.512	0.228	0.383	0.383	0.383
2000	0.000	0.000	0.002	0.020	0.050	0.120	0.129	0.157	0.239	0.281	0.396	0.741	0.662	0.451	0.451	0.451
2001	0.000	0.000	0.001	0.011	0.028	0.081	0.094	0.091	0.104	0.160	0.195	0.225	0.373	0.229	0.229	0.229
2002	0.000	0.000	0.002	0.018	0.046	0.114	0.196	0.207	0.187	0.221	0.370	0.379	0.425	0.404	0.404	0.404
2003	0.000	0.000	0.001	0.013	0.033	0.079	0.117	0.182	0.179	0.167	0.205	0.284	0.279	0.278	0.278	0.278
2004	0.000	0.000	0.001	0.009	0.023	0.044	0.077	0.105	0.151	0.153	0.149	0.154	0.202	0.187	0.187	0.187
2005	0.000	0.000	0.002	0.014	0.035	0.072	0.096	0.155	0.198	0.302	0.320	0.259	0.257	0.296	0.296	0.296
2006	0.000	0.000	0.002	0.016	0.039	0.069	0.114	0.139	0.211	0.283	0.463	0.404	0.311	0.334	0.334	0.334
2007	0.000	0.000	0.002	0.015	0.038	0.083	0.096	0.146	0.167	0.264	0.373	0.509	0.424	0.327	0.327	0.327
2008	0.000	0.000	0.002	0.022	0.053	0.143	0.169	0.179	0.257	0.306	0.533	0.639	0.880	0.490	0.490	0.490
2009	0.000	0.000	0.003	0.025	0.063	0.107	0.249	0.267	0.263	0.401	0.510	0.761	0.888	0.610	0.610	0.610
2010	0.000	0.000	0.003	0.032	0.081	0.097	0.199	0.443	0.441	0.450	0.772	0.806	1.250	0.863	0.863	0.863
2011	0.000	0.000	0.004	0.034	0.085	0.118	0.146	0.278	0.597	0.621	0.669	0.958	0.949	0.931	0.931	0.931
2012	0.000	0.000	0.002	0.021	0.051	0.072	0.101	0.113	0.197	0.418	0.453	0.396	0.510	0.465	0.465	0.465
2013	0.000	0.000	0.001	0.010	0.024	0.033	0.047	0.060	0.063	0.111	0.233	0.209	0.179	0.194	0.194	0.194
2014	0.000	0.000	0.001	0.007	0.017	0.041	0.034	0.044	0.053	0.056	0.104	0.182	0.158	0.138	0.138	0.138
2015	0.000	0.000	0.001	0.006	0.014	0.036	0.045	0.034	0.041	0.051	0.057	0.088	0.148	0.106	0.106	0.106
2016	0.000	0.000	0.001	0.007	0.016	0.044	0.059	0.068	0.048	0.060	0.078	0.073	0.110	0.125	0.125	0.125
2017	0.000	0.000	0.001	0.011	0.028	0.073	0.110	0.138	0.148	0.107	0.140	0.153	0.139	0.230	0.230	0.230
2018	0.000	0.000	0.001	0.010	0.023	0.055	0.086	0.119	0.140	0.154	0.116	0.128	0.135	0.190	0.190	0.190
2019	0.000	0.000	0.001	0.011	0.027	0.051	0.089	0.128	0.165	0.201	0.232	0.146	0.155	0.217	0.217	0.217
2020	0.000	0.000	0.001	0.013	0.031	0.060	0.085	0.111	0.135	0.170	0.224	0.247	0.264	0.258	0.258	0.258

Table 3. NSS herring. TISVPA. Estimates of fishing mortality coefficients

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Survey report

MS *Eros* and **MS** *Vendla* **12.-26.02.2021**

Distribution and abundance of Norwegian spring-spawning herring during the spawning season in 2021

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Summary

During the period 12-26th of February 2021 the spawning grounds of Norwegian spring-spawning herring from Møre (62º20´N) to Nordvestbanken (70º40´N) were covered acoustically by the commercial vessels MS *Eros* and MS *Vendla*. The estimated biomass was around 23 % higher and the estimated total number was about 35 % higher this year compared to the last year's survey. The uncertainty of the estimates in 2021 was approximately equal to last year. The surveyed population of NSS herring was dominated by the 2016 year class; 59 % in number and 48 % in biomass. In this survey, the 2016 year class is estimated to be on the same level as the strong 1983, 1991 and 2002 year classes. The spatial distribution of the spawning stock in 2021 was different compared to the last six surveys as a large fraction of the stock was found at and around the Røst bank west of Lofoten. The herring here were far in their maturation, either spawning or close to spawning, indicating a northern spawning distribution this year. As usual, the herring in the southern part of the spawning area were older than those found in the northern part. The estimates of relative abundance from the survey in 2020 are recommended to be used in this year's ICES stock assessment of Norwegian spring-spawning herring.

Survey participants 12-26.02.2019:

MS *Eros*	
Erling Kåre Stenevik	Cruise leader
Lage Drivenes	Instrument/Acoustics
Jori Neteland-Kyte	Instrument /Acoustics
Ørjan Sørensen	Biology
Jostein Røttingen	Biology
Christine Djønne	Biology
Lea Marie Hellenbrecht	Biology
Sindre Vatnehol	Acoustics
MS *Vendla*	
Are Salthaug	Cruise leader and Survey coordinator
Jarle Kristiansen	Instrument/Acoustics
Kristoffer Ingebrigtsen Monsen	Instrument/Acoustics
Valantine Anthonypillai	Biology
Adam Custer	Biology
Timo Meissner	Biology
Erling Boge	Biology

Introduction

Acoustic surveys on Norwegian spring-spawning herring during the spawning season has been carried out regularly since 1988, with some breaks (in 1992-1993, 1997, 2001-2004 and 2009-2014). In 2015 the survey was initiated again partly based on the feedback from fishermen and fishermen's organizations that IMR should conduct more surveys on this commercially important stock. Since then this survey, hereafter termed the NSSH spawning survey, has continued with a survey design using commercial vessels. In the ICES benchmark assessment of NSS herring in 2016 it was decided to use the data from this time series as input to the stock assessment, together with the ecosystem survey in the Norwegian Sea in May and catch data. Thus, the results from the NSSH spawning survey, have significant influence on the ICES catch advice.

The objective of the NSSH spawning survey 2021 was to continue the time series of abundance estimates, both mean estimates and uncertainty in, for use in the ICES WGWIDE stock assessment. Moreover, other biological information about the surveyed spawning stock of Norwegian spring-spawning herring is also presented: spatial distribution of biomass and acoustic densities, total biomass and stock numbers with sample uncertainty, spatial patterns in age and maturity and geographical variations in temperature.

Material and methods

Survey design

During the period 12-26th of February 2021 (same period as in 2017-2020) the spawning grounds from Møre (62º20´N) to Troms (70º40´N) were covered acoustically by the commercial fishing vessels MS *Eros* and MS *Vendla*. The survey was planned based on information from the previous spawning cruises and the distribution of the herring fishery during the autumn 2020 up to the survey start February 12th 2021 (Figure 1). The fishery prior to the survey in 2021 indicated that the herring wintering in the Norwegian Sea were entering the coast in the Træna deep south of Røst and following the eastern shelf edge around 200 m depth southwards from Træna as also observed in 2016-2020. Moreover, a quite extensive fishery in October-January 2020/2021 occurred along the continental slope north of Andenes in addition to the fishery in the Kvænangen fjord area that also have been taking place the three previous years. Biological samples from catches from the northern fishery indicate that the 2016 year class dominated in this area. The survey coverage was therefore planned to also take account of a potentially large flux of herring entering the spawning area from the north. As seen from Figure 1, the fishery during the survey in 2021 mainly took place between Træna and Vikna (65-66.5°N).

The survey design followed a standard stratified design (Jolly and Hampton 1990), where the survey area was stratified before the survey start according to the assumed density structures of herring during the spawning migration (based on previous surveys and fisheries). All strata this year were covered with a zigzag design since this is the most efficient use of survey effort (Harbitz 2019). The survey planner function in the Rstox package in r was used to generate the transects, and this function generates survey tracks with uniform coverage of strata and a random starting position in the start of each stratum. Each straight line in the zigzag track within a stratum was considered as a transect and a primary sampling unit (Simmonds and MacLennan 2005). Transit tracks between strata, i.e. from the end of the zigzag in one stratum to the start of the zigzag in the next stratum, were not used as primary sampling units. At the start of the survey in 2021 the fishing fleet was located west of Træna which is further north than usual in mid-February. It was estimated that the fleet had moved south to the Sklinna bank area around 65°N when the survey entered this area, therefore the survey coverage (see Aglen 1989) was planned to be relatively low south of 64°N since it was assumed that the fishing fleet followed the front of the herring migrating south and that the abundance of herring south of the fleet therefore was insignificant.

Biological sampling

Trawl sampling was planned to be carried out on a regular basis during the survey to confirm the acoustic observations and to be able to give estimates of abundance for different size and age groups. Vendla used a commercial herring trawl while Eros used a Multpelt 832 scientific sampling trawl. Both vessels used small meshed (20 mm) inner net in the codend and a slit (so called "splitt") close to the codend to avoid too large catches. The following variables of individual herring were analysed for from each station with herring catch: total weight in grams and total length in cm (rounded down to the nearest 0.5 cm) of up to 100 individuals per sample. In addition, age from scales, sex, maturity stage, stomach fullness and gonad weight in grams were measured in up to 50 individuals per sample. Some genetic samples and otoliths were also collected to be used in later research projects.

Additional data collection

CTD casts (using Seabird 911 systems) were taken by both vessels, spread out haphazardly in the survey area. These measurements will be used to analyse and explore the temperature conditions during the survey and the temperature and salinity measurements will be used for general oceanographic analyses in future projects. ADCP data was recorded on Eros as described in Annex 2 in Salthaug et al. (2020). These data will later be used to analyse swimming speed and direction of herring below the vessel.

Acoustic data processing

Echosounder data from the 38 kHz transducers was, as usual, the basis for measurement of fish density. The software LSSS version 2.10.0 was use for post-processing. Echogram scrutinisation was carried out by at least two experienced persons. Data was partitioned into the following categories: "herring", "other" and "air bubbles" (upper 20 meters from the transducer near field).

Abundance estimation methods

The acoustic density values were stored by species category in nautical area scattering coefficient (NASC) [m^2 $n.mi.^{-2}$] units (MacLennan et al. 2002) in a database with a horizontal resolution of 0.1 nmi and a vertical resolution of 10 m, referenced to the sea surface. To estimate the mean and variance of NASC, we use the methods established by Jolly and Hampton (1990) and implemented in the software Stox version 3.0 (Johnsen et al. 2019). The primary sampling unit is the sum of all elementary NASC samples of herring along the transect multiplied with the resolution distance. The transect (*t*) has NASC value (*s)* and distance length *L*. The average NASC (S) in a stratum (*i*) is then:

$$\hat{S}_i = \frac{1}{n_i} \cdot \sum_{i=1}^{n_i} w_{it} s_{it} \tag{1}$$

where $w_{it} = L_{it} / \overline{L}_t$ (t= 1,2,.. n_i) are the lengths of the n_i sample transects, and

$$\overline{L}_i = \frac{1}{n_i} \sum_{t=1}^{n_i} L_{it} \tag{2}$$

The final mean NASC is given by weighting by stratum area, A;

$$\hat{S} = \frac{\sum_i A_i \hat{S}_i}{\sum_i A_i} \tag{3}$$

Variance by stratum is estimated as:

$$\hat{V}\left(\hat{S}_i\right) = \frac{n}{n_i - 1} \sum_{t=1}^{n} w_{it}^2 \left(s_t - \bar{s}\right)^2 \quad \text{with } \bar{s}_i = \frac{1}{n_i} \cdot \sum_{t=1}^{n_i} s_t \tag{4}$$

Where $w_{it} = L_{it} / \overline{L}_t$ (t= 1,2,.. n_i) are the lengths of the n_i sample transects.

The global variance is estimated as

$$\hat{V}(\hat{S}) = \frac{\sum_i A_{i=1}^2 \hat{V}(\hat{S})}{\left(\sum_i A\right)^2} \tag{5}$$

The global relative standard error of NASC

$$RSE = 100 \sqrt{\frac{\hat{V}(\hat{S})}{N}} \Big/ \hat{S} \tag{6}$$

where N is number of strata.

In order to verify acoustic observations and to analyse year class structure over the surveyed area, trawling was carried out regularly along the transects. All trawl stations with herring were used to derive a common length distribution for all transect within the respective strata. All stations had equal weight.

Relative standard error by number of individuals by age group was estimated by combining Monto Carlo selection from estimated NASC distributions by stratum with bootstrapping techniques of the assigned trawl stations.

The acoustic estimates presented in this report use the 38 kHz NASC, and the mean was calculated for data scrutinized as herring and collected along the transects (acoustic recordings taken during trawling, and for experimental activity are excluded). The number of herring (*N*) in each length group (*l*) within each stratum (*i*) is then computed as:

$$N_l = \frac{f_l \cdot \hat{S}_i \cdot A_i}{\langle \sigma \rangle}$$

Where

$$f_l = \frac{n_l L_i^2}{\sum_{l=1}^{m} n_l L_l}$$

is the ”acoustic contribution” from the length group L_l to the total energy and <s_i>is the mean nautical area scattering coefficient [m^2/nmi^2] (NASC) of the stratum. A is the area of the stratum [nmi^2] and σ is the mean backscattering cross section at length L_l. The conversion from number of fish by length group *(l)* to number by age is done by estimating an age ratio from the individuals of length group *(l)* with age measurements. Similar, the mean weight by length and age grouped is estimated.

The mean target strength (TS) is used for the conversion where $\sigma = 4\pi\ 10^{(TS/10)}$ is used for estimating the mean backscattering cross section. Traditionally, TS = 20logL – 71.9 (Foote 1987) has been used for mean target strength of herring during the spawning surveys, however, several papers question this mean target strength. Ona (2003) describes how the target strength of herring may change with changes with depth, due to swimbladder compression. He measured the mean target strength of herring to be TS = 20logL – 2.3 log(1 + z/10) – 65.4 where z is depth in meters. Given that previous surveys were estimated using Foote (1987), the estimation this year was also done with this TS, for direct comparison and possible inclusion in the stock assessment by ICES WGWIDE 2021 as another year in the time series.

Sonar data and analyses

Data from Simrad low-frequency sonars were logged on board all vessels with the objective to measure the presence and magnitude of potential bias related to vertical distribution (fish in blind zone above the echo sounder transducer) and avoidance behaviour of the herring relative to the presence of the vessel. Data from fisheries sonars have been collected from all participating vessels since 2015. Methods to quantify or evaluate the extent of these biases are presently being developed.

Results and discussion

Survey coverage

The cruise tracks of the NSSH spawning survey in 2021 are shown in Figure 2. As mentioned above, the coverage south of 64°N was fairly low since we expected low abundance in this area, which turned out to be the case (see below). Thus, most of the available survey effort was used to carry out dense coverage of the strata north of 64°N. The survey coverage (see Aglen 1989) of the first three strata north of 64°N was 11 while it was 9 in the two northernmost strata. Pelagic trawl hauls were carried out regularly (Fig. 2) in the areas where herring like records were observed on the echo sounder, to confirm the acoustic observations based on species composition in the catch and to obtain biological samples like size, maturity stage and age of herring. A total of 24 CTD casts were carried out in the surveyed area (Fig. 2). Nautical area scattering coefficients (NASC) from acoustic transects by each nautical mile are shown in Figure 3. Significant herring marks on the echosounders started to occur around 65°N as expected, and herring was observed in the entire area north of this. A difference compared with earlier years was that large amounts of herring was observed on the Røst bank west of Lofoten. In earlier years the herring was mainly distributed around the shelf edge further west in this area. Moreover, herring was also abundant in the northernmost stratum and the zero line was not established in the west here.

Estimates of abundance

The abundance estimates from this survey are viewed as relative, i.e. as indices of abundance, since there are highly uncertain scaling parameters like acoustic target strength and compensation for herring migrating in the opposite direction of the survey. The abundance estimates are shown in Table 1 and 2. For quality assurance, independent estimates were made by two scientists, giving less than 0.1% difference between estimates of abundance at age. The 2016 year class (age 5) dominated both in numbers (59 %) and biomass (48 %). The point estimate of total stock biomass (TSB) in the survey area was 4.02 tons which is 23 % higher than last year's estimate (mean of 1000 bootstrap replicates). The time series of total stock biomass from the survey is shown in Figure 4. This year's estimate of TSB is very close to the mean of the time series. The point estimate of total stock number (TSN) in the survey area was 17.3 billion which is 35 % higher than last year's estimate. The time series of total stock number from the survey is shown in Figure 5. This year's estimate of TSN is slightly above the mean of the time series. The relative standard error (CV) of the TSB estimate in 2021 is 15 % (Tab. 2) and the CV of the TSN estimate is 16 % (Tab. 1). These estimates of sample uncertainty are very similar to those from last year's survey. The CV per age (Tab.1 and 2) shows the normally observed pattern with high uncertainty for the very young and old year classes and moderate (20-30 %) for the most abundant ages in the survey. Figure 6a shows estimates of number per year class in the seven most recent surveys. The estimated numbers from the survey in 2021 seems to decline as excepted for the year classes that are fully recruited to the survey and the estimated year class strengths are in line with the estimates from earlier surveys. The number of age 5 (2016 year class) is the highest observed for an age group during the seven last years (Fig. 6a). Figure 6b shows estimates of number per year class from the two most recent IESNS surveys which are carried out in the Norwegian Sea in May together with the two most recent NSSH spawning surveys. Both surveys use the same target strength for herring, but the herring behave very differently during spawning and feeding migration, which may affect the acoustic abundance estimation. Still, the indices of year class abundance and their trends from these surveys are well in line with each other, signifying that both surveys are capturing the dynamics in this stock well despite different survey coverage and design. The 2016 year class started to recruit notably to the IESNS survey as 3 year olds in 2019 and slightly more to the spawning survey as 4 year olds in 2020 while strongly to IESNS in 2020. This indicates that a large proportion of the 2016 year class still was immature as 4 year olds. In the 2021 spawning survey the 2016 year class started to recruit strongly as 5 year olds, however the estimate is a bit lower than in IESNS 2020. Note that the estimates for most year classes are lower in IESNS than in the spawning survey within the same year, despite that the surveys are carried out only 3 months apart. These differences may be due to mortality and/or differences in survey catchability. The time series from the spawning survey of age 5 is shown in Figure 7 for comparison of the 2016 year class estimate with earlier strong year classes, and this year class is estimated to be on the same level as the strong 1983, 1991 and 2002 year classes. Mean weight and length from the 2021 spawning survey are shown in Table 3.

Spatial distribution of the stock

The relative distribution of the estimated biomass per stratum is shown in Figure 8. A large proportion of the biomass (64%) was found in the two strata west of Lofoten on and around the Røst bank. The northernmost stratum also contained a significant proportion of the biomass (17 %). Compared with the most recent surveys the biomass was found further north this year. Age compositions per stratum are shown in Figure 9. The proportions of age 5 (2016 year class) are high in all strata but they decline from north to south, which is in line with the normally observed pattern with the oldest herring furthest south and domination of young herring in the north. However, the proportion of herring older than ten years was significant in all strata south of 69°N and this is also the case for the moderate 2013 year class (age 8). The pattern with large and old fish in the southern part of the spawning area and younger and older herring in the north has been thoroughly discussed in Slotte and Dommasnes, 1997, 1998, 1999, 2000; Slotte, 1998b; Slotte, 1999a, Slotte 2001, Slotte et al. 2000, Slotte & Tangen 2005, 2006). The main hypothesis is that this could be due to the high energetic costs of migration, which is relatively higher in small compared to larger fish (Slotte, 1999b). Large fish and fish in better condition will have a higher migration potential and more energy to invest in gonad production and thus the optimal spawning grounds will be found farther south (Slotte and Fiksen, 2000), due to the higher temperatures of the hatched larvae drifting northwards and potentially better timing to the spring bloom (Vikebø et al. 2012). Figure 10 shows the proportion of different maturation stages in each stratum. Spawning (or running) herring were found in all strata which means that spawning occurred over a large area this year. Most of the sampled individuals were either maturing, ripe or spawning, but a small fraction of the herring in the northernmost stratum was immature and some spent/resting individuals were found south of Lofoten. The fact that a large proportion of the herring from Sklinna and northwards along Vesterålen were in ripe stages (just about to spawn) suggest that the spawning this year would tend to occur in the areas we observed the high densities of herring. Hence, a very northern spawning this year, which also was confirmed through the fishery that was very low at the historically important spawning grounds off Møre and dried out quickly in the Sklinna area after the spawning survey ended.

Geographical variation in temperatures experienced by the herring

Temperatures experienced by herring from close to the surface and down to deeper waters than 200 m varied from 5°-8°C (Figure 11). At typical spawning depths of herring at 100-200 m depth, the temperature conditions were quite similar to those observed during the most recent NSSH spawning surveys.

Quality of the survey

In 2021 both vessels were equipped with multifrequency equipment on a drop keel. Even though the weather conditions were sometimes challenging with occasionally strong wind, acoustic data with good quality was recorded and trawling on registrations could be carried out most of the time. Correction for air bubble attenuation (see Annex 3 in Slotte et al. 2019) had to be done in only a very few instances. As in earlier years, some of the young herring in the north was sometimes found close to the surface and it is therefore assumed that some herring was "lost" in the blind zone, especially during the night. Moreover, an unknown fraction of the 2016 year class was distributed outside the survey area in the north since the zero line not was established on the western limit of the northernmost stratum. However, the capelin survey covered this area a week after and the observations indicates that the amount of herring outside the NSSH spawning survey area was low. It should be noted that it is assumed in the ICES stock assessment of NSS herring that 5 year olds are not fully recruited in this survey (this information is contained in the catchability parameters). To conclude, the acoustic and biological data recorded in 2021 on the NSSH spawning survey were of satisfactory quality and the estimates from the survey are recommended to be used in the stock assessment of Norwegian spring-spawning herring in 2021.

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Tables

Table 1. Abundance estimates (million individuals) of Norwegian spring-spawning herring during the spawning survey 12.-26. February 2021, based on 1000 bootstrap replicates.

Age	5th percentile	Median	95th percentile	Mean	SD	CV
2	2	20	47	21	14	0.68
3	41	99	225	112	60	0.53
4	142	285	488	293	106	0.36
5	7197	10124	13346	10210	1892	0.19
6	376	738	1101	733	222	0.30
7	515	729	984	738	149	0.20
8	1352	1890	2627	1932	389	0.20
9	243	423	617	427	116	0.27
10	307	442	626	451	97	0.21
11	166	305	484	312	100	0.32
12	127	216	325	219	61	0.28
13	162	387	653	395	145	0.37
14	129	201	318	208	58	0.28
15	325	502	717	510	119	0.23
16	87	181	301	185	67	0.36
17	213	348	512	353	93	0.26
18	23	99	192	102	54	0.53
20	2	2	6	3	2	0.62
TSN	12888	17124	21790	17250	2705	0.16

Table 2. Abundance estimates (thousand tons) of Norwegian spring-spawning herring during the spawning survey 12.-26. February 2021, based on 1000 bootstrap replicates.

Age	5th percentile	Median	95th percentile	Mean	SD	CV
2	0	1	3	1	1	0.79
3	3	9	21	10	6	0.56
4	23	43	68	44	14	0.32
5	1352	1900	2492	1912	355	0.19
6	86	160	235	160	45	0.28
7	145	206	278	209	42	0.20
8	404	563	779	575	115	0.20
9	78	133	194	135	36	0.27
10	102	146	206	148	31	0.21
11	58	107	171	110	35	0.32
12	47	78	118	80	22	0.27
13	59	136	223	138	49	0.36
14	46	72	114	75	21	0.28
15	118	184	264	186	44	0.24
16	31	66	109	67	24	0.36
17	79	127	187	129	34	0.26
18	9	37	73	39	20	0.53

Age	5th percentile	Median	95th percentile	Mean	SD	CV
20	1	1	2	1	1	0.59
TSB	3038	3997	5072	4021	622	0.15

Table 3. Estimated length and weight of individuals by age group of Norwegian spring-spawning herring during the spawning survey 12.-26. February 2021, based on 1000 bootstrap replicates.

Age	Mean weight (g)	CV weight	Mean length (cm)	CV length
2	44.3	0.256	19.8	0.096
3	103.1	0.179	25.3	0.045
4	160.3	0.064	28.9	0.018
5	193.0	0.015	30.1	0.003
6	222.4	0.037	31.5	0.010
7	285.1	0.011	33.7	0.004
8	302.1	0.007	34.3	0.002
9	321.1	0.015	35.2	0.005
10	335.6	0.017	35.6	0.006
11	352.0	0.017	36.5	0.005
12	365.5	0.013	36.9	0.004
13	358.1	0.020	36.6	0.009
14	360.7	0.015	36.8	0.004
15	372.6	0.010	37.1	0.003
16	376.7	0.040	37.5	0.008
17	376.3	0.014	37.3	0.004
18	379.7	0.028	37.6	0.009
20	341.7	0.017	35.5	0.000

Figures

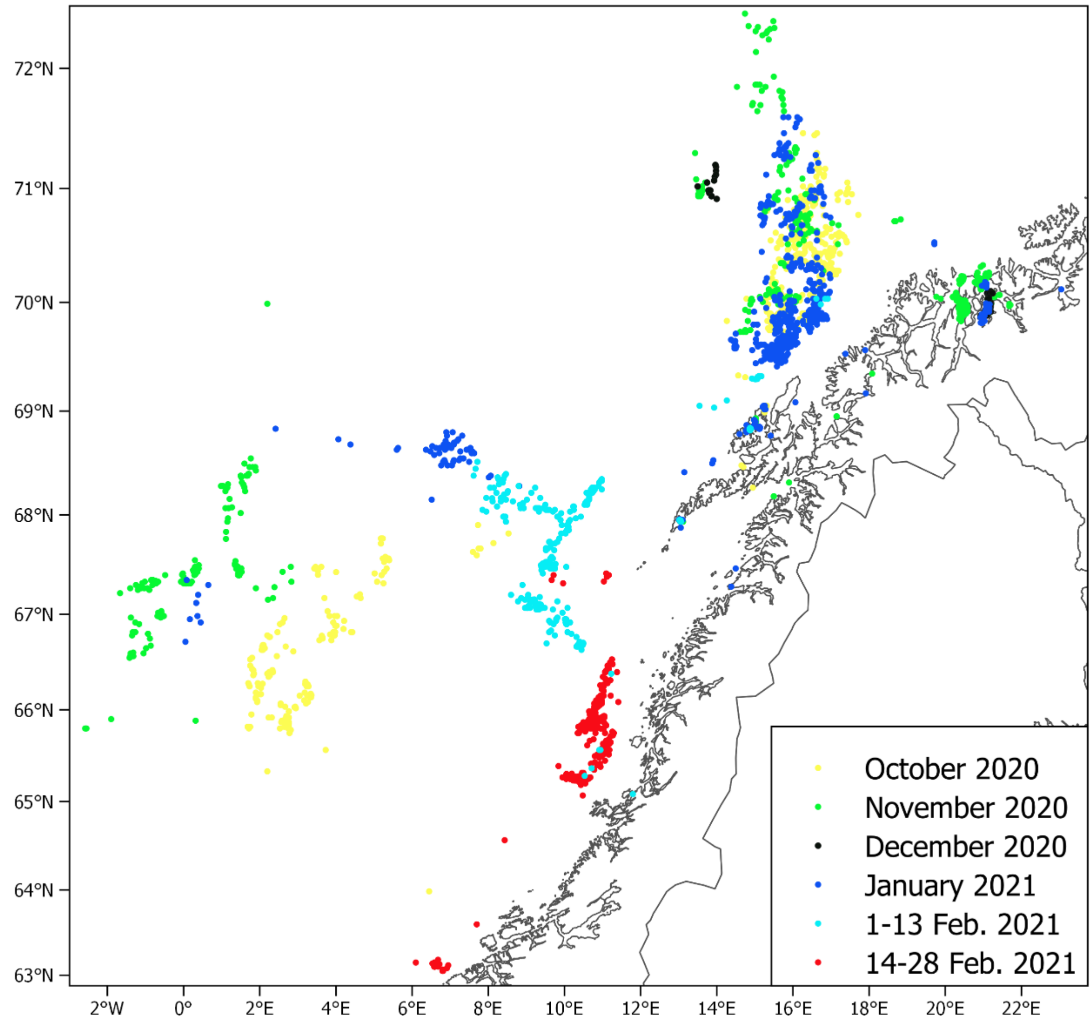


Figure 1. Distribution of commercial catches of Norwegian spring-spawning herring from October 2020 until February 2021, based on electronic logbooks. Each point represent one catch, only catches larger than 10 tons are shown.

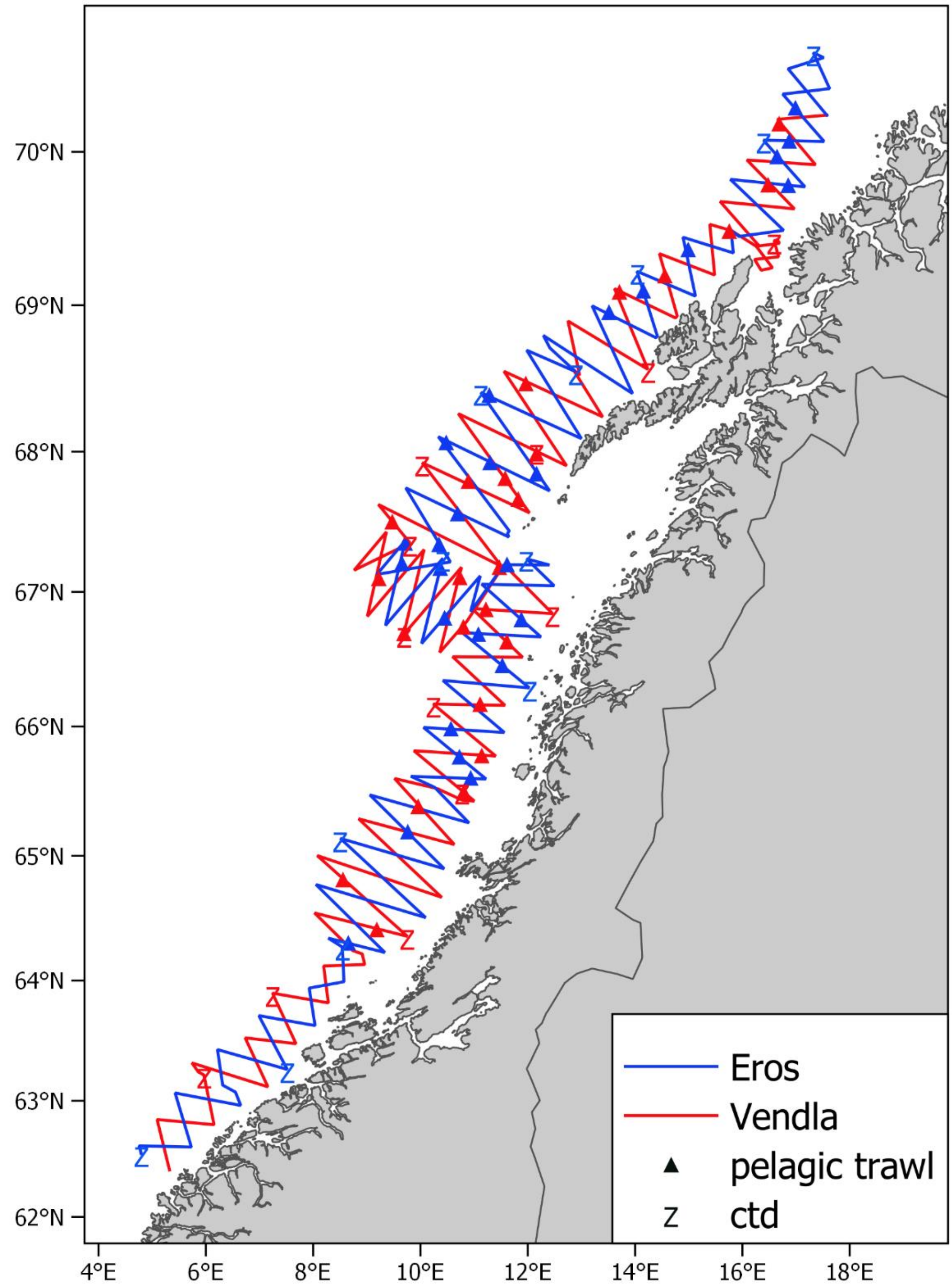


Figure. 2. Cruise tracks (mostly acoustic transects), pelagic trawl stations (triangles), and CTD stations (Z) covered by *Eros* and *Vendla* on the Norwegian spring-spawning herring spawning survey 12.-26. February 2021.

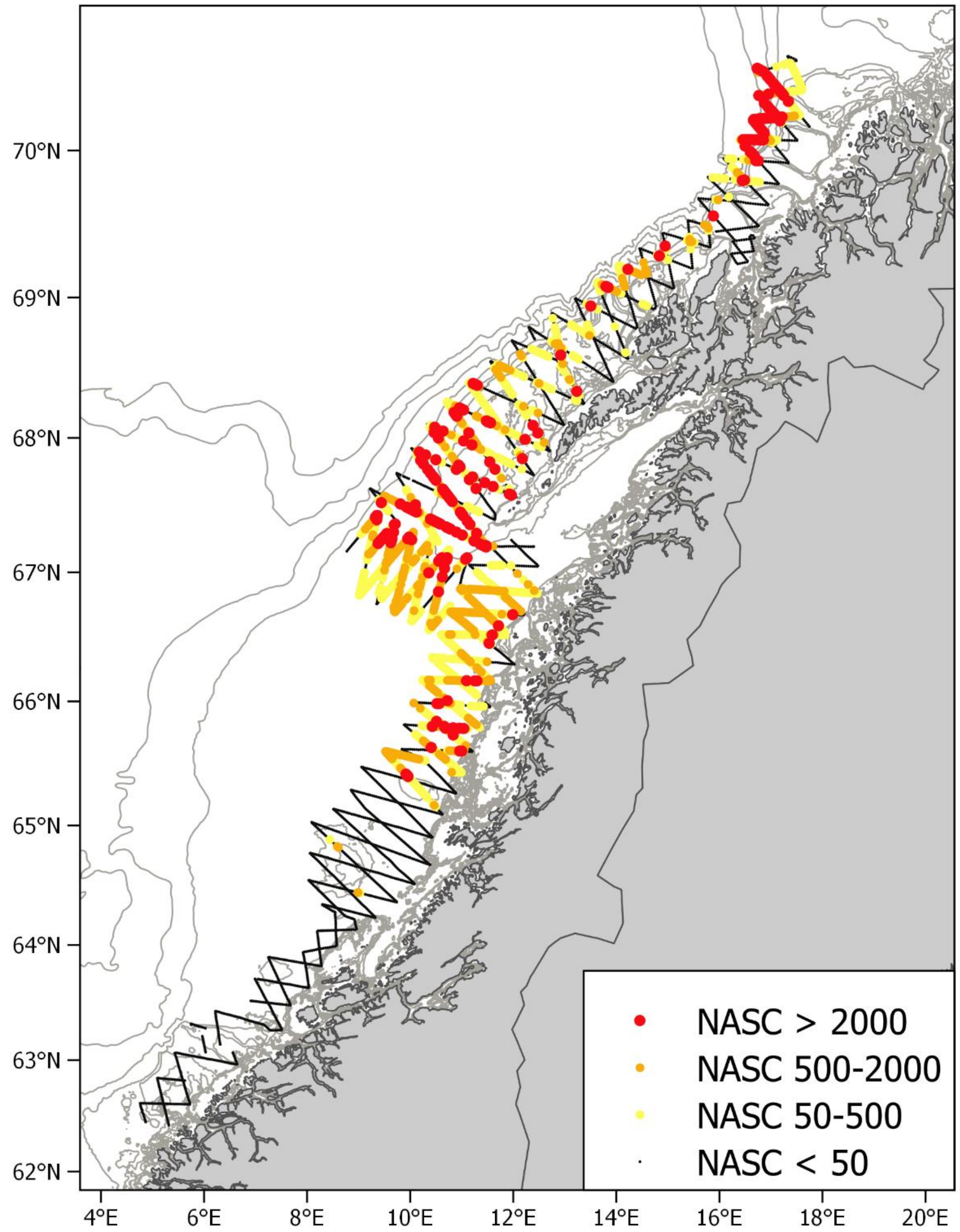


Figure 3. Acoustic densities (NASC) of herring recorded during the Norwegian spring-spawning herring spawning survey 12.-26. February 2021. Points represent NASC values per nautical mile. Depth contours are shown for 50 m, 100 m, 150 m, 200 m, 500 m, 1000 m, 1500 m and 2000 m.

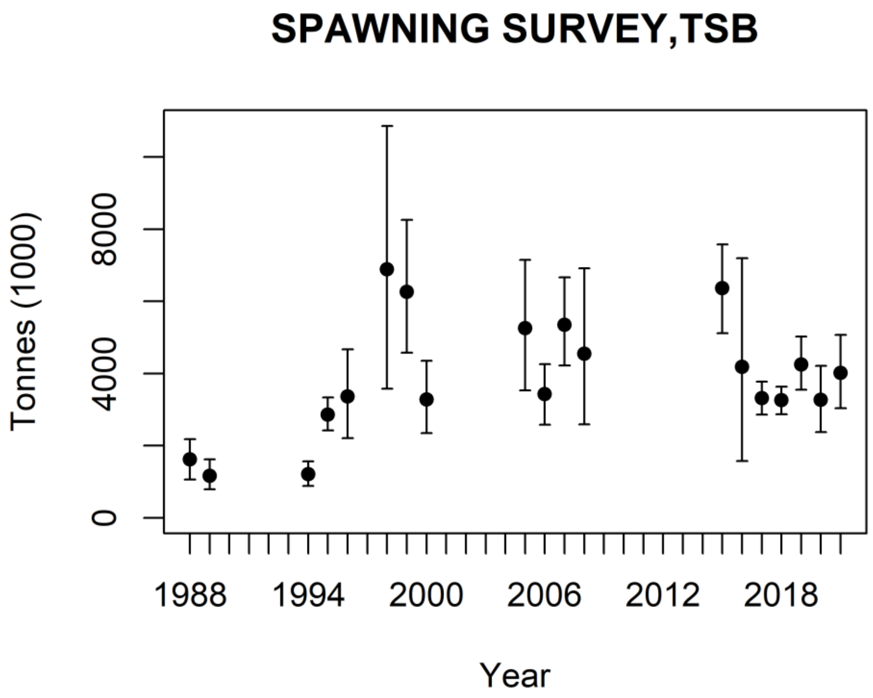


Figure 4. Estimates of total biomass from the Norwegian spring-spawning herring spawning surveys during1988-2021. The estimates are mean of 1000 bootstrap replicates and the error bars represent 90 % confidence intervals.

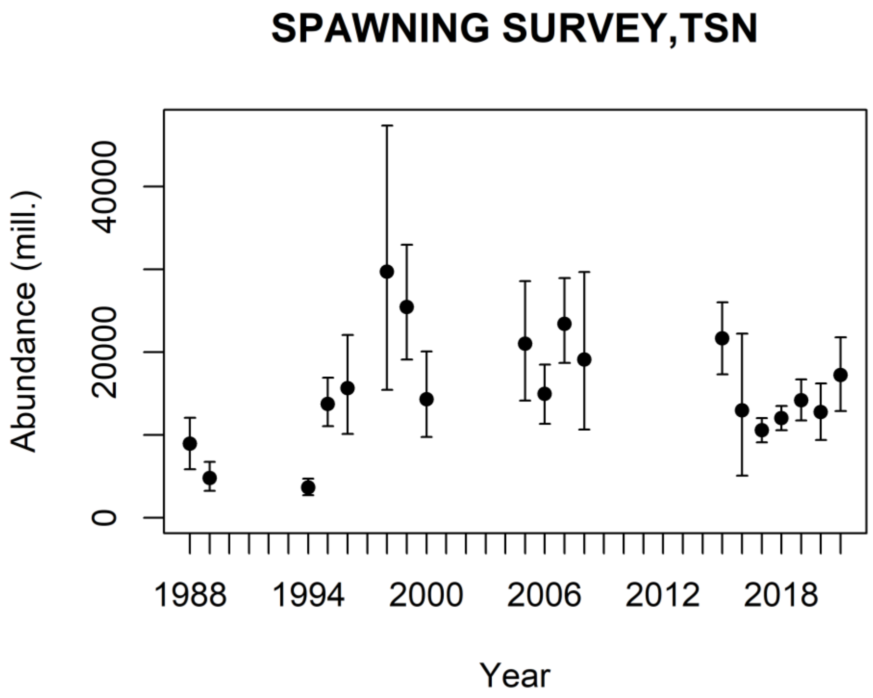


Figure 5. Estimates of total number from the Norwegian spring-spawning herring spawning surveys during1988-2021. The estimates are mean of 1000 bootstrap replicates and the error bars represent 90 % confidence intervals.

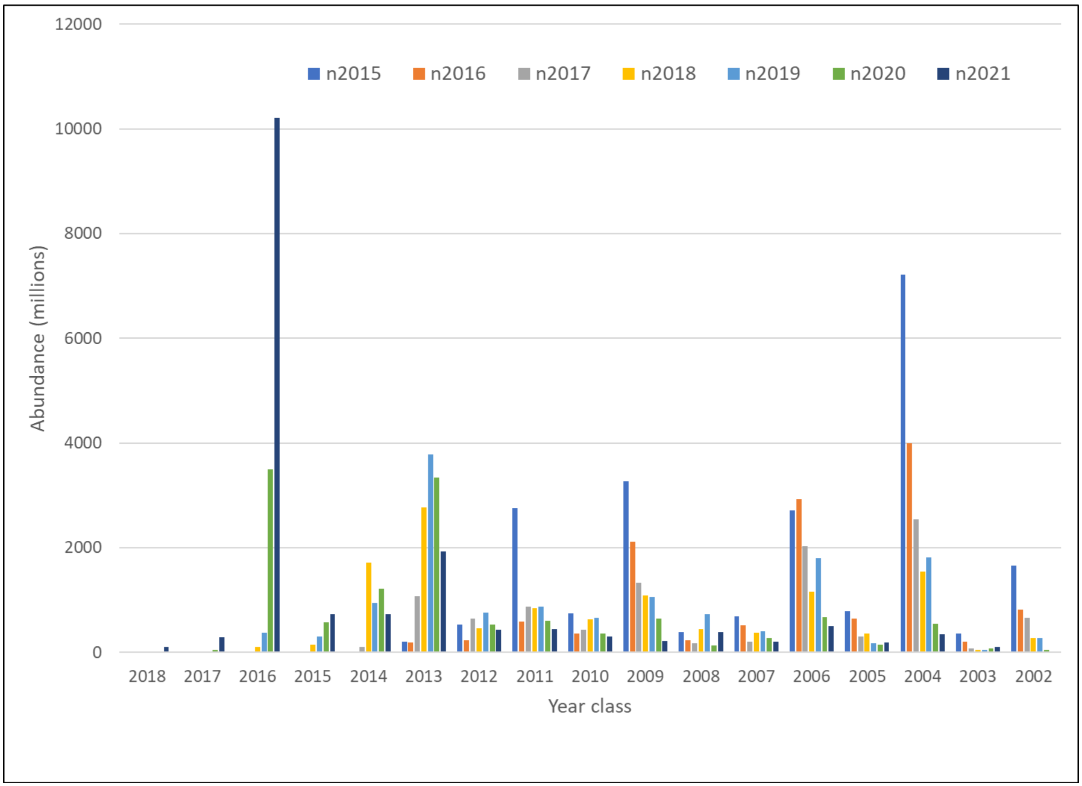


Figure 6a. Abundance by year class estimated during the Norwegian spring-spawning herring spawning surveys 2015-2021 (mean of 1000 bootstrap replicates). Legend: Separate colour for each survey year.

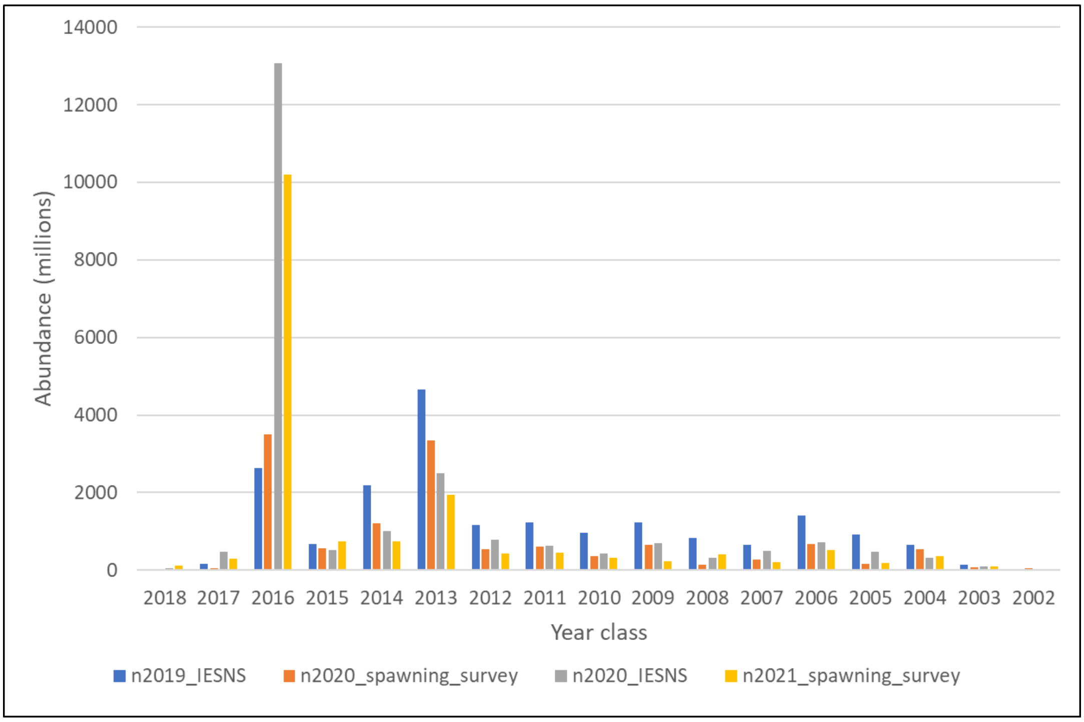


Figure 6b. Abundance by year class estimated during the International Ecosystem Survey in Nordic Seas (IESNS) 2019-2020 and the Norwegian spring-spawning herring spawning survey 2020-2021 (mean of 1000 bootstrap replicates). Legend: Separate colour for each survey and year.

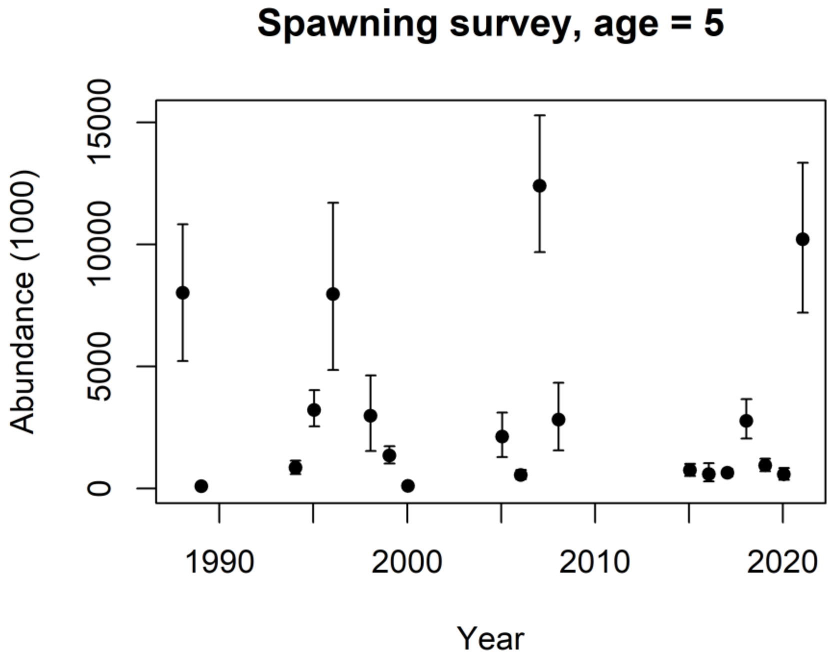


Figure 7. Estimated abundance of 5 year old herring from Norwegian spring-spawning herring spawning surveys during1988-2021. The estimates are mean of 1000 bootstrap replicates and the error bars represent 90 % confidence intervals.

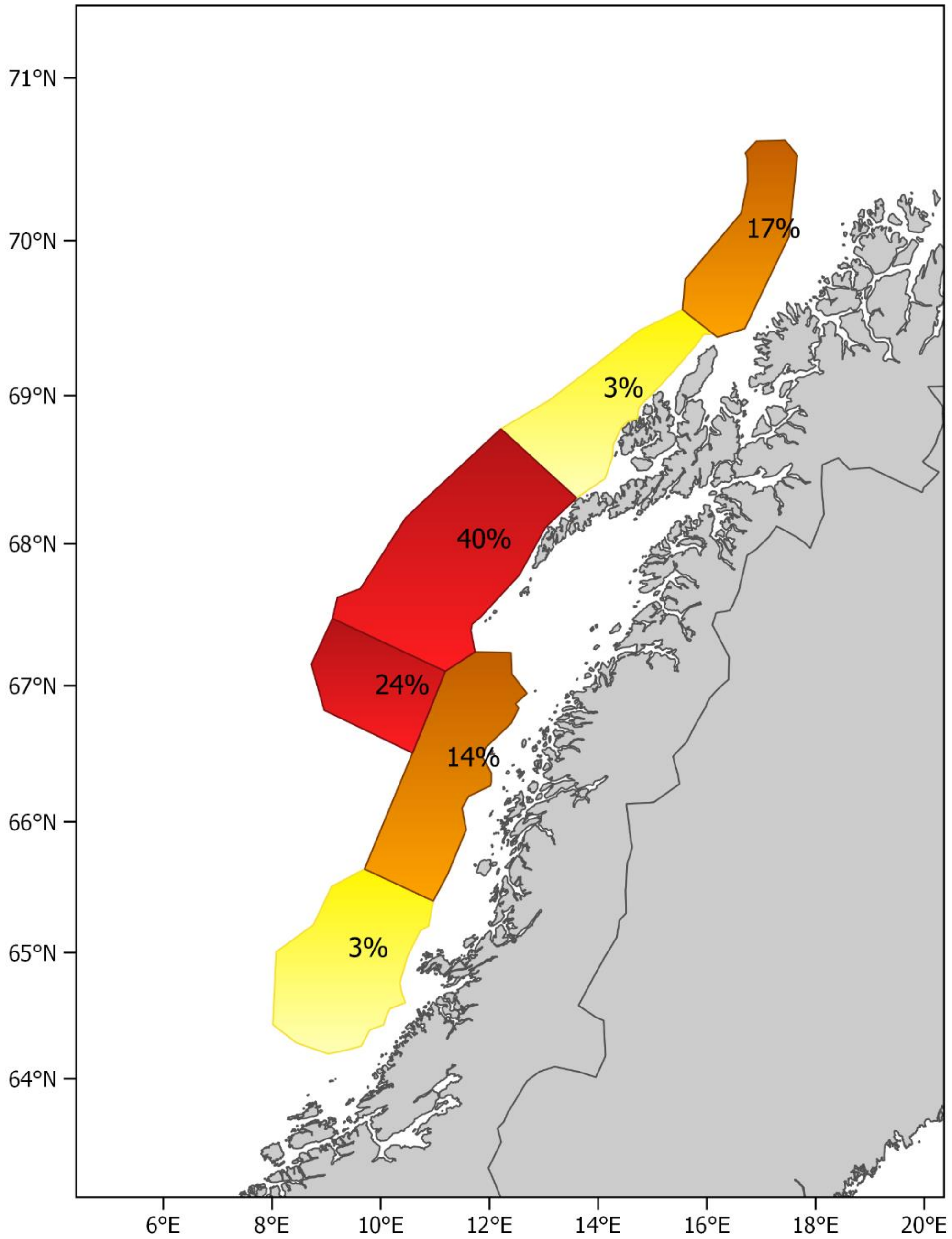


Figure 8. Relative distribution by stratum of the biomass of herring (mean of 1000 bootstrap replicates) from the Norwegian spring-spawning herring spawning survey 12.-26. February 2021.

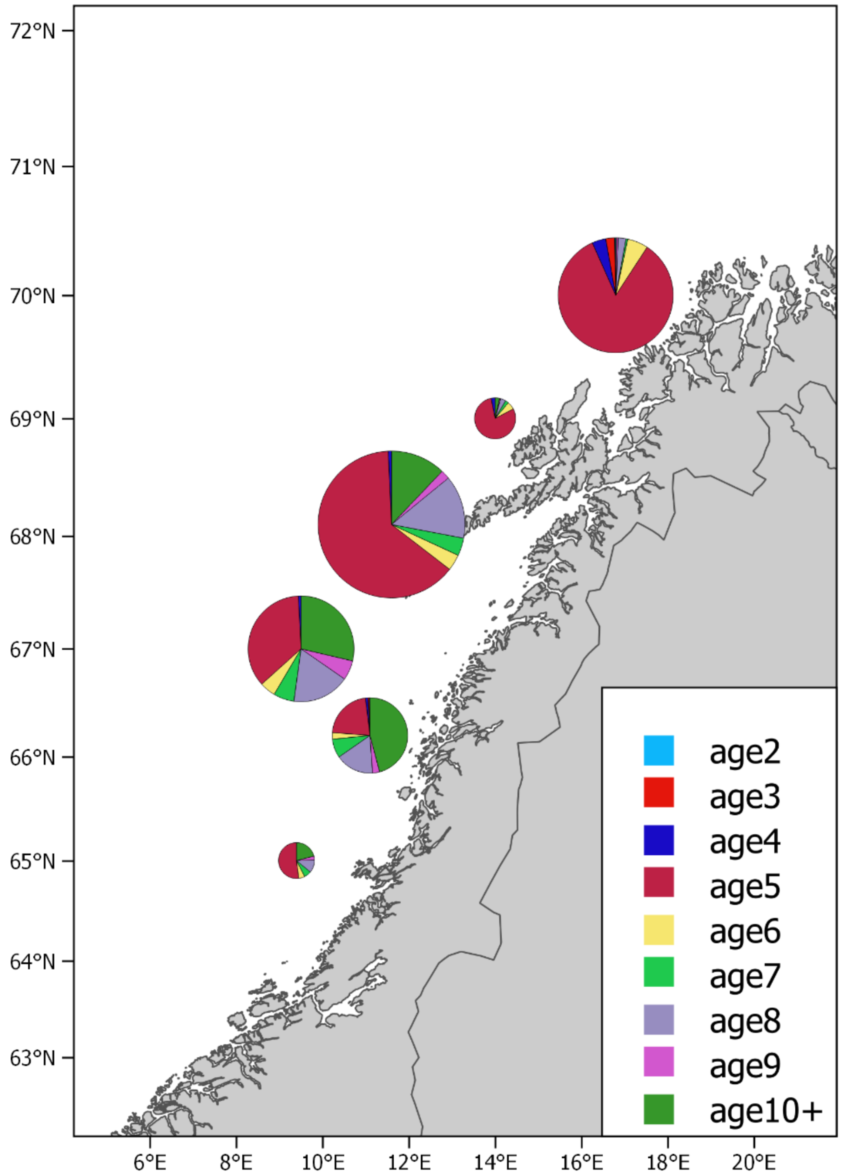


Figure 9. Age distribution per stratum from the Norwegian spring-spawning herring spawning survey 12.-26. February 2021. The area of the bubbles is scaled with the total number estimated in each stratum.

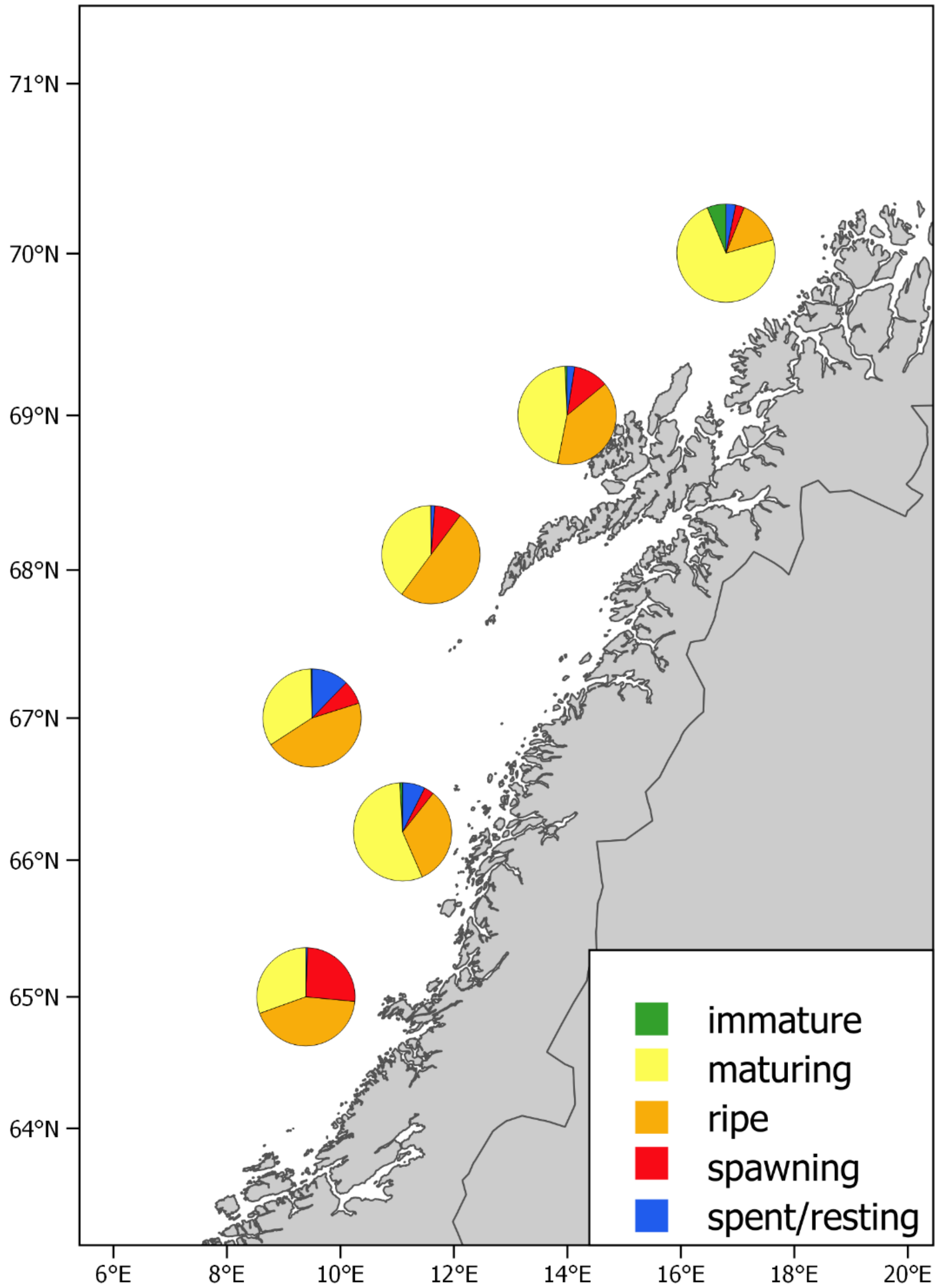


Figure 10. Proportions of different maturity stages from the Norwegian spring-spawning herring spawning survey 12.-26. February 2021.

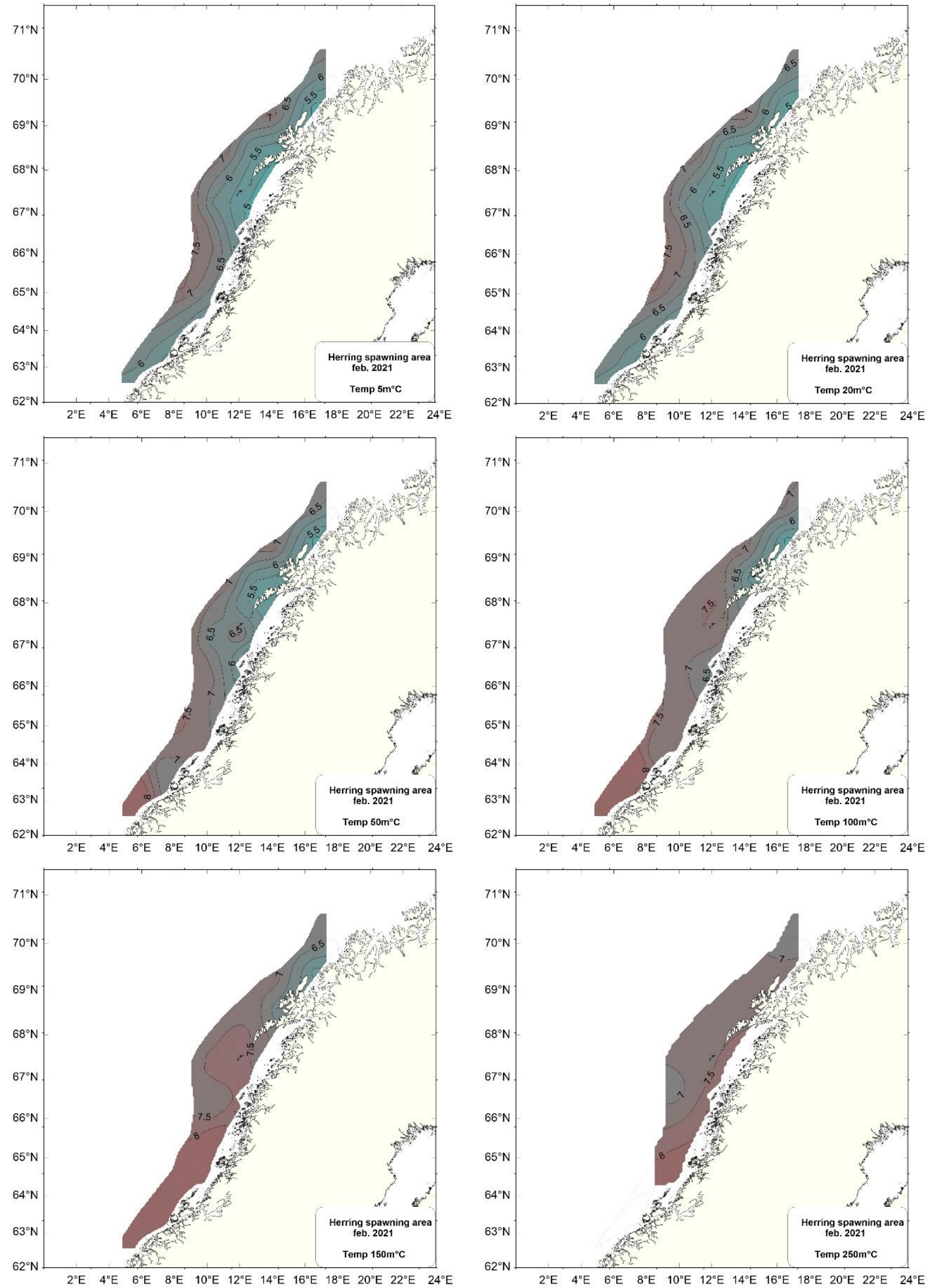
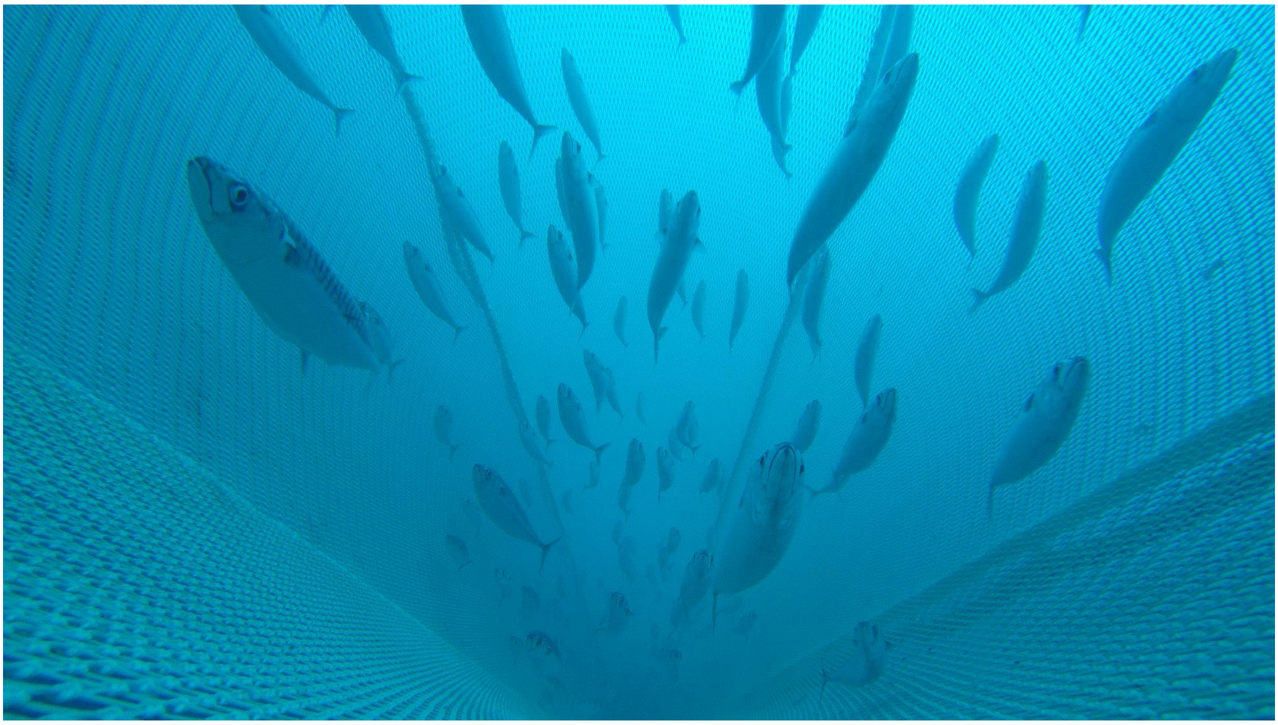


Figure 11. Temperature at 5, 20, 50, 100, 150, 250 m in the area covered during the Norwegian spring-spawning herring spawning survey 12.-26. February 2021.

Working Document to

ICES Working Group on Widely Distributed Stocks (WGWIDE, No. 09)
ICES HQ, Copenhagen, Denmark, (digital meeting) 25. – 31. August 2021

Cruise report from the International Ecosystem Summer Survey in the Nordic Seas (IESSNS) 30th June – 3rd August 2021



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Contents

1 Executive summary

The International Ecosystem Summer Survey in the Nordic Seas (IESSNS) was performed within approximately 5 weeks from June 30th to August 3rd in 2021 using five vessels from Norway (2), Iceland (1), Faroe Islands (1) and Denmark (1). The main objective is to provide annual age-segregated abundance index, with an uncertainty estimate, for northeast Atlantic mackerel (*Scomber scombrus*). The index is used as a tuning series in stock assessment according to conclusions from the 2017 and 2019 ICES mackerel benchmarks. A standardised pelagic swept area trawl method is used to obtain the abundance index and to study the spatial distribution of mackerel in relation to other abundant pelagic fish stocks and to environmental factors in the Nordic Seas, as has been done annually since 2010. Another aim is to construct a new time series for blue whiting (*Micromesistius poutassou*) abundance index and for Norwegian spring-spawning herring (NSSH) (*Clupea harengus*) abundance index. This is obtained by utilizing standardized acoustic methods to estimate their abundance in combination with biological trawling on acoustic registrations. The time series for blue whiting and NSSH now consists of six years (2016-2021).

The survey coverage area included in calculations of the mackerel index was 2.2 million km^2 in 2021, which is 24% smaller coverage compared to 2020. Survey coverage was reduced in the western area as Greenlandic waters, Iceland basin (south of latitude 62°45′) and the Reykjanes ridge (south of latitude 62°45′) were not surveyed in 2021. Furthermore, 0.29 million km^2 was surveyed in the North Sea in July 2021 but those stations are excluded from the mackerel index calculations.

The total swept-area mackerel index in 2021 was 5.15 million tonnes in biomass and 12.2 billion in numbers, a decreased by 58% for biomass and 54% for abundance compared to 2020. Reduced survey coverage in the western area did not contribute to the observed decline as the zero mackerel boundary was established north, west, and south of Iceland. In 2021, the most abundant year classes were 2019, 2016, 2014, 2017 and 2012, respectively. The cohort internal consistency was slightly reduced compared to last year, particularly for ages 5-8 years.

Mackerel was distributed mostly in the central and northern Norwegian Sea, with low densities and limited distribution in Icelandic waters. Mackerel distribution in the North Sea was similar to 2020, but the biomass nearly doubled compared to 2020. Zero boundaries of the summer distribution of mackerel were found in most parts of the survey area, except towards northwest in the Norwegian Sea, southward boundaries in the North Sea and west of the British Isles.

The total number of Norwegian spring-spawning herring (NSSH) recorded during IESSNS 2021 was 19.6 billion and the total biomass index was 5.91 million tonnes, which are similar results to 2020. The 2016 year-class (5year olds) dominated in the stock and contributed to 54% and 59% to the total biomass and total abundance, respectively, whereas the 2013 year-class (8-year olds) contributed 13% and 11% to the total biomass and total abundance, respectively. The 2016 year-class is considered fully recruited to the spawning stock in 2021, and also fully recruited to the survey area. The survey is considered to contain the whole adult part of the NSSH stock during the 2021 IESSNS.

The total biomass of blue whiting registered during IESSNS 2021 was 2.2 million tonnes, which is a 22% increase compared to 2020. Stock abundance (ages 1+) was estimated to 26.2 billion compared to 16.5 billion in 2020. The 2020 year-class dominate the estimate in 2021 and contributed 51% and 69% to the total biomass and abundance, respectively.

As in previous years, there was overlap in the spatio-temporal distribution of mackerel and herring. This overlap occurred between mackerel and North Sea herring in major parts of the North Sea and partly in the southernmost part of the Norwegian Sea. There were also some overlapping distributions of mackerel and Norwegian spring-spawning herring (NSSH) in the western, north-western and north-eastern part of the Norwegian Sea.

Other fish species also monitored are lumpfish (*Cyclopterus lumpus*) and Atlantic salmon (*Salmo salar*). Lumpfish was caught at 78% of surface trawl stations distributed across the surveyed area from southwestern part of Iceland, central part of North Sea to southwestern part of the Svalbard. Abundance was greater north of latitude 72°N compared to southern areas. A total of 35 North Atlantic salmon were caught in 25 stations both in coastal and offshore areas from 60°N to 76°N in the upper 30 m of the water column. The salmon ranged from 0.089 kg to 6.5 kg in weight, dominated by postsmolt weighing 89-425 grams and 1 sea-winter individuals (grilse) weighing 1.9-2.4 kg.

Satellite measurements of the sea surface temperature (SST) showed that the central and eastern part of the Norwegian Sea were roughly on same level as average for July 1990-2009. SST was 1-3 °C warmer than the long-term average in the Iceland Sea and the Greenland Sea. The North Sea SST was 1-2 °C warmer than long term average. CTD measurements from the central part of the Norwegian Sea indicated more stratification in the surface layer than in 2020.

Average zooplankton biomass in the Norwegian Sea has been relatively stable since 2013. There was, however, a small decrease in 2021 compared to last year, especially in the central and southern areas. A small increase was observed in the Iceland region compared to last year.

2 Introduction

During approximately five weeks of survey in 2021 (30th of June to 3rd of August), five vessels; the M/V "Eros" and M/V "Vendla" from Norway, R/V "Jákup Sverri" operating from Faroe Islands, the R/V "Árni Friðriksson" from Iceland and M/V "Ceton" operating in the North Sea by Danish scientists, participated in the International Ecosystem Summer Survey in the Nordic Seas (IESSNS).

The main aim of the coordinated IESSNS was to collect data on abundance, distribution, migration and ecology of Northeast Atlantic (NEA) mackerel (*Scomber scombrus*) during its summer feeding migration phase in the Nordic Seas. The resulting abundance index will be used in the stock assessment of NEA mackerel at the annual meeting of ICES working group of widely distributed stocks (WGWIDE). The IESSNS mackerel index time series goes back to 2010. Since 2016, systematic acoustic abundance estimation of both Norwegian spring-spawning herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*) have also been conducted. This is considered as potential input for stock assessment, when the time series are sufficiently long. Furthermore, the IESSNS is a pelagic ecosystem survey collecting data on physical oceanography, plankton and other fish species such as lumpfish and Atlantic salmon. Opportunistic whale observations are also recorded from Norway, Iceland and Faroe Islands. The wide geographical coverage, standardization of methods, sampling on many trophic levels and international cooperation around this survey facilitates research on the pelagic ecosystem in the Nordic Seas, see e.g. Nøttestad et al. (2016), Olafsdottir et al. (2019), Bachiller et al. (2018), Jansen et al. (2016), Nikolioudakis et al. (2019).

The methods have evolved over time since the survey was initiated by Norway in the Norwegian Sea in the beginning of the 1990s. The main elements of standardization were conducted in 2010. Smaller improvements have been implemented since 2010. Faroe Islands and Iceland have participated in the joint mackerel-ecosystem survey since 2009. Greenland since 2013 and Denmark from 2018. Greenland did not participate in 2021.

The North Sea was included in the survey area for the fourth time in 2021, following the recommendations of WGWIDE. This was done by scientists from DTU Aqua, Denmark. The commercial fishing vessels "Ceton S205" was used, and in total 39 stations (CTD and fishing with the pelagic Multpelt 832 trawl) were successfully conducted. No problems applying the IESSNS methods were encountered. Area coverage, however, was restricted to the northern part of the North Sea at water depths deeper than 50 m and no plankton samples were taken (see Appendix 1 for comparison with 2018 - 2020 results).

3 Material and methods

Coordination of the IESSNS 2021 was done during the WGIPS 2021 virtual meeting in January 2021, and by correspondence in spring and summer 2021. The participating vessels together with their effective survey periods are listed in Table 1.

Overall, the weather conditions were rougher in 2021 with periods of less favourable survey conditions for the Norwegian vessels for oceanographic monitoring, plankton sampling, acoustic registrations and pelagic trawling. The weather was windier and rougher sea conditions in longer periods than usual, especially during the last part of the first part and during the second part of the survey for the two Norwegian vessels in central and northern Norwegian Sea. There were also more days with fog in both the southern, central and northern part of the Norwegian Sea than previous years, influencing the visual observations. The Icelandic vessel, operating in Icelandic waters, experienced mostly calm weather with only 12-hours storm delay in total. The weather was mostly calm for the Faroese vessel operating mainly in Faroese, east Icelandic and international waters. The chartered vessel Ceton had excellent weather throughout the survey.

During the IESSNS, the special designed pelagic trawl, Multpelt 832, has been applied by all participating vessels since 2012. This trawl is a product of cooperation between participating institutes in designing and constructing a standardized sampling trawl for the IESSNS. The work was led by trawl gear scientist John Willy Valdemarsen, Institute of Marine Research (IMR), Bergen, Norway (Valdemarsen et al. 2014). The design of the trawl was finalized during meetings of fishing gear experts and skippers at meetings in January and May 2011. Further discussions on modifications in standardization between the rigging and operation of Multpelt 832 was done during a trawl expert meeting in Copenhagen 17-18 August 2012, in parallel with the post-cruise meeting for the joint ecosystem survey, and then at the WKNAMMM workshop and tank experiments on a prototype (1:32) of the Multpelt 832 pelagic trawl, conducted as a sequence of trials in Hirtshals, Denmark from 26 to 28 February 2013 (ICES 2013a). The swept area methodology was also presented and discussed during the WGISDAA workshop in Dublin, Ireland in May 2013 (ICES 2013b). The standardization and quantification of catchability from the Multpelt 832 pelagic trawl was further discussed during the mackerel benchmark in Copenhagen in February 2014. Recommendations and requests coming out of the mackerel benchmark in February 2014, were considered and implemented during the IESSNS survey in July-August 2014 and in the surveys thereafter. Furthermore, recommendations and requests resulting from the mackerel benchmark in January-February 2017 (ICES 2017), were carefully considered and implemented during the IESSNS survey in July-August 2017. In 2018, the Faroese and Icelandic vessels employed new, redesigned cod-ends with the capacity to hold 50 tonnes. This was done to avoid the cod-end from bursting during hauling of large catches as occurred at three stations in the 2017 IESSNS.

Table 1. Survey effort by each of the five vessels during the IESSNS 2021. The number of predetermined ("fixed") trawl stations being part of the swept-area stations for mackerel in the IESSNS are shown after the total number of trawl stations.

Vessel	Effective survey period	Length of cruise track (nmi)	Total trawl stations/ Fixed stations	CTD stations	Plankton stations
Árni Friðriksson	5/7-26/7	4322	64/54	53	50
Jákup Sverri	2-19/7	3050	41/34	34	34
Ceton	30/6-9/7	2100	39/39	39	-
Vendla	1/7-3/8	5967	96/74	75	75
Eros	1/7-3/8	5836	79/69	75	75
Total	30/6-3/8	21275	319/270	276	234

3.1 Hydrography and Zooplankton

The hydrographical and plankton stations by all vessels combined are shown in Figure 1. Eros, Vendla, Árni Friðriksson and Jákup Sverri were all equipped with a SEABIRD CTD sensor and Árni Friðriksson and Jákup Sverri moreover also had a water rosette. Eros used a SEABIRD 19+V2 CTD sensor. Ceton used a Seabird SeaCat offline CTD. The CTD-sensors were used for recording temperature, salinity and pressure (depth) from the surface down to 210 m, or to the bottom when at shallower depths.

Zooplankton was sampled with a WP2-net on 4 of 5 vessels, since Ceton did not take any plankton samples. Mesh sizes were 180 μm (Eros and Vendla) and 200 μm (Árni Friðriksson and Jákup Sverri). The net was hauled vertically from a depth of 200 m (or bottom depth at shallower stations) to the surface at a speed of 0.5 m/s. All samples were split in two, one half preserved for species identification and enumeration, and the other half dried and weighed. Detailed description of the zooplankton and CTD sampling is provided in the survey manual (ICES 2014a).

Not all planned CTD and plankton stations were taken due to bad weather. The number of stations taken by the different vessels is provided in Table 1.

3.2 Trawl sampling

All vessels used the standardized Multpelt 832 pelagic trawl (ICES 2013a; Valdemarsen et al. 2014; Nøttestad et al. 2016) for trawling, both for fixed surface stations and for trawling at greater depths to confirm acoustic registrations. Standardization of trawl deployment was emphasised during the survey as in previous years (ICES 2013a; ICES 2014b; ICES 2017). Sensors on the trawl doors, headrope and ground rope of the Multpelt 832 trawl recorded data, and allowed live monitoring, of effective trawl width (actually door spread) and trawl depth. The properties of the Multpelt 832 trawl and rigging on each vessel is reported in Table 2.

Trawl catch was sorted to the highest taxonomical level possible, usually to species for fish, and total weight per species recorded. The processing of trawl catch varied between nations. The Icelandic and Norwegian vessels sorted the whole catch to species but the Faroese vessel sub-sampled the catch before sorting if catches were more than 500 kg. Sub-sample size ranged from 90 kg (if it was clean catch of either herring or mackerel) to 200 kg (if it was a mixture of herring and mackerel). The biological sampling protocol for trawl catch varied between nations in number of specimens sampled per station (Table 3).

Results from the survey expansion southward into the North Sea are analyzed separately from the traditional survey grounds north of latitude 60°N as per stipulations from the 2017 mackerel benchmark meeting (ICES 2017). However, data collected with the IESSNS methodology from the Skagerrak and the northern and western part of the North Sea are now available for 2018, 2019, 2020 and 2021.

Table 2. Trawl settings and operation details during the international mackerel survey in the Nordic Seas from 30th June to 3rd August 2021. The column for influence indicates observed differences between vessels likely to influence performance. Influence is categorized as 0 (no influence) and + (some influence).

Properties	**Árni Friðriksson**	**Vendla**	**Ceton**	**Jákup Sverri**	**Eros**	**Influ-ence**
Trawl producer	Hampiðjan new 2017 trawl	Egersund Trawl AS	Egersund Trawl AS	Vónin	Egersund Trawl AS	0
Warp in front of doors	Dynex-34 mm	Dynex -34 mm	Dynex	Dynex – 38 mm	Dynex-34 mm	+
Warp length during towing	350	350	300-350	350	350-400	0
Difference in warp length port/starb. (m)	16	2-10	10	0-7	5-10	0
Weight at the lower wing ends (kg)	2×400 kg	2×400	2×400	2×400	2×400	0
Setback (m)	14	6	6	6	6	+
Type of trawl door	Jupiter	Seaflex 7.5 m² adjustable hatches	Thybron type 15	Injector F-15	Seaflex 7.5 m² adjustable hatches	0
Weight of trawl door (kg)	2200	1700	1970	2000	1700	+
Area trawl door (m²)	6	7.5 with 25% hatches (effective 6.5)	8	6	7 with 50% hatches (effective 6.5)	+
Towing speed (knots) mean (min-max)	5.2 (4.4-5.7)	4.6 (4.1-5.5)	4.8 (4.3-5.3)	4.5 (3.5-5.3)	4.7 (4.1-5.725)	+
Trawl height (m) mean (min-max)	33 (27-48)	28-37	27 (22-36)	45.1 (39 – 56)	25-32	+
Door distance (m) mean (min-max)	113 (102 - 118)	121.8 (118-126)	140 (125-153)	98.7 (89 – 111)	135 (113-140)	+
Trawl width (m)*	65.6	63.8	75.4	56.6	67.5	+
Turn radius (degrees)	5	5-12	5-10	5-6 BB turn	5-8 SB turn	+
Fish lock front of cod-end	Yes	Yes	Yes	Yes	Yes	+
Trawl door depth (port, starboard, m) (min-max)	4-14, 5-28	6-22, 8-23	4-16	5-24, 6-26	(6-20)	+
Headline depth (m)	0	0	0	0	0	+
Float arrangements on the headline	Kite + 2 buoys on wings	Kite with fender buoy +2 buoys on each wingtip	Kite with fender buoy + 2 buoys on each wingtip	Kite with + 2 buoys on each wingtip	Kite + 2 buoy on each wingtips	+
Weighing of catch	All weighted	All weighted	All weighted	All weighed	All weighted	+

* calculated from door distance (Table 6)

Table 3. Protocol of biological sampling during the IESSNS 2021. Numbers denote the maximum number of individuals sampled for each species for the different determinations.

	Species	Faroes	Iceland	Norway	Denmark
Length measurements	Mackerel	200/100*	150	100	≥ 125
	Herring	200/100*	200	100	75
	Blue whiting	200/100*	100	100	75
	Lumpfish	all	all	all	all
	Salmon	-	all	all	-
	Capelin		100		
	Other fish sp.	20-50	50	25	As appropriate
Weight, sex and maturity determination	Mackerel	15-25	50	25	***
	Herring	15-25	50	25	0
	Blue whiting	6-50	50	25	0
	Lumpfish	10	1^	25	0
	Salmon	-	0	25	0
	Capelin		100		
	Other fish sp.	0	0	0	0
Otoliths/scales collected	Mackerel	15-25	25	25	***
	Herring	15-25	25	25	0
	Blue whiting	6-50	50	25	0
	Lumpfish	0	1	0	0
	Salmon	-	0	0	0
	Capelin		100		
	Other fish sp.	0	0	0	0
Fat content	Mackerel	0	10**	0	0
	Herring	0	10**	0	0
	Blue whiting	0	10	0	0
Stomach sampling	Mackerel	6	10**	10	0
	Herring	6	10**	10	0
	Blue whiting	6	10	10	0
	Other fish sp.	0	0	10	0
Tissue for genotyping	Mackerel	0	0	0	0
	Herring	0	0	0	0

*Length measurements / weighed individuals
**Sampled at every third station
*** One fish per cm-group ≤ 28 cm and two fish > 28 cm from each station was weighed and aged.
^All live lumpfish were tagged and released, only otoliths taken from fish which were dead when brought aboard

This year's survey was well synchronized in time and was conducted over a relatively short period (less than 5 weeks) given the large spatial coverage of around 2.2 million km^2 (Figure 1). This was in line with recommendations put forward in 2016 that the survey period should be around four weeks with mid-point around 20th July. The main argument for this time period was to make the survey as synoptic as possible in space and time, and at the same time be able to finalize data and report for inclusion in the assessment for the same year.

Underwater camera observations during trawling

M/V "Eros" and M/V "Vendla" employed an underwater video camera (GoPro HD Hero 4 and 5 Black Edition, www.gopro.com) to observe mackerel aggregation, swimming behaviour and possible escapement from the cod end and through meshes. The camera was put in a waterproof box which tolerated pressure down to approximately 100 m depth. No light source was employed with cameras; hence, recordings were limited to day light hours. Some recordings were also taken during night-time when there was midnight sun and good underwater visibility. Video recordings were collected at 95 trawl stations. The camera was attached on the trawl in the transition between 200 mm and 400 mm meshes.

Deep Vision underwater stereo-camera system

A pilot study was conducted onboard M/V "Vendla" during first part of the IESSNS 2021 survey in the southern part of the Norwegian Sea using the underwater stereo camera system Deep Vision (Rosen et al. 2013). The major goal of this pilot study was to explore the practical and operational feasibility of applying and quantifying the use of stereo camera technology related correct species identification, catch numbers and size distribution of different species caught in the Multpelt 832 pelagic trawl, with particular focus on NEA mackerel. A total number of five trawl hauls were conducted onboard Vendla with the deep vision system from 1-18 July 2021. Results will be available later including an evaluation of whether Deep Vision can be used to quantify mackerel catches in a reliable way without collecting the mackerel, but rather trawl with an open cod-end.

3.3 Marine mammals

Opportunistic observations of marine mammals were conducted by scientific personnel and crew members from the bridge between 1st July and 2nd August 2021 onboard M/V "Eros" and M/V "Vendla", and aboard R/V Árni Friðriksson from 5st until 26th July 2021. On board Jákup Sverri (between 1st and 19th July 2021) opportunistic observations were done from the bridge by crew members.

3.4 Lumpfish tagging

Lumpfish caught during the survey by vessels R/V "Árni Friðriksson", M/V "Eros" and M/V "Vendla" were tagged with Peterson disc tags and released. When the catch was brought aboard, any lumpfish caught were transferred to a tank with flow-through sea water. After the catch of other species had been processed, all live lumpfish larger than ~15 cm were tagged. The tags consisted of a plastic disc secured with a titanium pin which was inserted through the rear of the dorsal hump. Contact details of Biopol (www.biopol.is) were printed on the tag. The fish were returned to the tank until all fish were tagged. The fish were then released, and the time of release was noted which was used to determine the latitude and longitude of the release location.

3.5 Acoustics

Multifrequency echosounder

The acoustic equipment onboard Vendla and Eros were calibrated 30th June and 1st July 2021 respectively, for 18, 38, 70, 120 and 200 kHz. Árni Friðriksson was calibrated on May 4th 2021 for frequencies 18, 38, 70, 120 and 200 kHz. Jákup Sverri was calibrated on 22nd April 2021 for 18, 38, 120, 200 and 333 kHz. Ceton did not conduct any acoustic data collection because no calibrated equipment was available, and acoustics are done in the same area and period of the year during the ICES coordinated North Sea herring acoustic survey (HERAS). All the other vessels used standard hydro-acoustic calibration procedure for each operating frequency (Foote 1987). CTD measurements were taken in order to get the correct sound velocity as input to the echosounder calibration settings.

Acoustic recordings were scrutinized to herring and blue whiting on daily basis using the post-processing software (LSSS, see Table 4 for details of the acoustic settings by vessel). Acoustic measurements were not conducted onboard Ceton in the North Sea. Species were identified and partitioned using catch information, characteristic of the recordings, and frequency between integration on 38 kHz and on other frequencies by a scientist experienced in viewing echograms.

To estimate the abundance from the allocated NASC-values the following target strengths (TS) relationships were used.

Blue whiting: TS = 20 log(L) – 65.2 dB (rev. acc. ICES CM 2012/SSGESST:01)
Herring: TS = 20.0 log(L) – 71.9 dB

Table 4. Acoustic instruments and settings for the primary frequency (38 kHz) during IESSNS 2021.

	R/V Árni Friðriksson	M/V Vendla	Jákup Sverri	Eros
Echo sounder	Simrad EK80	Simrad EK60	Simrad EK80	Simrad EK80
Frequency (kHz)	18, 38, 70, 120, 200	18, 38, 70, 120, 200	18, **38**, 70, 120, 200, 333	18, 38, 70, 120, 200, 333
Primary transducer	ES38-7	ES38B	ES38-7	ES38B
Transducer installation	Drop keel	Drop keel	Drop keel	Drop keel
Transducer depth (m)	8	9	6-9	8
Upper integration limit (m)	15	15	15	15
Absorption coeff. (dB/km)	10.5	10.1	10.7	9.3
Pulse length (ms)	1.024	1.024	1.024	1.024
Band width (kHz)	2.425	2.43	3.064	2.43
Transmitter power (W)	2000	2000	2000	2000
Angle sensitivity (dB)	18	21.90	21.9	21.9
2-way beam angle (dB)	-20.3	-20.70	-20.4	-20.7
TS Transducer gain (dB)	27.05	25.46	26.96	25.50
s_A correction (dB)	-0.02	-0.02	-0.16	-0.6
3 dB beam width alongship:	6.42	0.19	6.55	6.87
3 dB beam width athw. ship:	6.47	0.08	5.45	6.83
Maximum range (m)	500	500	500	500
Post processing software	LSSS v.2.10.1	LSSS v.2.8.1	LSSS 2.10.1	LSSS v.2.8

M/V Ceton: No acoustic data collection because other survey in the same area in June/July (HERAS).

Multibeam sonar

Both M/V Eros and M/V Vendla were equipped with the Simrad fisheries sonar SH90 (frequency range: 111.5-115.5 kHz), with a scientific output incorporated which allow the storing of the beam data for post-processing. Acoustic multibeam sonar data was stored continuously onboard Eros and Vendla for the entire survey.

Cruise tracks

The five participating vessels followed predetermined survey lines with predetermined surface trawl stations (Figure 1). Calculations of the mackerel index are based on swept area approach with the survey area split into 13 strata, of which 11 are permanent and two dynamic (Figure 2). Distance between predetermined surface trawl stations is constant within stratum but variable between strata and ranged from 35-90 nmi. The survey design using different strata is done to allow the calculation of abundance indices with uncertainty estimates, both overall and from each stratum in the software program StoX (see Salthaug et al. 2017). Temporal survey progression by vessel along the cruise tracks in July-August 2021 is shown in Figure 3. The cruising speed was between 10-11 knots if the weather permitted, otherwise the cruising speed was adapted to the weather situation.

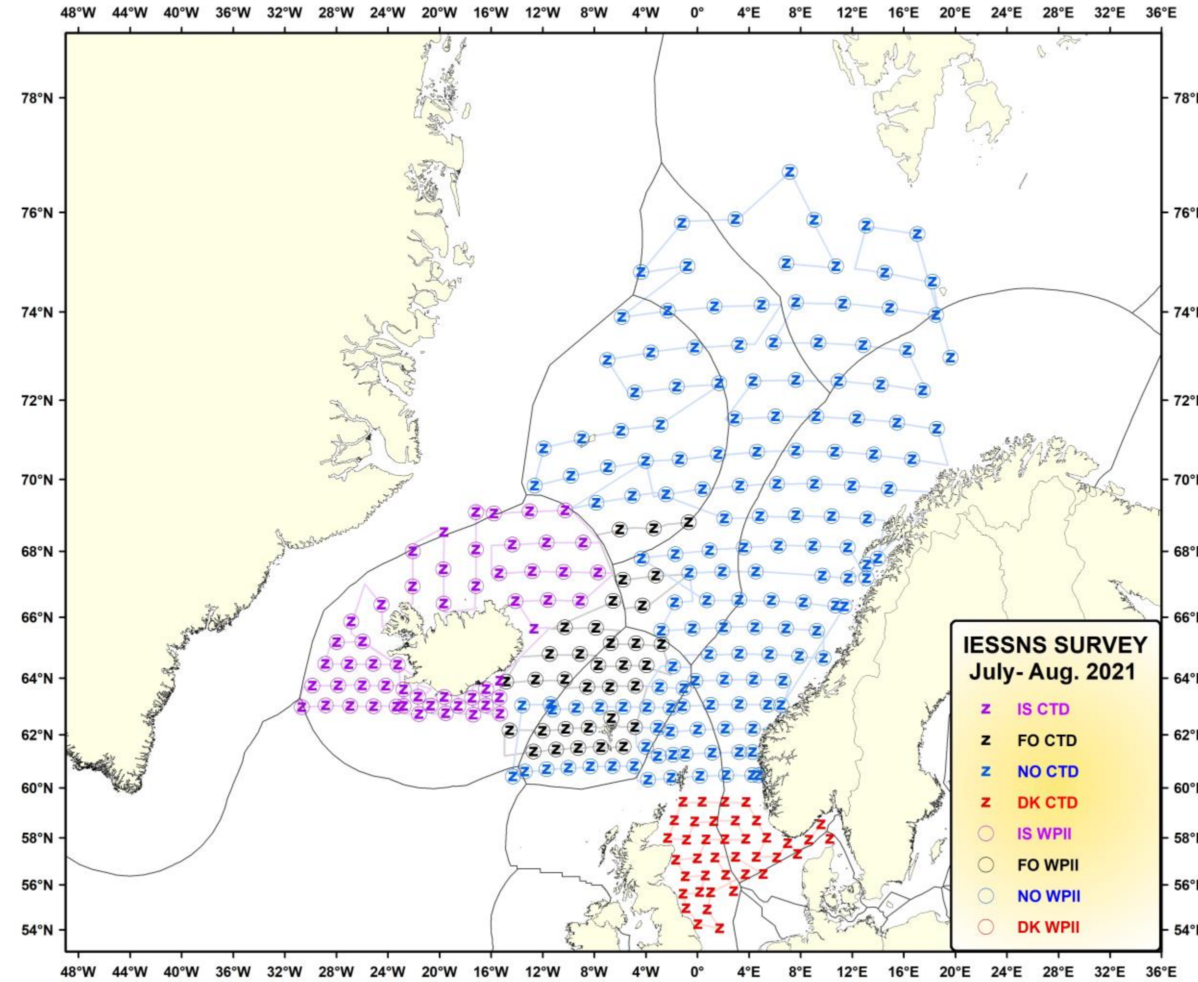


Figure 1. Fixed predetermined trawl stations (shown for CTD and WP2) included in the IESSNS from June 30th to August 3rd 2021. At each station a 30 min surface trawl haul, a CTD station (0-500 m) and WP2 plankton net samples (0-200 m depth) was performed. The colour codes, Árni Friðriksson (purple), Jákup Sverri (black), Vendla and Eros (blue), and Ceton (red).

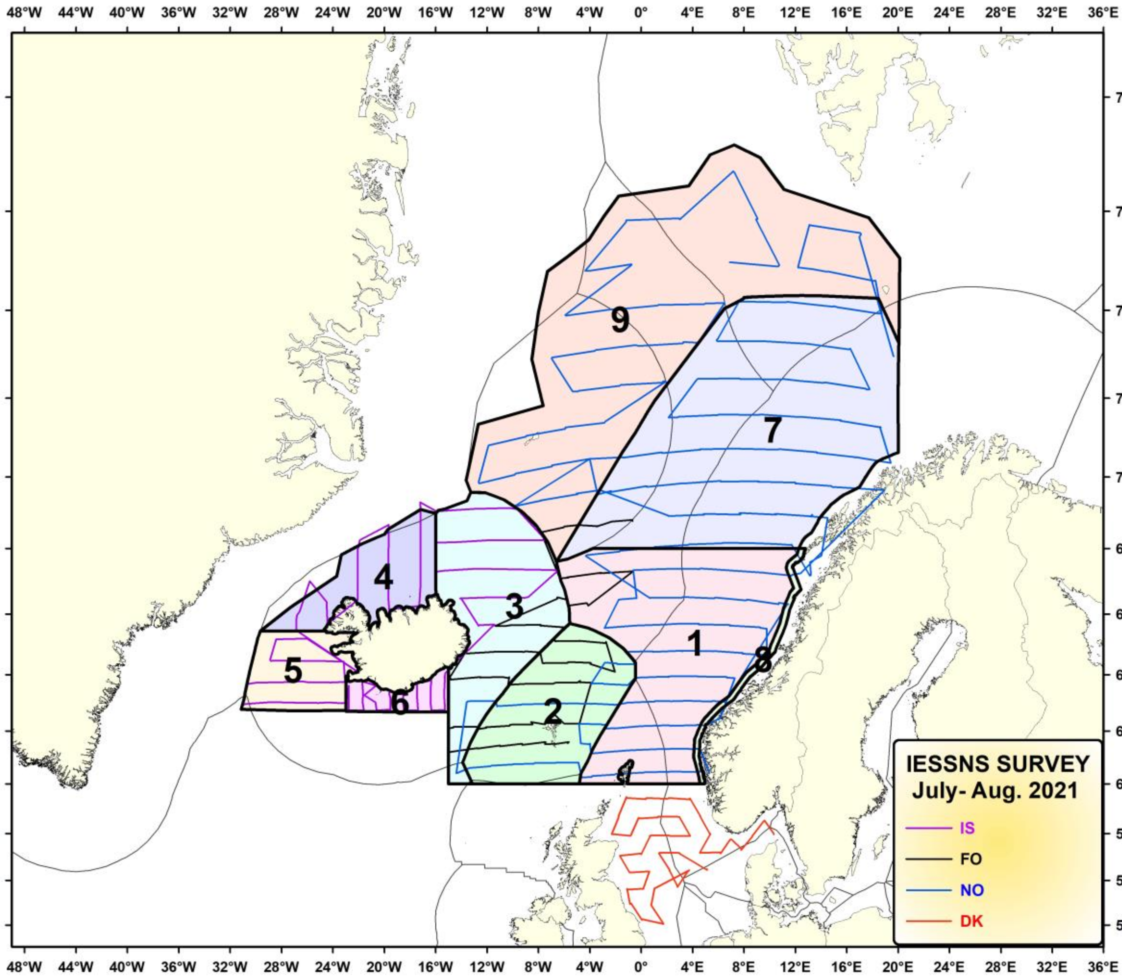


Figure 2. Permanent and dynamic strata used in StoX for IESSNS 2021. The dynamic strata are: 4 and 9.

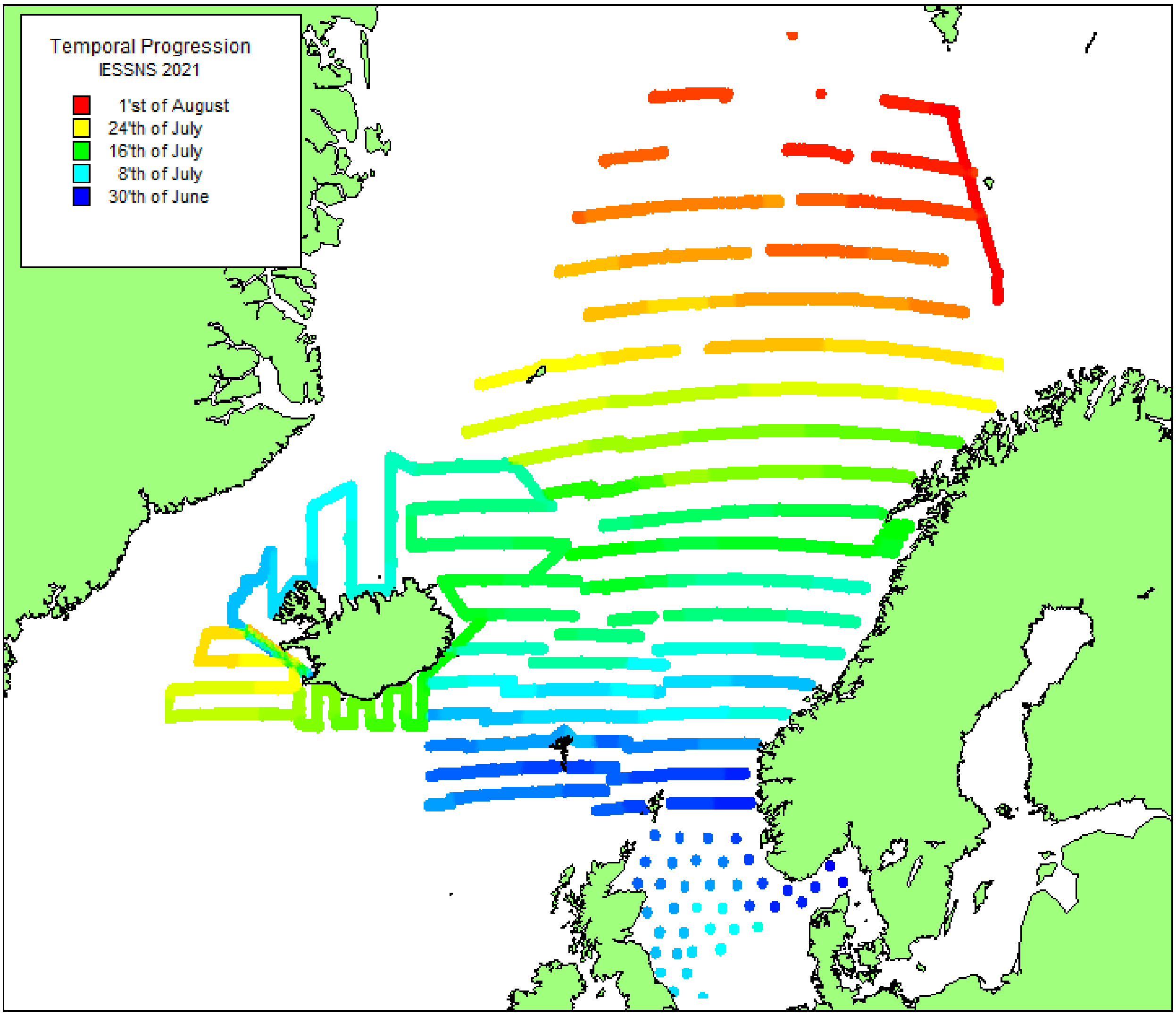


Figure 3. Temporal survey progression by vessel along the cruise tracks during IESSNS 2021: blue represents effective survey start (30th of June) progressing to red representing a five-week span (survey ended 3rd of August). As Ceton did not record acoustics, they have been represented by station positions.

3.6 StoX

The recorded acoustic and biological data were analysed using the StoX software package which has been used for some years now for WGIPS coordinated surveys. A description of StoX can be found in Johnsen et al. (2019) and here: www.imr.no/forskning/prosjekter/stox. Mackerel (swept-area), excluding the North Sea, herring and blue whiting indices were calculated using StoX version 3.1.0. Mackerel index including catch data from the North Sea was calculated using version 2.7.

3.7 Swept area index and biomass estimation

The swept area age segregated index is calculated separately for each stratum (see stratum definition in Figure 2). Individual stratum estimates are added together to get the total estimate for the whole survey area which is approximately defined by the area between 60°N and 77°N and 31°W and 20°E in 2021. The density of mackerel on a trawl station is calculated by dividing the total number caught by the assumed area swept by the trawl. The area swept is calculated by multiplying the towed distance by the horizontal opening of the trawl. The horizontal opening of the trawl is vessel specific, and the average value across all hauls is calculated based on door spread (Table 5 and Table 6). For the Faroese vessel the average door spread was 98.5 m, 1½ m less than the minimum spread in Table 6, so a calculation was done from the standard formulae for 4.5 knots to obtain the trawl width. An estimate of total number of mackerel in a stratum is obtained by taking the average density based on the trawl stations in the stratum and multiplying this with the area of the stratum.

Table 5. Descriptive statistics for trawl door spread, vertical trawl opening and tow speed for each vessel during IESSNS 2021. Number of trawl stations used in calculations is also reported. Horizontal trawl opening was calculated using average vessel values for trawl door spread and tow speed (details in Table 6).

	Jákup Sverri	RV Árni Friðriksson	Eros	Vendla	Ceton
Trawl doors horizontal spread (m)					
Number of stations	32	53	59	52	39
Mean	98.7	113	122	113	140
max	111	118	136	125	153
min	89	102	115	105	125
st. dev.	4.6	3.6	4.8	4.6	5.1
Vertical trawl opening (m)					
Number of stations	31	54	59	52	39
Mean	45.1	33.8	28.4	30.4	27
max	56	48.2	33	32	36
min	39	27.5	25	23	22
st. dev.	3.5	3.7	2.9	3.0	3.9
Horizontal trawl opening (m)					
mean	56.6	65.6	67.5	63.8	75.4
Speed (over ground, nmi)					
Number of stations	32	53	59	52	39
mean	4.5	5.2	4.6	4.7	4.8
max	5.3	5.7	5.5	5.6	5.3
min	3.5	4.4	4.1	4.2	4.3
st. dev.	0.4	0.2	0.3	0.3	0.2

Horizontal trawl opening was calculated using average vessel values for trawl door spread and tow speed (Table 6). The estimates in the formulae were based on flume tank simulations in 2013 (Hirtshals, Denmark) where formulas were developed from the horizontal trawl opening as a function of door spread, for two towing speeds, 4.5 and 5 knots:

Towing speed 4.5 knots: Horizontal opening (m) = 0.441 * Door spread (m) + 13.094

Towing speed 5.0 knots: Horizontal opening (m) = 0.3959 * Door spread (m) + 20.094

Table 6. Horizontal trawl opening as a function of trawl door spread and towing speed. Relationship based on simulations of horizontal opening of the Multpelt 832 trawl towed at 4.5 and 5 knots, representing the speed range in the 2014 survey, for various door spread. See text for details. In 2017, the towing speed range was extended from 5.0 to 5.2, and in 2020 the door spread was extended to 122 m.

	Towing speed							
Door spread(m)	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2
100	57.2	57.7	58.2	58.7	59.2	59.7	60.2	60.7
101	57.6	58.1	58.6	59.1	59.6	60.1	60.6	61.1
102	58.1	58.6	59.0	59.5	60.0	60.5	61.0	61.4
103	58.5	59.0	59.5	59.9	60.4	60.9	61.3	61.8
104	59.0	59.4	59.9	60.3	60.8	61.3	61.7	62.2
105	59.4	59.9	60.3	60.8	61.2	61.7	62.1	62.6
106	59.8	60.3	60.7	61.2	61.6	62.1	62.5	62.9
107	60.3	60.7	61.2	61.6	62.0	62.5	62.9	63.3
108	60.7	61.1	61.6	62.0	62.4	62.9	63.3	63.7
109	61.2	61.6	62.0	62.4	62.8	63.2	63.7	64.1
110	61.6	62.0	62.4	62.8	63.2	63.6	64.1	64.5
111	62.0	62.4	62.8	63.2	63.6	64.0	64.4	64.8
112	62.5	62.9	63.3	63.7	64.0	64.4	64.8	65.2
113	62.9	63.3	63.7	64.1	64.4	64.8	65.2	65.6
114	63.4	63.7	64.1	64.5	64.9	65.2	65.6	66.0
115	63.8	64.2	64.5	64.9	65.3	65.6	66.0	66.3
116	64.3	64.6	65.0	65.3	65.7	66.0	66.4	66.7
117	64.7	65.0	65.4	65.7	66.1	66.4	66.8	67.1
118	65.1	65.5	65.8	66.1	66.5	66.8	67.1	67.5
119	65.6	65.9	66.2	66.6	66.9	67.2	67.5	67.9
120	66.0	66.3	66.6	67.0	67.3	67.6	67.9	68.2
121	66.5	66.8	67.1	67.4	67.7	68.0	68.3	68.6
122	66.9	67.2	67.5	67.8	68.1	68.4	68.7	69.0

4 Results and discussion

4.1 Hydrography

Satellite measurements (NOAA OISST) of sea surface temperature (SST) in the central and eastern part of the Norwegian Sea in July 2021 were roughly on same level as the long-term average for July 1990-2009 based on SST anomaly plots (Figure 4). In the western areas, north of Iceland and the coastal regions of Greenland (The Iceland Sea and the Greenland Sea) the SST was 1-3 °C warmer than the long-term average. South of Iceland and in the Irminger Sea, the SST was on level with the long-term average. Further south, all the way from Greenland to the European Shelf, the SST was slightly warmer (~1 °C). However, along the southern part of the Norwegian Shelf and in the North Sea, the temperatures were 1-2 °C warmer than long term average.

It should be mentioned that the NOAA SST are sensitive to the weather conditions (i.e. wind and cloudiness) prior to and during the observations and do therefore not necessarily reflect the oceanographic condition of the water masses in the areas, as seen when comparing detailed in situ features of SSTs between years (Figures 5-8). However, since the anomaly is based on the average for the whole month of July, it should give representative results of the surface temperature.

In situ measurements from the survey showed that the upper layer (10 m depth) in 2021 generally was similar to 2020, except for the cold tongue of East Icelandic water, which penetrates into the Norwegian Sea from the Iceland Sea. In 2020 the tongue was clearly visible in the surface layer, but during the 2021 survey it was much less pronounced in the surface layer, indicating that stratification was stronger in this region in 2021 compared to last year (Figure 5). In the deeper layers (50 m and deeper; Figures 6-8), the hydrographical features in the area were similar to previous years. At all depths there is a clear signal from the cold East Icelandic Current which carries cold and fresh water into the central and south-eastern part of the Norwegian Sea. Along the Norwegian Shelf and in the southernmost areas, the water masses are dominated by warmer waters of Atlantic origin.

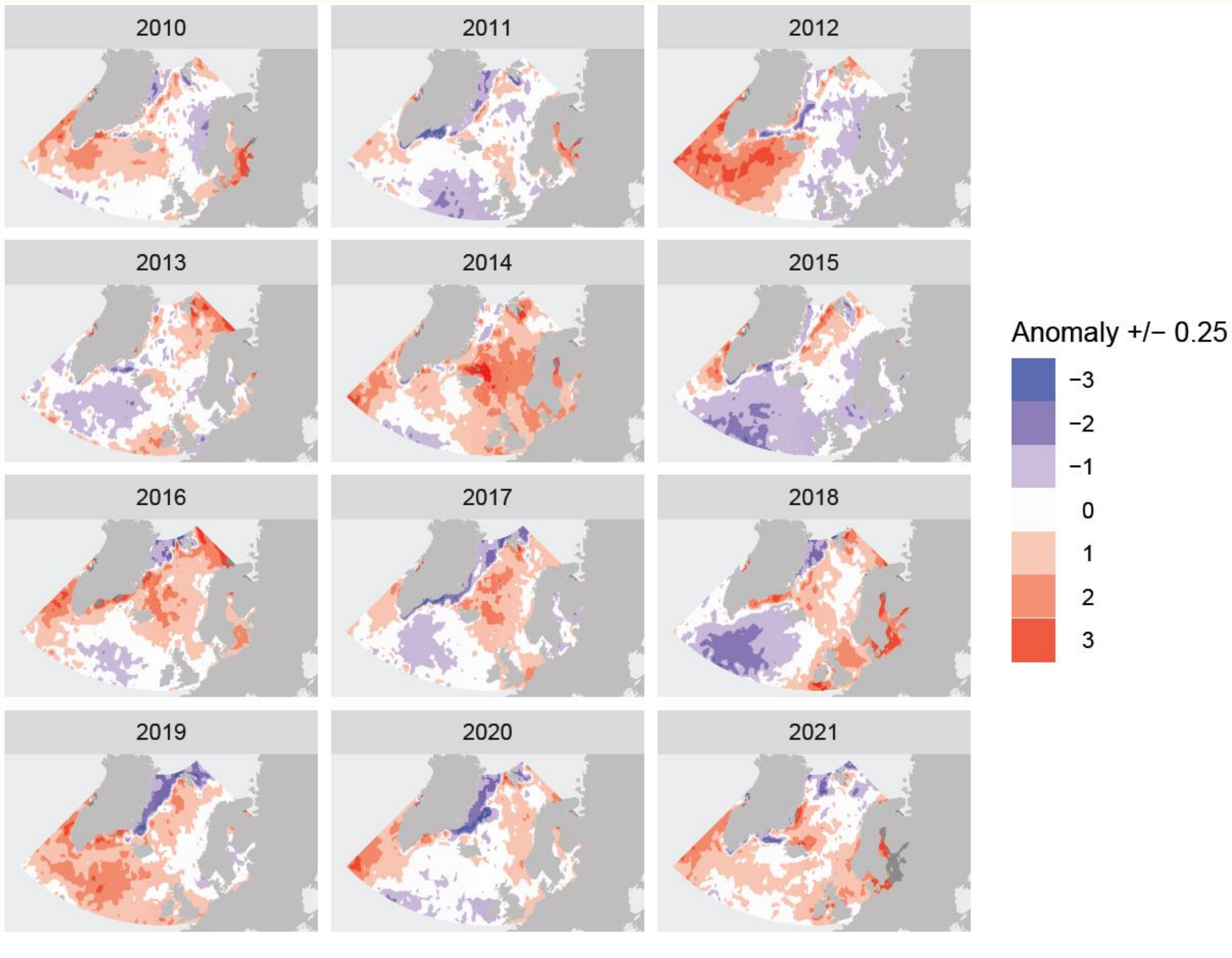


Figure 4. Annual sea surface temperature anomaly (-3 to +3°C) in Northeast Atlantic for the month of July from 2010 to 2021 showing warm and cold conditions in comparison to the average for July 1990-2010. Based on monthly averages of daily Optimum Interpolation Sea Surface Temperature (Ver. 2.1 NOAA OISST, AVHRR-only, Banzon et al. 2016, https://www.ncdc.noaa.gov/oisst).

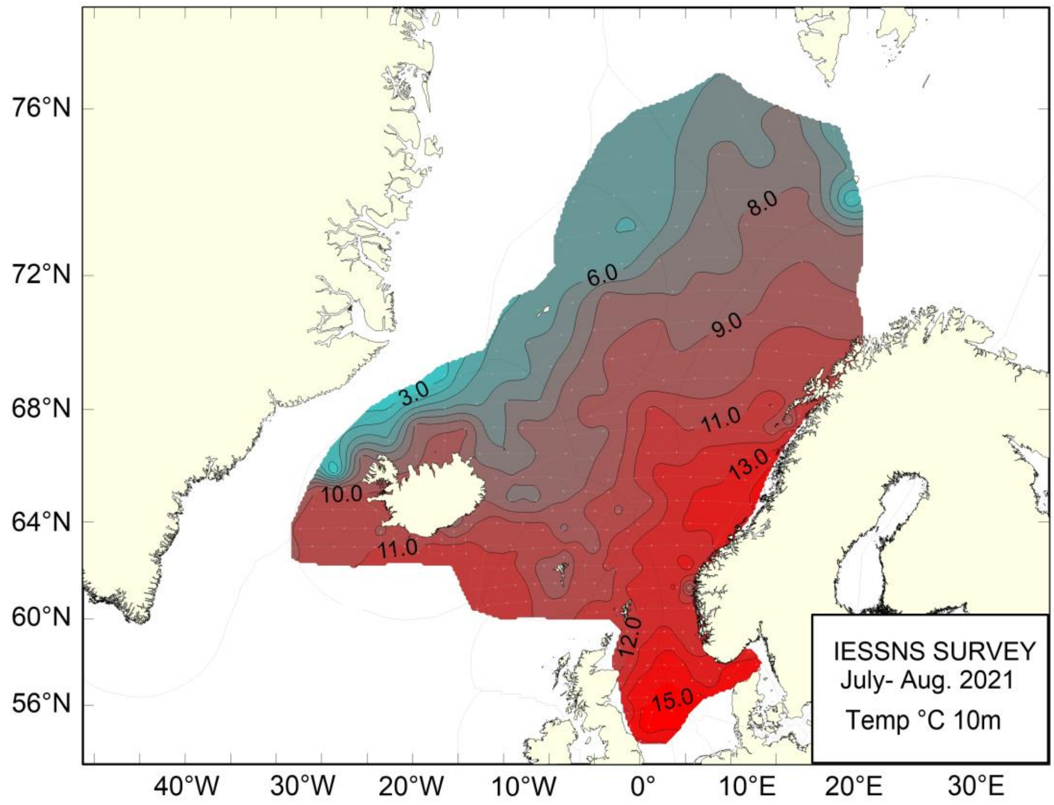


Figure 5. Temperature (°C) at 10 m depth in Nordic Seas and the North Sea in July-August 2021.

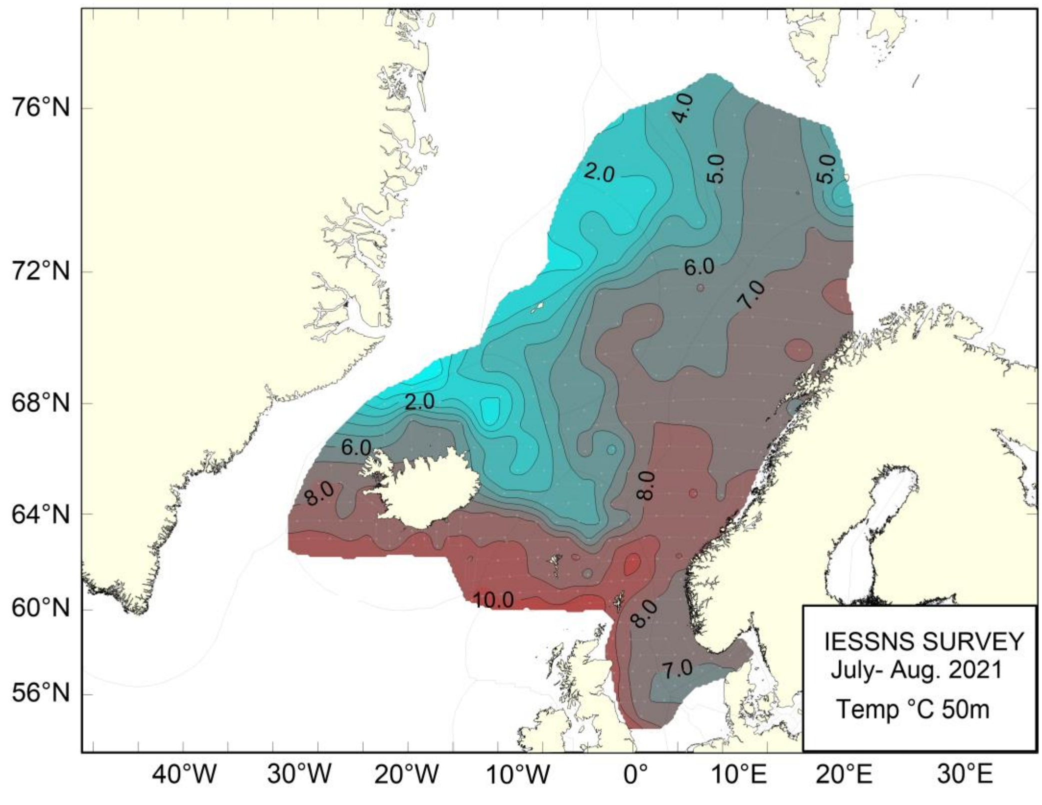


Figure 6. Temperature (°C) at 50 m depth Nordic Seas and the North Sea in July-August 2021.

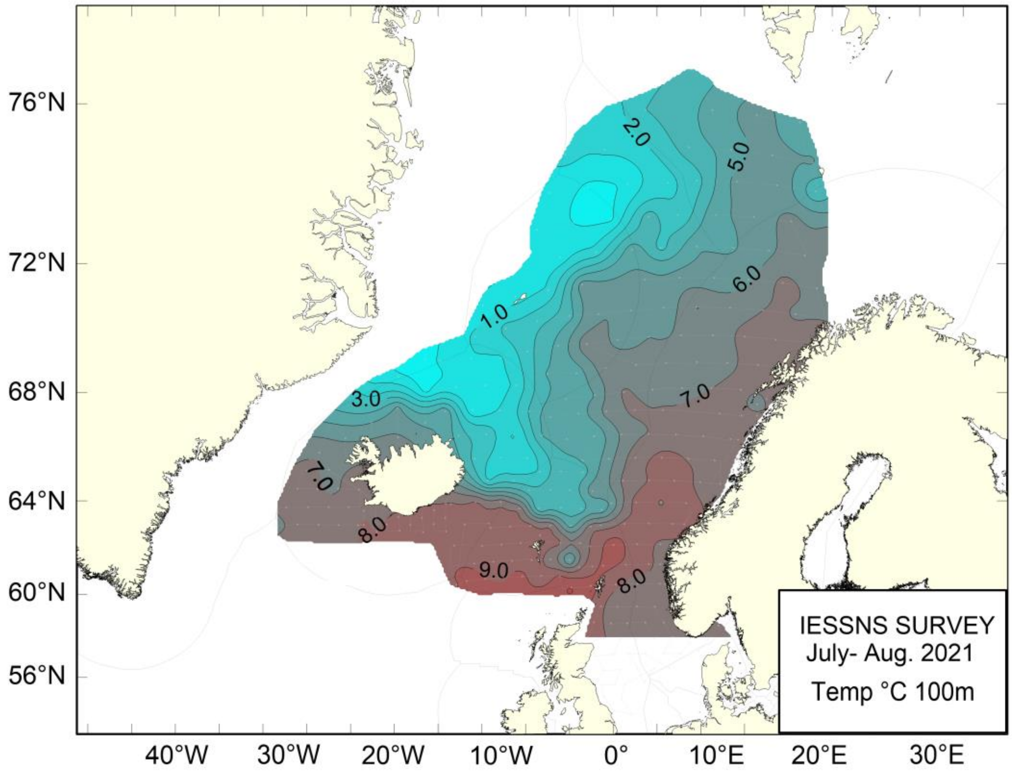


Figure 7. Temperature (°C) at 100 m depth in Nordic Seas and the North Sea in July-August 2021.

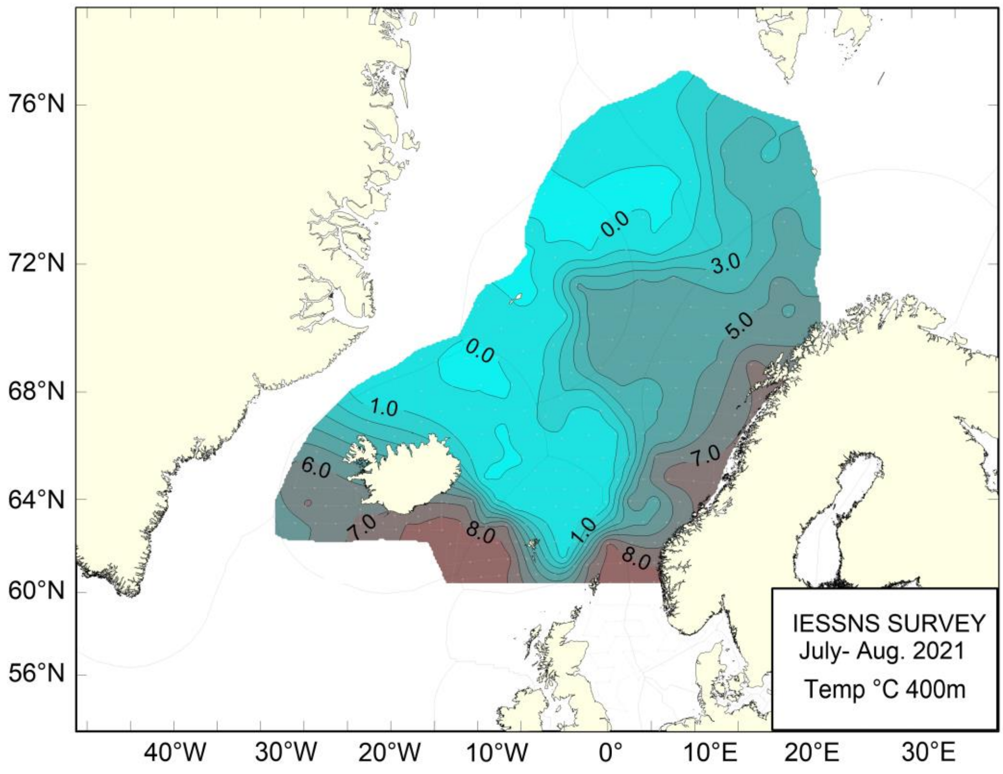


Figure 8. Temperature (°C) at 400 m depth in Nordic Seas and the North Sea in July-August 2021.

4.2 Zooplankton

The zooplankton biomass varied between areas with a patchy distribution throughout the area (Figure 9a). Greenland waters were not covered in 2021. In the Norwegian Sea areas, the average zooplankton biomass was slightly lower than last year as seen from Figure 9a, and this was especially apparent in the central and southern areas.

The time-series of average zooplankton biomass averaged by three subareas: Greenland region, Iceland region and the Norwegian Sea region is shown in Figure 9b (see definitions in legend). In the Greenland area a decrease was observed in 2019 and further in 2020 from very high values in 2017-2018 (no survey in 2021). A similar trend was also observed in the Icelandic region with somewhat less variations, and a levelling out in 2021 (Figure 9b). The two time-series co-vary (2014-2020, r = 0.89). The biomass indices has varied substantially less ion the Norwegian Sea areas, with a decrease in 2021 from a relatively stable level since 2013 (Figure 9b). The lower variability might in part be explained by the more homogeneous oceanographic conditions in the area defined as Norwegian Sea.

These plankton indices should be treated with some caution as it is only a snapshot of the standing stock biomass, not of the actual production in the area, which complicates spatio-temporal comparisons.

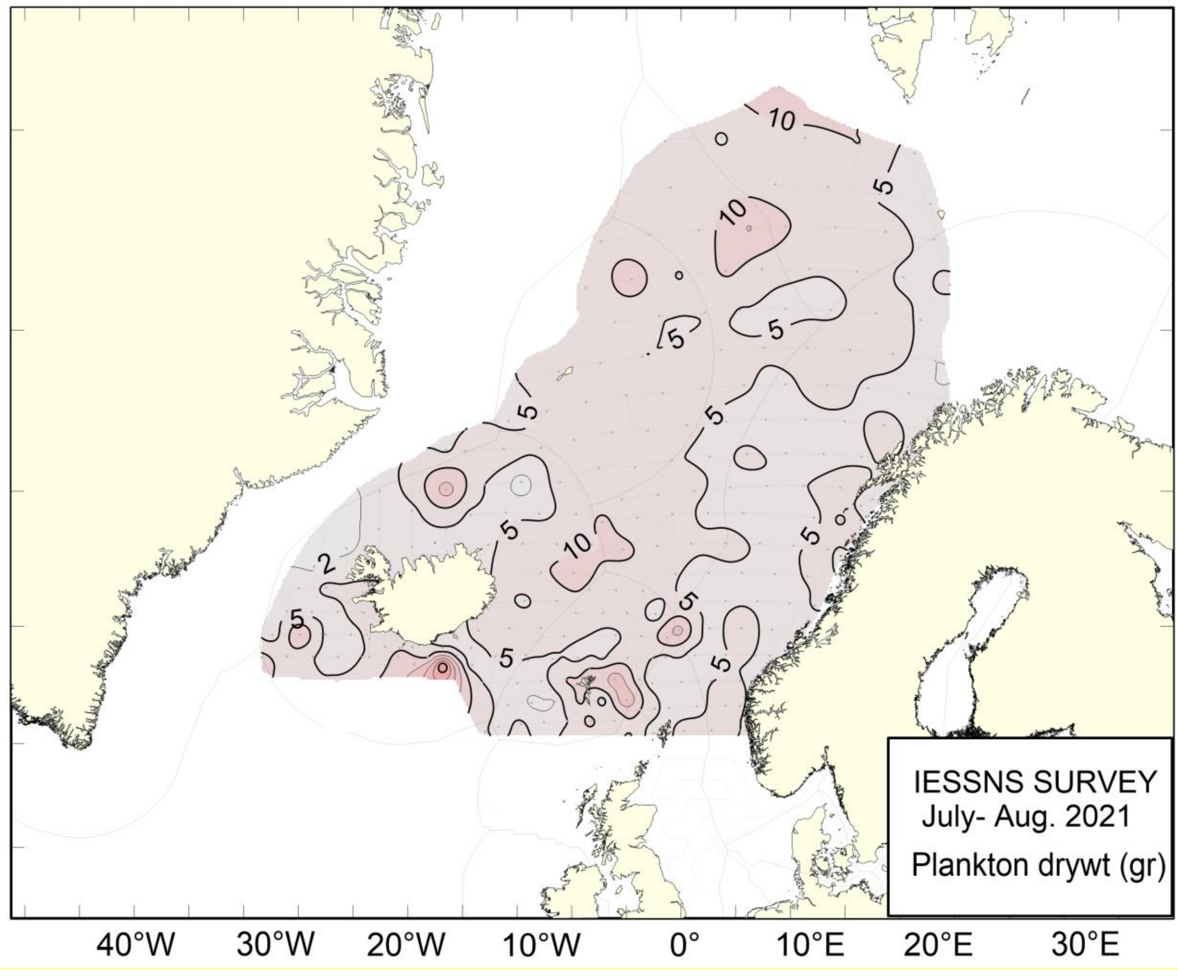


Figure 9a. Zooplankton biomass (g dw/m², 0-200 m) in Nordic Seas in July-August 2021.

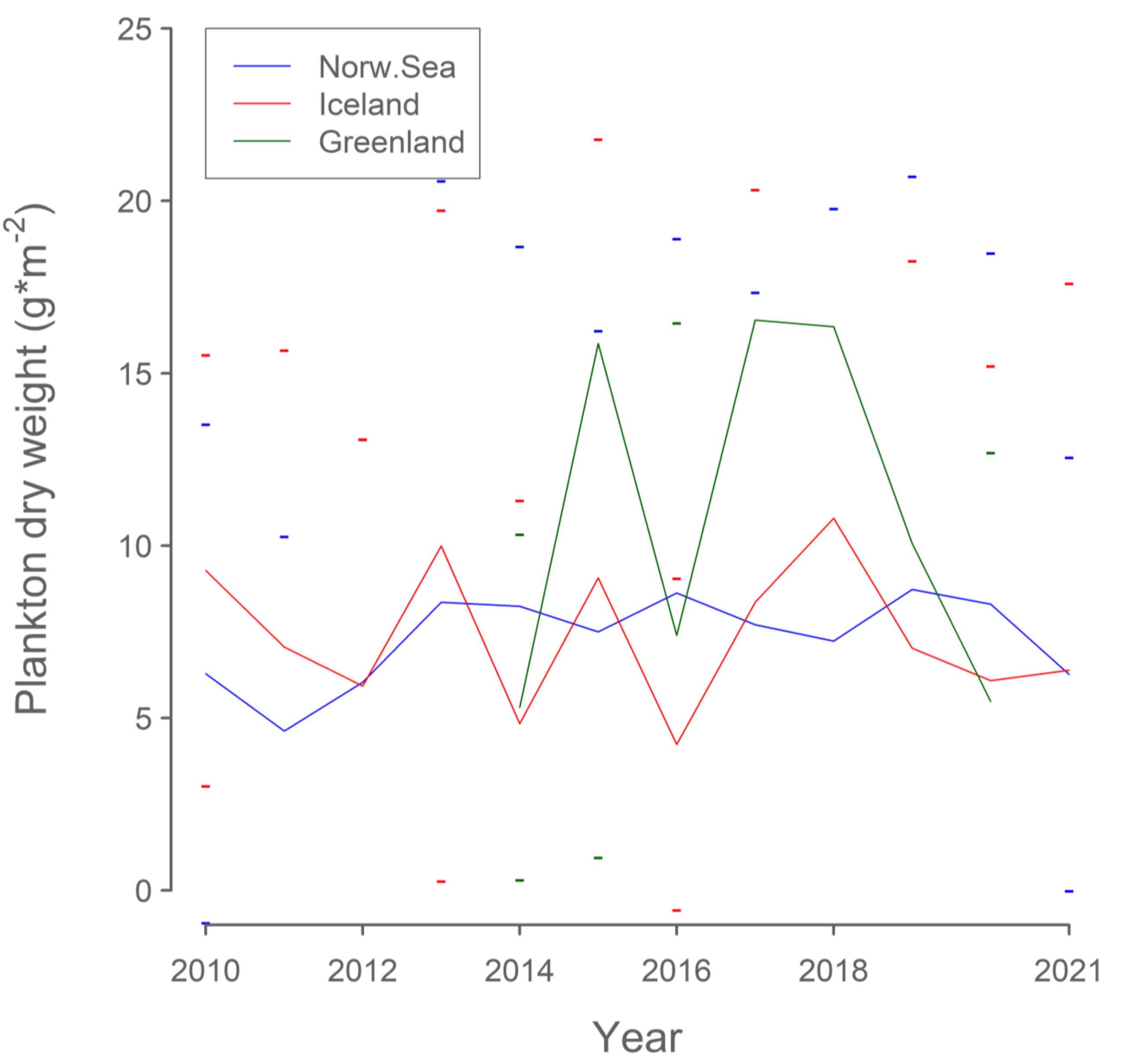


Figure 9b. Zooplankton biomass indices (g dw/m², 0-200 m). Time-series (2010-2021) of mean zooplankton biomass for three subareas within the survey range: Norwegian Sea (between 14°W-17°E & north of 61°N), Icelandic waters (14°W-30°W) and Greenlandic waters (2014-2020, west of 30°W).

4.3 Mackerel

The total swept-area mackerel index in 2021 was 5.15 million tonnes in biomass and 12.2 billion in numbers, a decreased by 58% for biomass and 54% for abundance compared to 2020. The survey coverage area (excl. the North Sea, 0.29 million km²) was 2.2 million km² in 2021, which is 24% smaller compared to previous years from 2018 to 2020. Reduced survey coverage in the western area did not contribute to the observed decline as the zero mackerel boundary was established north, west, and south of Iceland. The mackerel catch rates by trawl station (from zero to 17 tonnes/km², mean = 2.2 tonnes/km²) measured at predetermined surface trawl stations in 2021 is presented in Figure 10 together with the mean catch rates per 2° lat. x 4° lon. rectangles. The mackerel was mainly distributed in the central Norwegian Sea, extending south into waters southeast of Iceland and into the North Sea. High density areas were only found in international waters in the central Norwegian Sea in 2021. Medium density areas were found in the central and partly northern Norwegian Sea in 2021, with very small concentrations in the western areas (Figure 10), as was also the case in 2020. In Icelandic waters, mackerel density was low, and distribution limited to waters east and southeast of Iceland. This was similar to the 2020 observations. The North Sea, on the other hand, experienced a notable increase. There was a doubling in mean catch rates of mackerel in 2021 compared to previous years, dominated by 1- and 2-year olds. The time series (2010-2021) of absolute distribution maps (Figure 11) and relative distribution maps (Figure 12) show western expansion from 2010 to 2017, then in 2018 there was an obvious decline in geographical distribution and abundance in the west, in 2019 limited abundance of mackerel was measured in Greenland waters, and in 2020 distribution in Icelandic waters had retracted to the southeast coast.

Greenland waters were not surveyed in 2021. However, the zero-line was reached west, south and north of Iceland and the Greenlandic industry did not catch mackerel in Greenlandic waters. Therefore, it is highly unlikely that any mackerel migrated into Greenlandic waters during summer 2021. It is assumed that IESSNS coverage mackerel geographical distribution range in the western area despite reduced survey area size.

The swept area results from the North Sea in 2021 showed almost a doubling in the biomass index from last year (Appendix 1). The increase was mainly due to the high abundances of 1- and 2-year old mackerel.

In summary, we found a substantial decrease in estimated biomass and abundance index of NEA mackerel in the main feeding area during summer for mackerel in 2021 compared to 2020. On the positive side, there seems to be high recruitment and a considerably higher estimated biomass and abundance of juvenile mackerel (1- and 2-years olds) in the North Sea in 2021 compared to 2020.

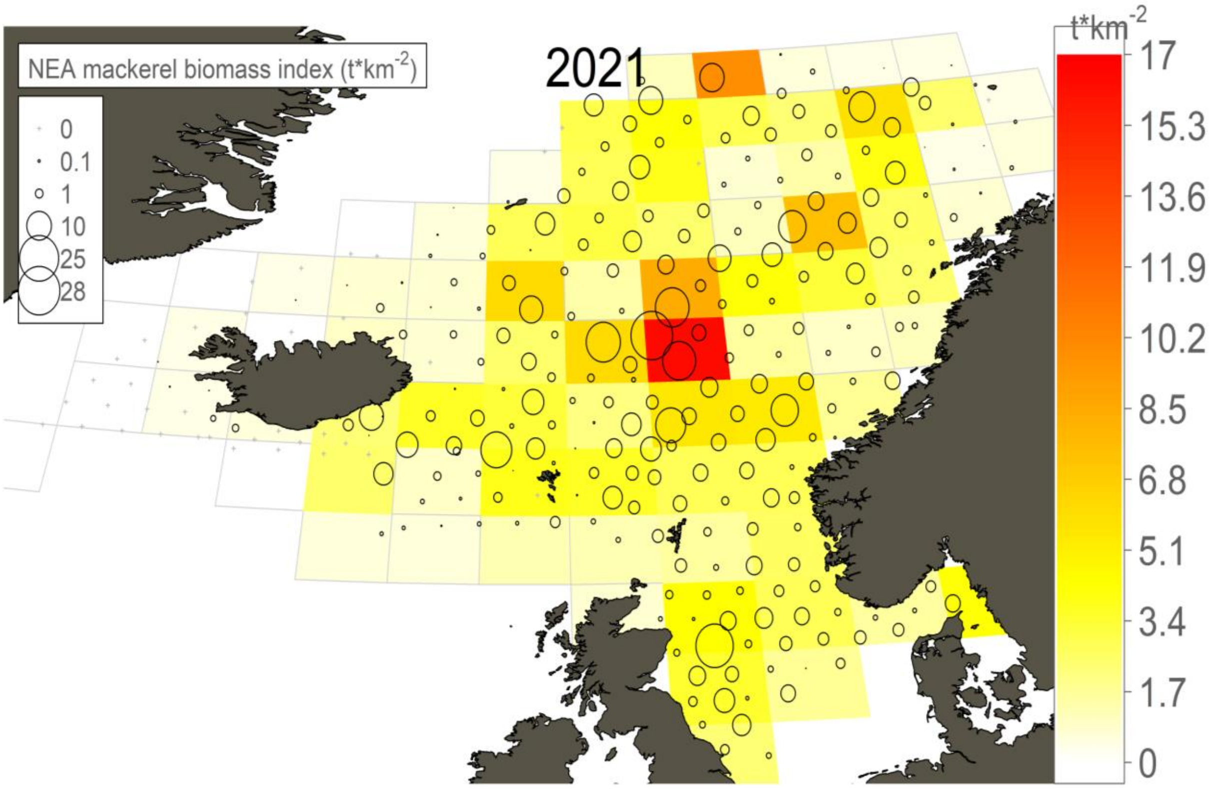


Figure 10. Mackerel catch rates by Multpelt 832 pelagic trawl haul at predetermined surface trawl stations (circle areas represent catch rates in kg/km²) overlaid on mean catch rates per standardized rectangles (2° lat. x 4° lon.).

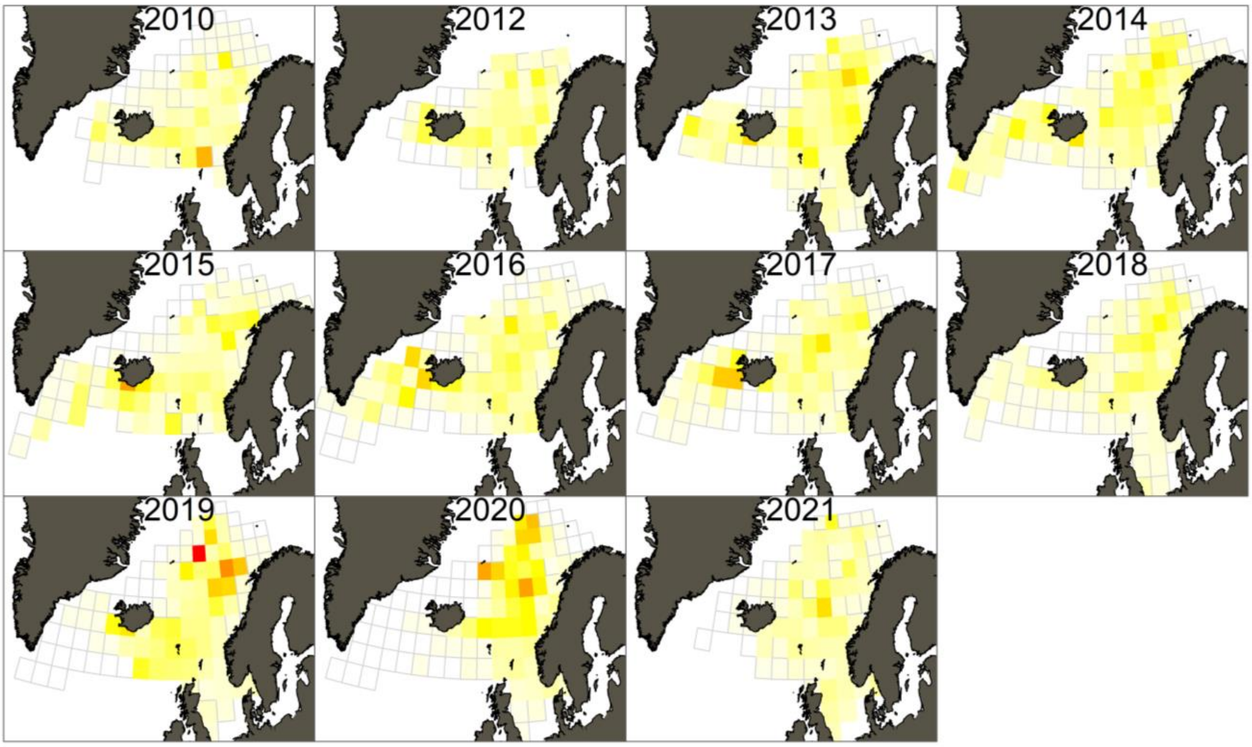


Figure 11. Annual distribution of mackerel proxied by the absolute distribution of mean mackerel catch rates per standardized rectangles (2° lat. x 4° lon.), from Multpelt 832 pelagic trawl hauls at predetermined surface trawl stations. Colour scale goes from white (= 0) to red (= maximum value for the highest year).

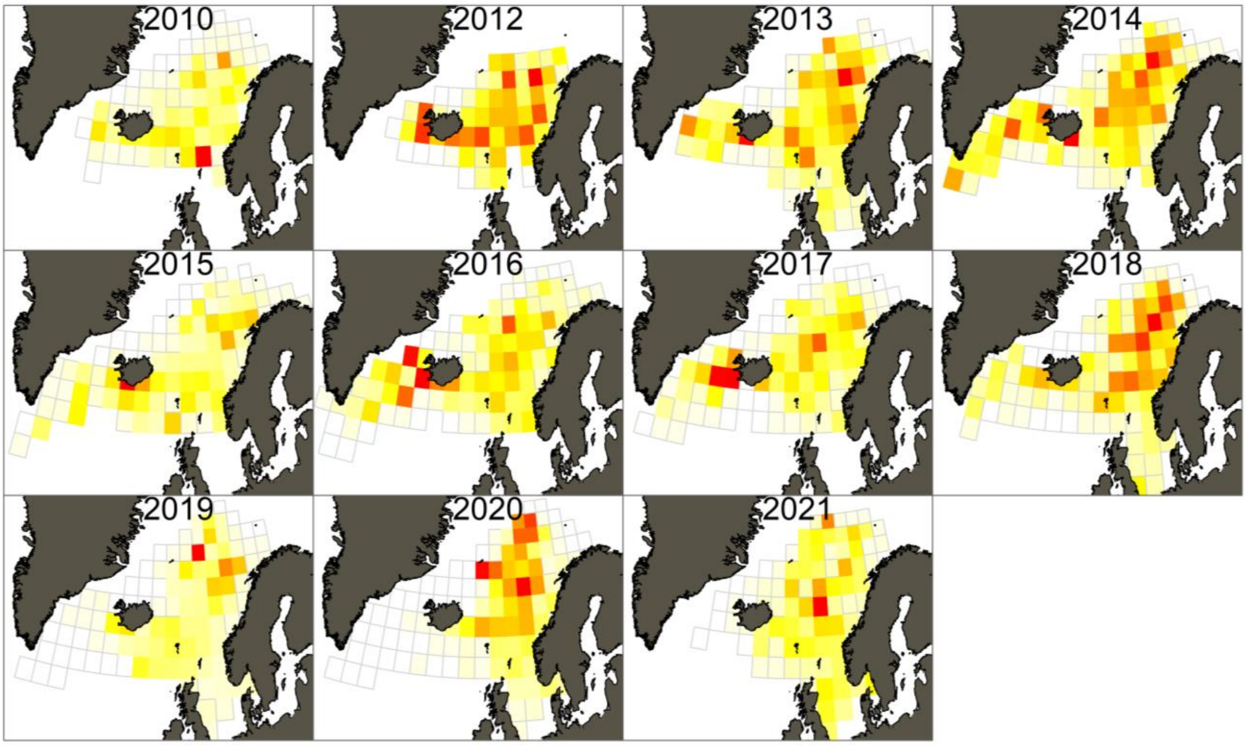


Figure 12. Annual distribution of mackerel proxied by the relative distribution of mean mackerel catch rates per standardized rectangles (2° lat. x 4° lon.), from Multpelt 832 pelagic trawl hauls at predetermined surface trawl stations. Colour scale goes from white (= 0) to red (= maximum value for the given year).

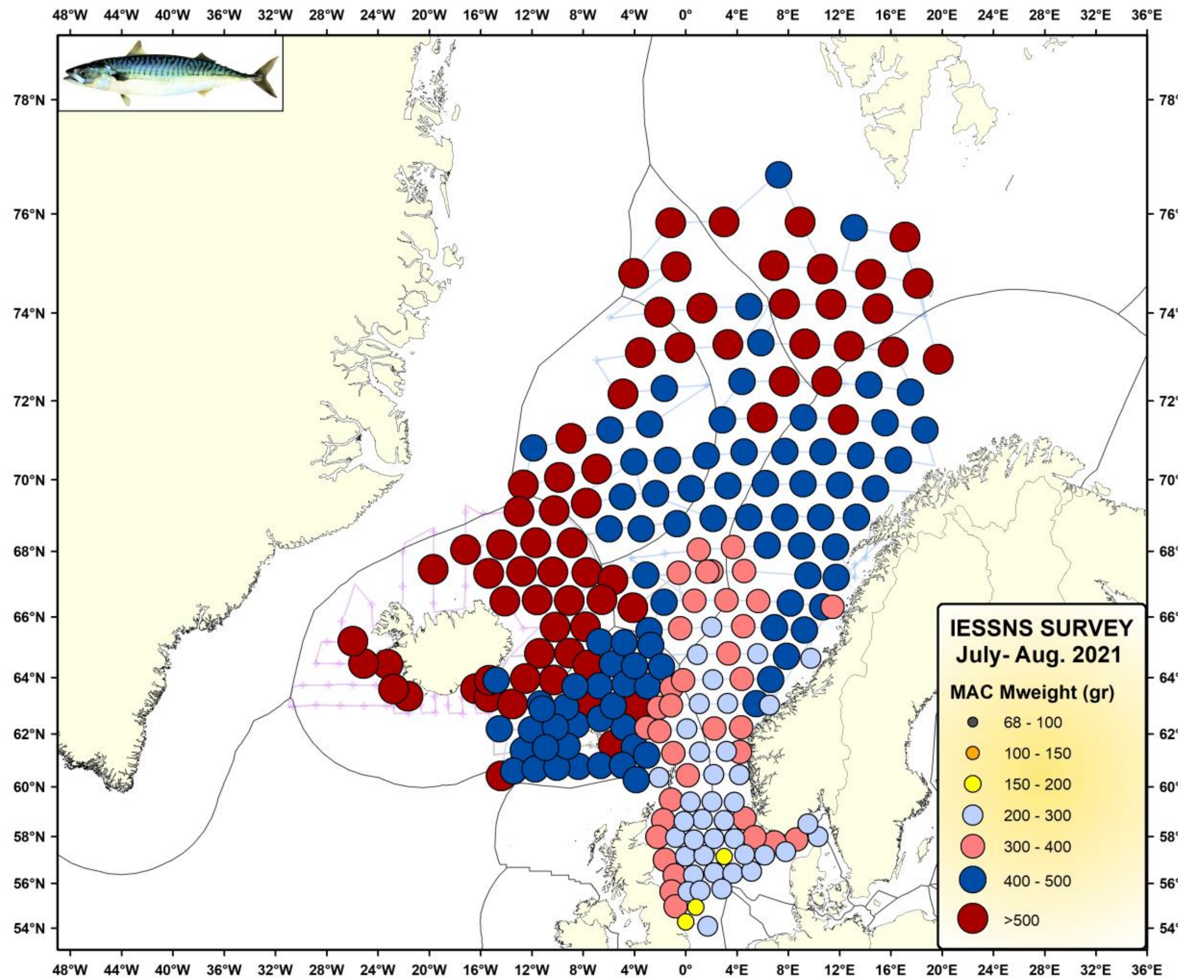


Figure 13. Average weight of mackerel at predetermined surface trawl stations during IESSNS 2021.

The mackerel weight varied between 51 to 874 g with an average of 421 g. The length of mackerel caught in the pelagic trawl hauls onboard the five vessels varied from 21.0 to 43.5 cm, with an average of 35.6 cm. Individuals in the length range 32–36 cm dominated in numbers and biomass. Mackerel length distribution followed the same overall pattern as previous years in the Norwegian Sea, with increasing size towards the distribution boundaries in the north and the north-west (Figure 13). The spatial distribution and overlap between the major pelagic fish species (mackerel, herring, blue whiting, salmon and lumpfish) in 2021 according to the catches are shown in Figure 14.

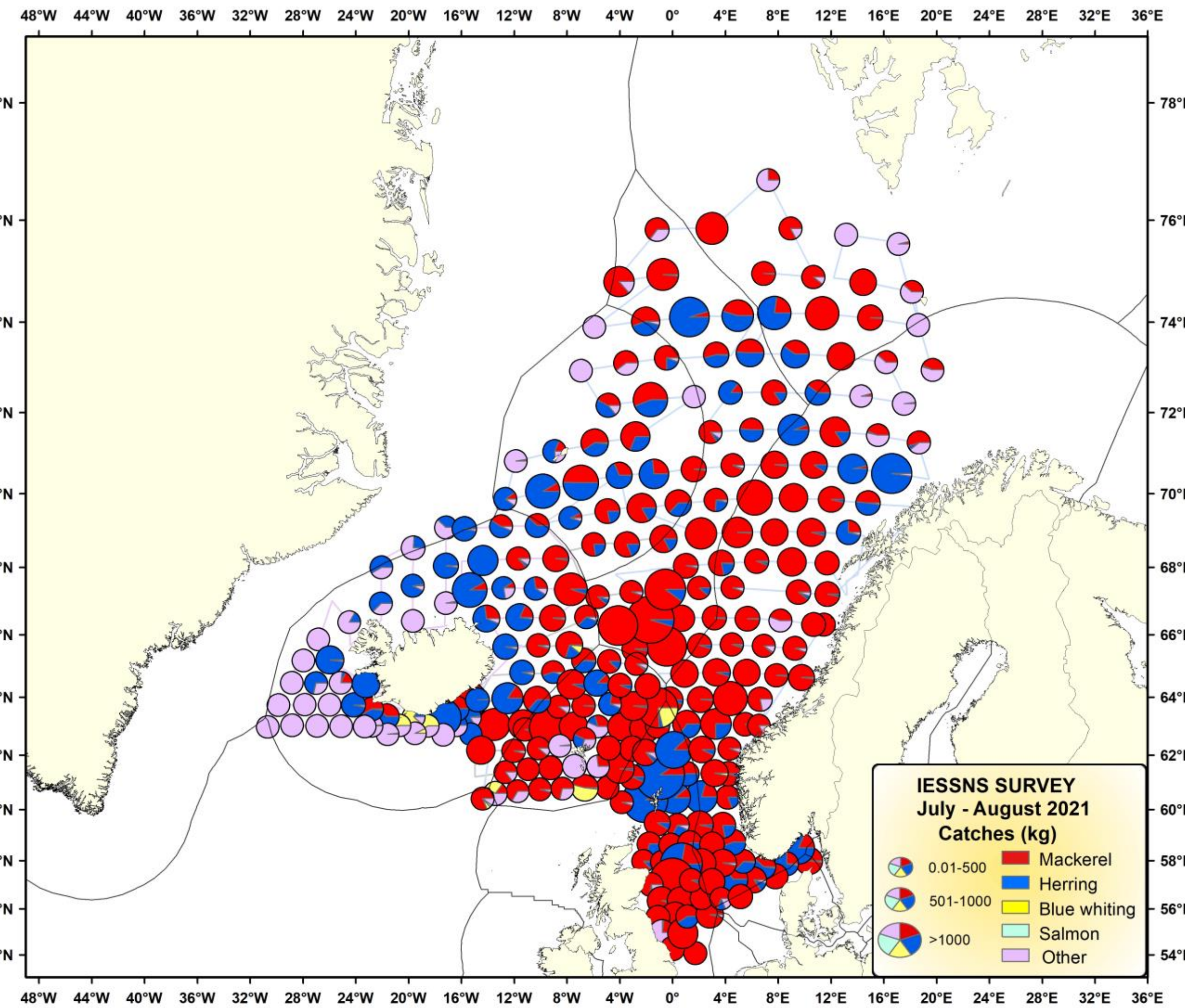


Figure 14. Distribution and spatial overlap between various pelagic fish species (mackerel, herring, blue whiting, salmon, and other (lumpfish)) in 2021 at all surface trawl stations. Vessel tracks are shown as continuous lines.

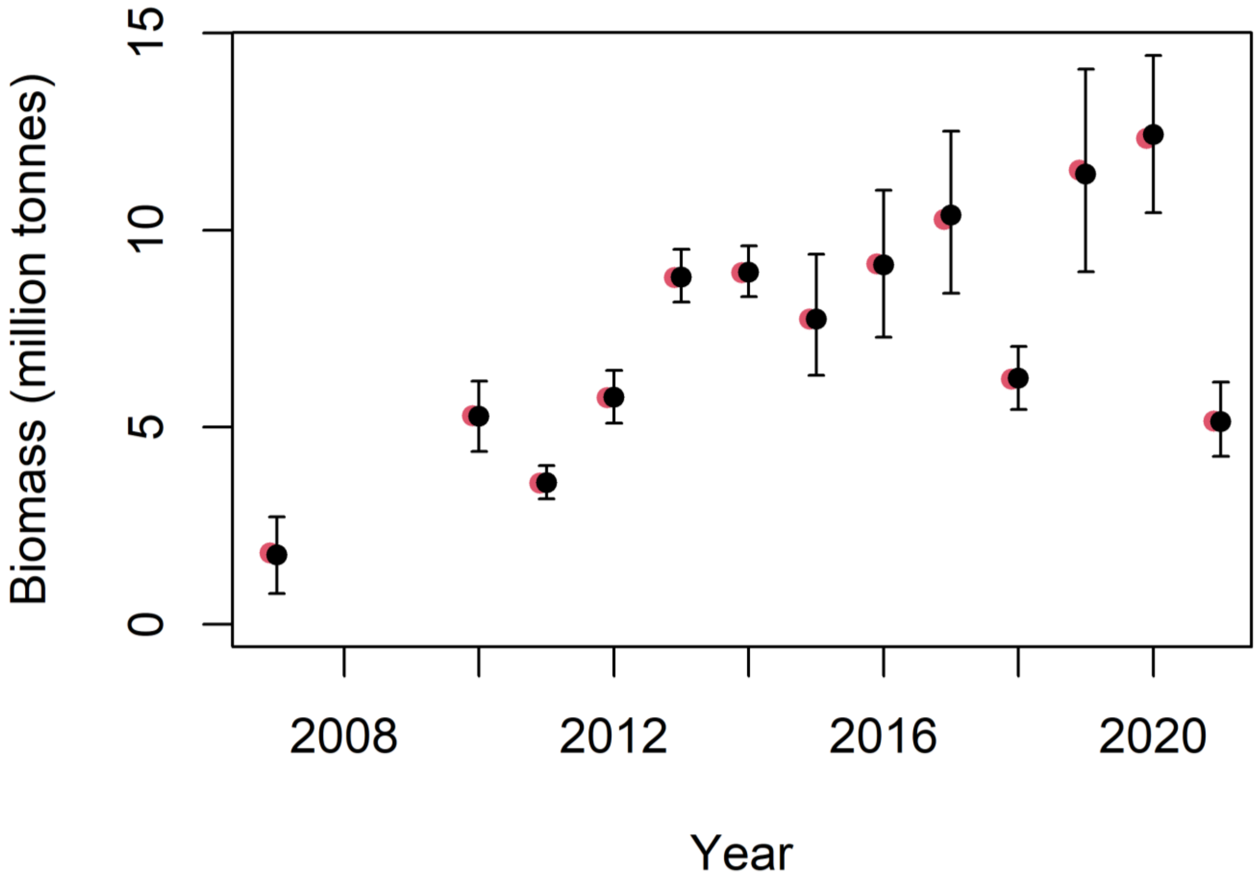
Swept area analyses from standardized pelagic trawling with Multpelt 832

The swept area estimates of mackerel biomass from the 2021 IESSNS were based on abundance of mackerel per stratum (see strata definition in Figure 2) and calculated in StoX version 3.10. The mackerel biomass and abundance indices in 2020 were the highest in the time series that started in 2010 (Table 7, Figure 15). In 2021 a drop of more than 50% was observed (Figure 15). The most abundant year-classes were 2019, 2016, 2014, 2017 and 2012, respectively (Figure 16). Mackerel of age 1, 2 and to some extent also age 3 are not completely recruited to the survey (Figure 18), information on recruitment is therefore uncertain. However, the abundance of 1- and 2-year olds from the 2019 and 2020 year-classes was quite high, particularly in the North Sea in July 2021, suggesting that these new year-classes may be promising. Variance in age index estimation is provided in Figure 17.

The overall internal consistency plot for age-disaggregated year classes was slightly reduced compared to last year (Figure 19). There is a good to strong internal consistency for the younger ages (1-4 years) and older ages (8-14+ years) with r between 0.70 and 0.89. However, the internal consistency is very poor to moderate (0.02 < r < 0.64) between age 4 to 8. The reason for this poor consistency is not clear.

Mackerel index calculations from the catch in the North Sea (Figure 2) were excluded from the index calculations presented in the current chapter to facilitate comparison to previous years and because the 2017 mackerel benchmark stipulated that trawl stations south of latitude 60 °N be excluded from index calculations (ICES 2017). Results from the mackerel index calculations for the North Sea are presented in Appendix 1.

The indices used for NEA mackerel stock assessment in WGIWIDE are the number-at-age indices for age 3 to 11 year (Table 7a).



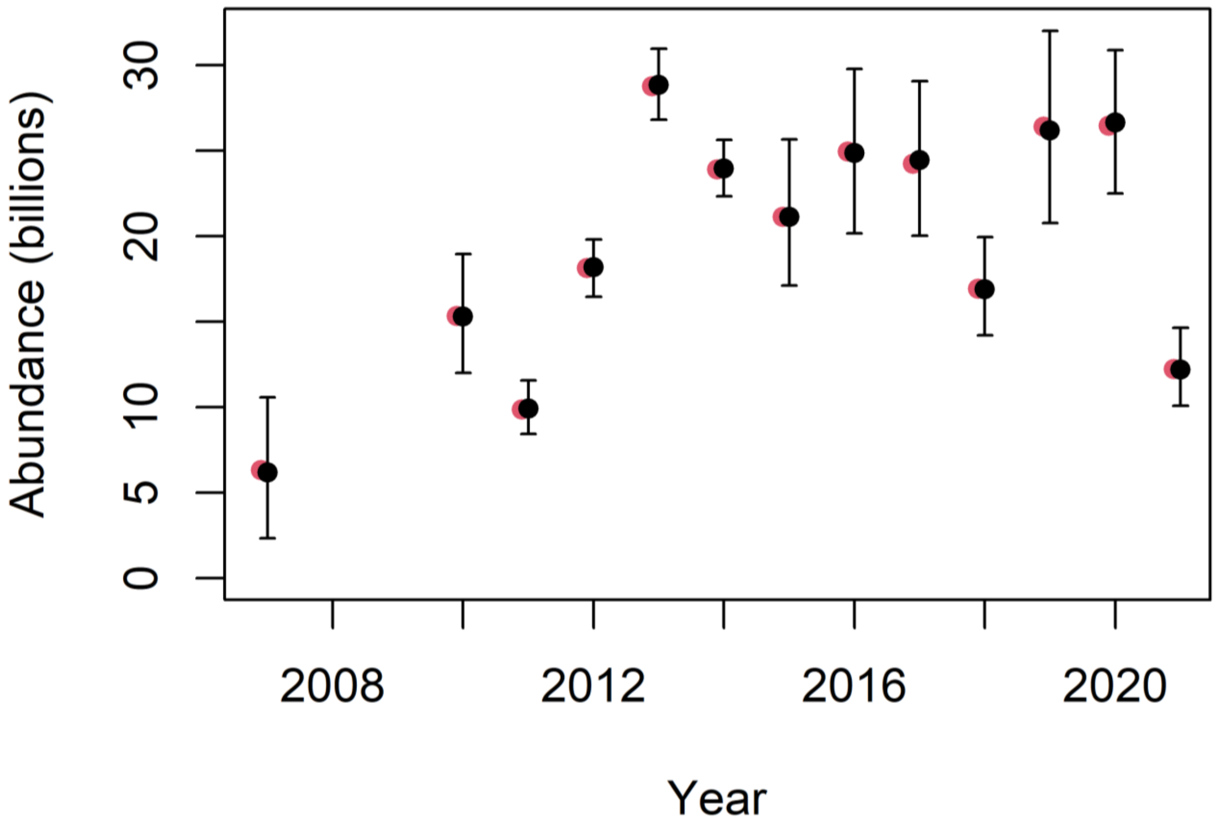


Figure 15. Estimated total stock biomass (upper panel) and total stock numbers (lower panel) of mackerel from StoX for the years 2007 and from 2010 to 2021. The red dots are baseline estimates, the black dots are mean of 1000 bootstrap replicates while the error bars represent 90 % confidence intervals based on the bootstrap.

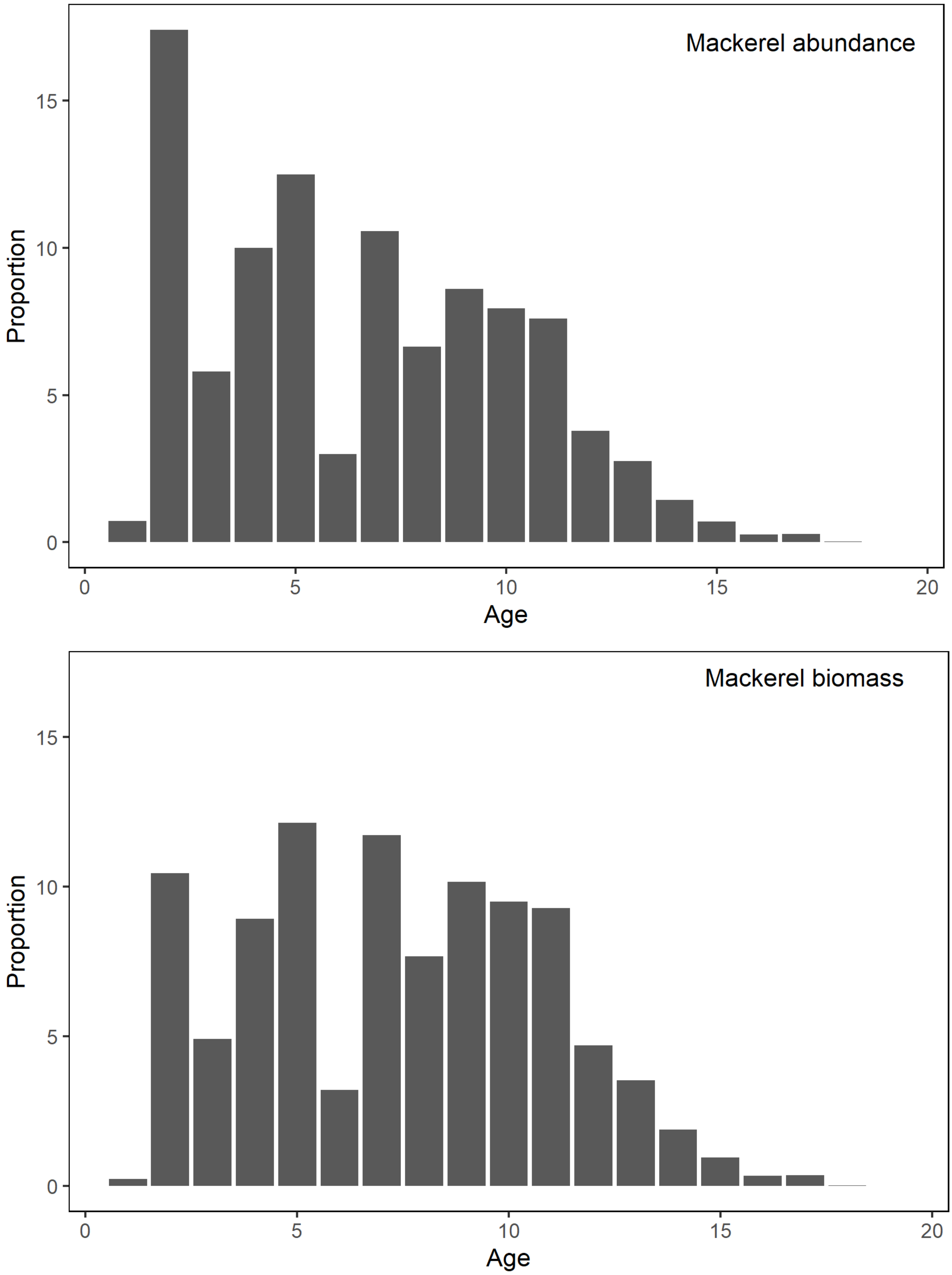


Figure 16. Age distribution in proportion represented as a) % in numbers and b) % in biomass of Northeast Atlantic mackerel in 2021.

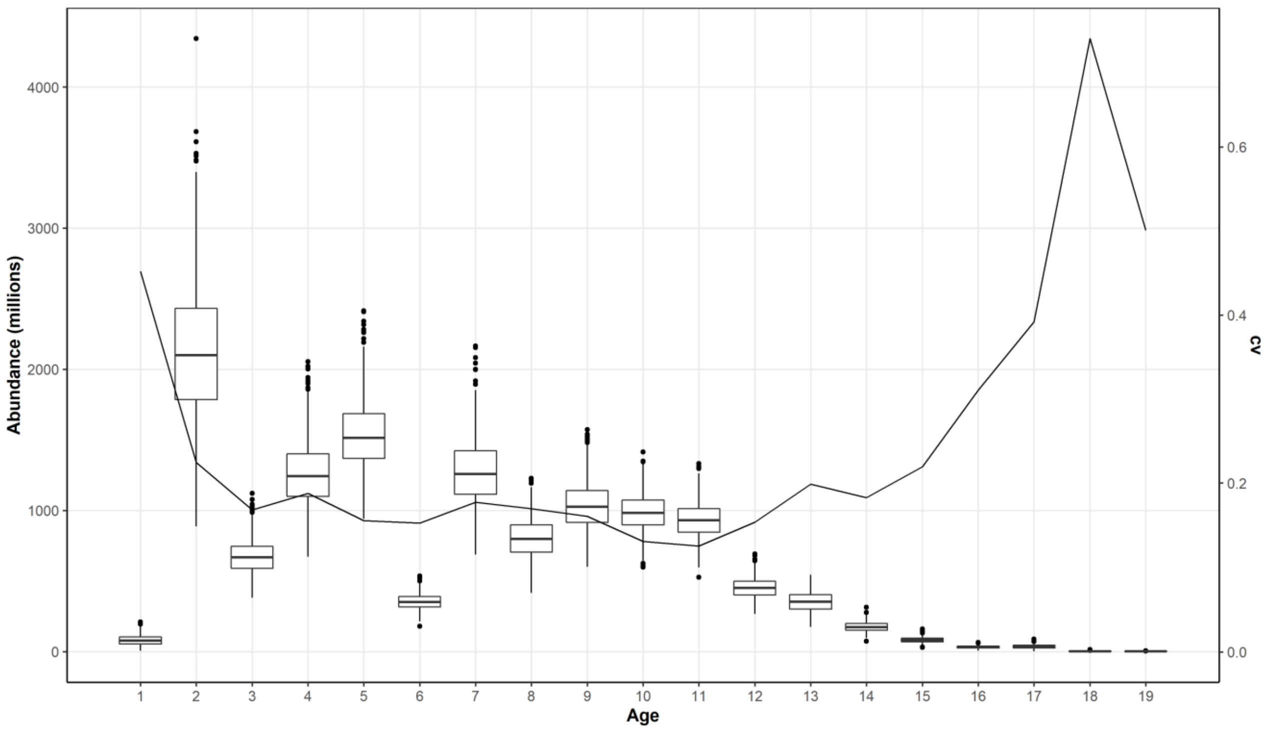


Figure 17. Number by age for mackerel in 2021. Boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 500 replicates using the StoX software.

Table 7. a-d) StoX baseline time series of the IESSNS showing (a) age-disaggregated abundance indices of mackerel (billions), (b) mean weight (grams) per age, (c) estimated biomass at age (million tonnes) in 2007 and from 2010 to 2021, and (d) estimates of abundance, biomass and mean weight by age and length, including coefficient of variation (cv) based on calculation in StoX for IESSNS 2021 (d). cv* values are from bootstrap calculations but other values from baseline calculations (point estimates).

a)

Year\Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14(+)	Tot N
2007	1.33	1.86	0.90	0.24	1.00	0.16	0.06	0.04	0.03	0.01	0.01	0.00	0.01	0.00	5.65
2010	0.03	2.80	1.52	4.02	3.06	1.35	0.53	0.39	0.20	0.05	0.03	0.02	0.01	0.01	13.99
2011	0.21	0.26	0.87	1.11	1.64	1.22	0.57	0.28	0.12	0.07	0.06	0.02	0.01	0.00	6.42
2012	0.50	4.99	1.22	2.11	1.82	2.42	1.64	0.65	0.34	0.12	0.07	0.02	0.01	0.01	15.91
2013	0.06	7.78	8.99	2.14	2.91	2.87	2.68	1.27	0.45	0.19	0.16	0.04	0.01	0.02	29.57
2014	0.01	0.58	7.80	5.14	2.61	2.62	2.67	1.69	0.74	0.36	0.09	0.05	0.02	0.00	24.37
2015	1.20	0.83	2.41	5.77	4.56	1.94	1.83	1.04	0.62	0.32	0.08	0.07	0.04	0.02	20.72
2016	<0.01	4.98	1.37	2.64	5.24	4.37	1.89	1.66	1.11	0.75	0.45	0.20	0.07	0.07	24.81
2017	0.86	0.12	3.56	1.95	3.32	4.68	4.65	1.75	1.94	0.63	0.51	0.12	0.08	0.04	24.22
2018	2.18	2.50	0.50	2.38	1.20	1.41	2.33	1.79	1.05	0.50	0.56	0.29	0.14	0.09	16.92
2019	0.08	1.35	3.81	1.21	2.92	2.86	1.95	3.91	3.82	1.50	1.25	0.58	0.59	0.57	26.4
2020	0.04	1.10	1.43	3.36	2.13	2.53	2.53	2.03	2.90	3.84	1.50	1.18	0.92	0.98	26.47
2021	0.09	2.13	0.71	1.22	1.53	0.37	1.29	0.81	1.05	0.97	0.93	0.46	0.34	0.33	12.22

b)

Year\Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14(+)
2007	133	233	323	390	472	532	536	585	591	640	727	656	685	671
2010	133	212	290	353	388	438	512	527	548	580	645	683	665	596
2011	133	278	318	371	412	440	502	537	564	541	570	632	622	612

2012	112	188	286	347	397	414	437	458	488	523	514	615	509	677
2013	96	184	259	326	374	399	428	445	486	523	499	547	677	607
2014	228	275	288	335	402	433	459	477	488	533	603	544	537	569
2015	128	290	333	342	386	449	463	479	488	505	559	568	583	466
2016	95	231	324	360	371	394	440	458	479	488	494	523	511	664
2017	86	292	330	373	431	437	462	487	536	534	542	574	589	626
2018	67	229	330	390	420	449	458	477	486	515	534	543	575	643
2019	153	212	325	352	428	440	472	477	490	511	524	564	545	579
2020	99	213	315	369	394	468	483	507	520	529	539	567	575	593
2021	140	253	357	377	409	451	467	487	497	505	516	523	544	559

c)

Year\Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14(+)	Tot B
2007	0.18	0.43	0.29	0.09	0.47	0.09	0.03	0.02	0.02	0.01	0.01	0.00	0.01	0.00	1.64
2010	0.00	0.59	0.44	1.42	1.19	0.59	0.27	0.20	0.11	0.03	0.02	0.01	0.01	0.00	4.89
2011	0.03	0.07	0.28	0.41	0.67	0.54	0.29	0.15	0.07	0.04	0.03	0.01	0.01	0.00	2.69
2012	0.06	0.94	0.35	0.73	0.72	1.00	0.72	0.30	0.17	0.06	0.03	0.01	0.00	0.00	5.09
2013	0.01	1.43	2.32	0.70	1.09	1.15	1.15	0.56	0.22	0.10	0.08	0.02	0.01	0.01	8.85
2014	0.00	0.16	2.24	1.72	1.05	1.14	1.23	0.80	0.36	0.19	0.05	0.03	0.01	0.00	8.98
2015	0.15	0.24	0.80	1.97	1.76	0.87	0.85	0.50	0.30	0.16	0.04	0.04	0.02	0.01	7.72
2016	<0.01	1.15	0.45	0.95	1.95	1.72	0.83	0.76	0.53	0.37	0.22	0.10	0.04	0.04	9.11
2017	0.07	0.03	1.18	0.73	1.43	2.04	2.15	0.86	1.04	0.33	0.28	0.07	0.05	0.03	10.29
2018	0.15	0.57	0.16	0.93	0.50	0.63	1.07	0.85	0.51	0.26	0.30	0.16	0.08	0.05	6.22
2019	0.01	0.29	1.24	0.43	1.25	1.26	0.92	1.86	1.87	0.77	0.65	0.33	0.32	0.32	11.52
2020	<0.01	0.23	0.45	1.24	0.84	1.18	1.22	1.03	1.51	2.03	0.81	0.67	0.53	0.58	12.33
2021	0.01	0.54	0.25	0.46	0.62	0.17	0.60	0.39	0.52	0.49	0.48	0.24	0.18	0.19	5.15

d)	Age in years (year class)																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Abundance	Biomass	Mean
Length (cm)	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	num. 10^6	1000 ton	weight (g)
21	5																			5	0	84
22	22																			22	2	90
23	14																			14	1	97
24	7																			7	1	119
25	6																			6	1	141
26	8	2																		11	2	159
27	3	26																		30	5	178
28	10	134	0																	144	29	200
29	13	486	42																	542	122	226
30		708		1																709	178	251
31		548	5	8																561	156	278
32		178	43	30	5															257	76	298
33		37	161	129	55			12												395	129	326
34		6	157	317	214	12	8													713	253	355
35		2	225	416	428	38	58	18		5	0	0								1190	458	385
36		0	67	260	482	93	138	63	22	3	11	10	1							1149	484	422
37			6	55	273	134	386	257	177	169	87	25	1	0	3					1575	722	459
38			2	5	48	41	542	202	411	310	230	90	47	17	8	5	7			1964	954	486
39			0		21	48	131	166	272	298	298	157	129	29	8	8	2			1568	810	517
40						1	28	81	140	150	182	111	70	62	36	8	14		1	884	485	548
41					1	0		10	16	31	105	61	61	49	10	1	6	0		351	204	581
42							1	2	13	3	14	8	24	14	16	11	1			107	67	627
43													3	2	7		4			16	10	655
44											1			1						2	1	687
45																				0	1	738
46																		2		2	2	748
TSN (mil)	88	2128	709	1221	1528	367	1292	811	1052	970	927	462	336	174	87	32	34	2	1	12222	5155	
cv (TSN)*	0.45	0.22	0.17	0.19	0.16	0.15	0.18	0.17	0.16	0.13	0.13	0.15	0.20	0.18	0.22	0.31	0.39	0.86	0.97			
TSB (1000 t)	12	539	253	460	625	166	604	395	523	490	478	242	183	98	49	18	19	2	1	5154		
cv (TSB)*	0.42	0.23	0.17	0.19	0.15	0.15	0.18	0.17	0.16	0.13	0.13	0.15	0.20	0.19	0.22	0.32	0.38	0.87	0.98			
Mean len. (cm)	24.7	30.1	33.9	34.7	35.6	36.8	37.5	37.8	38.4	38.5	39.0	39.2	39.7	40.1	40.4	40.2	40.1	45.9	40.0			
Mean wei. (g)	140	253	357	377	409	451	467	487	497	505	516	523	544	559	568	558	544	743	545			

Table 8. Bootstrap estimates from StoX (based on 500 replicates) of mackerel in 2021. Numbers by age and total number (TSN) are in millions and total biomass (TSB) in million tons.

Age	5th percentile	Median	95th percentile	Mean	SD	CV
1	22.6	77.0	144.1	79.8	36.1	0.45
2	1397.9	2100.0	2935.7	2124.0	477.8	0.22
3	498.1	666.6	864.6	671.5	113.3	0.17
4	891.4	1243.2	1686.4	1258.5	236.9	0.19
5	1178.3	1514.8	1929.9	1536.0	239.2	0.16
6	268.5	350.8	445.7	353.1	54.0	0.15
7	962.1	1257.9	1688.1	1278.2	227.0	0.18
8	585.5	797.5	1037.3	801.7	136.4	0.17
9	773.9	1025.1	1329.6	1035.5	166.6	0.16
10	780.8	982.3	1198.9	986.9	129.3	0.13
11	756.2	930.6	1135.3	932.2	117.2	0.13
12	340.5	450.0	569.2	451.4	69.5	0.15
13	242.5	353.8	471.7	354.1	70.6	0.20
14	125.4	173.2	226.1	174.6	32.0	0.18
15	54.3	82.0	113.2	82.3	18.1	0.22
16	15.7	31.4	48.2	31.5	9.8	0.31
17	13.5	33.7	59.6	34.9	13.7	0.39
18	0.0	2.4	7.1	2.8	2.4	0.86
19	0.0	1.3	3.8	1.4	1.3	0.97
Unknown	1.4	6.2	19.3	7.7	5.9	0.77
TSN	10078	12133	14637	12198	1376	0.11
TSB	4.26	5.13	6.15	5.14	0.58	0.11

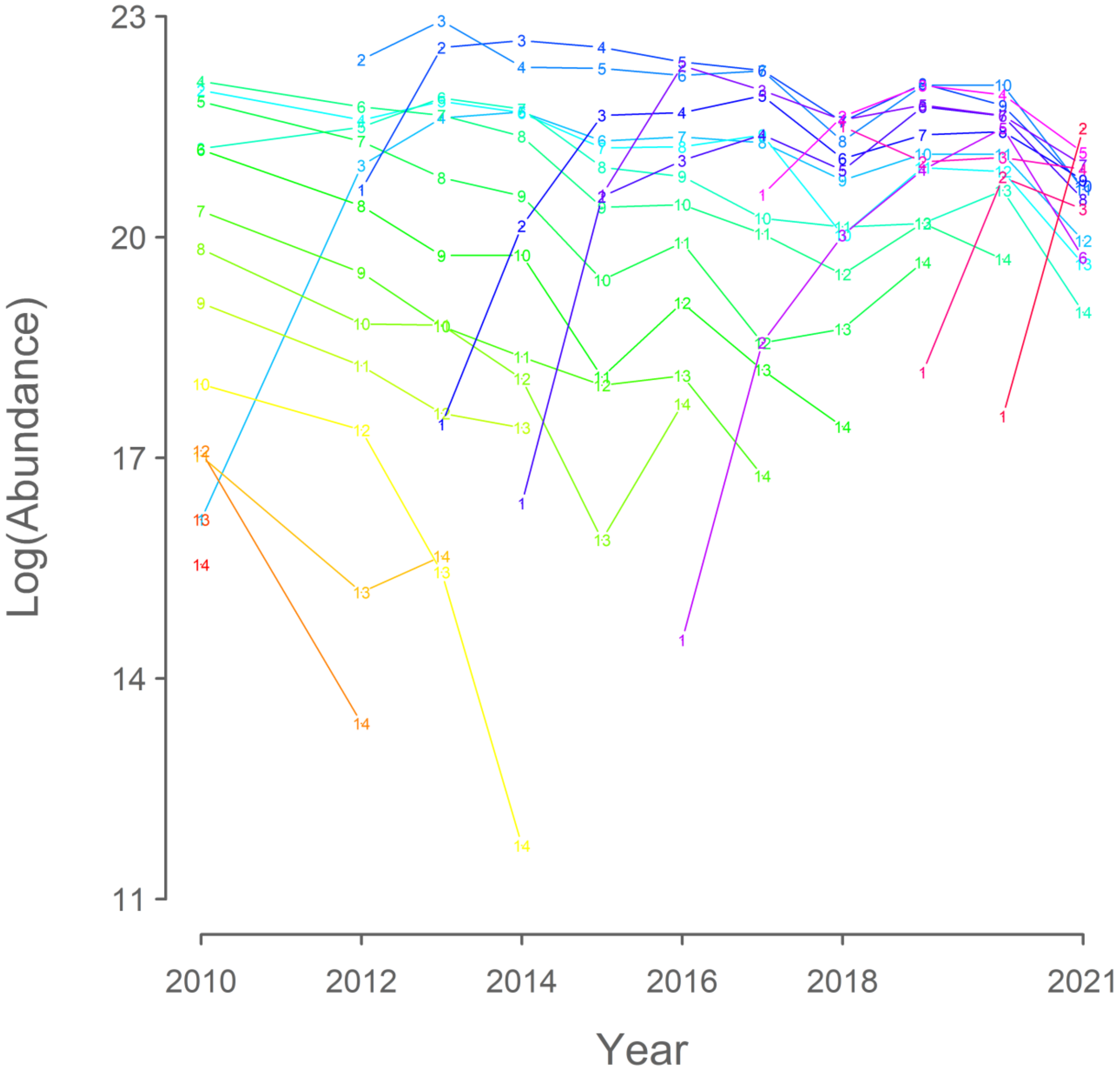


Figure 18. Catch curves in 2021. Each cohort of mackerel is marked by a uniquely coloured line that connects the estimates indicated by the respective ages.

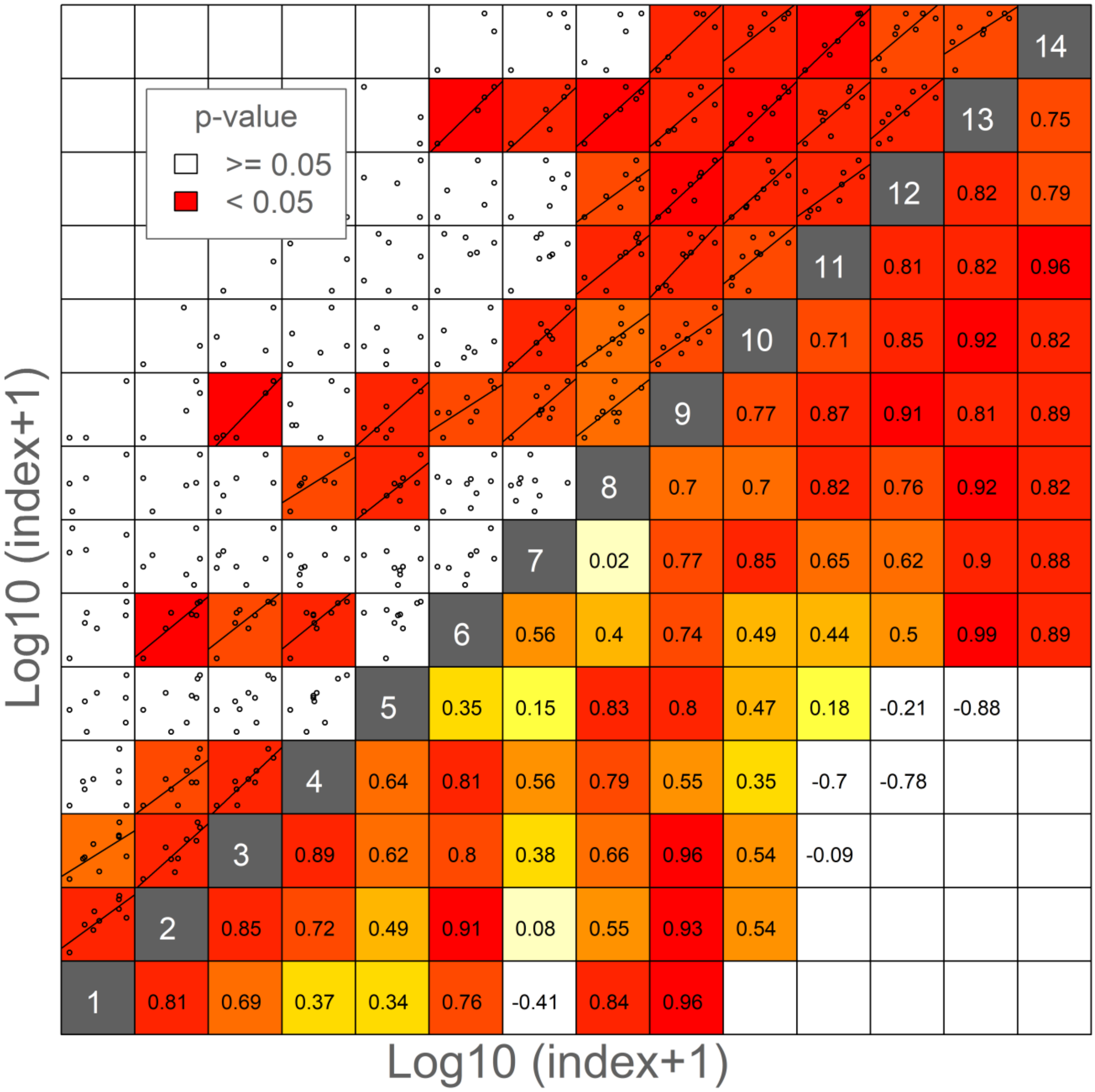


Figure 19. Internal consistency of the of mackerel density index from 2012 to 2021. Ages indicated by white numbers in grey diagonal cells. Statistically significant positive correlations (*p<0.05*) are indicated by regression lines and red cells in upper left half. Correlation coefficients (r) are given in the lower right half.

The zero boundaries for mackerel distribution were found in majority of survey area with a notable exception of some mackerel abundance in the north-western region of the Norwegian Sea particularly towards the Fram Strait west of Svalbard.

The swept area method assumes that potential distribution of mackerel outside the survey area – both vertically and horizontally – is a constant percentage of the total biomass. In some years, this assumption may be violated, e.g. when mackerel may be distributed below the lower limit of the trawl or if the proportion of mackerel outside the survey coverage varies among years. In order to improve the precision of the swept area estimate it would be beneficial to extend the survey coverage further south, such that it covers the southwestern waters south of 60°N, e.g. UK waters.

The standard swept area method using the average horizontal trawl opening by each participating vessel (ranging 56.6.5-75.4 m; Table 5), assuming that a constant fraction of the mackerel inside the horizontal trawl opening are caught. Further, that if mackerel is distributed below the depth of the trawl (footrope), this fraction is assumed constant from year to year.

The large variation in the swept area index in recent years might be due to the large spread in catch rates with a varying proportion taken each year of some few extremely large catches (>10 t/30min). It is suspected that these extreme catches might have relatively high impact on the calculated average, with a potential to bias the survey index. The problem arises if the number of these extreme catches is linked to the distribution of mackerel but not to the biomass. The group recommends investigating this potential problem. In 2021 we had no large or extremely large catch of mackerel compared to e.g. 2019 and 2020.

As in previous years, there was overlap in the spatio-temporal distribution of mackerel and herring (Figure 14). This overlap occurred between mackerel and North Sea herring in major parts of the North Sea and partly in the southernmost part of the Norwegian Sea. There were also some overlapping distributions of mackerel and Norwegian spring-spawning herring (NSSH) in the western, north-western and north-eastern part of the Norwegian Sea.

4.4 Norwegian spring-spawning herring

Norwegian spring-spawning herring (NSSH) was recorded in the southwestern (east and north of Iceland) and northern part of the Norwegian Sea basin (Figure 20a). The acoustic registrations in the southern and eastern parts of the Norwegian Sea were low or absent in July 2021. This is in contrast to the more southerly distribution of the adult stock in May, where the herring was observed from the area north of the Faroes northwest towards Iceland. In July 2021 a relatively large part of the adult NSSH stock was distributed north of 68°N (Figure 20a). Herring registrations south of 62°N in the eastern part were allocated to a different stock, North Sea herring, while the herring to the south and west in Icelandic waters (west of 14°W south of Iceland) were allocated to Icelandic summer-spawners, and these were removed from the biomass estimation of NSSH, except some putative North Sea herring in the southeastern area north of Shetland (Figure 20b).

The total number of NSSH recorded during IESSNS 2021 was 20.3 billion and the total biomass index was 6.10 million tonnes, which at the same level as in 2020 (20.3 and 5.93, respectively) (Table 10 and 11). The 2016 year-class (5 year olds) dominated in the stock and contributed to 55% and 60% to the total biomass and total abundance, respectively, whereas the 2013 year-class (8 year olds) contributed 13% and 11% to the total biomass and total abundance, respectively (Figure 21 and Table 9). The 2016 year-class was considered to be fully recruited to the adult stock in 2021, and also fully recruited to the survey area.

Bootstrap estimates of numbers by age are shown in Figure 21. The uncertainty (CV) around the age disaggregated abundance indices from the 2021 survey varied around 0.25-0.3 for age groups 4-15 (Figure 21), which is considered satisfactory.

The internal consistency among year classes was generally high, with the lowest correlation (r = 0.57) between age 5 and 6 (Figure 22).

The 0-boundary of the distribution of the adult part of NSSH was considered to be reached in all directions. The herring was mainly observed in the upper surface layer as relatively small schools. This shallow distribution of herring might have lead to an unknown portion of herring being in the "blind zone" above the transducer depth of the vessels (i.e. shallower than 10-15 m, Table 4), and therefore not being registered by the vessels. However, the group considered the acoustic biomass estimate of herring to be of good quality in the 2021 IESSNS as in the previous survey years.

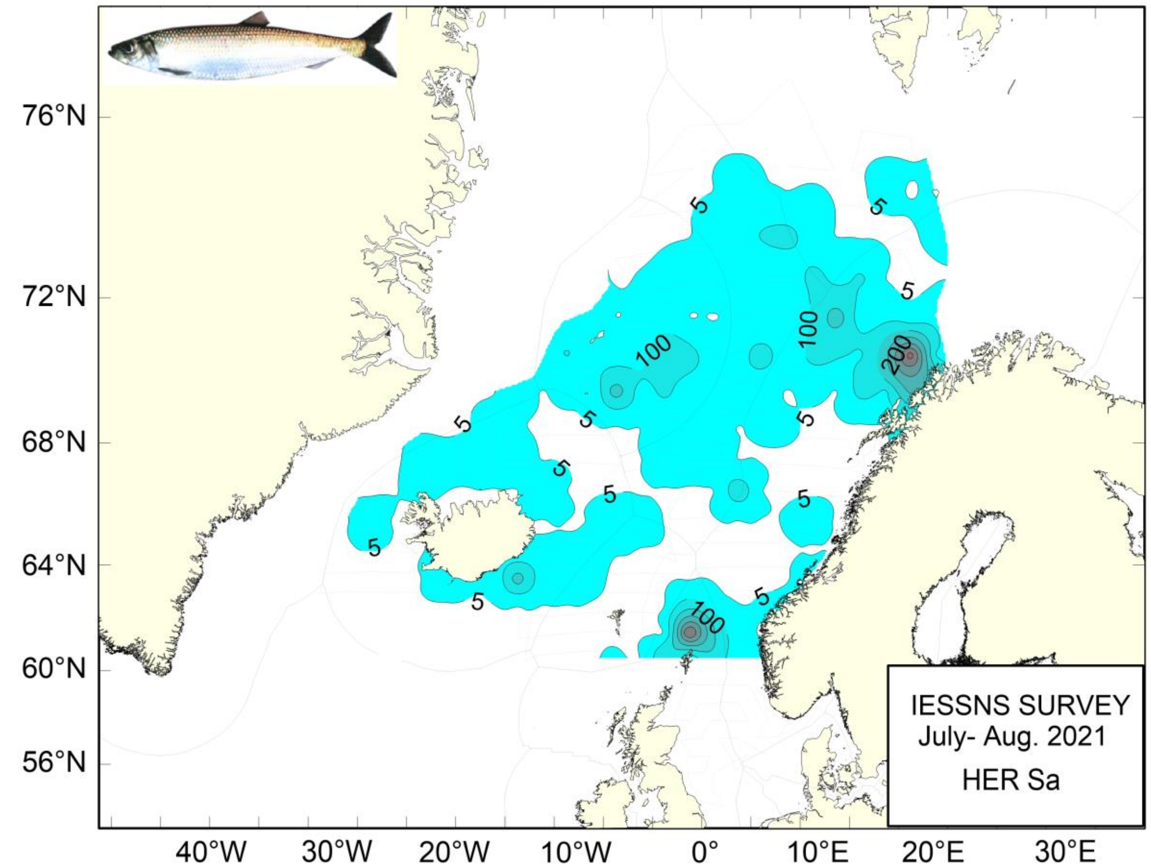


Figure 20a. The sA/Nautical Area Scattering Coefficient (NASC) values of herring along the cruise tracks in 2021 presented as contour lines. Values north of 62ºN, and east of 14ºW, are considered to be Norwegian spring-spawning herring. South and west of this area the herring observed are other stocks, *i.e.* Icelandic summer spawners, Faroese autumn spawners and North Sea herring in the southeast.

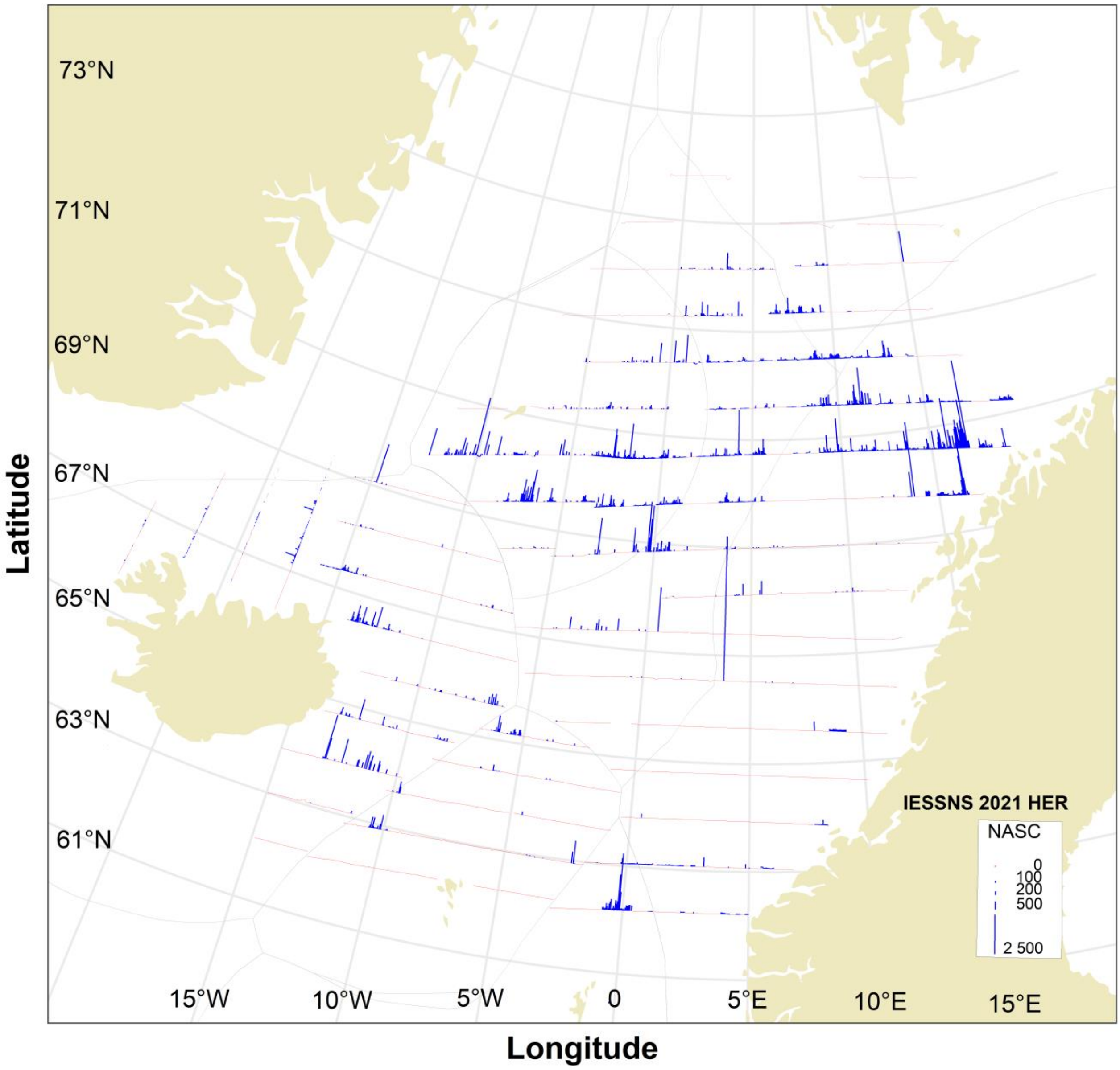


Figure 20b. The sA/Nautical Area Scattering Coefficient (NASC) values of Norwegian spring-spawning herring along the cruise tracks in 2021, presented as bar plot.

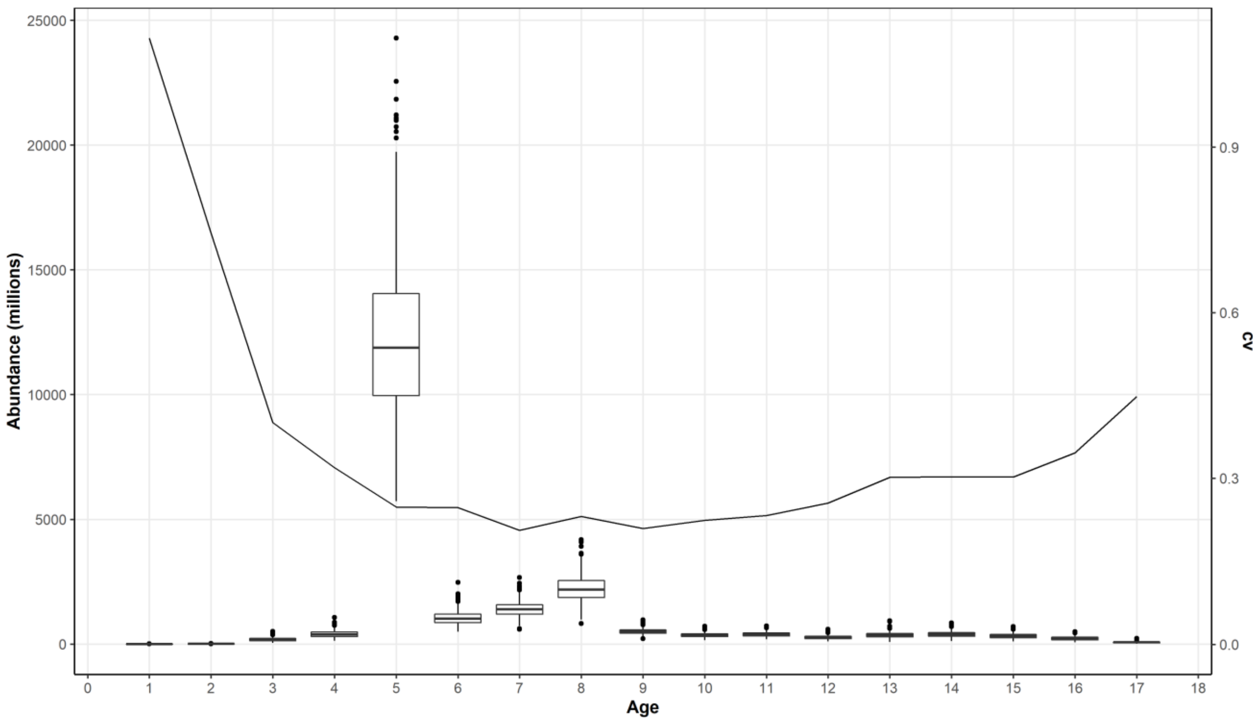


Figure 21. Abundance by age for Norwegian spring-spawning herring during IESSNS 2021. Boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 500 replicates using the StoX software.

Table 9. Estimates of abundance, mean weight and mean length of Norwegian spring-spawning herring based on calculation in StoX for IESSNS 2021.

	Age in years (year class)																		Number	Biomass	Mean
Length	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18			weight
(cm)	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	(10^6)	(10^6 kg)	(g)
15-16																					26.5
16-17																					31.8
17-18																					36.0
18-19	0.5																		0.5	0.0	47.8
19-20																				0.2	57.3
20-21			12.8																12.8	0.8	62.5
21-22			18.0																18.0	1.3	69.2
22-23			26.6																26.6	2.3	83.9
23-24			3.3																3.3	0.3	92.0
24-25			5.0																5.0	0.7	126.6
25-26			18.5	6.4															25.0	3.7	153.6
26-27		4.0	29.1	17.5	4.6														55.3	8.9	166.3
27-28			17.1	78.2	56.4	7.5	8.7	1.7											169.6	30.5	184.2
28-29			25.0	40.1	167.9	23.5	7.4	22.2	2.5	3.7									292.2	59.2	205.2
29-30			16.1	73.9	695.0	9.9	18.3	7.5	28.8	11.7	6.0				0.5				867.8	199.4	230.3
30-31			10.9	86.0	2895.6	156.0	25.5	30.6	13.8	12.6	9.5	5.9	7.5	0.6	1.8				3 256.5	823.7	252.4
31-32				48.3	3743.5	146.3	94.3	51.9	24.1	12.7	8.8	13.6	0.7	5.6	0.6				4 150.4	1133.2	273.2
32-33			2.0	28.0	3040.3	161.3	229.2	89.7	27.0	23.1	14.8	8.9	11.8	0.8		0.8	1.8		3 639.4	1080.8	296.8
33-34				16.3	1354.5	279.8	398.2	473.7	68.9	25.8	4.7	6.3	2.9						2 631.0	848.7	320.6
34-35					154.7	230.4	404.9	862.9	97.6	28.3	12.8	15.5	1.4		5.4				1 814.0	626.8	341.3
35-36						30.5	185.3	580.3	122.1	103.0	52.2	30.2	7.6	15.4	3.6	17.7			1 147.8	422.2	359.8
36-37							25.4	94.4	102.4	76.2	131.0	83.6	127.2	112.3	83.3	32.7	17.2		885.7	340.7	378.7
37-38				3.8				11.4	15.2	52.4	132.1	71.5	144.5	165.3	139.5	38.2	24.4		798.2	318.9	394.8
38-39					3.3		0.9			12.0	21.1	32.8	35.3	66.3	89.3	93.3	17.0		371.4	154.5	416.2
39-40													21.0	21.1		45.5	3.4		91.0	40.8	451.0
40-41					1.3									4.5			5.1		10.9	5.2	460.9
																				0.4	
TSN(mill)	0.5	4.0	184.5	398.5	12117.0	1045.4	1398.1	2226.3	502.4	361.5	393.1	268.2	359.8	391.9	324.0	228.2	69.0		20 279.7		
cv (TSN)	1.55	0.87	0.40	0.32	0.25	0.25	0.21	0.23	0.21	0.22	0.23	0.26	0.30	0.30	0.30	0.35	0.45		0.20		
TSB(1000 t)	0.0	0.7	27.4	92.5	3 348.2	316.7	456.3	763.2	173.3	128.5	146.5	101.1	141.9	154.0	128.4	95.3	28.3		6 103.2		
cv (TSB)	1.55	0.87	0.37	0.30	0.25	0.25	0.21	0.23	0.21	0.23	0.24	0.26	0.31	0.30	0.31	0.35	0.45		0.20		
Mean length(cm)	15.3	26.0	26.0	29.3	31.1	32.2	33.0	33.8	33.7	34.6	35.8	35.6	36.4	36.9	36.9	37.6	37.4				
Mean weight(g)	28.7	165.6	166.2	233.9	276.7	300.9	320.5	336.3	333.8	349.9	370.6	371.2	388.1	389.2	392.0	419.5	414.5				

Table 10. IESSNS bootstrap time series (mean of 1000 replicates) from 2016 to 2021. StoX abundance estimates of Norwegian spring-spawning herring (millions).

	Age												
Year	1	2	3	4	5	6	7	8	9	10	11	12+	TSB(1000 t)
2016	38	119	747	577	1,622	1,636	1,967	1,588	1,274	2,001	2,164	6,245	6,676
2017	1,232	240	1,318	4,653	1,003	1,184	795	1,716	1,004	1,115	1,657	4,040	5,821
2018	0	587	656	864	3,054	924	1,172	746	971	1,078	663	2,704	4,379
2019	0	143	1,910	616	1,101	3,487	814	751	510	780	470	4,660	4,794
2020	0	15	117	8,280	1,710	2,367	4,087	696	520	305	594	1,827	5,991
2021	1	4	184	398	12,117	1,045	1,398	2,226	502	361	393	1,641	6,103

Table 11. IESSNS baseline time series from 2016 to 2021. StoX abundance estimates of Norwegian spring-spawning herring (millions).

	Age												
Year	1	2	3	4	5	6	7	8	9	10	11	12+	TSB(1000 t)
2016	41	146	752	604	1,637	1,559	2,010	1,614	1,190	2,023	2,151	6,467	6,753
2017	1,216	248	1,285	4,586	1,056	1,188	816	1,794	1,022	1,131	1,653	4,119	5,885
2018	0	577	722	879	3,078	931	1,264	734	948	1,070	694	2,792	4,465
2019	0	153	1,870	590	1,067	3,475	859	702	520	700	463	4,808	4,780
2020	0	7	111	8,082	1,697	2,335	4,102	714	491	294	590	1,833	5,930
2021	1	3	196	388	11,988	1,109	1,342	2,292	491	365	386	1,649	6,085

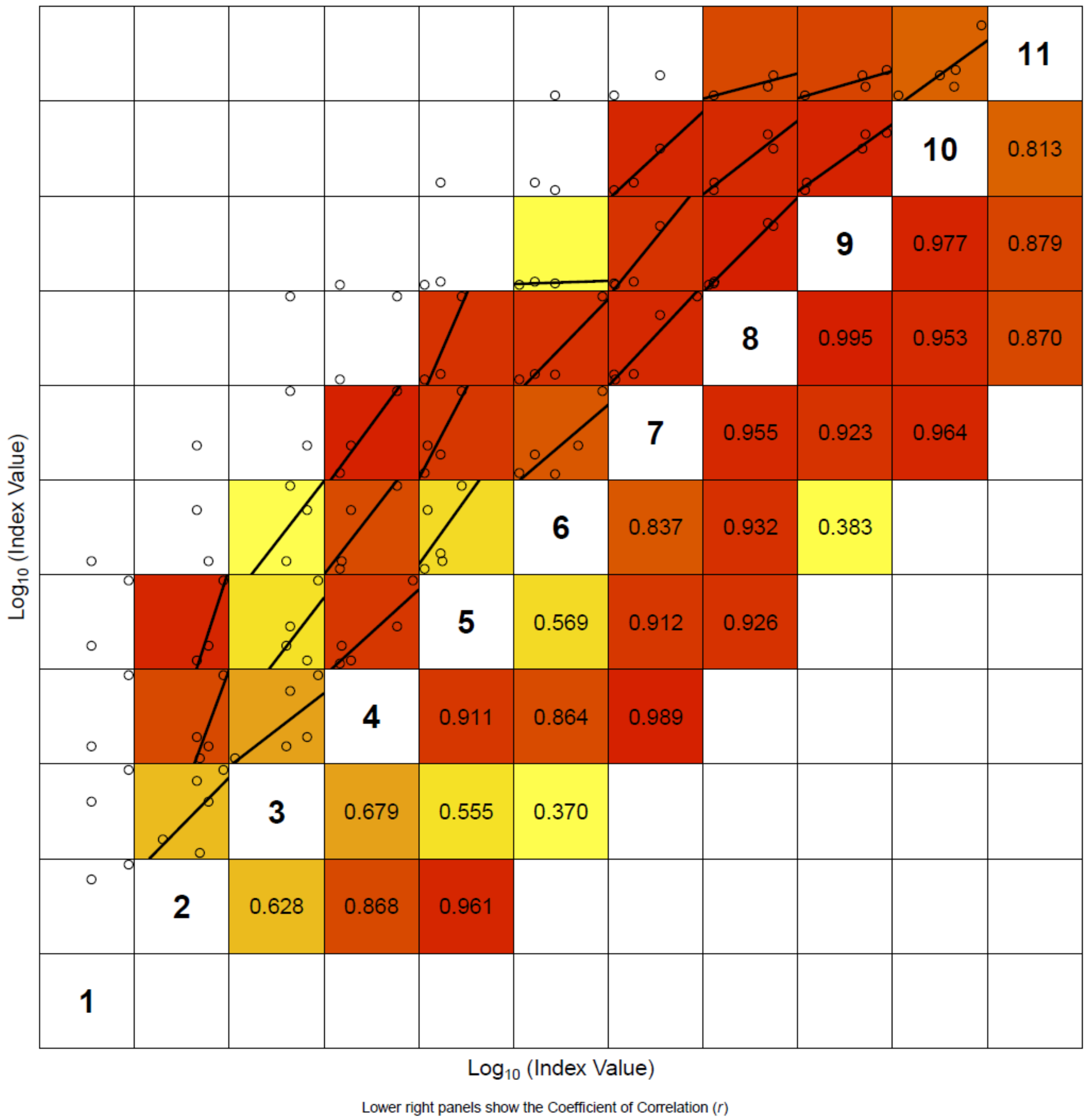


Figure 22. Internal consistency for Norwegian spring-spawning herring within the IESSNS 2021. The upper left part of the plots shows the relationship between log index-at-age within a cohort. Linear regression line shows the best fit to the log-transformed indices. The lower-right part of the plots shows the correlation coefficient (r) for the two ages plotted in that panel. The background colour of each panel is determined by the r value, where red equates to r=1 and white to r<0.

4.5 Blue whiting

Blue whiting was distributed in parts of the survey area dominated by warm Atlantic waters and had a continuous distribution from the southern boundary of the survey area (60 °N) to Spitsbergen (72 °N). High blue whiting density (s_A-values) was observed in the southern part of the Norwegian Sea, along the Norwegian continental slope, around the Faroe Islands, and southeast of Iceland. Concentrations of older fish (age2+) were low and they were mainly observed on the continental slope, both in the eastern and the southern part of the Norwegian Sea (Figure 23). The distribution in 2021 is comparable to 2020 with the exception of more blue whiting recorded south and southwest of Iceland, mostly age-0 fish. As in previous years no blue whiting was registered in the cold East Icelandic Current, between Iceland and Jan Mayen.

The total biomass of blue whiting registered during IESSNS 2021 was 2.2 million tons (Table 12), which is an increase of 24% compared to 2020 (1.8 mill tons). Estimated stock abundance (ages 1+) was 26.2 billion compared to 16.5 billion in 2020, which is an increase of 60%. Age 1 dominated the estimate in 2021 as it contributed 51% and 69% of biomass and abundance, respectively.

Bootstrap estimates of numbers by age, with uncertainty estimates, for blue whiting during IESSNS 2021 are shown in Figure 24. The baseline point estimates from 2016-2021 are shown in table 13. The internal consistency among year classes is shown in Figure 25 and indicates good to moderate consistency for ages 3-6, but poorer fit for other ages.

The group considered the acoustic biomass estimate of blue whiting to be of good quality in the 2021 IESSNS as in the previous survey years.

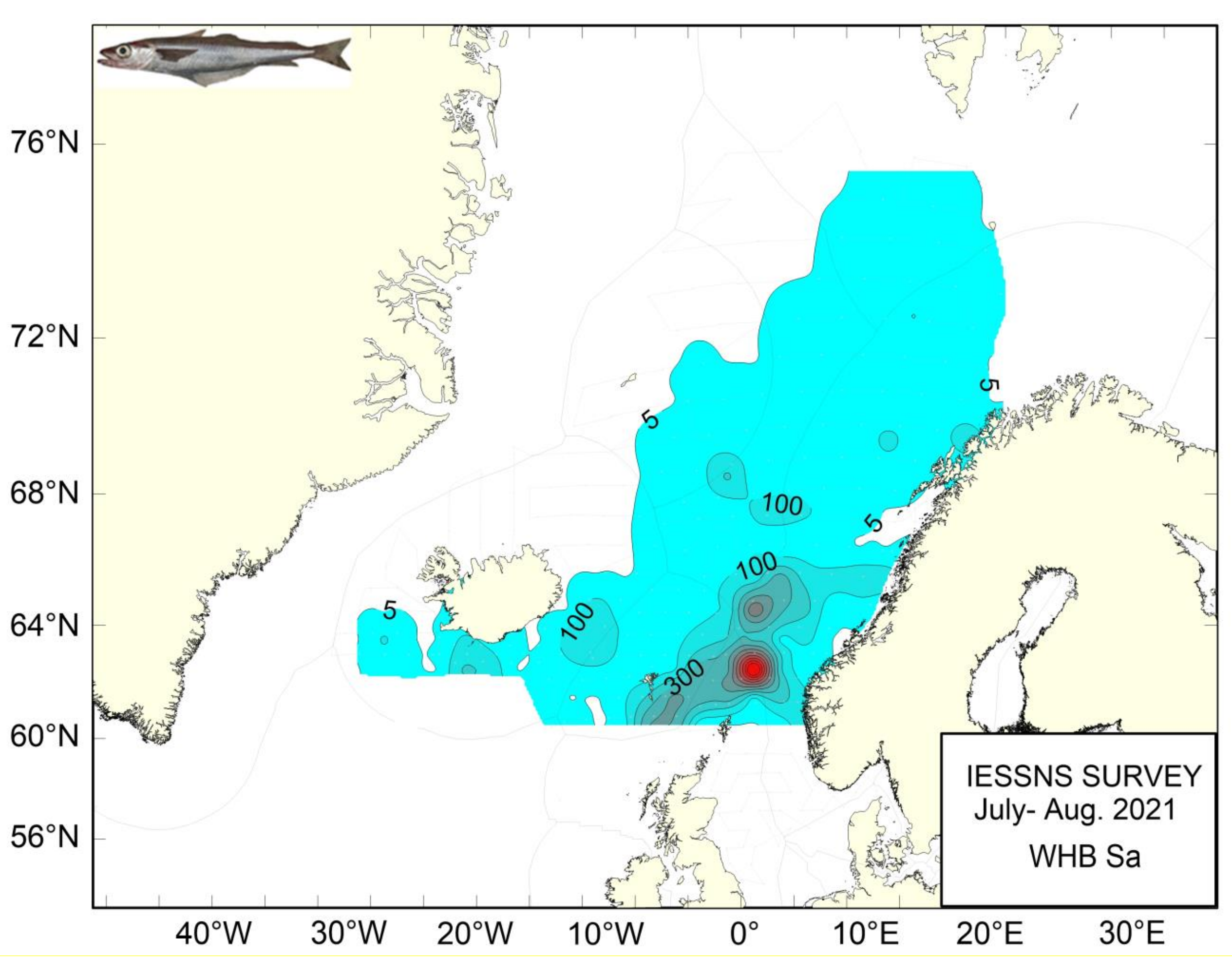


Figure 23a. The sA/Nautical Area Scattering Coefficient (NASC) values of blue whiting along the cruise tracks in IESSNS 2021. Presented as contour lines.

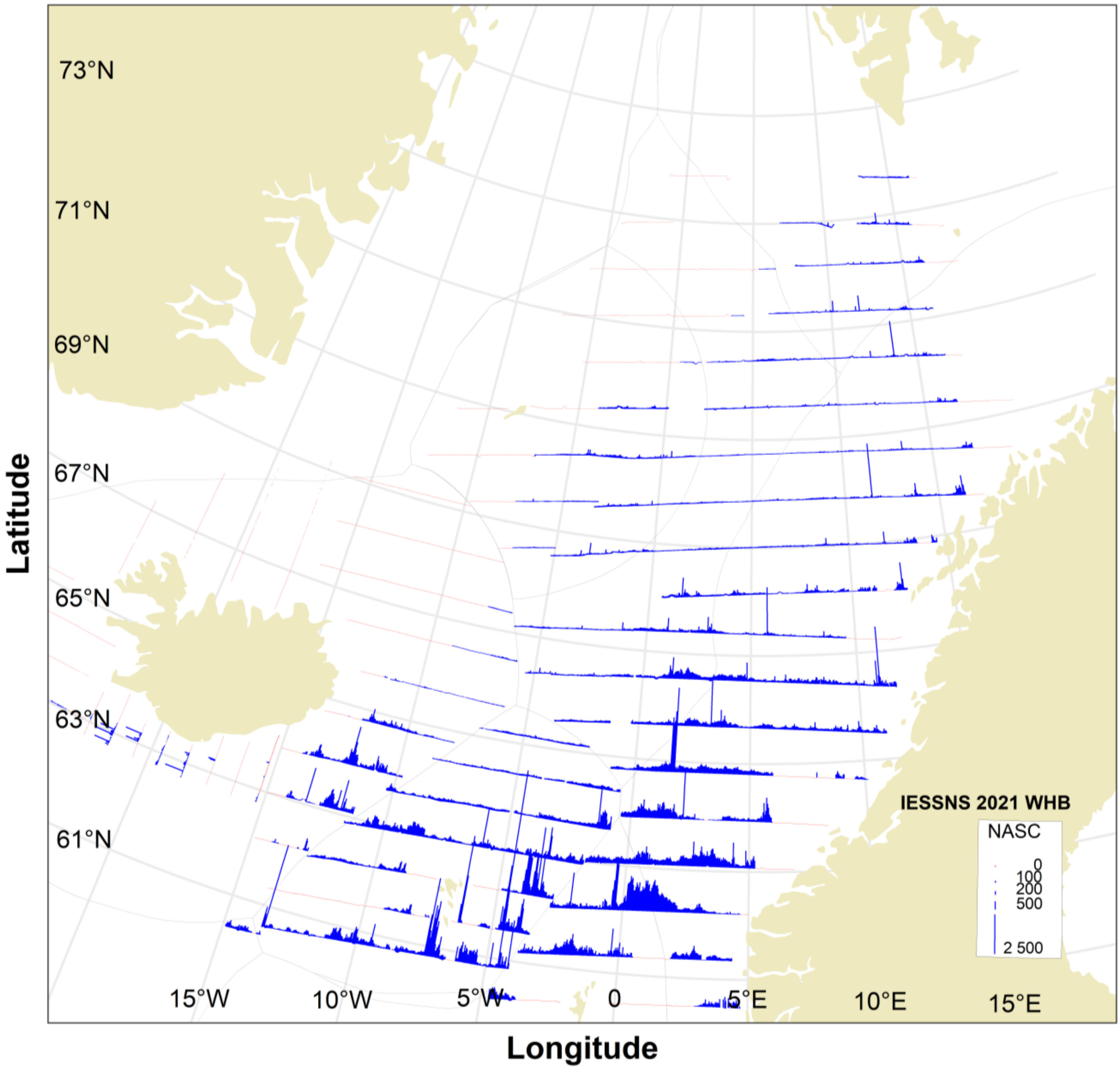


Figure 23b. The sA/Nautical Area Scattering Coefficient (NASC) values of blue whiting along the cruise tracks in IESSNS 2021. Presented as bar plot.

Table 12. Estimates of abundance, mean weight and mean length of blue whiting based on calculation in StoX for IESSNS 2021.

Length	Age in years (year class)											Number	Biomass	Mean
	0	1	2	3	4	5	6	7	8	9	10			weight
(cm)	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	(10^6)	(10^6 kg)	(g)
10-11	27.8											27.8		
11-12	311.1											311.1	0.1	5.0
12-13	961.4											961.4	0.2	5.9
13-14	989.4											989.4	2.6	8.5
14-15	753.9											753.9	9.8	10.5
15-16	588.3											588.3	12.9	14.1
16-17	329.0											329.0	12.8	17.6
17-18	284.6											284.6	12.7	22.2
18-19	175.5	299.0										474.5	9.1	27.9
19-20	34.2	1020.9										1 055.1	9.5	33.3
20-21	14.6	3304.4	19.3									3 338.3	17.5	37.7
21-22		5998.2		57.5								6 055.7	43.6	40.6
22-23		5077.7	31.5									5 109.2	163.6	48.6
23-24		1799.3	255.7	13.6								2 068.6	346.8	57.5
24-25		632.2	276.3	25.3	7.5							941.3	323.9	63.9
25-26		250.5	529.6	279.0	14.0							1 073.1	145.7	71.9
26-27		72.8	754.5	212.8	13.5	8.9						1 062.5	77.9	84.3
27-28		24.5	261.8	427.7	23.1	54.8		13.7				805.6	106.3	98.8
28-29		3.2	167.9	290.8	314.5	83.3	227.2	97.4			11.0	1 195.5	115.6	110.9
29-30		1.4	75.6	79.0	149.1	188.0	321.5	162.6	57.4	33.8	57.8	1 126.2	96.3	120.8
30-31				96.1	234.6	179.0	327.7	128.5		31.4		997.1	156.5	132.8
31-32					89.0	204.0	301.1	98.6				692.7	161.5	146.0
32-33						133.1	234.0	44.8				411.9	156.6	159.7
33-34				12.0			67.4	43.3				122.7	122.8	179.0
34-35							13.2	20.7	13.8	14.1		61.8	80.0	192.7
35-36							0.8	8.2			8.2	17.3	26.3	214.0
36-37								17.0				17.0	14.1	223.5
37-38													4.6	274.2
38-39											7.1	7.1	5.1	330.2
TSN(mill)	4470	18484	2372	1494	845	851	1493	635	71	79	84	30 896.0		
cv (TSN)	0.46	0.17	0.21	0.27	0.32	0.30	0.34	0.37	0.58	0.64	0.72	0.12		
TSB(1000 t)	79.1	1 093.1	242.4	177.4	121.2	134.7	245.4	105.9	11.5	12.2	13.6	2 237.3		
cv (TSB)	0.40	0.17	0.21	0.27	0.32	0.30	0.34	0.36	0.60	0.63	0.62	0.11		
Mean length(cm)	14.5	21.5	25.0	26.7	28.8	29.9	30.3	30.4	29.8	30.8	31.3			
Mean weight(g)	21	62	97	119	145	159	168	175	156	162	197			

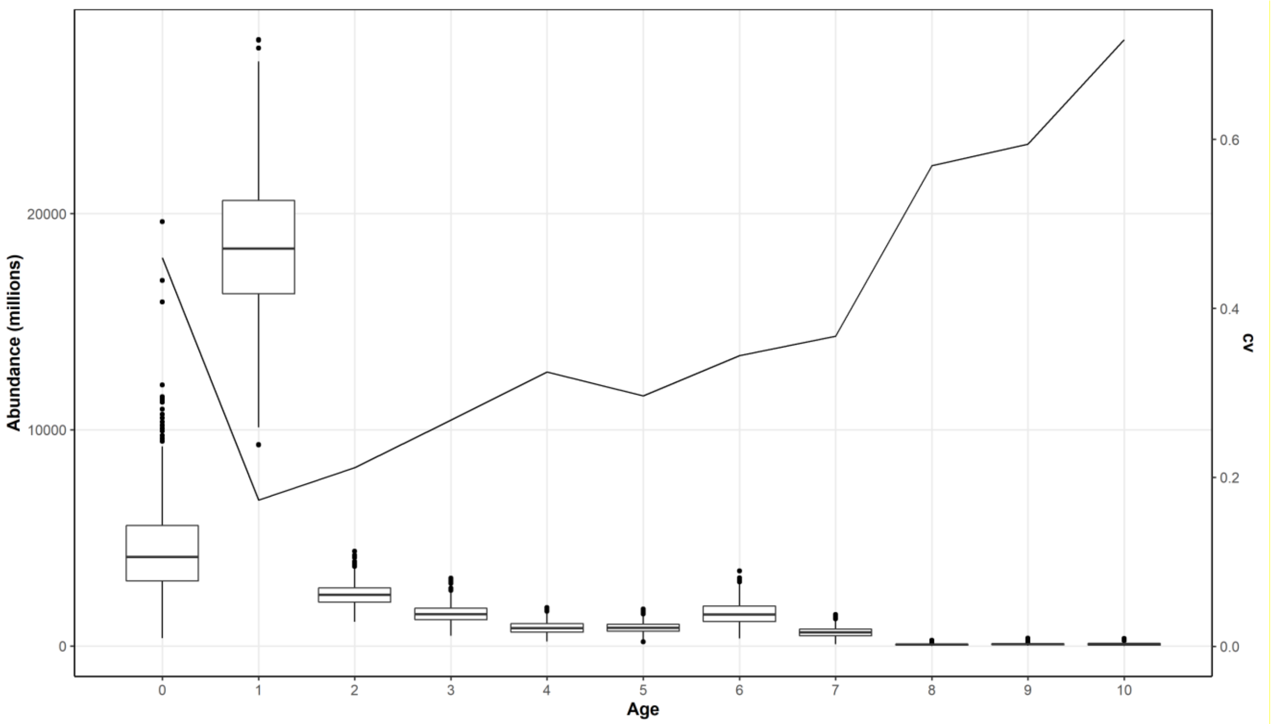


Figure 24. Number by age with uncertainty for blue whiting during IESSNS 2021. Boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 1000 replicates using the StoX software.

Table 13. IESSNS baseline time series from 2016 to 2021. StoX abundance estimates of blue whiting (millions).

	Age											
Year	0	1	2	3	4	5	6	7	8	9	10+	TSB(1000 t)
2016	3,869	5,609	11,367	4,373	2,554	1,132	323	178	177	8	233	2,283
2017	23,137	2,558	5,764	10,303	2,301	573	250	18	25	0	25	2,704
2018	0	915	1,165	3,252	6,350	3,151	900	385	100	52	41	2,039
2019	2,153	640	1,933	2,179	4,348	5,434	1,151	209	229	5	8	2,028
2020	4,066	5,804	2,996	1,629	1,205	1,718	1,990	939	201	21	30	1,806
2021	4,023	18,056	2,300	1,664	841	982	1,543	609	60	91	74	2,238

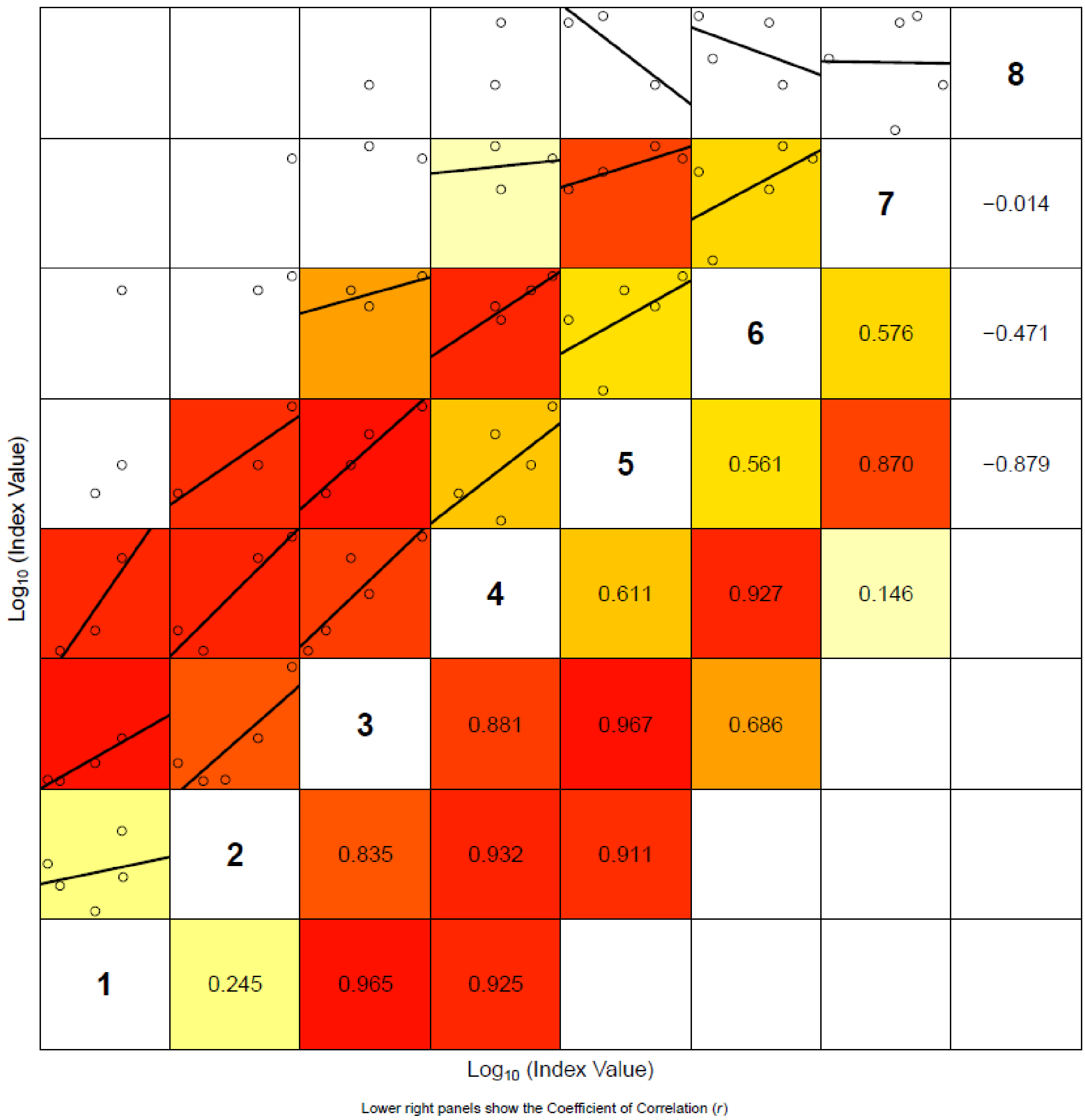


Figure 25. Internal consistency for blue whiting within the IESSNS. The upper left part of the plots shows the relationship between log index-at-age within a cohort. Linear regression line shows the best fit to the log-transformed indices. The lower-right part of the plots shows the correlation coefficient (r) for the two ages plotted in that panel. The background colour of each panel is determined by the r value, where red equates to r=1 and white to r<0.

4.6 Other species

Lumpfish (*Cyclopterus lumpus*)

Lumpfish was caught in 82% of trawl stations across the five vessels (Figure 26) and where lumpfish was caught, 69% of the catches were ≤10kg. Lumpfish was distributed across the entire survey area, from west of Iceland to the central Barents Sea in the northeast part of the covered area.

Abundance was greatest north of 72°N, and lowest directly south of Iceland, and western side of the North Sea and central part of the Norwegian Sea. The zero line was not hit to the north, northwest and southwest of the survey so it is likely that the distribution of lumpfish extends beyond the survey coverage. The length of lumpfish caught varied from 5 to 56 cm with a bimodal distribution with the left peak (5-20 cm) likely corresponding to 1-group lumpfish and the right peak consisting of a mixture of age groups (Figure 27). For fish ≥20 cm in which sex was determined, the males exhibited a unimodal distribution with a peak around 25-27 cm. The females also exhibited a bimodal distribution but with a peak around 22-30 cm and another around 35-44 cm. Generally, the mean length and mean weight of the lumpfish was highest in Faroese waters, southern part of Iceland and the coastal waters and along the shelf edges of Norway and lowest in the central and northern Norwegian Sea.

A total of 606 fish (451 by R/V "Árni Friðriksson", 55 by M/V "Eros" and 100 by M/V Vendla) between 7 and 56 cm were tagged during the survey (Figure 28).

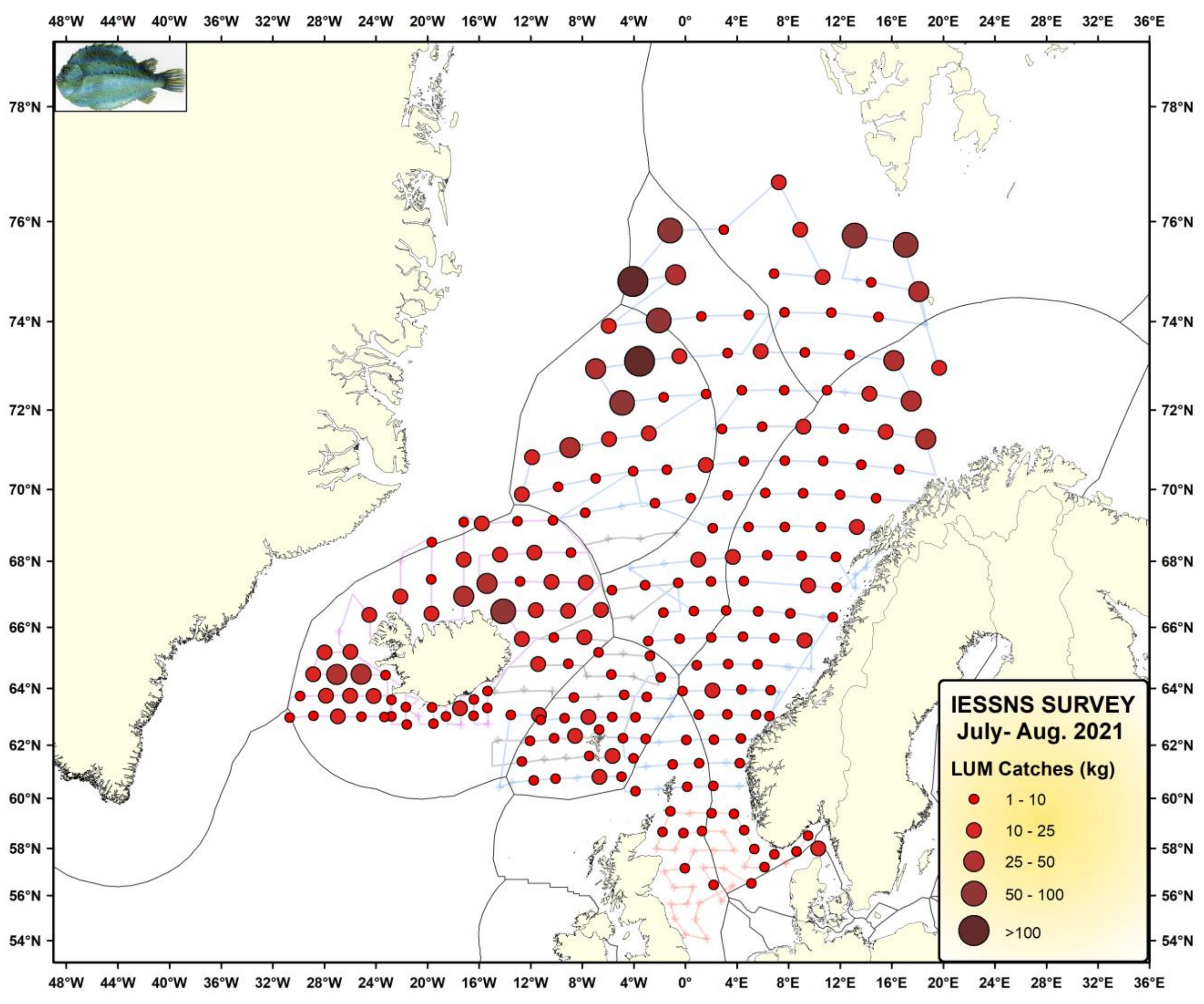


Figure 26. Lumpfish catches at surface trawl stations during IESSNS 2021.

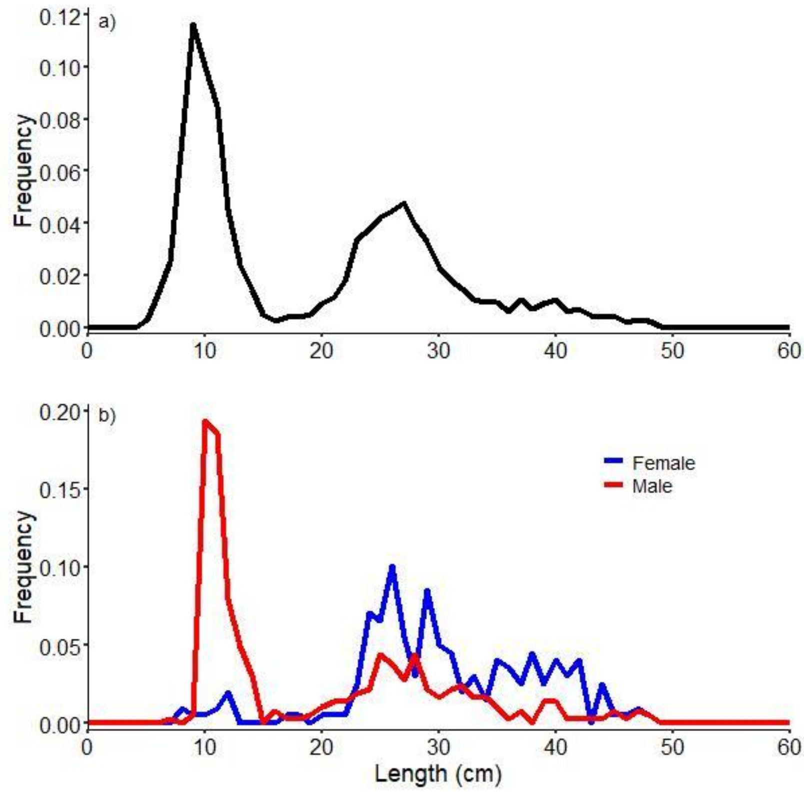


Figure 27. Length distribution of a) all lumpfish caught during the survey and b) length distribution of fish in which sex was determined.

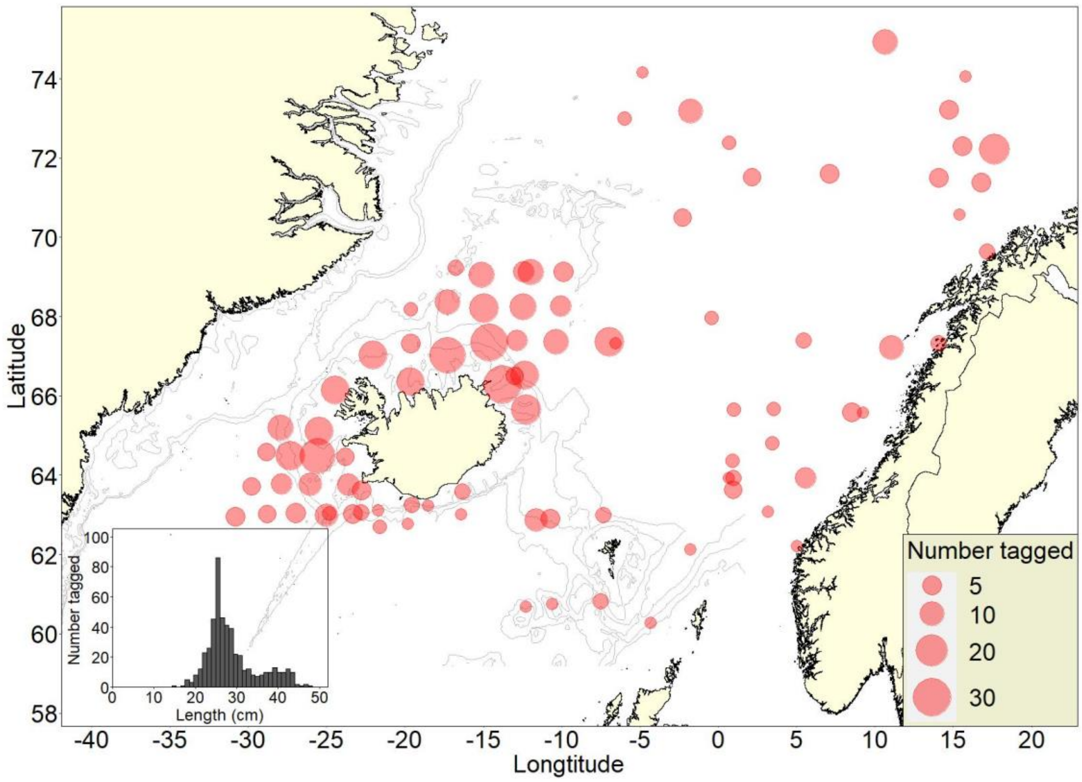


Figure 28. Number tagged, and release location, of lumpfish. Insert shows the length distribution of the tagged fish.

Salmon (*Salmo salar*)

A total of 35 North Atlantic salmon were caught in 25 stations both in coastal and offshore areas from 60°N to 76°N in the upper 30 m of the water column during IESSNS 2020 (Figure 29). The salmon ranged from 0.089 kg to 6.5 kg in weight, dominated by post-smolt weighing 89-425 grams and 1 sea-winter individuals weighing 1.9-2.4 kg. We caught from 1 to 4 salmon during individual surface trawl hauls. The length of the salmon ranged from 21.5 cm to 87 cm, with a pronounced bimodal distribution of <30 cm and >53 cm long salmon. The entire time series on post-smolt distribution, ecology and genetics with many sampled specimens originating from the IESSNS 2007-2020 surveys, have now been included in two new publications (Utne et al. in press, Gilbert et al. 2021)

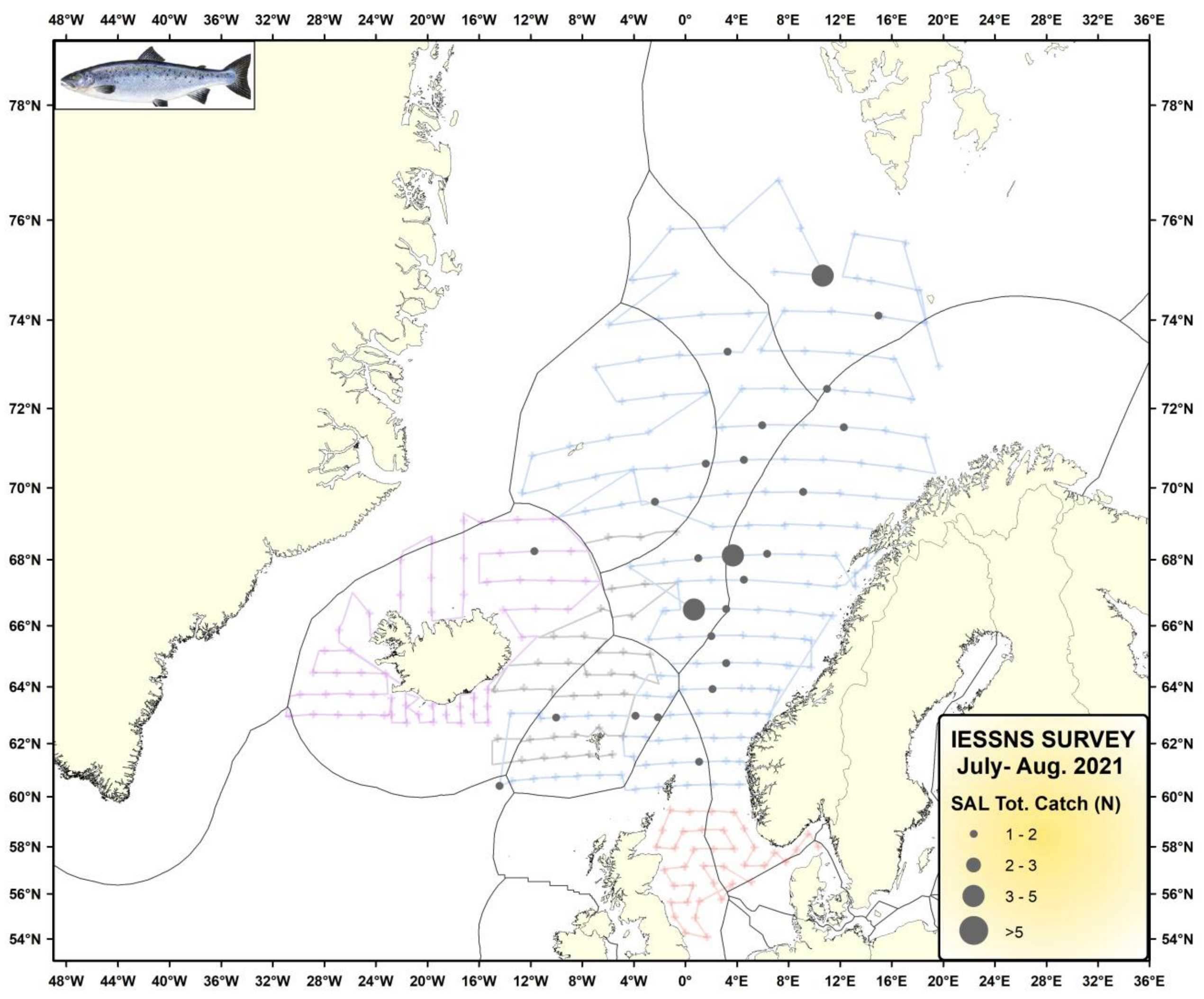


Figure 29. Catches of salmon at surface trawl stations during IESSNS 2021.

Capelin (*Mallotus villosus*)

Capelin was caught in the surface trawl on 12 stations primarily along the cold fronts: Between East Greenland and Iceland, west and North-East of Jan Mayen and at the entrance to the Barents Sea (Figure 30). This was less than in 2020, where 28 hauls contained capelin (plus 14 in the Greenlandic survey). (Figure 30). Large capelin, total length range 13 cm to 19 cm, was caught at three stations north of Iceland, and the catch weight ranged from 23 kg to 240 kg. This is the first time that such large capelin has been caught in the survey as usually juvenile capelin is caught, length < 12 cm.

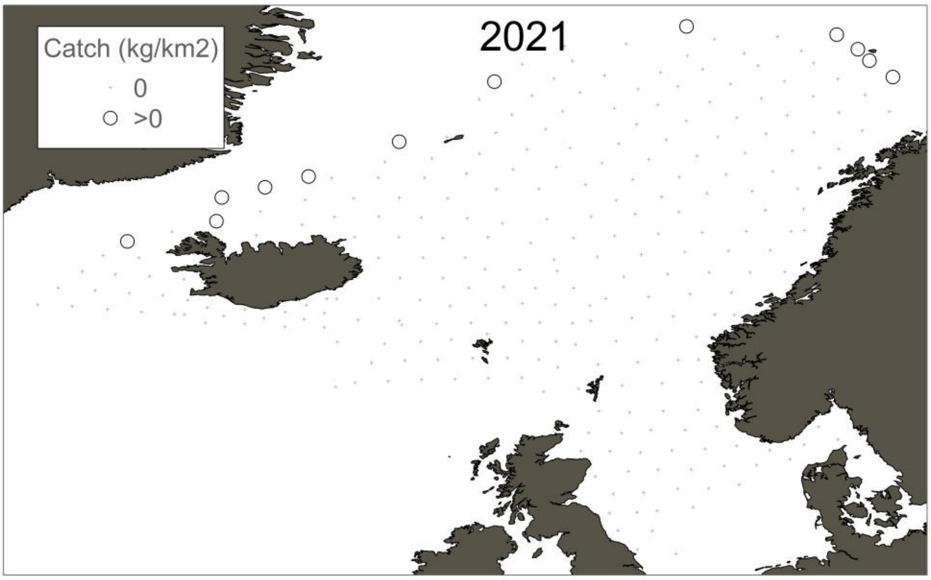


Figure 30. Presence of capelin in surface trawl stations.

4.7 Marine Mammals

Opportunistic whale observations were done by M/V "Eros" and M/V "Vendla" from Norway in addition to R/V "Árni Friðriksson" from Iceland and R/V "Jákup Sverri" from Faroe Islands in 2021 (Figure 31). Overall, 1029 marine mammals of 9 different species were observed, which was an increase from 802 marine mammals observed in 2020, The increase in number of marine mammals observed was primarily because R/V "Jákup Sverri" from Faroe Islands participated with opportunistic whale observations in 2021 and not in previous years. Both Eros and Vendla experienced several days with fog and very reduced visibility in the central and north-western region (Jan Mayen area) and northernmost areas between Bear Island and Svalbard. An increased number of days with low visibility possibly influenced the reduced number of marine mammals observed on Eros and Vendla in the normally abundant marine mammal habitats in the northernmost part of the surveyed area. R/V "Árni Friðriksson" had also occasional periods with fog north and south of Iceland, whereas R/V "Jákup Sverri" experienced primarily good visibility throughout the survey.

The species that were observed included; fin whales (*Balaenoptera physalus*), minke whales (*Balaenoptera acutorostrata*), humpback whales (*Megaptera novaeangliae*), bottlenose whales (*Hyperoodon ampullatus)*, pilot whales (*Globicephala sp.*), killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*) and white beaked dolphins (*Lagenorhynchus albirostris*). The dominant number of marine mammal observations were found around Iceland, Faroe Islands and along the continental shelf between the north-eastern part of the Norwegian Sea and in a line between Finnmark to southwest of Svalbard. We observed very few marine mammals in the central part of the Norwegian Sea in July 2021. Fin whales (n = 86, group size = 1-8 (average groups size = 2.2)) and humpback whales (n = 21, group size = 1-4 (average groups size = 1.6)) dominated among the large whale species, and they were present west and northwest of Iceland and from Norwegian coast outside Finnmark stretching north/northwest via Bear Island to southwest of Svalbard. Fin whales also appeared to be present in the northeastern and northern part of the Norwegian Sea feeding where they probably were feeding on the abundant 2016 herring year-class. Very few sperm whales (n = 9, group size =

1-2 (average groups size = 1.1)) where observed. Killer whales (n = 127, group size = 1-30 (average groups size = 6.4)) dominated in the southern, northern and north-eastern part of the Norwegian Sea, partly overlapping and presumably feeding on NEA mackerel in the upper water masses. Pilot whales (n = 559, group size = 2-150 (average groups size = 37.3)) dominated totally in numbers of observations during IESSNS 2021, with more than 50% of all marine mammal observations. They were exclusively observed around Faroe Islands and east of Iceland, with a hot-spot area north of Faroe Islands. White beaked dolphins (n = 162, group size = 3-15 (average groups size = 7.0)) were present in the northern part of the Norwegian Sea. Minke whales (n = 56, group size = 1-9 (average groups size = 1.8)) were distributed over large areas from western coast of Norway to western part of Iceland, and from 60°N to 75°N, including overlapping and likely feeding on NSS herring in the upper 40 m of the water column. There is now available a new publication summarizing the main results on marine mammals from the IESSNS surveys from 2013 to 2018, with major focus on hot spot areas of fin whales and humpback whales from 2013 to 2018 (Løviknes et al. 2021)

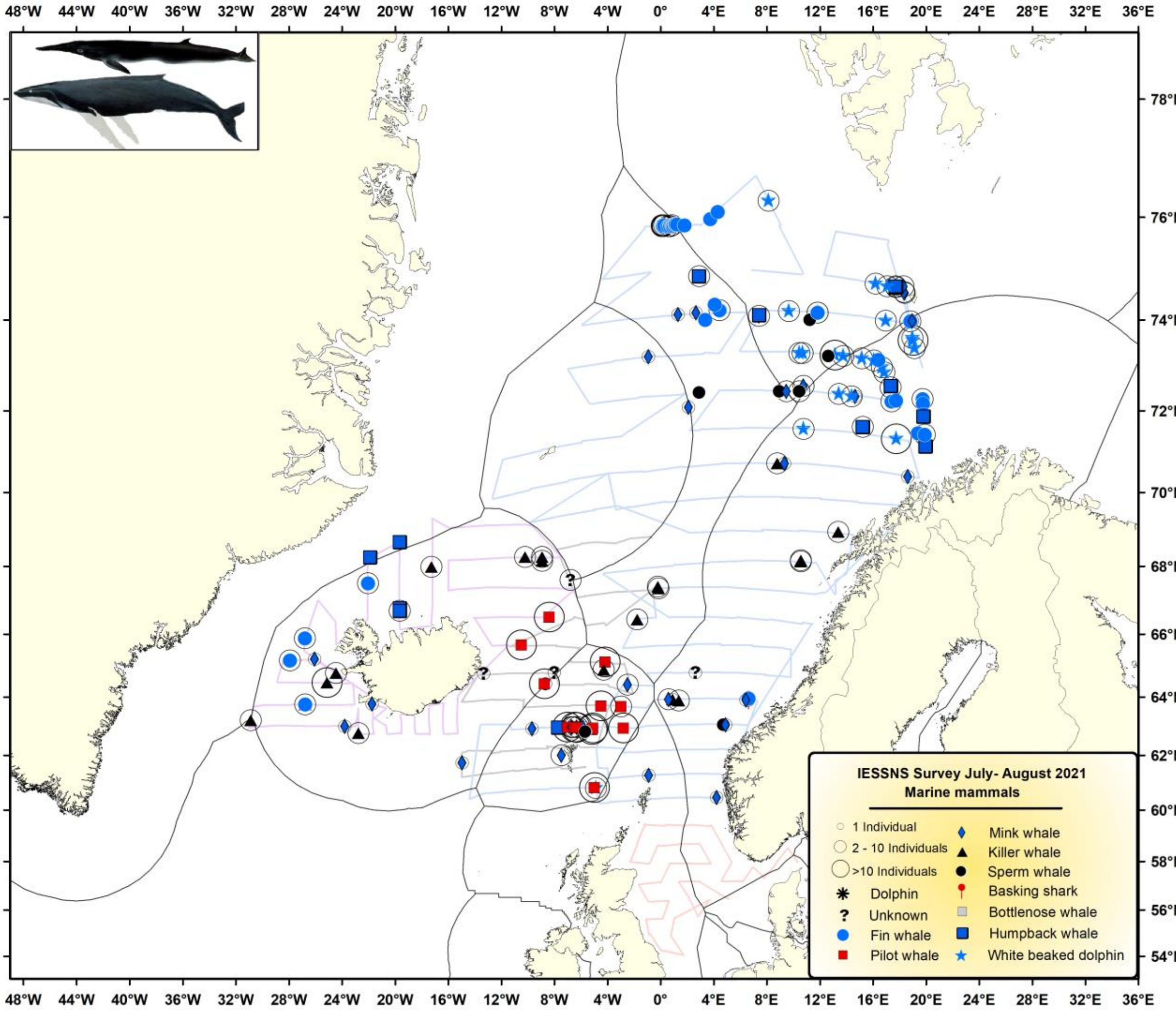


Figure 31. Overview of all marine mammals sighted during IESSNS 2021.

5 Recommendations

The group suggested the following recommendation from WGIPS	To whom
The occasional large catches of mackerel have a relatively large impact on the overall results and possibly bias the stock indices. WGIPS recommends that the ability of the present and alternative methods (such as more advanced statistical models) to represent this overdispersion is evaluated.	National institutes and WGISDAA
The surveys conducted by Denmark in 2018, 2019, 2020 and 2021 have clearly demonstrated that the IESSNS methodology works also for the northern North Sea (i.e. north and west from Doggerbank) and the Skagerrak area deeper than 50 m. The survey provides essential fishery-independent information on the stock during its feeding migration in summer and WGIPS recommends that the Danish survey should continue as a regular annual survey.	WGWIDE, RCG NANSEA
In 2022 the IESSNS survey in the North Sea have been conducted for five consecutive years (2018-2022). It is recommended that a comprehensive report is written about the major results from the NEA mackerel time series from the IESSNS surveys in the North Sea, where the internal consistency between years in the survey for selected age groups is also evaluated. A major aim will be to at some stage evaluate and consider the possibility to include and implement the IESSNS survey in the North Sea as an abundance index used in ICES for NEA mackerel.	

6 Action points for survey participants

Action points
The guidelines for trawl performance should be revised to reflect realistic manoeuvring of the Multpelt832 trawl.
Criteria and guidelines should be established for discarding substandard trawl stations using live monitoring of headline, footrope and trawl door vertical depth, and horizontal distance between trawl doors. For predetermined surface trawl station, discarded hauls should be repeated until performance is satisfactory. Explicit guideline for incomplete trawl hauls is to repeat the station or exclude it from future analysis. It is not acceptable to visually estimate mackerel catch, it must be hauled onboard and weighed. If predetermined trawl hauls are not satisfactory according to criteria the station will be excluded from mackerel index calculations, i.e. treated as it does not exist, but not as a zero mackerel catch station.
We recommend continuing the international tagging of lumpfish for two new year’s; 2022 and 2023, and we encourage all participating country to contribute.
We recommend that observers collect sighting information of marine mammals on all vessels.
Table 3 – biological sampling - needs to be changed to reflect what is sampled on the different vessels.
We should consider calculating the zooplankton index from annually gridded field polygons to extract area-mean time-series.

For next year's survey, the group should slightly change the both the strata system and transect system to accommodate better the curvature of the long east-west transects to avoid empty areas in the overall spatial coverage.
For next year's survey, the group should consider distributing transects differently among vessels, such that synoptic coverage becomes even better than this year and survey time is optimally used.

7 Survey participants

M/V "Eros":
Leif Nøttestad (International coordinator and cruise leader), Institute of Marine Research, Bergen, Norway
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1 Appendix 1:

Denmark joined the IESSNS in 2018 for the first time extending the original survey area into the North Sea. The commercial fishing vessels “Ceton S205” was used. No problems applying the IESSNS methods were encountered. Area coverage, however, was restricted to the northern part of the North Sea at water depths larger 50 m. No plankton samples were taken, and no acoustic data were recorded because this is covered by the HERAS survey in June/July in this area.

In 2021, 39 stations were taken (PT and CTD, no plankton and no appropriate acoustic equipment available). The locations of stations differed slightly from the previous year focussing on the area north and west of Doggerbank and extended into the eastern Skagerrak.

Average mackerel catch in 2021 amounted 2429 kg/km^2, which was considerably higher than in the previous years (2020: 1318 kg/km^2, 2019: 1009 kg/km^2, 2018: 1743 kg/km^2). The length and age composition indicate a relative high amount of small (< 25 cm) individuals (Tab. A.1) whereas the abundance of older (≥ age 6) mackerel was similar to the two previous years (Fig. A.1.).

StoX (version 2.7) baseline estimate of mackerel abundance in the North Sea was 560 198 tonnes (Table A1-1). This is based on a preliminary defined polygon for the surveyed area in which the northern border was set to 60°N (border to stratum 1; Fig. 2), and the eastern, southern and western limits were either the coastline or extrapolated using half the longitudinal or latitudinal distance between the adjacent stations.

Table A1-1. StoX (version 2.7) baseline estimate of age segregated and length segregated mackerel index for the North Sea in 2021. Also provided is average length and weight per age class.

Length bin (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Number (thousand)	Biomass (ton)	Mean Weight (g)
18-19	85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	85	4.3	50
19-20	403	-	-	-	-	-	-	-	-	-	-	-	-	-	-	403	17.5	43.37
20-21	9604	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9604	637.2	66.35
21-22	25212	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25212	1979.4	78.51
22-23	176284	-	-	-	-	-	-	-	-	-	-	-	-	-	-	176284	15888.7	90.13
23-24	349744	-	-	-	-	-	-	-	-	-	-	-	-	-	-	349744	35918.1	102.7
24-25	301762	-	-	-	-	-	-	-	-	-	-	-	-	-	-	301762	34876.6	115.58
25-26	120019	1780	-	-	-	-	-	-	-	-	-	-	-	-	-	121800	15346.9	126
26-27	42253	8853	-	-	-	-	-	-	-	-	-	-	-	-	-	51107	7816	152.93
27-28	91118	42581	-	-	-	-	-	-	-	-	-	-	-	-	-	133699	24132.3	180.5
28-29	384792	157557	-	-	-	-	-	-	-	-	-	-	-	-	-	542349	108574.4	200.19
29-30	312039	148579	1624	1624	-	-	-	-	-	-	-	-	-	-	-	463866	99842.9	215.24
30-31	83197	75339	1584	556	812	-	-	-	-	-	-	-	-	-	-	161488	39089.4	242.06
31-32	5225	64241	5172	2804	781	-	-	-	-	-	-	-	-	-	-	78224	20794.3	265.83
32-33	-	72348	14581	4014	36	283	-	-	-	-	-	-	-	-	-	91262	26475.4	290.1
33-34	-	21964	25330	24418	242	72	-	-	255	-	-	-	-	-	-	72281	22558.5	312.1
34-35	-	5047	27231	35559	17920	2371	1346	255	-	-	-	-	-	-	-	89729	30551.4	340.49
35-36	-	526	-	25732	30513	9483	1088	-	490	-	-	406	-	-	-	68238	25902	379.58
36-37	-	-	-	13000	12936	25200	3039	-	3104	191	-	1413	-	-	-	58885	23118.2	392.6
37-38	-	-	-	1776	2502	11611	10330	1698	122	36	590	1561	-	-	-	30226	12833.9	424.6
38-39	-	-	-	-	-	1557	2113	7946	796	813	648	363	-	-	-	14236	6320.4	443.96
39-40	-	-	-	-	-	-	243	1373	4579	382	-	543	346	-	-	7466	3841.3	514.54
40-41	-	-	-	-	-	-	-	609	281	292	100	109	-	36	-	1425	815.7	572.3
41-42	-	-	-	-	-	-	-	-	373	4171	-	-	324	-	-	4867	2545.5	522.99
42-43	-	-	-	-	-	-	-	36	-	-	-	36	-	-	-	72	51.4	714
43-44	-	-	-	-	-	-	-	-	-	-	-	-	260	36	-	296	221.9	749.27
44-45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45-46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	64	64	44.5	700
TSN(1000)	1901737	598817	75522	109484	65742	50577	18160	11916	9999	5884	1337	4431	930	72	64	2854671	-	-
TSB(1000kg)	291990.5	139041.2	23664.1	37357.4	24174	20502.6	7260.4	5400.4	4774.7	2986.7	563	1850	540.1	48.3	44.5	-	560197.9	-
Mean length (cm)	25.73	29.44	32.88	34.05	34.88	35.98	36.63	38	37.72	40.22	37.71	36.94	40.81	41.5	45	-	-	-
Mean weight (g)	153.54	232.19	313.34	341.21	367.71	405.38	399.8	453.21	477.52	507.57	421.06	417.5	580.52	672	700	-	-	196.24

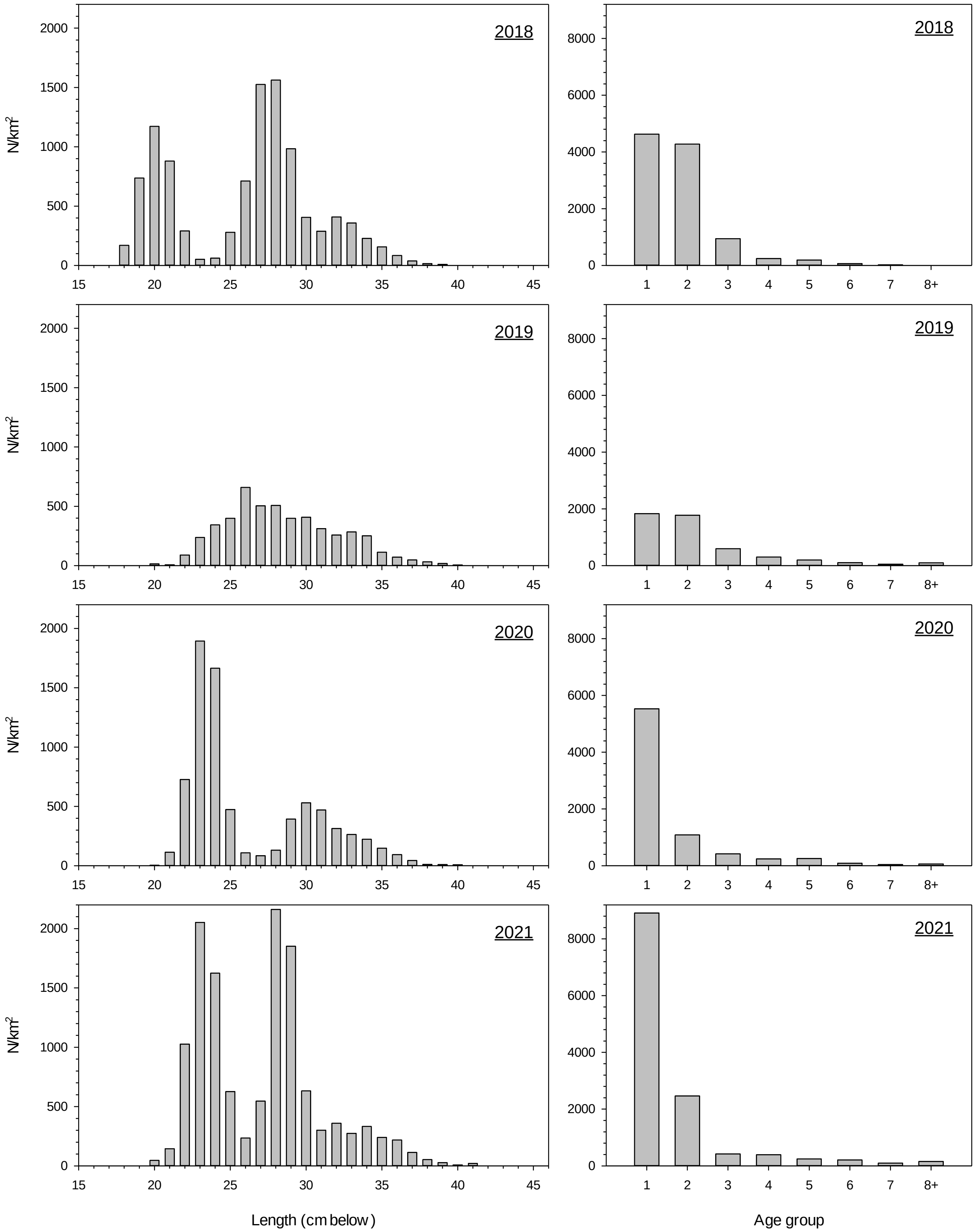

Fig. A1. Comparison of length and age distribution of mackerel in the North Sea 2018, 2019, 2020 and 2021.

2 Appendix 2:

The mackerel index is calculated on all valid surface stations. That means, that invalid and potential extra surface stations and deeper stations need to be excluded. Below is the exclusion list used when calculating the mackerel abundance index for IESSNS 2021.

Table A2-1: Trawl station exclusion list and average horizontal trawl opening per vessel for IESSNS 2021 for calculating the mackerel abundance index.

Vessel	Country	Horizontal trawl opening (m)	Exclusion list	
			Cruise	Stations
Vendla	Norway	63.8	2021816	58,61,62,66,69,71,74,75,80,81,83,87,89,93,98,100, 105,111,122,132,142,146
Eros	Norway	67.5	2021817	32,43,51,61,62,67,69,70,71,73
Árni Friðriksson	Iceland	65.6	A12-2021	298,318,325,333,337,340,343,349,351,357
Jákup Sverri	Faroe Islands	56.6	2130	13,14,27,34,53,68,73 *
Ceton	EU (Denmark)	75.4	IESSNS2021	none

* Observe that in PGNAPES and the national database station numbers are 4-digit numbers preceded by 2130 (e.g. ‘21300025’)

Working document 10, WGWIDE 2021

Full time-series of catch by rectangle

Martin Pastoors, 27/08/2021

Introduction

WGWIDE and its precursors WGMHSA and WGNPBW have been publishing catch per rectangle plots in their reports for many years already. Catch by rectangle has been compiled by WG members and generally provide a WG estimate of catch per rectangle. In most cases the information is available by quarter whereas most recently, the data has been requested by month. Previously, the catch by rectangle has mostly presented for one single year in the WG reports. Here, we collated all the catch by rectangle data that is available for herring, blue whiting, mackerel and horse mackerel for as many years as available.

Results

An overview of the available catches by species and year is shown in the text table below. For horse mackerel and mackerel, a long time series is available, starting in 2001 (HOM) and 1998 (MAC). The time series for herring and blue whiting are shorter (starting in 2011) although additional information could be derived from earlier WG reports.

species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
HER	0	0	0	0	0	0	0	0	0	0	0	0
HOM	0	0	0	242971	220889	226642	204409	218002	182172	162691	111071	261563
MAC	634501	573960	614831	664986	648890	568184	579449	505956	447288	550033	584410	713180
WHB	0	0	0	0	0	0	0	0	0	0	0	0

Table: Table continues below

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	(all)
0	993001	819755	684723	461383	328679	383081	715545	592555	776193	715429	6470344
252455	211305	181505	220870	141685	108136	113592	122009	118276	144149	128475	3572867
861394	936099	874986	920066	1374495	1166138	1083641	1151726	1016924	831564	1025807	18328508
0	103861	377079	616511	1139737	1389447	1175687	1540077	1698078	1507471	1478397	11026345

For each species an overview table is presented of catch by country and year and a figure with catch by rectangle and year. Catches by rectangle have been grouped in logarithmic classes (1-10, 10-100 etc).

Discussion

While the aggregation and presentation of the catch per rectangle data for mackerel, horse mackerel, blue whiting and atlanto-scandian herring does not constitute rocket-science, it does provide us with meaningful insights into the changes of catching areas over time. This could be relevant also in understanding the impacts of climate change on fisheries and in relating changes in the distribution of prey or predator species (e.g. bluefin tuna). As such, these graphical representations of catching areas provide a useful addition to the WG report.

One important check that still needs to be carried out is the check on data availability by country and year that may not be consistent over the time series. Making the time-series complete would improve the useability of the information.

Mackerel

country	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
BEL	0	0	0	0	0	0	0	0	0	0	0	0
DEU	21490	19956	22977	25323	26532	24059	23368	19123	16599	18221	15503	22703
DNK	28157	30208	32693	31133	32180	27198	25311	22921	24230	24877	26726	23228
ESP	44607	45914	38320	44143	31845	23858	34968	53192	54569	63235	64785	114141
EST	0	0	0	0	0	0	0	0	0	0	0	0
FRA	0	0	0	0	0	0	0	0	15968	14997	15454	9740
FRO	11229	11620	21023	24004	19768	14014	13029	9769	12066	13393	11289	14061
GBR.EW	26694	19403	0	25868	26082	24446	21806	14676	7725	14653	2299	2973
GBR.N	8030	0	0	0	0	0	10933	8037	8369	5544	1797	2735
GBR.S	144984	139918	164069	163941	165017	146129	141988	129987	79721	113487	109848	151302
GRL	0	0	0	0	0	0	0	0	0	0	0	0
GUY	0	0	0	0	0	0	0	0	0	0	0	0
IMN	0	0	0	0	0	0	0	0	0	0	0	0
IRL	69171	59578	71226	70443	72173	63588	58929	42530	38563	46675	44318	61086
ISL	0	0	0	0	0	0	0	0	4220	36496	112220	116157
JEY	0	0	0	0	0	0	0	0	0	0	7	7
LTU	0	0	0	0	0	0	0	0	0	0	0	0
NLD	46127	28070	32403	49815	42254	34263	35680	41432	24007	23912	19933	23355
NOR	158179	160728	174098	180595	184291	163404	157363	119680	121981	131697	121470	121225
POL	0	0	0	0	0	0	0	0	0	977	0	0
PRT	2846	1981	2253	3049	2934	2749	2143	1479	2591	2598	2367	1742
RUS	67837	51348	50772	41568	45811	40026	49489	39922	33462	35408	32728	41413
SWE	5146	5233	4995	5099	0	4447	4437	3202	3210	3858	3660	7303
(all)	634497	573957	614829	664981	648887	568181	579444	505950	447281	550028	584404	713171

Table: Table continues below

country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	(all)
BEL	0	0	38	60	0	51	142	128	167	66	124	776
DEU	19055	24082	18974	20933	28451	28207	23411	24857	19882	16904	25031	505641
DNK	41045	29213	36503	33261	41903	45015	40655	37899	29865	30401	34391	729013
ESP	53350	23988	17735	13069	44244	33744	29591	34425	28196	21056	34238	947213
EST	0	0	0	1366	0	0	0	0	0	0	0	1366
FRA	12108	12393	17859	14642	21695	0	20171	22920	21370	17855	21871	239043
FRO	70987	122049	107629	143001	150419	107993	93266	99499	81078	62663	69064	1282913
GBR.EW	17722	20041	19186	16542	26562	32260	23699	26421	20439	16203	22465	428165
GBR.N	4293	11344	14945	12347	20351	12597	2302	16887	14873	11878	14854	182116
GBR.S	138403	150243	135602	134412	240503	202104	190817	182096	154686	123721	166171	3469149
GRL	0	162	5319	52796	78672	30410	36194	46498	63024	30469	26552	370096
GUY	0	0	0	8	8	4	0	0	0	0	0	20
IMN	0	11	0	7	3	4	7	0	3	2	0	37
IRL	57993	63188	63058	56611	103178	88738	76523	84914	66743	53311	74113	1486650
ISL	122337	159008	149584	151326	172960	169257	170374	166601	168328	128076	151533	1978477
JEY	0	6	0	0	6	2	2	0	0	0	0	30
LTU	0	0	0	0	0	553	2539	0	0	0	815	3907
NLD	25062	34500	32554	21159	46665	39807	37752	43765	30392	22697	30321	765925
NOR	233941	208077	176031	164602	277724	242233	210569	222397	187030	159107	211672	4088094
POL	0	0	0	0	0	0	0	0	4056	3706	5302	14041
PRT	2355	938	821	253	636	928	619	633	4564	3941	4799	49219
RUS	59310	73601	74578	80756	116086	128292	121336	138077	118254	126543	128816	1695433
SWE	3428	3247	4563	2906	4421	3930	3662	3700	3965	2957	3668	91037
(all)	861389	936091	874979	920057	1374487	1166129	1083631	1151717	1016915	831556	1025800	18328361

Table 1: Catch of mackerel (tonnes) included in the rectangle data by year and country

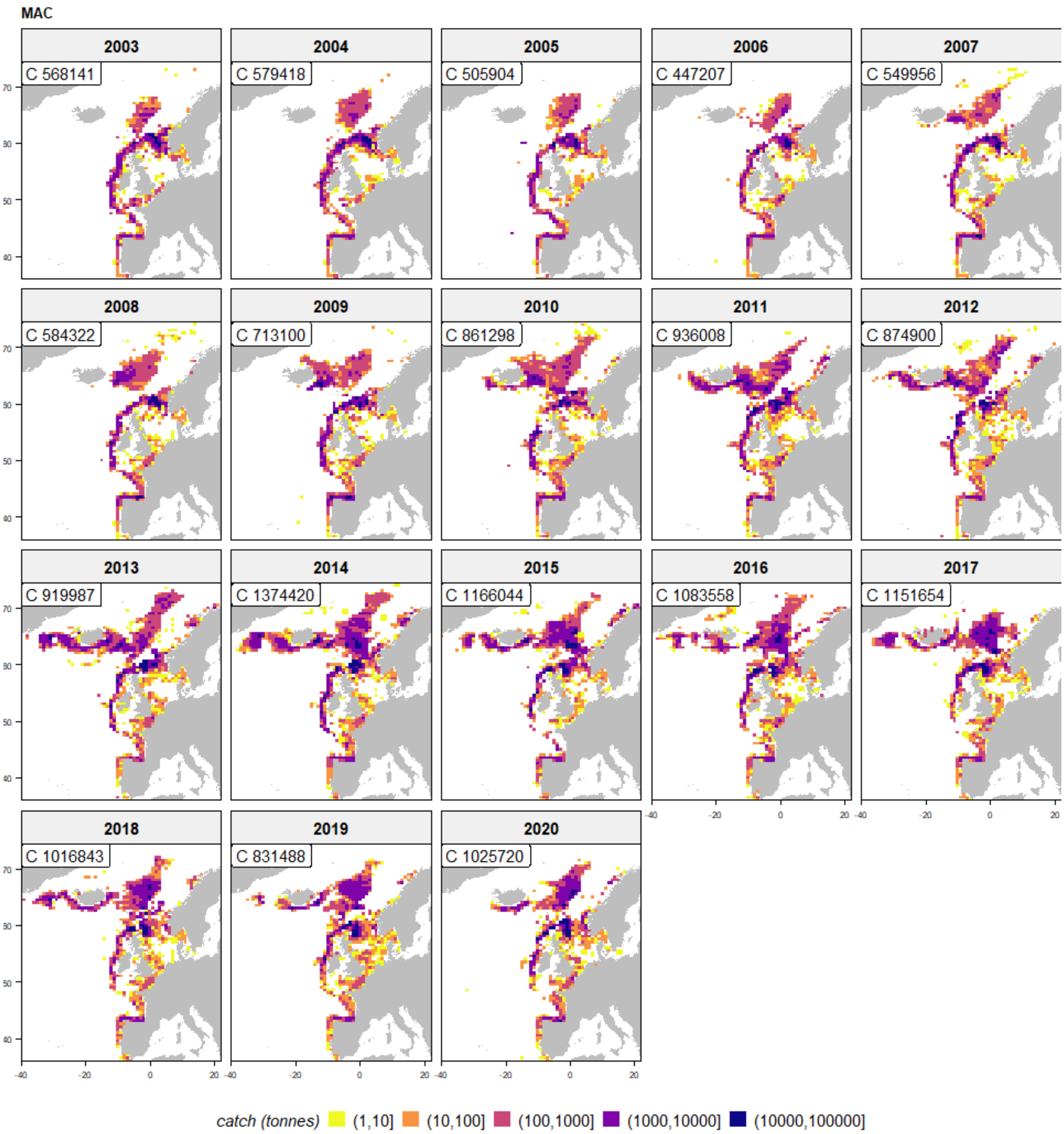

Figure 1: Catch of mackerel (tonnes) by year and rectangle

Horse Mackerel

country	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
BEL	0	0	0	0	0	0	0	0	0	0	0	0
DEU	12510	15925	18762	22792	18978	12453	5871	12882	16420	21482	21114	22588
DNK	0	12478	14636	20256	14135	9794	7885	0	6097	5935	6100	4674
ESP	34688	34258	32926	27947	26435	23829	27319	34169	36722	54230	32942	12373
FRA	0	0	0	0	0	0	0	0	0	0	0	0
FRO	0	0	808	3846	3695	0	477	477	0	0	0	0
GBR.EW	10430	8294	6405	10251	7418	0	12404	4425	16209	14604	13466	13057
GBR.N	0	0	0	0	426	223	0	0	0	0	0	0
GBR.S	8028	2907	0	1524	0	769	1403	1082	1417	2459	13466	1574
IRL	52212	36482	35854	26432	35359	28856	30091	36508	40779	44475	38464	45306
NLD	103349	59585	86162	68733	73130	64413	61433	0	60459	85042	71981	78552
NOR	7992	36689	20515	10749	25115	27225	5425	12247	72615	12500	13770	3378
PRT	13759	14269	10571	11874	13307	14607	10380	9278	10840	11726	0	0
SWE	0	0	0	0	0	0	0	0	0	0	0	0
(all)	242968	220887	226639	204404	217998	182169	162688	111068	261558	252453	211303	181502

Table: Table continues below

2013	2014	2015	2016	2017	2018	2019	2020	(all)
0	0	63	0	67	44	0	39	213
27959	19056	10061	13293	8121	8121	8462	959	297809
0	0	0	0	0	0	0	5733	107723
39507	32907	37896	32851	33860	37109	44473	53358	689799
0	0	0	0	5785	3443	1869	4510	15607
0	0	0	0	50	0	0	0	9353
45306	9197	0	0	0	0	7657	5854	184977
2325	1578	0	0	0	0	1959	0	6511
675	1650	737	970	0	190	50	0	38901
35783	32660	21647	27606	23559	25347	28899	17389	663708
62519	29975	28150	27685	19906	19906	31862	19042	1051884
6791	14658	9560	11184	11184	10742	11274	12755	336368
0	0	0	0	19473	13370	7641	8745	169840
1	1	18	0	0	0	0	83	103
220866	141682	108132	113589	122005	118272	144146	128467	3572796

Table 2: Catch of horse mackerel (tonnes) included in the rectangle data by year and country

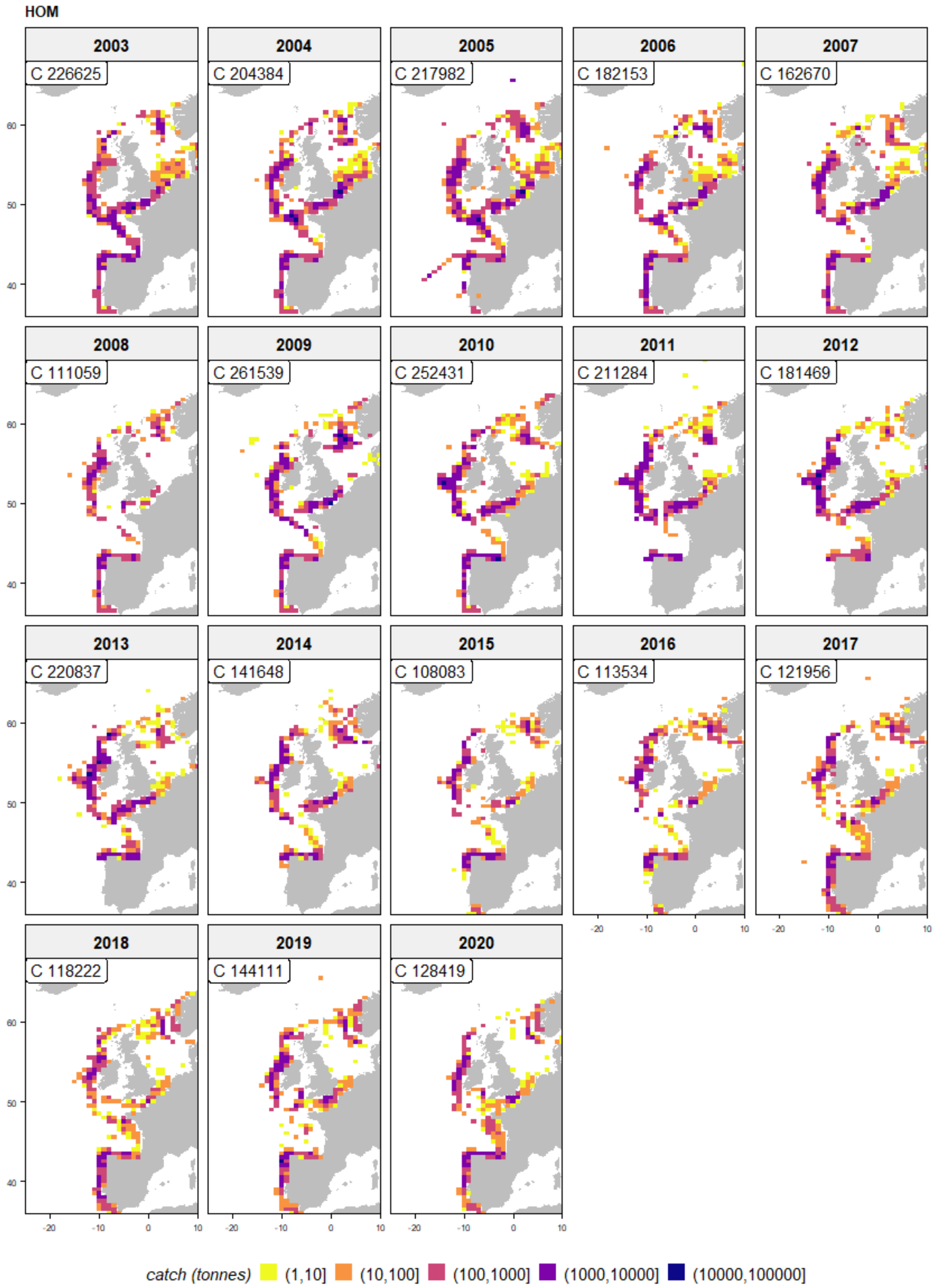

Figure 2: Catch of horse mackerel (tonnes) by year and rectangle

Blue whiting

country	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	(all)
ALL	0	377079	0	0	0	0	0	0	0	0	377079
DEU	266	0	11528	24487	24106	20024	45555	47797	38243	42362	254368
DNK	0	0	0	27945	45047	39134	60866	83564	64169	54585	375310
ESP	2416	0	13388	25140	24967	27493	27433	21059	20621	22705	185222
FRA	4337	0	8978	10410	9657	10345	13221	16409	16095	13768	103220
FRO	16404	0	85767	224699	282477	282364	356501	349837	336568	343371	2277988
GBR	0	0	0	0	0	1374	0	1860	0	0	3234
GBR.EW	0	0	0	0	0	0	3442	0	4027	7449	14918
GBR.N	0	0	0	2205	0	0	0	0	2899	2958	8062
GBR.S	1331	0	8166	24630	30508	36896	64690	66514	53830	41173	327738
GRL	0	0	0	0	0	0	20212	23333	19753	19611	82909
IRL	1194	0	13205	21467	24785	26329	43237	49902	38568	39179	257866
ISL	5887	0	104912	182873	214868	186907	228934	292951	268351	243725	1729408
LTU	0	0	0	4718	0	1129	5299	0	0	0	11146
NLD	4595	0	51634	38524	56397	58148	81155	121864	75020	62309	549646
NOR	20539	0	196246	399520	489438	310412	399363	438426	351428	354032	2959404
POL	0	0	0	0	0	0	0	12152	27184	47614	86950
PRT	0	0	2014	1303	1429	1429	1625	1497	2659	2026	13982
RUS	46888	0	120669	151810	185763	173655	188449	170891	188006	181496	1407627
SWE	0	0	0	1	0	42	89	15	43	25	215
(all)	103857	377079	616507	1139732	1389442	1175681	1540071	1698071	1507464	1478388	11026292

Table 3: Catch of blue whiting (tonnes) included in the rectangle data by year and country

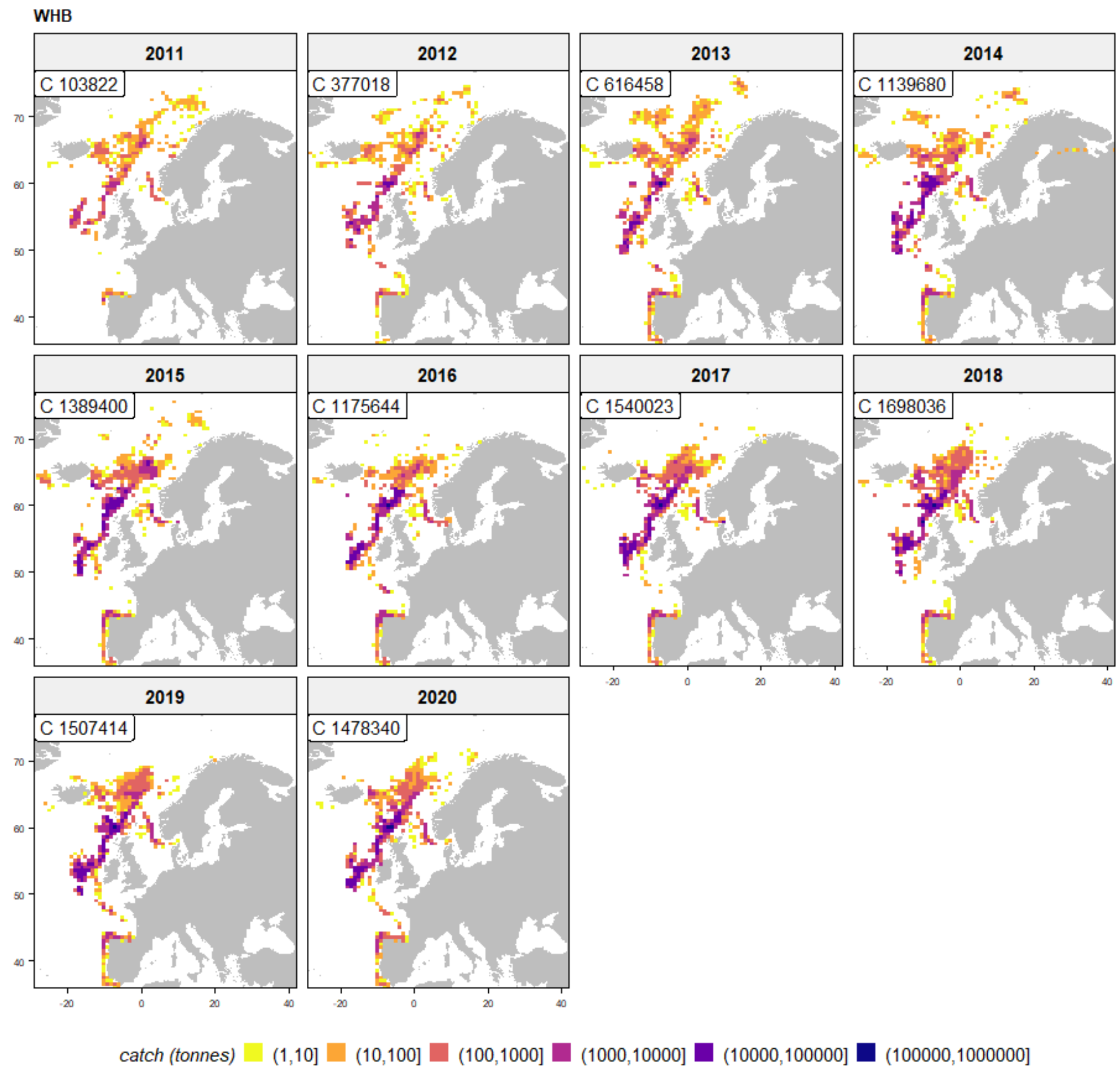

Figure 3: Catch of blue whiting (tonnes) by year and rectangle

Atlanto-scandian herring

country	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	(all)
ALL	0	819755	0	0	0	0	0	0	0	0	819755
DEU	13295	0	4243	668	2660	2582	5201	1994	4188	2969	37800
DNK	26732	0	17159	12513	9105	10384	17373	17051	20247	12328	142892
FRO	53270	0	105037	38527	33030	44726	98170	82062	113940	103029	671791
GBR	0	0	0	4233	0	3899	0	0	0	0	8132
GBR.S	14045	0	8342	0	0	0	0	2581	1800	143	26911
GRL	3426	0	11787	13187	12434	17507	12569	2465	3190	3547	80112
IRL	5738	0	3814	705	1399	2048	3494	2428	2775	2703	25104
ISL	151078	0	90729	58827	42626	50457	90400	83392	108044	98171	773724
NLD	8348	0	5625	9175	5248	3519	6678	4289	5110	5059	53051
NOR	572637	0	359458	263252	176321	197500	389383	331717	430501	409348	3130117
POL	0	0	0	0	0	0	0	0	1327	0	1327
RUS	144429	0	78501	60291	45853	50454	91119	64147	84362	75064	694220
SWE	0	0	23	0	0	0	1155	425	705	3065	5373
(all)	992998	819755	684718	461378	328676	383076	715542	592551	776189	715426	6470309

Table 4: Catch of Atlanto-scandian herring (tonnes) included in the rectangle data by year and country

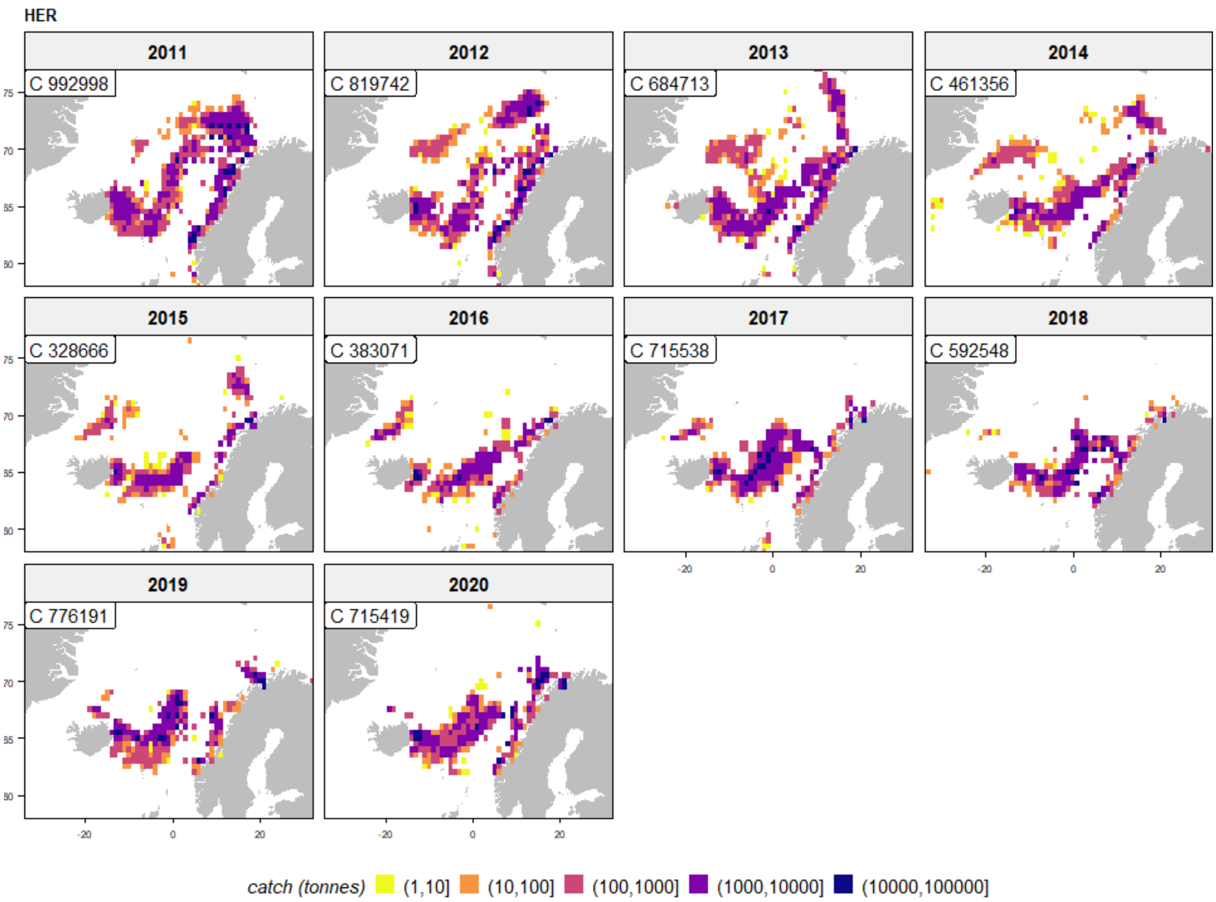

Figure 4: Catch of Atlanto-scandian herring (tonnes) by year and rectangle

Blue whiting

An alternative assessment including more surveys

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Introduction

During WGWIDE 2020 we saw how vulnerable a stock assessment is when we only have one survey input to base the assessment on, and that survey is cancelled. In 2020 it was due to the covid-19 pandemic, but in the future there might be other unforeseen events that may cause the survey being cancelled or something may go wrong in the data collection so that we do not have reliable data for a specific year. To avoid this issue of potentially having no fishery independent data and make the assessment more robust against problems with the IBWSS, we will in this report consider including the IESNS and IESSNS survey data for blue whiting in the assessment.

Data description

For the IESNS survey we have data from 2008 to 20201 and for the IESSNS from 2016 to 2021. We use ages from 1-4+ and 1-6+ from the two surveys. This age selection was made based on the consistency plots in Figure 4. From the original assessment, we also have catch data (ages 1-10+, 1981-2021) and the IBWSS (ages 1-8, 2004-2021), where 2010 and 2020 is missing. The model has been configured based on data available in 2020, but we will include everything that is available at the time of the WGWIDE 2021 meeting in 25.-31. August 2021. An overview of the data selected for the alternative assessment is found in Figure 5 and each time series is plotted in Figure 6 for each age group and Figure 7 for each year class.

Model description

Today's assessment is using the R package stockassessment and the SAM model. Including additional survey data as input in this framework is a relatively simple task. The effort is mostly needed for deciding how to set up the configuration of the model. The procedure of how we have selected the model configuration is that we have included the two additional survey data sources and start out with a default SAM configuration. Then we start at the top of the configuration and make incremental changes and compare different settings until we get the best model fit in terms of AIC. Then we move on to the next configuration setting. We only consider configurations that are somewhat sensible. For instance, we do not consider putting the same catchability on 1 year old and 8-year-old fish, with some other catchability for those in-between. We only consider cases where neighbouring age groups share the same parameters. The final configuration file is included in the appendix. For details on diagnostic, see appendix.

Model output

Once we have fitted the model, we can look at model output. In Figure 1 we have plotted SSB, Fbar and recruitment for the period 1980-2021 according to the fitted model. The black line with grey confidence interval is the official WGWIDE2021 assessment model for comparison.

In terms of SSB, we see a slight increase in the point estimates since around 2013, but the change is well within the confidence interval for the WGWIDE21 assessment model. The main difference is clearly that we get smaller confidence intervals, i.e. higher accuracy, by adding more data to the model. For Fbar the picture is more or less the same, only the alternative model point estimate is lower than WGWIDE for most of the same period. In recruitment we see a bigger discrepancy in 2021. The alternative model gives a higher recruitment in 2021. For all three measures, the confidence intervals are narrower for the alternative model compared to WGWIDE2021. Hence, the alternative assessment is consistent with the WGWIDE2021 assessment, but it has higher accuracy.

Leave-out analysis

A standard diagnostic is to leave out one survey at the time and see what effect this has on the output. This is achieved by taking out one data source at the time and refitting the model. This can give us an idea of how that particular data source affects the total. The leaveout plots are presented in Figure 2.

For the SSB the differences are not so big, but if we for instance take out IBWSS, we see that SSB and its uncertainty will increase a bit in 2020-21. Taking out any of the others have minor effect on SSB. We also see a similar pattern for Fbar. For the recruitment there is more happening. Taking out IESSNS will give the lowest recruitment, while if we take out IBWSS we get the highest for 2021. Going back in time, the leaveout scenarioes give more or less the same result.

Another interesting scenario we can run is: What if we take out all the surveys and run the SAM model with only catch data. The results of such a model run is presented in Figure … compared to the WGWIDE2021 assessment.

Conclusion

This exploratory model run shows that it is possible to include IESNS and IESSNS into the SAM model for Blue Whiting. It reduces the uncertainty and may provide more information about the younger fish. It will certainly reduce the risk for not having any survey to base the assessment on, by having two-three surveys instead of just one. The data is already being collected, and ready to use.

Appendix

Diagnostics

Jit run

A jitter run means that we re-estimate the model using randomly selected initial values and report the maximum difference in each parameter and model output. Ideally there should not be any major changes due to the initial values. The results from the jitter run indicates that there is little effect on the different model parameters due to varying the initial values.

```
##                         max(|delta|)
## logFpar                 1.460165e-12
## logSdLogFsta            8.597567e-13
## logSdLogN               8.884005e-13
## logSdLogObs             3.005381e-12
## logSdLogTotalObs        6.362910e-12
## transfIRARdist          8.205492e-12
## itrans_rho              3.820055e-12
## logFScaleMSY            7.991791e-01
## implicitFunctionDelta 6.778069e-01
## logScaleFmsy            7.149034e-01
## logScaleFmax            6.369347e-01
```

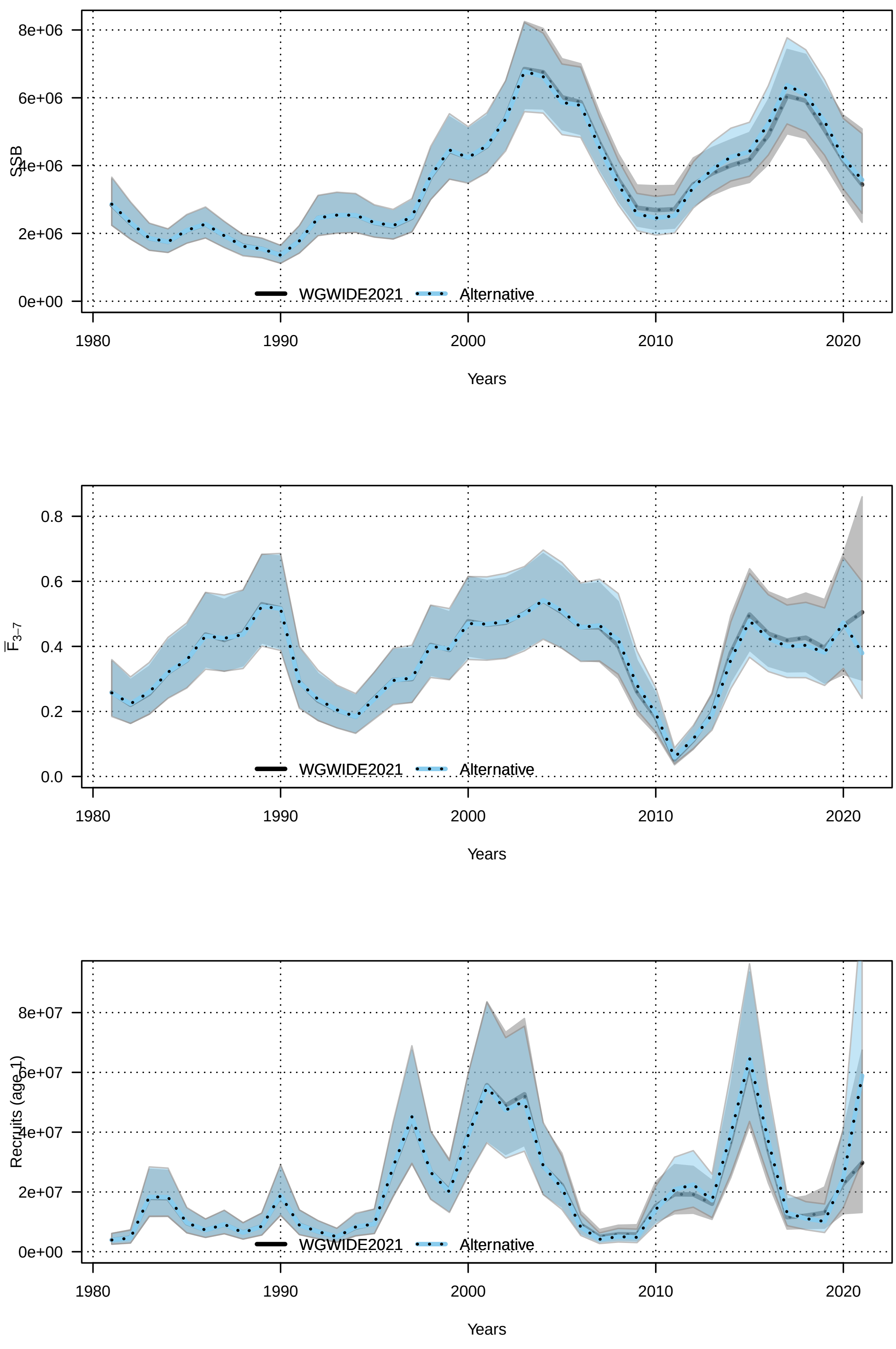

Figure 1: Model output in terms of SSB, Fbar and recruitment with 95 percent confidence intervals.

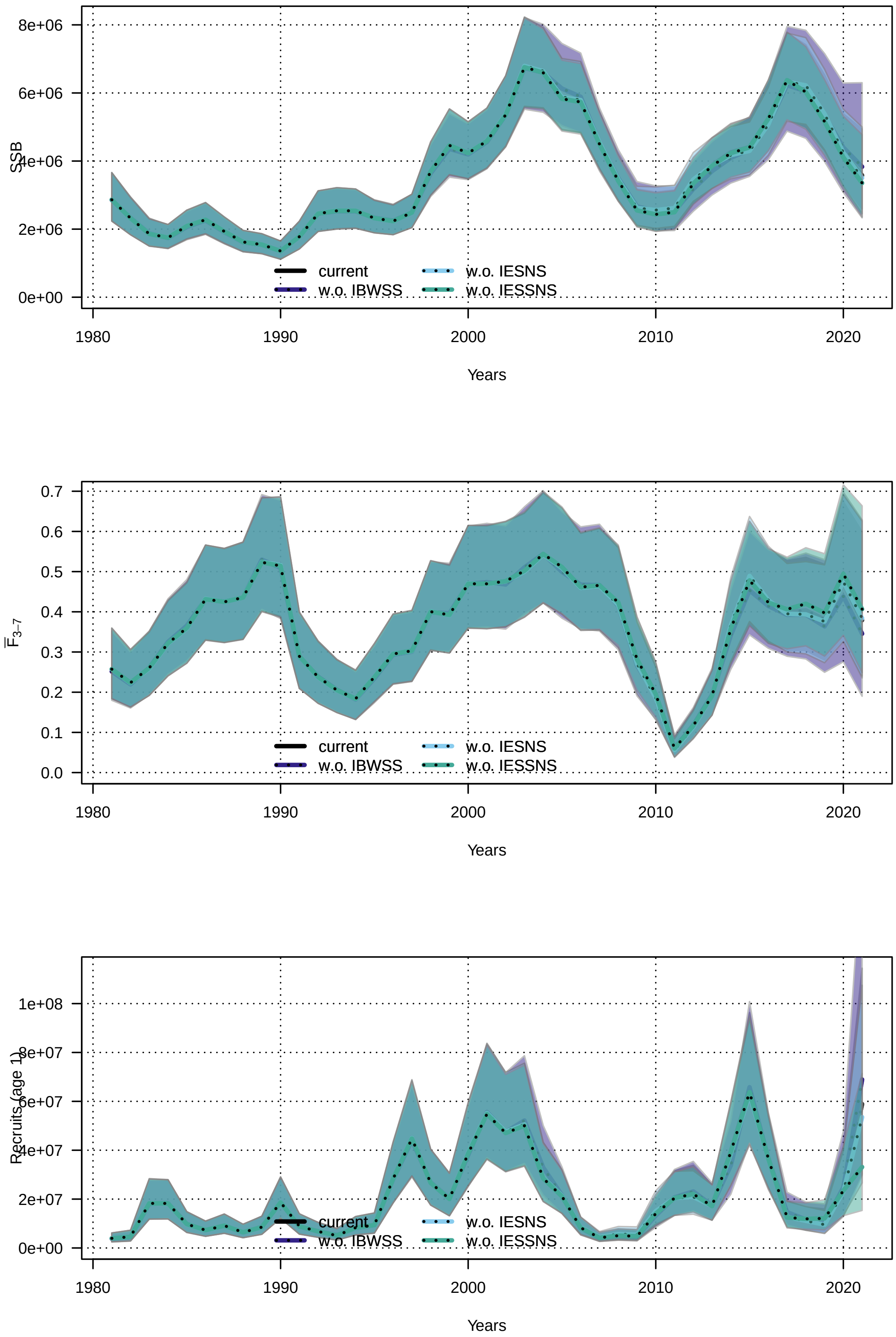

Figure 2: Leaveout plots for alternative assessment.

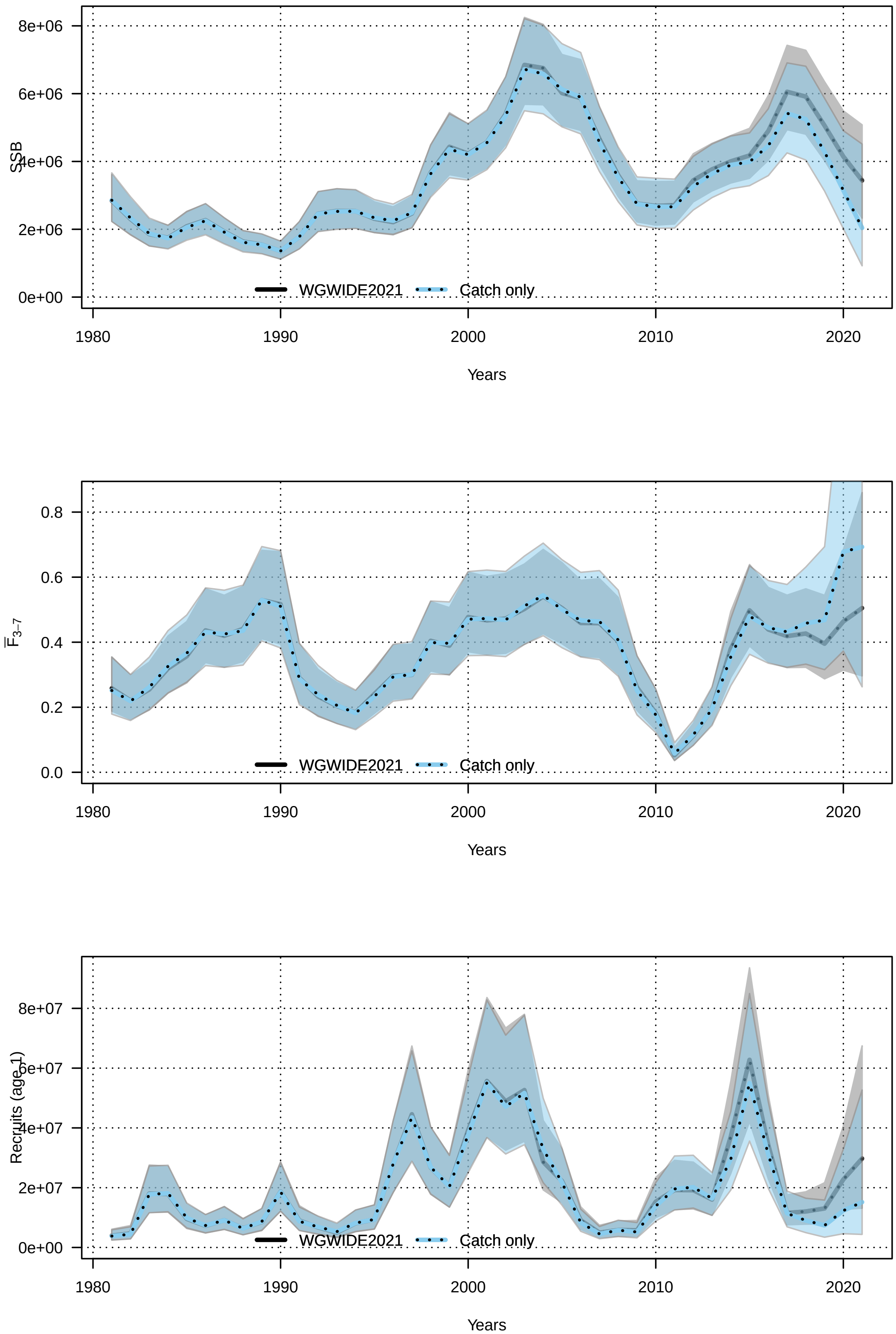

Figure 3: Comparison of assessment with catch only vs WGWIDE2021 assessment.

```
## logScaleF01          8.160139e-01
## logScaleFcrash       6.245671e-01
## logScaleFext         6.302892e-01
## logScaleFlim         6.237161e-01
## logF                 1.702949e-10
## logN                 1.624194e-10
## missing              2.735119e-10
## ssb                  4.437063e-04
## fbar                 3.286099e-11
## rec                  5.357973e-03
## catch                7.252139e-05
## logLik               3.283276e-10
```

Simulation study

Another test is to do a simulation study, where we simulate the processes going into the model and compare this to the model output based on the observations. Ideally, the simulations should stay within the 95% confidence intervals with a probability of 0.95. Here we use 50 simulations. It seems that most of the simulations fall within the confidence intervals, with some exceptions. This is expected.

Retrospective plots

Peeling off one year at the time and fitting the model based on those data. In the retrospective plots (Figure 13) we can see how well the last year's assessment fits with what the model predicts with one more year of data. Mohn's ρ for the retrospective analysis of SSB, Fbar and recruitment is respectively, 0.0783, -0.0756 and -0.0168.

Figures

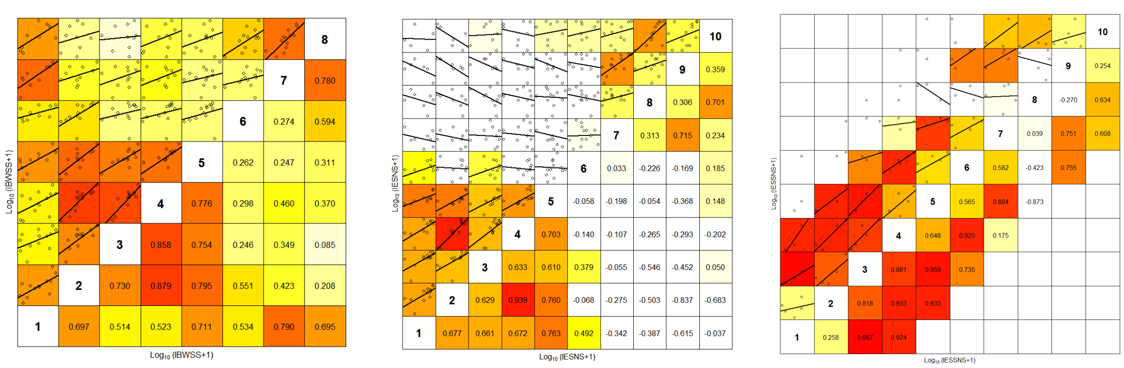

Figure 4: Internal consistency/correlation plots for IBWSS, IESNS and IESSNS. We use $\log(x+1)$ to avoid issues when x is 0. For IBWSS ages 1-8 are used, while in the alternative model 1-4+ and 1-6+ is used for IESNS and IESSNS, respectively.

Figure 5: Dataplot showing for which ages and years we use observations from the different data sources. For all except IBWSS the oldest age group is a plus group.

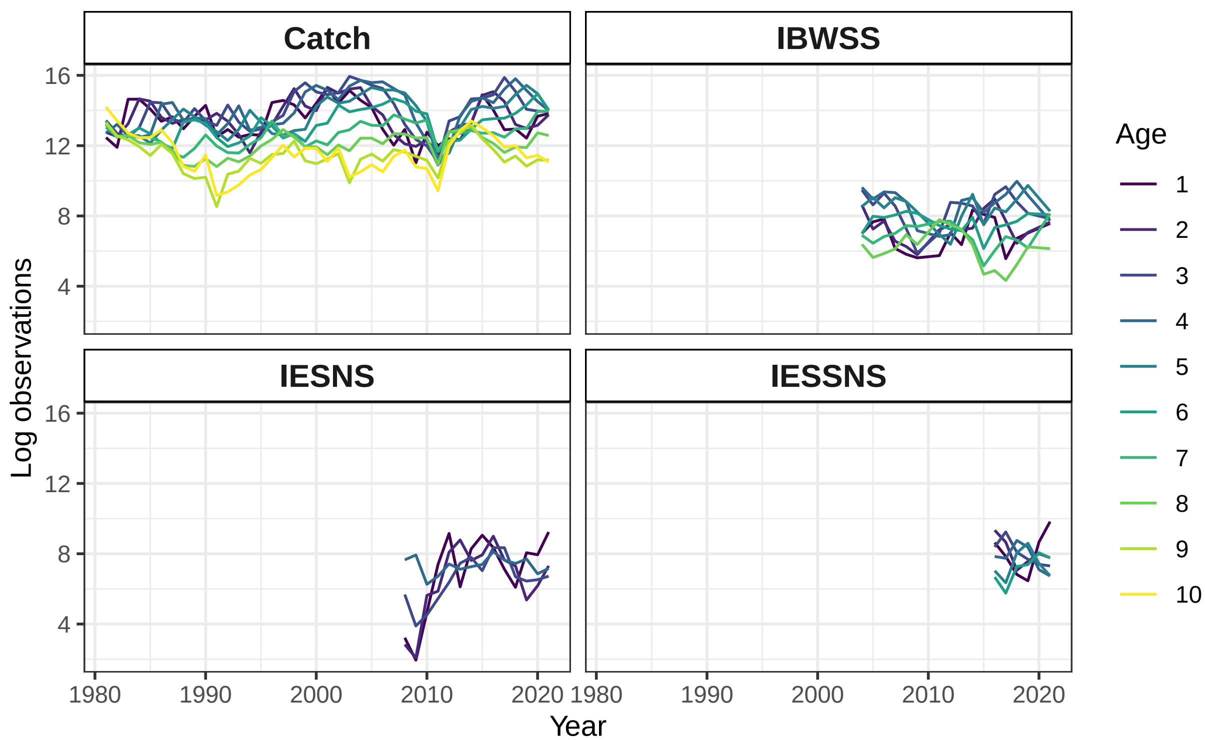

Figure 6: Time series for all data sources on log scale – one line per age group.

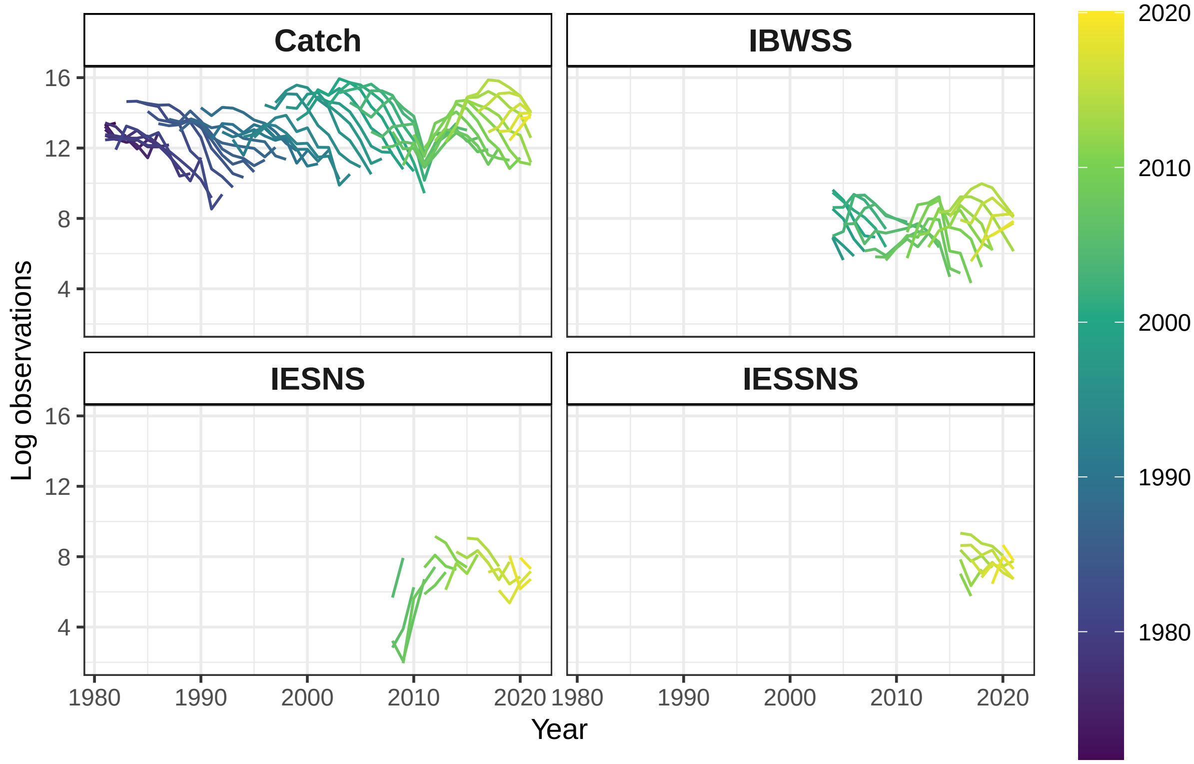

Figure 7: Time series of the different data sources on log scale – one line per year class.

Config

Here we print out the configuration file for the alternative assessment.

```
print(conf)
```

```
## $minAge
## [1] 1
##
## $maxAge
## [1] 10
##
## $maxAgePlusGroup
## [1] 1 0 1 1
##
## $keyLogFsta
##      V1 V2 V3 V4 V5 V6 V7 V8 V9 V10
## [1,]  0  1  2  3  4  5  6  7  8   8
## [2,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
## [3,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
## [4,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
##
## $corFlag
## [1] 2
##
## $keyLogFpar
##      V1 V2 V3 V4 V5 V6 V7 V8 V9 V10
## [1,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
```

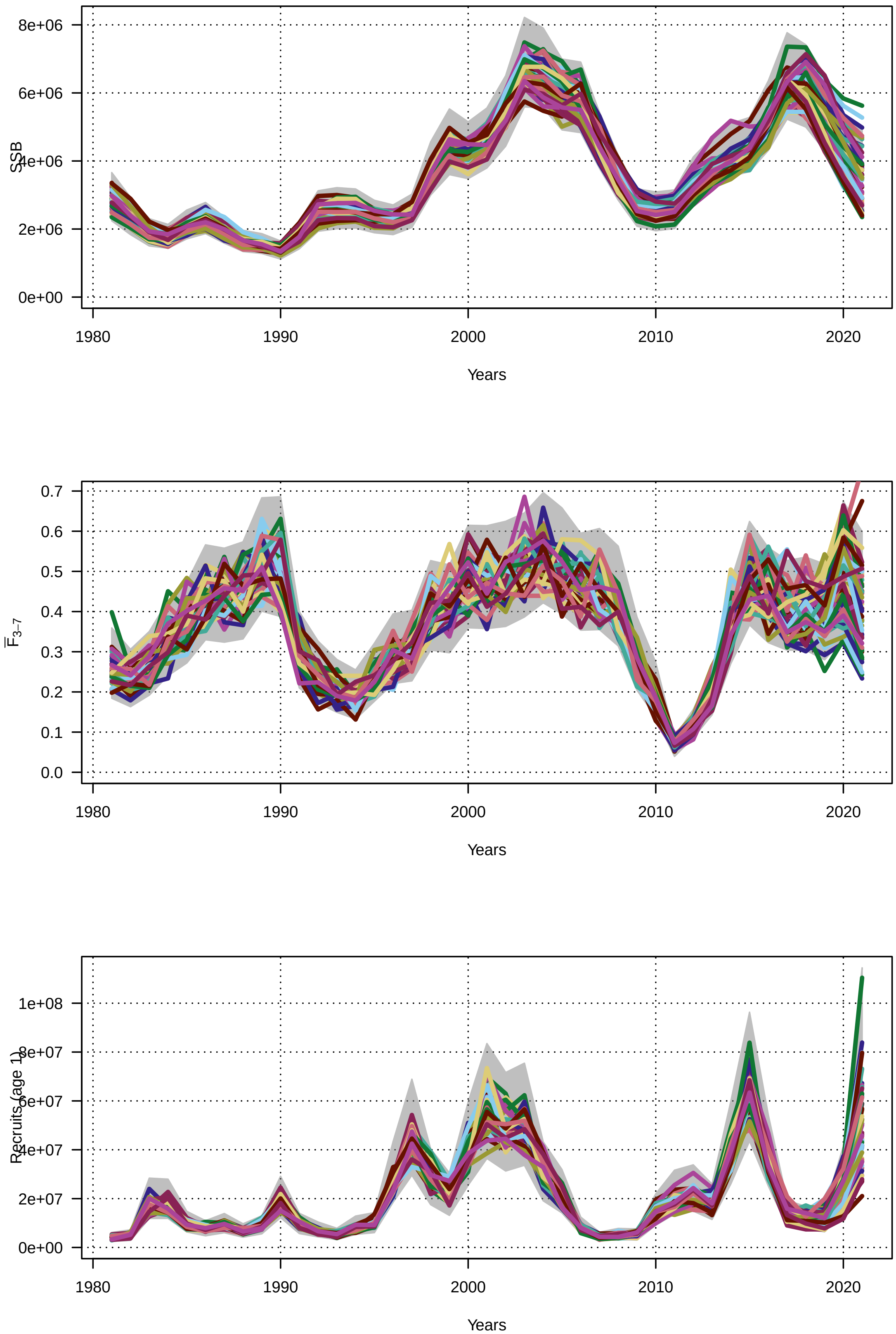

Figure 8: QQ-normality plots for model residuals by data source.

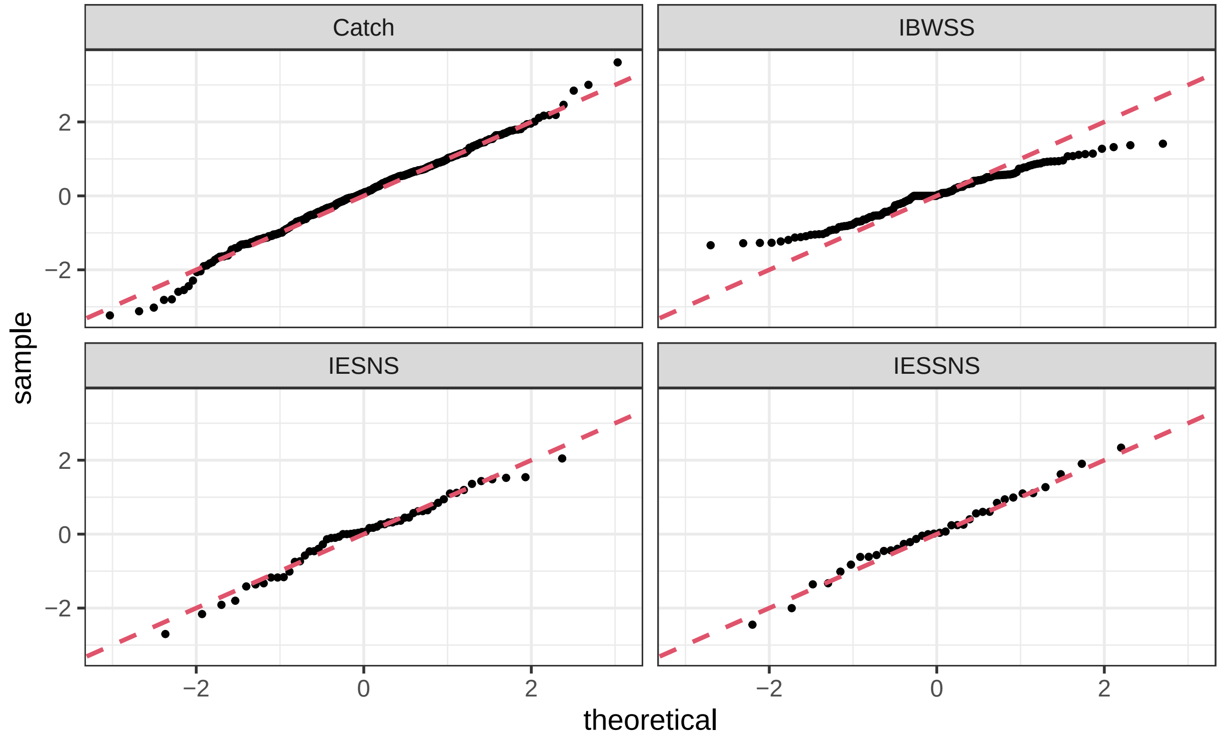

Figure 9: QQ-normality plots for model residuals by data source.

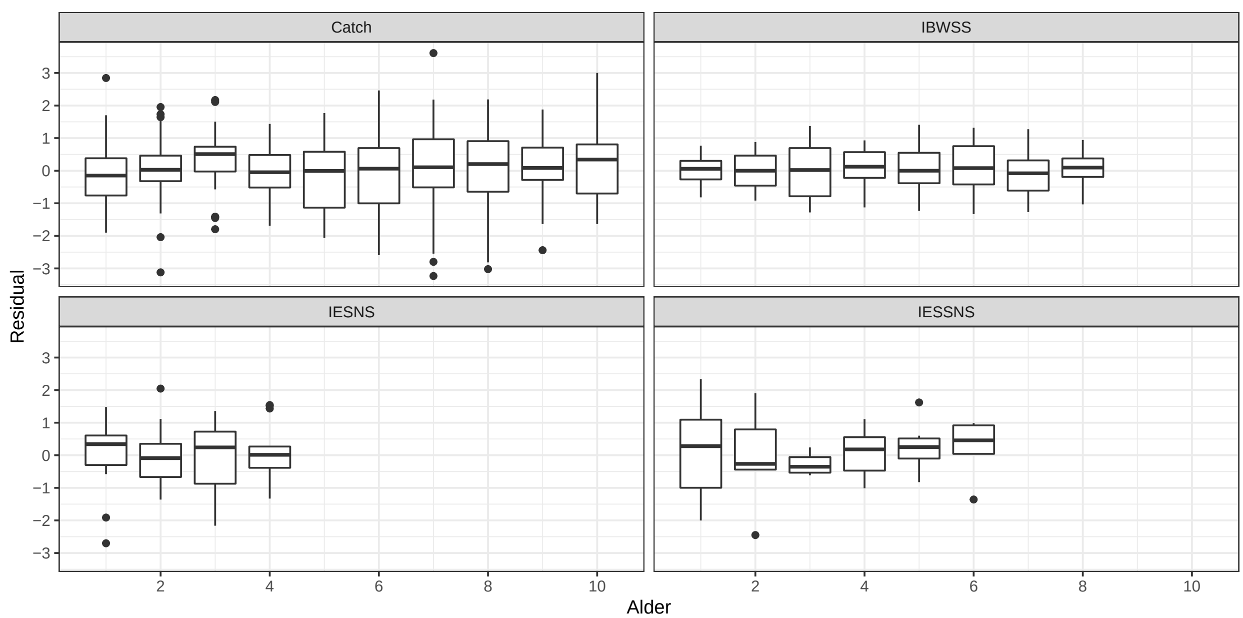

Figure 10: Boxplots of residuals by age for each fleet.

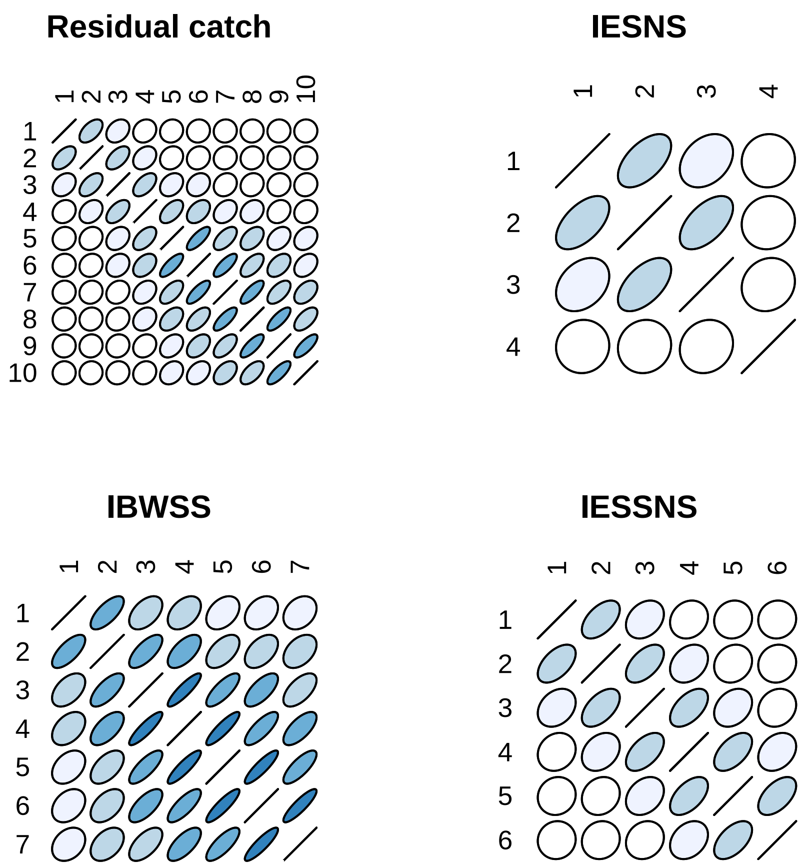

Figure 11: Correlation plot (model estimated).

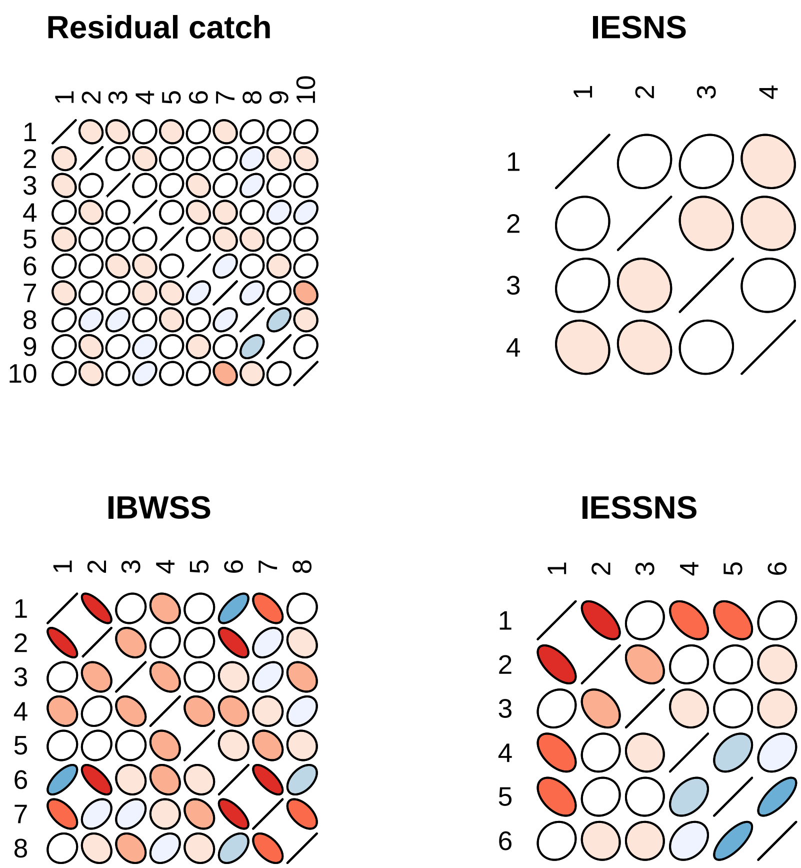

Figure 12: Empirical correlation plot.

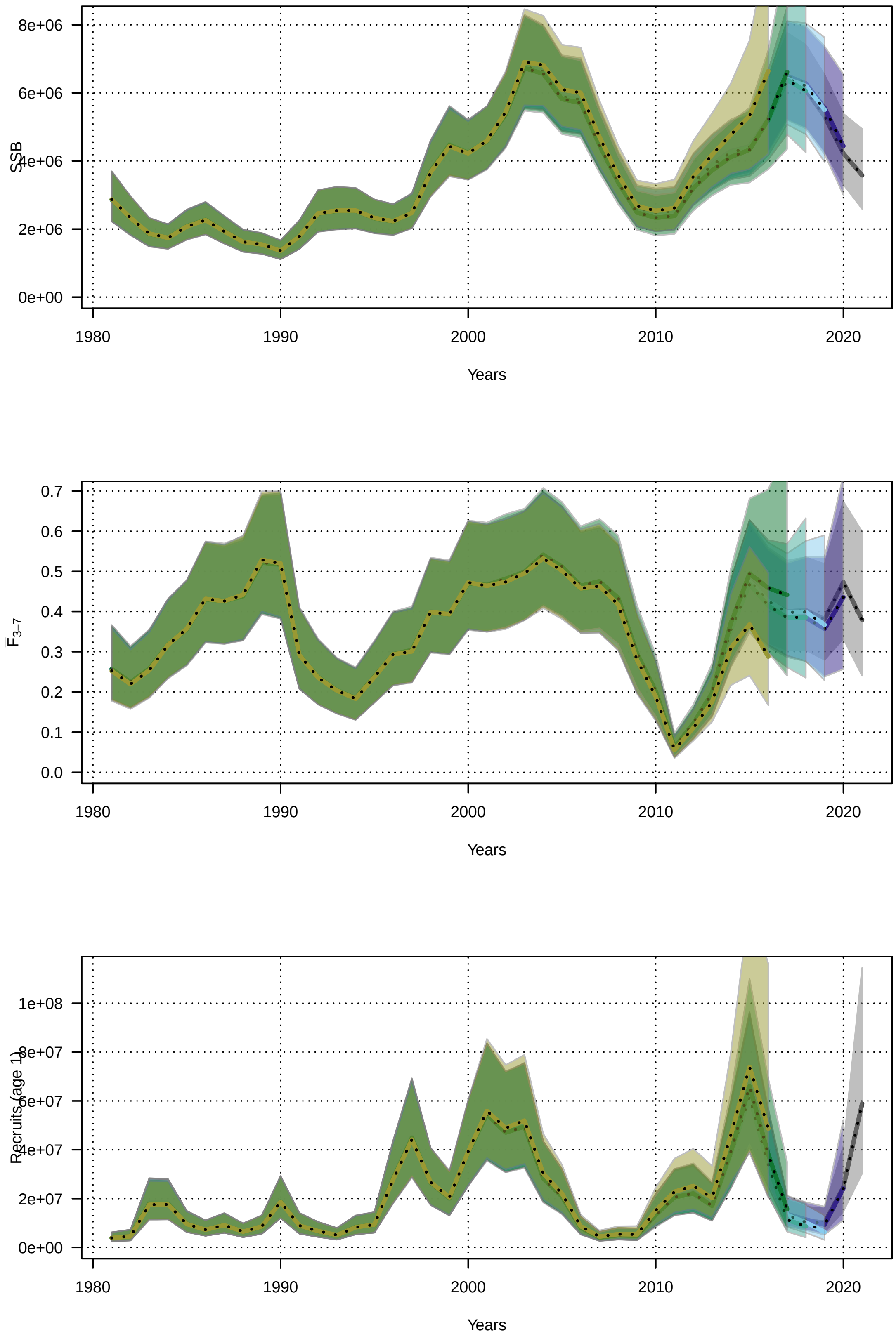

Figure 13: Retrospective plots for SSB, Fbar and Recruitment.

```
## [2,]  0  1  2  3  4  4  4  4 -1  -1
## [3,]  5  6  7  7 -1 -1 -1 -1 -1  -1
## [4,]  8  9 10 10 10 10 -1 -1 -1  -1
##
## $keyQpow
##      V1 V2 V3 V4 V5 V6 V7 V8 V9 V10
## [1,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
## [2,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
## [3,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
## [4,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
##
## $keyVarF
##      V1 V2 V3 V4 V5 V6 V7 V8 V9 V10
## [1,]  0  0  0  0  0  0  0  0  0   0
## [2,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
## [3,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
## [4,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
##
## $keyVarLogN
##  [1] 0 1 1 1 1 1 1 1 1 1
##
## $keyVarObs
##      V1 V2 V3 V4 V5 V6 V7 V8 V9 V10
## [1,]  0  1  2  2  2  2  2  2  3   3
## [2,]  4  5  6  7  7  7  8  8 -1  -1
## [3,]  9  9 10 10 -1 -1 -1 -1 -1  -1
## [4,] 11 11 11 11 11 11 -1 -1 -1  -1
##
## $obsCorStruct
## [1] AR AR AR AR
## Levels: ID AR US
##
## $keyCorObs
##      V1 V2 V3 V4 V5 V6 V7 V8 V9
## [1,]  0  0  0  0  1  1  1  1  1
## [2,]  2  2  3  3  3  3  3 -1 -1
## [3,]  4  4  5 -1 -1 -1 -1 -1 -1
## [4,]  6  6  6  6  6 -1 -1 -1 -1
##
## $stockRecruitmentModelCode
## [1] 0
##
## $noScaledYears
## [1] 0
##
## $keyScaledYears
## numeric(0)
##
## $keyParScaledYA
## <0 x 0 matrix>
##
## $fbarRange
## [1] 3 7
##
```

```
## $keyBiomassTreat
## [1] -1 -1 -1 -1
##
## $obsLikelihoodFlag
## [1] LN  ALN LN  LN
## Levels: LN ALN
##
## $fixVarToWeight
## [1] 0
##
## $fracMixF
## [1] 0
##
## $fracMixN
## [1] 0
##
## $fracMixObs
## [1] 0 0 0 0
##
## $constRecBreaks
## numeric(0)
##
## $predVarObsLink
##      V1 V2 V3 V4 V5 V6 V7 V8 V9 V10
## [1,] -1 -1 -1 -1 -1 -1 -1 -1 -1  -1
## [2,] -1 -1 -1 -1 -1 -1 -1 -1 NA  NA
## [3,] -1 -1 -1 -1 NA NA NA NA NA  NA
## [4,] -1 -1 -1 -1 -1 -1 NA NA NA  NA
##
## $hockeyStickCurve
## [1] 20
##
## $stockWeightModel
## [1] 0
##
## $keyStockWeightMean
##  [1] NA NA NA NA NA NA NA NA NA NA
##
## $keyStockWeightObsVar
##  [1] NA NA NA NA NA NA NA NA NA NA
##
## $catchWeightModel
## [1] 0
##
## $keyCatchWeightMean
##  [1] NA NA NA NA NA NA NA NA NA NA
##
## $keyCatchWeightObsVar
##  [1] NA NA NA NA NA NA NA NA NA NA
##
## $matureModel
## [1] 0
##
## $keyMatureMean
```

```
##  [1] NA NA NA NA NA NA NA NA NA NA
##
## $mortalityModel
## [1] 0
##
## $keyMortalityMean
##  [1] NA NA NA NA NA NA NA NA NA NA
##
## $keyMortalityObsVar
##  [1] NA NA NA NA NA NA NA NA NA NA
##
## $keyXtraSd
##      [,1] [,2] [,3] [,4]
```

WGWIDE 2021 WD

Blue Whiting stock assessment by means of TISVPA

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The TISVPA model (Vasilyev, 2005; 2006) was applied to the same data as the SAM model, including surveys data starting from age 1.

In order to produce more clear and less controversial signal from all sources of the data the settings of the model were taken as: so called "mixed" version, assuming errors both in catch-at-age and in separable approximation; additional restriction on the solution was the unbiased model approximation of separable representation of fishing mortality coefficients. The generation - dependent factors in triple - separable representation of fishing mortality coefficients were estimated and applied for age groups from 3 to 7. For the survey the measure of closeness of fit was simple sum of squared logarithmic residuals, and for catch-at-age data – the absolute median deviation (AMD) of residuals in logarithmic catch-at-age as a more robust analogue to the least squares approach. Overall objective function of the model was the sum the two components

Profiles of the components of the TISVPA loss function with respect to SSB in 2021 are shown in Figure 1. As it can be seen, for the model option described above, catch-at-age data and all the "survey" gives generally similar indication about the SSB in 2021.

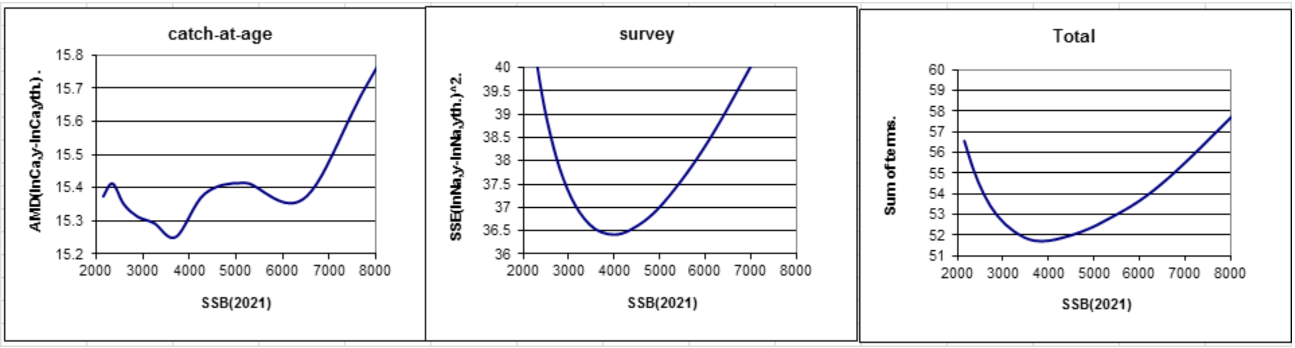

Figure 1. Profiles of the components of the TISVPA objective function

Figure 2 shows the estimates of relative selection by age and years from the "triple-separable model" of the TISVPA (the values are normalized to sum=1 for each year.

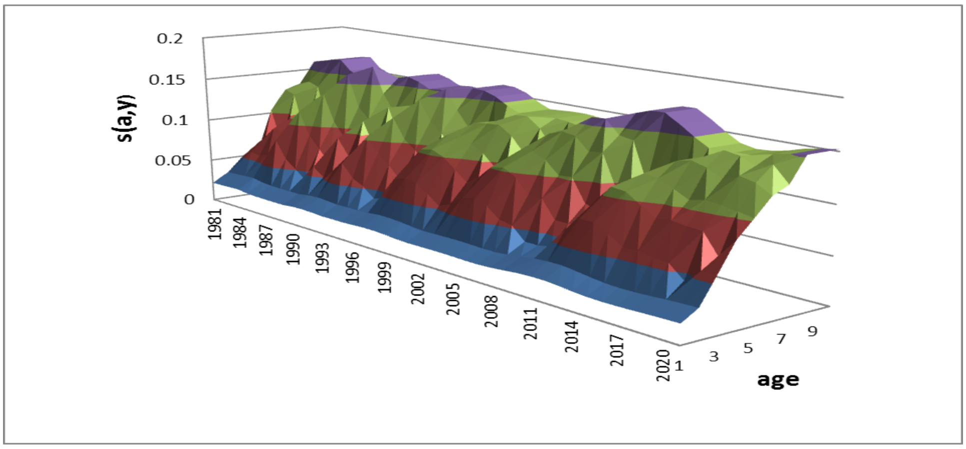

Figure 2. TISVPA-derived selection pattern

Figure 3 represents the results of retrospective analysis.

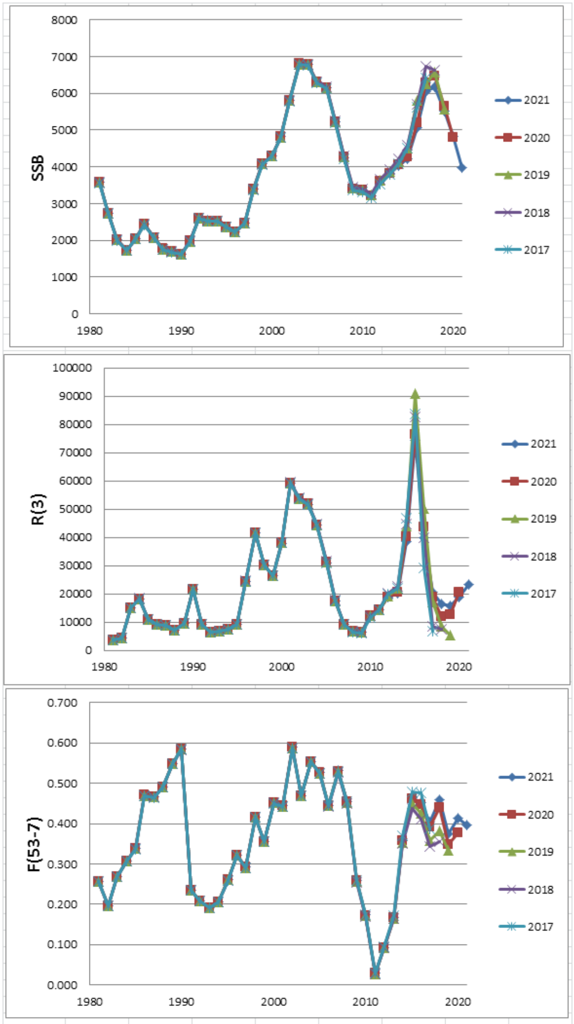

Figure 3. Retrospective runs for TISVPA

The residuals of the model approximation of catch-at-age and survey are presented in Figure 4.

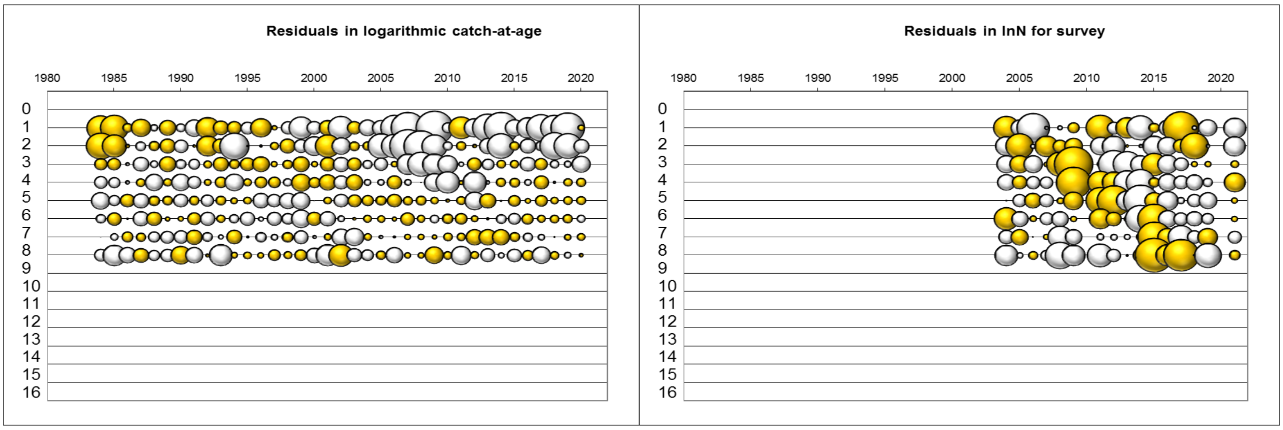

Figure 4. Residuals of the TISVPA data approximation.

The estimates of uncertainty in the results (parametric conditional bootstrap with respect to catch-at-age; survey data were noised by lognormal noise with sigma=0.3) are presented on Figure 5.

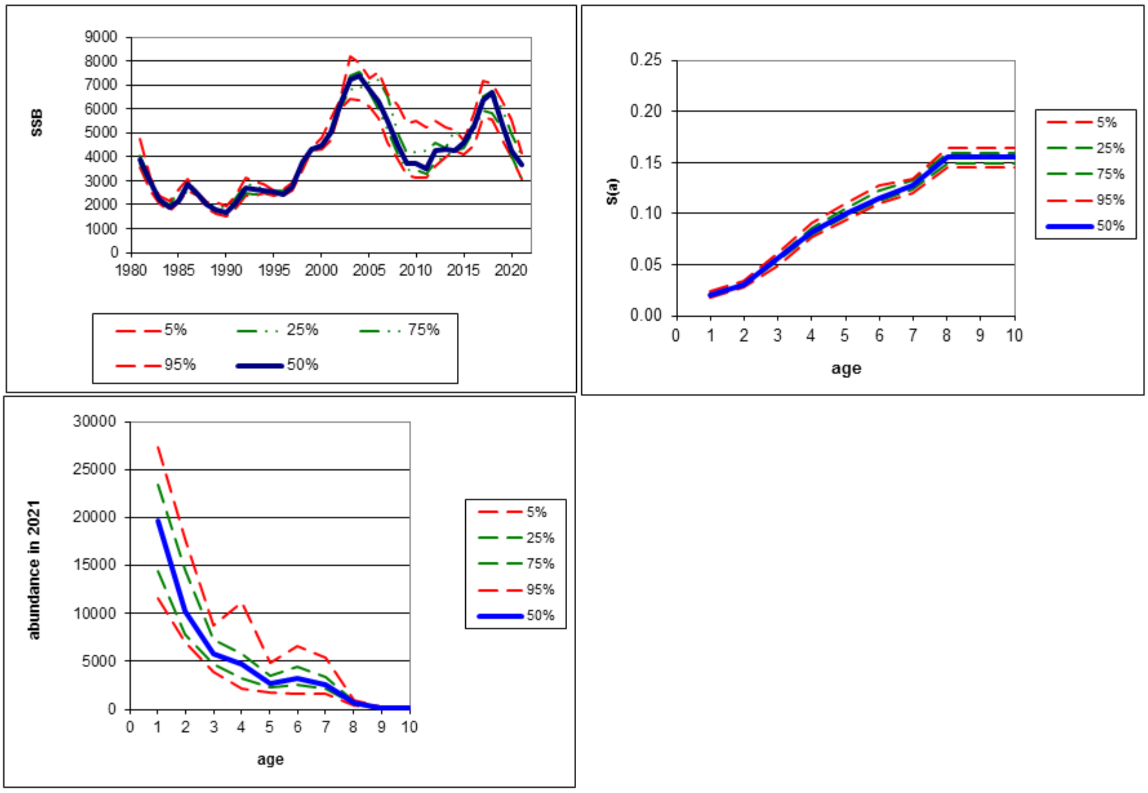

Figure 5. Bootstrap- estimates of uncertainty in the results.

The results of the assessment are presented in the Tables 1-3.

year	B(1+)	SSB	R(1)	F(3-7)
1981	4123	3577	3585	0.257
1982	3226	2740	4351	0.196
1983	2922	2008	15078	0.269
1984	2925	1736	18224	0.308
1985	3194	2045	10888	0.338
1986	3409	2439	9026	0.470
1987	3064	2078	8917	0.467
1988	2619	1768	7131	0.492
1989	2643	1693	9413	0.549
1990	2948	1621	21635	0.586
1991	3491	1980	9249	0.235
1992	3664	2607	6483	0.208
1993	3494	2535	6698	0.192
1994	3452	2520	7450	0.205
1995	3415	2362	9048	0.261
1996	3638	2232	24433	0.322
1997	5192	2466	41442	0.292
1998	6402	3391	30218	0.417
1999	7164	4082	26462	0.356
2000	7683	4305	37919	0.452
2001	9343	4819	59254	0.444
2002	11003	5808	53655	0.589
2003	11787	6805	51647	0.469
2004	10869	6785	44323	0.554
2005	9568	6312	31007	0.526
2006	8736	6160	17310	0.445
2007	6813	5221	9139	0.531
2008	5402	4255	6585	0.455
2009	4323	3402	6310	0.258
2010	4397	3349	12367	0.173
2011	4580	3207	14168	0.028
2012	5041	3602	18720	0.093
2013	5727	3819	20189	0.166
2014	6813	4026	38407	0.358
2015	8444	4214	74138	0.464
2016	9491	5057	39665	0.452
2017	9235	6034	20354	0.403
2018	8616	6186	16227	0.459
2019	7732	5506	15752	0.374
2020	7077	4833	18767	0.413
2021	5930	3982	23249	0.396

Table 1. Blue whiting. The results of the assessment by TISVPA

	1	2	3	4	5	6	7	8	9	10
1981	3585	4194	5442	3561	2551	2192	1867	2047	1761	4447
1982	4351	2751	3147	3887	2564	1575	1258	1059	1054	2497
1983	15078	3418	2066	2283	2703	1841	1000	765	602	894
1984	18224	11080	2446	1442	1496	1768	1208	539	357	591
1985	10888	13485	7681	1617	903	877	997	742	232	645
1986	9026	8104	9674	4673	1009	543	455	562	358	818
1987	8917	6815	5878	6143	2182	506	269	202	219	414
1988	7131	6673	4994	3993	3348	945	256	129	69	105
1989	9413	5422	4832	3483	2447	1623	290	121	49	75
1990	21635	7026	3861	2916	2146	1272	677	84	44	155
1991	9249	16100	4989	2473	1461	1181	513	218	16	32
1992	6483	7254	12225	3555	1701	879	752	295	120	45
1993	6698	5026	5476	8535	2395	1164	548	505	167	75
1994	7450	5271	3870	3979	5645	1600	782	346	320	126
1995	9048	5846	4125	2846	2784	3513	1026	500	201	141
1996	24433	7092	4455	3029	1913	1726	1983	599	266	225
1997	41442	18620	5307	3149	2024	1195	934	937	280	454
1998	30218	31966	13886	3521	2085	1335	700	489	424	172
1999	26462	22971	22799	8256	1836	1254	752	314	166	339
2000	37919	20528	17124	14090	4227	997	767	449	129	310
2001	59254	29065	15285	10863	7262	2000	407	425	189	162
2002	53655	45063	20800	10110	5951	3623	954	180	203	282
2003	51647	41162	33034	13281	5779	2842	1341	349	46	62
2004	44323	39183	30123	20108	7155	3051	1287	584	150	74
2005	31007	33787	28186	17878	9887	3284	1360	473	211	116
2006	17310	23734	25222	17573	8898	4260	1418	618	171	93
2007	9139	13491	17980	16818	9442	4174	1904	681	290	199
2008	6585	7105	10219	12259	9651	4342	1520	710	267	300
2009	6310	5028	5397	7475	7286	5076	1845	578	294	162
2010	12367	4997	3882	4092	5370	4533	2996	965	287	180
2011	14168	9765	3868	2979	3054	3796	2853	1829	562	281
2012	18720	11489	7905	3105	2389	2438	3008	2228	1429	1065
2013	20189	15026	9080	5922	2343	1824	1812	2177	1504	1679
2014	38407	16092	11717	6547	3990	1550	1284	1234	1344	1695
2015	74138	30072	12223	7535	3585	2073	844	752	561	1056
2016	39665	57191	22092	7844	4019	1654	941	405	329	723
2017	20354	30806	42880	14791	4587	2040	712	424	174	404
2018	16227	15940	23168	28505	8535	2481	977	325	212	384
2019	15752	12602	12057	15408	16370	4316	1129	402	133	212
2020	18767	12341	9593	8611	9254	8946	2095	534	186	149
2021	23249	14332	9180	6533	5462	4868	4287	891	220	197

Table 2. Blue whiting. Estimates of abundance-at-age

	1	2	3	4	5	6	7	8	9	10
1981	0.0517	0.0793	0.1257	0.1370	0.2816	0.3597	0.3799	0.4742	0.4742	0.4742
1982	0.0422	0.0646	0.1174	0.1554	0.1342	0.2688	0.3062	0.3712	0.3712	0.3712
1983	0.0590	0.0907	0.1574	0.2586	0.2722	0.2276	0.4267	0.5617	0.5617	0.5617
1984	0.0684	0.1054	0.1991	0.2871	0.3772	0.3881	0.2875	0.6852	0.6852	0.6852
1985	0.0635	0.0978	0.2749	0.2869	0.3251	0.4186	0.3833	0.6194	0.6194	0.6194
1986	0.0775	0.1198	0.2561	0.5663	0.4479	0.4997	0.5812	0.8198	0.8198	0.8198
1987	0.0750	0.1158	0.2051	0.3928	0.6935	0.5258	0.5192	0.7805	0.7805	0.7805
1988	0.0757	0.1169	0.1651	0.3256	0.4971	0.8929	0.5780	0.7918	0.7918	0.7918
1989	0.0807	0.1248	0.2669	0.2747	0.4354	0.6676	1.1015	0.8711	0.8711	0.8711
1990	0.0991	0.1540	0.2572	0.5498	0.4293	0.6974	0.9941	1.2286	1.2286	1.2286
1991	0.0489	0.0749	0.1465	0.1867	0.2952	0.2313	0.3149	0.4430	0.4430	0.4430
1992	0.0417	0.0638	0.1545	0.1902	0.1914	0.2955	0.2082	0.3657	0.3657	0.3657
1993	0.0355	0.0543	0.1074	0.2004	0.1945	0.1912	0.2646	0.3034	0.3034	0.3034
1994	0.0386	0.0589	0.1022	0.1789	0.2679	0.2536	0.2238	0.3335	0.3335	0.3335
1995	0.0468	0.0717	0.0987	0.1916	0.2698	0.4038	0.3395	0.4197	0.4197	0.4197
1996	0.0583	0.0895	0.1288	0.1896	0.2983	0.4193	0.5752	0.5524	0.5524	0.5524
1997	0.0587	0.0903	0.2062	0.1995	0.2332	0.3625	0.4575	0.5584	0.5584	0.5584
1998	0.0799	0.1235	0.3068	0.4653	0.3434	0.3965	0.5710	0.8572	0.8572	0.8572
1999	0.0660	0.1016	0.2484	0.3950	0.4617	0.3324	0.3419	0.6519	0.6519	0.6519
2000	0.0717	0.1106	0.2500	0.4367	0.5490	0.6324	0.3944	0.7321	0.7321	0.7321
2001	0.0647	0.0995	0.1926	0.3525	0.4818	0.5923	0.5994	0.6340	0.6340	0.6340
2002	0.0809	0.1252	0.2737	0.3899	0.5810	0.8101	0.8919	0.8748	0.8748	0.8748
2003	0.0695	0.1071	0.2727	0.3666	0.4050	0.5886	0.7128	0.7000	0.7000	0.7000
2004	0.0800	0.1237	0.3339	0.5208	0.5448	0.5909	0.7811	0.8599	0.8599	0.8599
2005	0.0754	0.1164	0.2929	0.5072	0.6122	0.6233	0.5942	0.7866	0.7866	0.7866
2006	0.0630	0.0969	0.2011	0.3811	0.5101	0.5981	0.5356	0.6123	0.6123	0.6123
2007	0.0712	0.1097	0.2173	0.3627	0.5548	0.7458	0.7732	0.7237	0.7237	0.7237
2008	0.0672	0.1035	0.1422	0.3206	0.4214	0.6372	0.7527	0.6683	0.6683	0.6683
2009	0.0475	0.0728	0.0928	0.1514	0.2665	0.3384	0.4427	0.4276	0.4276	0.4276
2010	0.0382	0.0584	0.0746	0.1123	0.1456	0.2496	0.2830	0.3298	0.3298	0.3298
2011	0.0071	0.0108	0.0199	0.0204	0.0243	0.0305	0.0455	0.0547	0.0547	0.0547
2012	0.0230	0.0351	0.0812	0.0986	0.0806	0.0945	0.1080	0.1872	0.1872	0.1872
2013	0.0357	0.0545	0.1349	0.1966	0.1899	0.1504	0.1599	0.3053	0.3053	0.3053
2014	0.0619	0.0952	0.2332	0.3864	0.4538	0.4246	0.2930	0.5979	0.5979	0.5979
2015	0.0676	0.1041	0.2354	0.4096	0.5393	0.6244	0.5118	0.6733	0.6733	0.6733
2016	0.0630	0.0970	0.2207	0.3439	0.4705	0.6082	0.6192	0.6125	0.6125	0.6125
2017	0.0582	0.0895	0.1929	0.3177	0.3884	0.5215	0.5954	0.5518	0.5518	0.5518
2018	0.0673	0.1036	0.2147	0.3562	0.4686	0.5675	0.6875	0.6692	0.6692	0.6692
2019	0.0605	0.0930	0.1398	0.2994	0.3899	0.5019	0.5368	0.5799	0.5799	0.5799
2020	0.0681	0.1050	0.2076	0.2452	0.4260	0.5512	0.6366	0.6810	0.6810	0.6810
2021	0.0686	0.1056	0.2090	0.3284	0.4071	0.4961	0.5376	0.6869	0.6869	0.6869

Table 3. Blue whiting. Estimates of fishing mortality coefficients

References

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Working Document

Working Group on International Pelagic Surveys
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Working Group on Widely Distributed Stocks
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INTERNATIONAL BLUE WHITING SPAWNING STOCK SURVEY (IBWSS) SPRING 2021

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Material and methods

Survey planning and Coordination

Coordination of the survey was initiated at the meeting of the Working Group on International Pelagic Surveys (WGIPS) in January 2021 and continued by correspondence until the start of the survey. During the survey effort was refined and adjusted by the survey coordinator (Norway) using real time observations. Participating vessels together with their effective survey periods are listed below:

Vessel	Institute	Survey period
Celtic Explorer	Marine Institute, Ireland	21/3 – 04/4
Jákup Sverri	Faroe Marine Research Institute, Faroe Islands	29/3 – 05/4
Tridens	Wageningen Marine Research, the Netherlands	18/3 – 03/4
Vendla	Institute of Marine Research, Norway	25/3 – 05/4
Vizconde de Eza	Spanish Institute of Oceanography, Spain	18/3 – 23/3

The survey design was based on methods described in ICES Manual for International Pelagic Surveys (ICES, 2015). Weather conditions were regarded as exceptionally poor and all vessels experienced multiple days of downtime, with the exception of the Spanish vessel working in the Porcupine Seabight. This considered, the stock was covered comprehensively and contained within the survey area. The entire survey was completed in 19 days, below 21-day target threshold (Figure 4).

Vessel cruise tracks and survey strata are shown in Figure 1. Trawl stations for each participant vessel are shown in Figure 2 and CTD stations in Figure 3. Communication between vessels occurred daily via email to the coordinator (Norway) exchanging up to date information on blue whiting distribution, echograms, fleet activity and biological information. Tridens keeps a weblog during the survey with echograms, catches and additional information.

Sampling equipment

All vessels employed a single midwater trawl for biological sampling, the properties of which are given in Table 1. Acoustic equipment for data collection and processing are presented in Table 2. Survey abundance estimates are based on acoustic data collected from calibrated scientific echo sounders using an operating frequency of 38 kHz. All transducers were calibrated using a standardised sphere calibration (Demer et al. 2015) prior, during or directly after the survey. Acoustic settings by vessel are summarised in Table 2.

Biological sampling

All components of the trawl haul catch were sorted and weighed; fish and other taxa were identified to species level. A summary of biological sampling by vessel is provided in Table 3.

Hydrographic sampling

Hydrographic sampling (vertical CTD casts) was carried out by each vessel at predetermined locations (Figure 3 and Table 3). Depth was capped at a maximum depth of 1000 m in open water, with the exception of the Spanish vessel where the maximum depth was 520 m. Not all pre-planned CTD stations were undertaken due to weather restrictions.

Plankton sampling

Plankton sampling by way of vertical WP2 casts were carried out by the RV *Jákup Sverri* (FO) to a depth of 200 m (Table 3). WP2 casts were also carried out by FV *Vendla*, with a focus on sampling blue whiting eggs to a depth of 400 m.

Acoustic data processing

Echogram scrutinisation for blue whiting was carried out by experienced personnel, with the aid of trawl composition information. Post-processing software and procedures differed among the vessels;

On RV *Celtic Explorer*, acoustic data were backed up every 24 hrs and scrutinised using EchoView (V 11.0) post-processing software for the previous day's work. Data was partitioned into the following categories: blue whiting and mesopelagic fish species. For mesopelagic fish, categorisation was based on criteria agreed at WGIPS 2021 (ICES 2021, Annex 22).

On RV *Jákup Sverri*, acoustic data were scrutinised every 24 hrs on board using LSSS post processing software. Data were partitioned into the following categories: plankton (<200 m depth layer), pearlside (surface down to 250 m), mesopelagics/krill and blue whiting. Partitioning of data into the above categories was based on trawl samples and acoustic characteristics on the echograms. The pearlside layer typically migrated above the transducer depth during night and reappeared on the echogram early in the morning.

On RV *Tridens*, acoustic data were backed up continuously and scrutinised every 24 hrs using the Large Scale Survey System LSSS (2.10.1) post-processing software. Blue whiting were identified and separated from other recordings based on trawl catch information and characteristics of the recordings.

On FV *Vendla*, the acoustic recordings were scrutinized using LSSS (V. 2.10.1) once or twice per day. Data was partitioned into the following categories: plankton (<120 m depth layer), mesopelagic species and blue whiting.

On RV *Vizconde de Eza*, acoustic data were backed up every 12 hrs and scrutinised after the survey using EchoView (V 9.0) post processing software. Data were partitioned into the following categories: Blue whiting and Müeller's pearlside which were identified and separated from other recordings based on trawl catch information and characteristics of the recordings.

Echogram scrutinisation for mesopelagic fish species was conducted by participants using guidelines developed at WGIPS 2021 (ICES 2021, Annex 22). This process is ongoing and requires further development in terms of categorisation and trawl sampling equipment. Progress updates will be reported through WGIPS.

Due to the bad weather conditions acoustic recording of all vessels suffered from transmission loss and spikes caused by wave impact on the ship's hull (Figure 8e). Scientists onboard RV *Tridens* analysed data collected during the survey to investigate the effects of bias. A case study showed that there was no significant bias and therefore no need to apply filtering or a correction factor. Further details are provided in Annex 1.

Acoustic data analysis

Acoustic data were analysed using the StoX software package (V3.0.5) and R-StoX packages software package (RStoX Framework 3.0.12, RStoX Base 1.3.8 and RStoX Data 1.1.3). A description of StoX software package is provided by Johnsen et. al. (2019). Estimation of abundance from acoustic surveys with StoX is carried out according to the stratified transect design model developed by Jolly and Hampton (1990). Baseline survey strata, established in

2017, were adjusted based on survey effort and observations in 2021 (Figure 1). Area stratification and transect design are shown in Figure 1 and 5. Length and weight data from trawl samples were equally weighted and applied across all transects within a given stratum (Figure 5).

Following the decisions made at the Workshop on implementing a new TS relationship for blue whiting abundance estimates (WKTSBLUES, ICES 2012), the following target strength (TS)-to-fish length (L) relationship (Pedersen et al. 2011) is used:

$$TS = 20 \log10 (L) - 65.2$$

In StoX an impute super-individual table is produced where abundance is linked to population parameters including age, length, weight, sex, maturity etc. This table is used to split the total abundance estimate by any combination of population parameters. The StoX project folder for 2021 is available on request.

Estimate of relative sampling error

For the baseline run, StoX estimates the number of individuals by length group which are further grouped into population characteristics such as numbers at age and sex.

A total length distribution is calculated, by transect, using all the trawl stations assigned to the individual transects. Conversion from NASC (by transect) to mean density by length group by stratum uses the calculated length distribution and a standard target strength equation with user defined parameters. Thereafter, the mean density by stratum is estimated by using a standard weighted mean function, where each transect density is weighted by transect distance. The number of individuals by stratum is given as the product of stratum area and area density.

The bootstrap procedure to estimate the coefficient of variance randomly replaces transects and trawl stations within a stratum on each successive run. The output of all runs are stored in a RData-file, which is used to calculate the relative sampling error.

Results

Distribution of blue whiting

In total 7,794 nmi (nautical miles) of survey transects were completed across seven strata, relating to an overall geographical coverage of 118,169 nmi² and is comparable to survey effort in 2019 (Figure 1, Tables 3 & 7). Effort in the Porcupine Seabight area was extended in 2021 and included as a new stratum area. The stock was considered well contained within core and peripheral abundance areas (Rockall Bank and south Porcupine Bank). The distribution of blue whiting as observed during the survey is shown in Figures 6 and 7.

The bulk of the stock in 2021 was located within the three strata that cover the shelf edge area (Strata 1-3 inclusive) accounting for 84% of total biomass observed (Table 4). The Rockall Trough, strata 3, contained less biomass than observed in 2019 (41% and 61 % of TSB respectively). Distribution in the Porcupine Bank (stratum 1) decreased by 69% compared to 2019. However, it should be noted that this stratum was subdivided into what is now stratum 7 (Porcupine Seabight). The three strata outside the core shelf edge area (stratum 4, 5, and 6) collectively increased from around 5% in 2019 to 10% in 2021 (Table 4). The new Porcupine Seabight area (stratum 7) contributed around 6% of the overall biomass of blue whiting in 2021.

The two northernmost strata South Faroes (stratum 4) and Shetland Channel (stratum 6) accounted for 3.2% of the biomass (Table 4).

Overall, the distribution of blue whiting was found to be highly compressed against the shelf edge from south to north, with the main body of the stock located in the mid-latitudes to the north of the Porcupine Bank (strata 2-3).

The highest s_A value (73,312 m²/nmi² - per 1 nmi EDSU) observed in the survey in 2021 was recorded by *Celtic Explorer* on the slope in the southern part of stratum 3 (Figure 8c). The second highest density value for the combined survey was also found in the same area in the eastern part of the northern slope of Porcupine Bank (stratum 2). Example echograms are provided in Figures 8a, 8b, 8g, showing high density layers of blue whiting extending onto the shelf area on the Porcupine Bank. Juvenile blue whiting, observed as weak scattering layers were found in the northern stratum of South Faroes and Faroe – Shetland Channel (Figure 8d).

The vertical distribution of blue whiting observed in 2021 did not extend deeper than 750 m as observed in 2018 and so were considered vertically contained in the insonified layer.

Stock size

The estimated total stock biomass of blue whiting for the 2021 international survey was 2.4 million tonnes, representing an abundance of $36.9x10^9$ individuals (Table 4). Spawning stock was estimated at 2.3 million tonnes and $18.1x10^9$ individuals (Table 5).

Stock composition

Survey samples show the age range of 1 to 13 years were observed during the survey.

The main contribution to the spawning stock biomass was composed of the age groups 5, 7 and 6 years representing 63% of the total. Five year olds (2016 year-class) being most abundant (20%), followed by the 7-year-olds (17%) and lastly the 6-year-olds (16%) (Table 5).

The highest mean lengths of blue whiting were caught in Stratum 1 and 7 (Figure 9). High mean weights were also found in this area but two samples in the northern part (Stratum 3 and 4) also had large blue whiting in relation to weight (Figure 10). Highest mean weight in 2021 was in Stratum 7 (Porcupine Seabight) representing 136g.

This year different age groups dominated in different strata (Figure 12). The oldest and largest fish were found in the southern part of the survey area. In the western and southern part of the Porcupine area (Strata 1 and 7) six-year olds (2015 year-class) dominated. On the northern slope of Porcupine (Stratum 2) two-year olds were the second most important age group, but still five-year olds were dominant. In the northern part of the survey area (Strata 4 and 6) the youngest fish were present, and the 2020 year-class dominated. In the core area (Stratum 3) three, five and seven-year olds were approx. at the same level with 15-16% of the estimate each. (Figure 12). The proportion of the different age groups in the total estimate in 2021 were considered evenly distributed and well represented from 1-7 years (Figure 13).

An uncertainty estimate at age based on a comparison of the abundance estimates was calculated for IBWSS for years 2018, 2019 and 2021 using StoX (Figure 11). By comparing the estimates from 2018 to 2021 it appears that good cohort tracking is achieved in the survey for some year classes. For example, the relative abundance of four year olds in 2018 (2014-year class) was high; the strong abundance of this cohort is also seen in 2019 as five year olds, and to some extent in 2021 as seven year olds. Similarly, the 2015 year-class were picked up as three-year olds in 2018, and subsequently the four and six year olds in 2019 and 2021 respectively are relatively strong. The CV of the abundant age groups 3 to 7 was below 0.25 in 2019 (Figure 11).

The CV of the total estimate of both biomass and abundance were 0.14, which is lower than the years before (0.16 - 0.17)

The survey time series (2004-2021) of TSN and TSB are presented in Figures 14 and 15 respectively and Table 6.

Hydrography

A total of 102 CTD casts were undertaken over the course of the survey (Table 1). Horizontal plots of temperature and salinity at depths of 50 m, 100 m, 200 m and 500 m as derived from vertical CTD casts are displayed in Figures 16-19 respectively. A decrease in salinity observed in 2017 persisted through 2018 and 2019, but seems to have reversed again in 2020 with an increasing trend (K.M. Larsen, pers. comm., Faroe Marine Research Institute). This is thought to have limited the western extent of the blue whiting spawning distribution on the Rockall and Hatton Bank areas in recent years.

Mesopelagic fish

Echogram scrutinisation for mesopelagic fish species was conducted by participants during the survey and included in uploads to the ICES database. However, due to the complexities involved and issues regarding representative trawl catches these data are considered as experimental and outputs reported to the ICES database should be treated as such.

Concluding remarks

Main results

- Weather conditions were regarded as exceptionally poor and all vessels experienced multiple days of downtime, except for the Spanish vessel working in the Porcupine Seabight. This considered, the stock was regarded as suitably contained within the survey area.
- The total area surveyed and acoustic sampling effort (miles) was the same as 2019.
- Overall, biological sampling saw an increased number of both measured and aged individuals compared to 2019.
- The International Blue Whiting Spawning Stock Survey 2021 shows a 44% decrease in total stock biomass and a corresponding 46% decrease in total abundance when compared to the 2019 estimate.
- The survey was carried out over 19 days, below the 21-day time window target. With core areas covered well by multiple vessels.
- Estimated uncertainty around the total stock biomass was lower than in 2019, CV=0.14 compared to 0.17.
- The stock biomass within the survey area was dominated by 5, 6 and 7-year-old fish contributing 61% of total stock biomass.
- There was no evidence of blue whiting below 750 m
- Immature fish (mainly 1-year-old) represent 3.6% of the TSB and 10% of TSN.
- The harmonisation of reporting of mesopelagic fish began in earnest and will be developed within the IBWSS survey over the coming years to report abundance and biomass of identified target groups.

Interpretation of the results

- The group considers the 2021 estimate of abundance as robust. Good stock containment was achieved for both core and peripheral strata. Sampling effort (biological and acoustic) was comparable to previous years.
- The bulk of SSB was distributed from the northern edge of the Porcupine Bank and continued northwards through the Rockall Trough and the Hebrides.
- The Northern migratory stock and the Porcupine Seabight; Spatio-temporal survey data and biological data from trawl hauls (RV *Vizconde de Eza*) were comparable in terms of length cohorts. The eastward extension of the survey area is necessary to contain the northern stock. Comparative analysis of age readings is required.

Recommendations

- The group recommends that coverage in the western Rockall/Hatton Bank (stratum 5) should be carried out based on real time observations. That is, effort should not be expended where no aggregations are evident and transects are terminated when no blue whiting is observed for 15 nmi consistent ‘clear water’ miles. This applies to peripheral regions to the west of the Rockall and Hatton Bank areas.

- To facilitate the process of calculating global biomass the group requires that all data be made available at least 72 hours in advance of the meeting start date and made available through the ICES database.
- Hydrographic and Plankton data along with Log book files formats should still be submitted in the PGNAPES format.
- The group recommends that the process of producing output reporting tables, figures and maps from StoX outputs files (StoX 3.2) are standardised and developed by WGIPS for wider use.
- Through WGIPS, agreement needs to be reached on the synchronisation of reporting blue whiting maturity by participants and how this is handled within the ICES database.
- It is recommended that the effective timing of the survey point is maintained to begin around the 20th March in 2022.

Achievements

- Acoustic sampling effort (track miles), trawling effort and biological metrics of blue whiting were comparable to 2019.
- All survey data were uploaded to the ICES trawl-acoustic database in advance of the post cruise meeting.
- Mesopelagic fish scrutinisation was carried out by all participants using the guidelines developed during WGIPS.
- Directed trawling on mesopelagic layers was carried out using a range of sampling nets (MiK and Macrozooplankton). Although still experimental, this is a further step towards reporting.

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Table 1. Country and vessel specific details, IBWSS March-April 2021.

	Celtic Explorer	Jákup Sverri	Tridens	Vendla	Vizconde de Eza
Trawl dimensions					
Circumference (m)	768	852	860	832	752
Vertical opening (m)	50	45	30-70	45	30
Mesh size in codend (mm)	20	45	40	40	20
Typical towing speed (kts)	3.5-4.0	3.0-4.0	3.5-4.0	3.5-4.0	4.0-4.5
Plankton sampling					
Sampling net	-	WP2 plankton net	-	WP2 plankton net	
Standard sampling depth (m)	-	200	-	400	
Hydrographic sampling					
CTD Unit	SBE911	SBE911	SBE911	SBE25	SBE25
Standard sampling depth (m)	1000	1000	1000	1000	520

Table 2. Acoustic instruments and settings for the primary acoustic sampling frequency, IBWSS March-April 2021.

	Celtic Explorer	Jákup Sverri	Tridens	Vendla	Vizconde de Eza
Echo sounder	Simrad EK 60	Simrad EK80	Simrad EK 60	Simrad EK 80	Simrad EK 80
Frequency (kHz)	**38**, 18, 120, 200	18, **38**, 70, 120, 200, 333	18, **38**, 70, 120, 200, 333	18, **38**, 70	**38**, 18, 70, 120, 200
Primary transducer	ES 38B	38-7	ES 38B	ES 38B	ES 38B
Transducer installation	Drop keel	Drop keel	Drop keel	Drop keel	Drop keel
Transducer depth (m)	8.7	6	8	8.5	7.5
Upper integration limit (m)	20	15	15	15	15
Absorption coeff. (dB/km)	9.8	10.7	9.5	9.5	9.2
Pulse length (ms)	1.024	1.024	1.024	1.024	1.024
Band width (kHz)	2.43	3.06	2.43	2.43	2.43
Transmitter power (W)	2000	2000	2000	2000	2000
Angle sensitivity (dB)	21.9	21.9	21.9	21.9	21.9
2-way beam angle (dB)	-20.6	-20.4	-20.6	-20.7	-20.6
Sv Transducer gain (dB)			27.28		
Ts Transducer gain (dB)	25.65	26.96	27.27	25.18	24.68
s_A correction (dB)	-0.64	-0.16	-0.01	-0.66	-0.54
3 dB beam width (dg)					
alongship:	6.97	6.55	6.86	7.01	6.90
athw. ship:	7.06	6.45	6.89	6.90	7.10
Maximum range (m)	1000	750	750	750	1000
Post processing software	Echoview	LSSS	LSSS	LSSS	Echoview

Table 3. Survey effort by vessel, IBWSS March-April 2021. Directed mesopelagic sampling 150-350 m depth layer) was carried out by the RV *Celtic Explorer* and RV *Tridens* using macrozooplankton and Mik net trawls respectively.

Vessel	Effective survey period	Length of cruise track (nmi)	Trawl stations	CTD stations	Mesopelagic sampling	Aged fish	Length-measured fish
Celtic Explorer	21/3-04/4	2123	15	19	3	550	6571
Jákup Sverri	25/3-5/4	1100	3	19	-	300	668
Vendla	25/3- 5/4	2100	9	19	-	239	800
Tridens	18/3-3/4	1574	13	31	5	1000	2836
Vizconde de Eza	18/3-23/3	897	5	14	-	-	1144
Total	28/3-11/4	7794	45	102	8	2089	12019

Table 4. Abundance and biomass estimates of blue whiting by strata in 2019 and 2018. IBWSS March-April 2021.

		2021				2019				Difference 2021-2019	
Strata	Name	TSB (10^3 t)	TSN (10^9)	% TSB	% TSN	TSB (10^3 t)	TSN (10^9)	% TSB	% TSN	TSB	TSN
1	Porcupine Bank	270	2 232	11.4	11.1	870	8 350	20.7	22.6	-69 %	-73 %
2	N Porcupine Bank	746	6 500	31.6	32.3	572	5 692	13.6	15.4	30 %	14 %
3	Rockall Trough	977	8 094	41.4	40.2	2 555	21 116	60.9	57.2	-62 %	-62 %
4	South Faroes	154	1 413	6.5	7.0	125	1 039	3.0	2.8	24 %	36 %
5	Rockall Bank	41	300	1.7	1.5	29	272	0.7	0.7	43 %	10 %
6	Faroe/Shetland Ch.	34	595	1.5	3.0	47	448	1.1	1.2	-27 %	33 %
7	Porcupine Seabight	139	984	5.9	4.9	0	0				
	Total	2 361	20 119	100	100	4 198	36 918	100	100	-44 %	-46 %

Table 5. Survey stock estimate of blue whiting, IBWSS March-April 2021.

Length (cm)	1 2020	2 2019	3 2018	4 2017	5 2016	6 2015	7 2014	8 2013	9 2012	10+	Number (10^6)	Biomass (10^6 kg)	Mean weight (g)	Prop Mature
	Age in years (year class)													
14-15										0	0	0	0.0	0
15-16	24										24	1	21.7	84
16-17	386										386	9	24.0	12
17-18	476										476	13	27.7	6
18-19	403	9									412	13	32.2	2
19-20	228										228	9	39.0	0
20-21	177										177	8	45.1	3
21-22	155										155	8	52.4	0
22-23	67	1	17								85	5	62.0	21
23-24	34	167	41								242	17	68.1	86
24-25		498	327	22	18						865	66	76.5	97
25-26		746	585	154	83	6					1 574	134	85.0	95
26-27		468	685	545	713	9	1	0			2 421	225	92.8	97
27-28		139	483	568	686	160	52	4			2 092	223	106.5	99
28-29		62	255	539	808	573	223	19	1		2 479	294	119.0	100
29-30			38	187	454	681	799	5	1		2 165	287	132.4	100
30-31		6	86	82	586	621	806	40	76		2 302	326	142.1	100
31-32			28	127	286	581	606	25	35	22	1 712	267	155.5	100
32-33				41	225	245	514	21			1 047	176	168.3	100
33-34				4	16	158	238	105			521	98	188.8	100
34-35				2	28	82	69	136	5	21	343	71	206.9	100
35-36				2	9	27	38	55	10	40	181	41	227.4	100
36-37				2		49	12	19	13	1	94	25	254.4	100
37-38						5	7	12	32		57	17	280.3	100
38-39						1		21		8	31	9	296.5	100
39-40							4			8	12	4	345.3	100
40-41									15		15	6	386.3	100
41-42							4				4	1	329.0	100
42-43										6	6	3	432.0	100
43-44										6	6	0	556.0	100
44-45							6				6	3	448.7	100
TSN(mill)	1 948	2 095	2 545	2 275	3 914	3 197	3 379	463	189	114	20 119			
TSB(1000 t)	68.8	179.3	243.9	265.0	470.0	469.0	504.1	98.5	35.2	20.9	2 357.3			
Mean length(cm)	18.1	25.0	26.1	27.5	28.3	30.0	30.5	33.3	33.0					
Mean weight(g)	35	84	98	111	122	144	152	199	206					
% Mature	6	96	95	100	100	100	100	100	100	100				
SSB (1000kg)	3.9	172.0	232.3	264.8	469.5	469.0	504.1	98.5	35.2	20.9	2 270.1			
SSN (mill)	109.1	2010.0	2423.6	2273.4	3910.1	3197.2	3379.0	462.6	189.1	113.7	18 067.7			

Table 6. Time series of StoX abundance estimates of blue whiting (millions) by age in the IBWSS. Total biomass in last column (1000 t).

	Age										
Year	1	2	3	4	5	6	7	8	9	10+	TSB(1000 t)
2004	1 097	5 538	13 062	15 134	5 119	1 086	994	593	164		3 505
2005	2 129	1 413	5 601	7 780	8 500	2 925	632	280	129	23	2 513
2006	2 512	2 222	10 858	11 677	4 713	2 717	923	352	198	31	3 512
2007	468	706	5 241	11 244	8 437	3 155	1 110	456	123	58	3 274
2008	337	523	1 451	6 642	6 722	3 869	1 715	1 028	269	284	2 639
2009	275	329	360	1 292	3 739	3 457	1 636	587	250	162	1 599
2010*											
2011	312	1 361	1 135	930	1 043	1 712	2 170	2 422	1 298	250	1 826
2012	1 141	1 818	6 464	1 022	596	1 420	2 231	1 785	1 256	1 022	2 355
2013	586	1 346	6 183	7 197	2 933	1 280	1 306	1 396	927	1 670	3 107
2014	4 183	1 491	5 239	8 420	10 202	2 754	772	577	899	1 585	3 337
2015	3 255	4 565	1 888	3 630	1 792	465	173	108	206	247	1 403
2016	2 745	7 893	10 164	6 274	4 687	1 539	413	133	235	256	2 873
2017	275	2 180	15 939	10 196	3 621	1 711	900	75	66	144	3 135
2018	836	628	6 615	21 490	7 692	2 187	755	188	72	144	4 035
2019	1 129	1 169	3 468	9 590	16 979	3 434	484	513	99	144	4 198
2020*											
2021	1 948	2 095	2 545	2 275	3 914	3 197	3 379	463	189	114	2 357

*Survey discarded.

Table 7. IBWSS survey effort time series.

Survey effort	Survey area (nmi²)	Transect n. miles (nmi)	Trawls	CTDs	Plankton	Bio sampling (WHB) Measured	Aged
2004	149 000		76	196			
2005	172 000	12 385	111	248	-	29 935	4 623
2006	170 000	10 393	95	201	-	7 211	2 731
2007	135 000	6 455	52	92		5 367	2 037
2008	127 000	9 173	68	161	-	10 045	3 636
2009	133 900	9 798	78	160	-	11 460	3 265
2010	109 320	9 015	62	174	-	8 057	2 617
2011	68 851	6 470	52	140	16	3 810	1 794
2012	88 746	8 629	69	150	47	8 597	3 194
2013	87 895	7 456	44	130	21	7 044	3 004
2014	125 319	8 231	52	167	59	7 728	3 292
2015	123 840	7 436	48	139	39	8 037	2 423
2016*	134 429	6 257	45	110	47	5 390	2 441
2017	135 085	6 105	46	100	33	5 269	2 477
2018	128 030	7 296	49	101	45	5 315	2 619
2019	121 397	7 610	38	118	17	6 228	1 938
2021	118 169	7 794	45	102	8	12 019	2 089

* End of Russian participation.

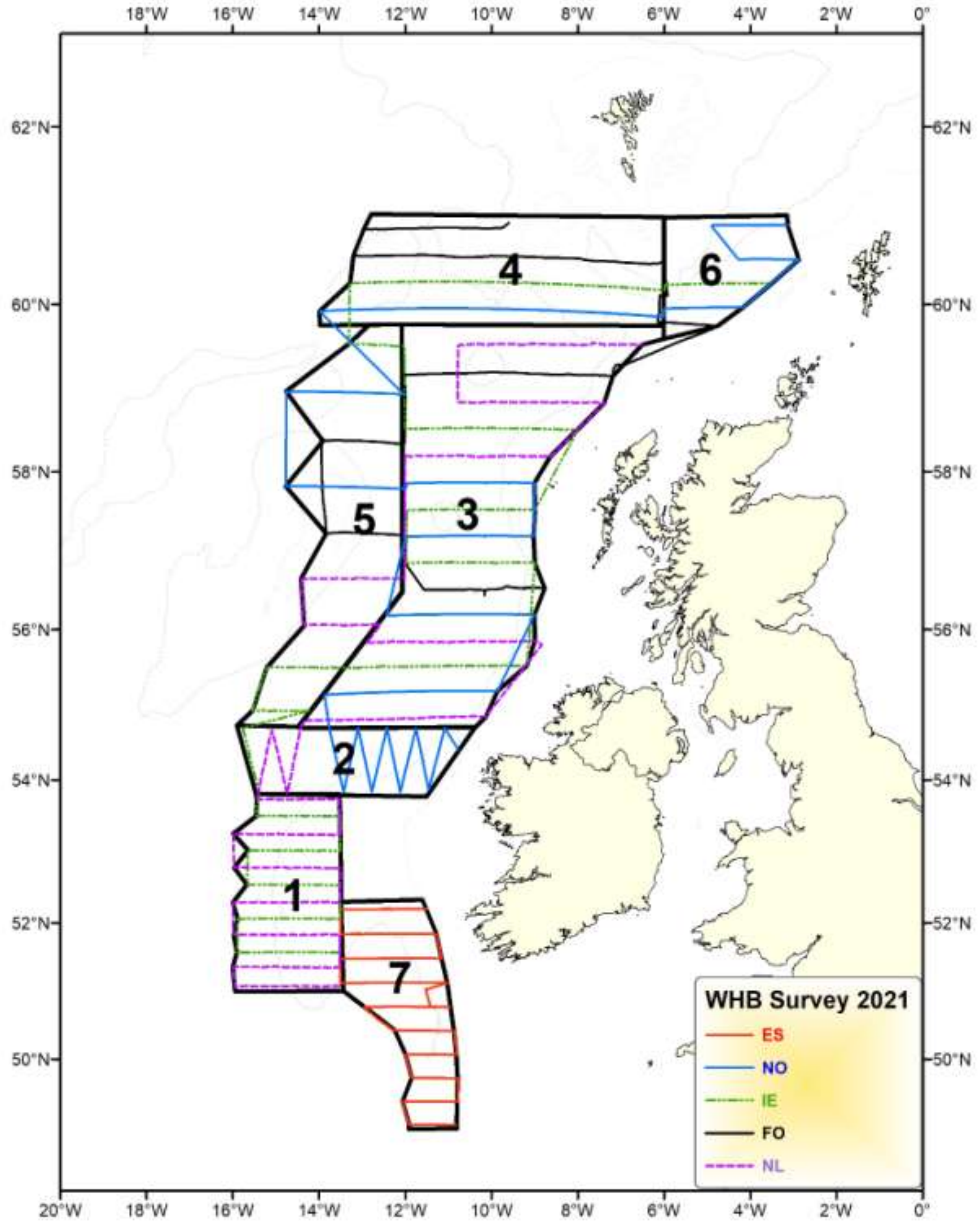


Figure 1. Strata and cruise tracks for the individual vessels (country) during the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021.

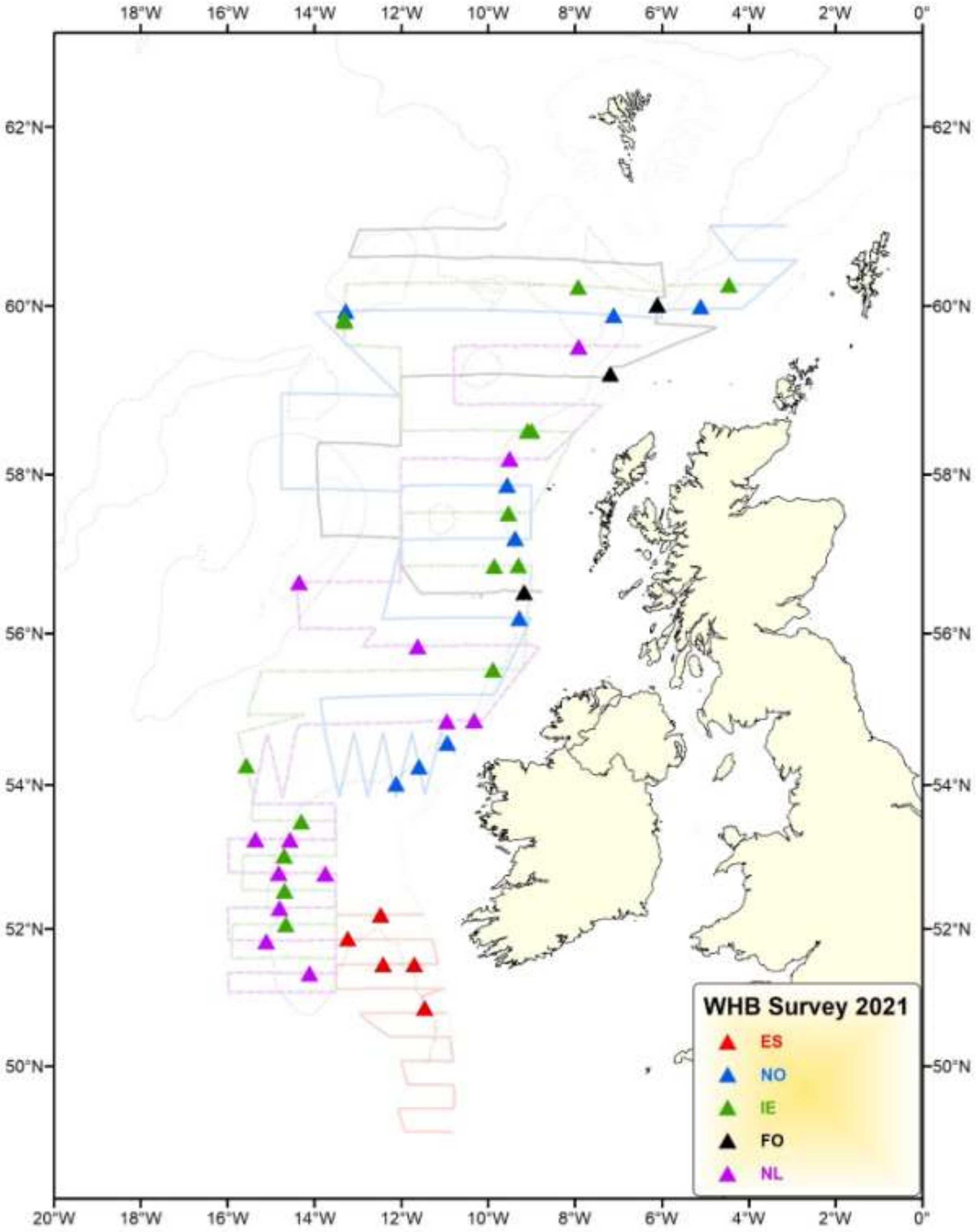


Figure 2. Vessel cruise tracks and trawl stations of the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021. ES: Spain (RV *Vizconde de Eza*); FO: Faroe Islands (RV *Jakúp Sverrí*); IE: Ireland (RV *Celtic Explorer*); NL: Netherlands (RV *Tridens)*; NO: Norway (FV *Vendla*).

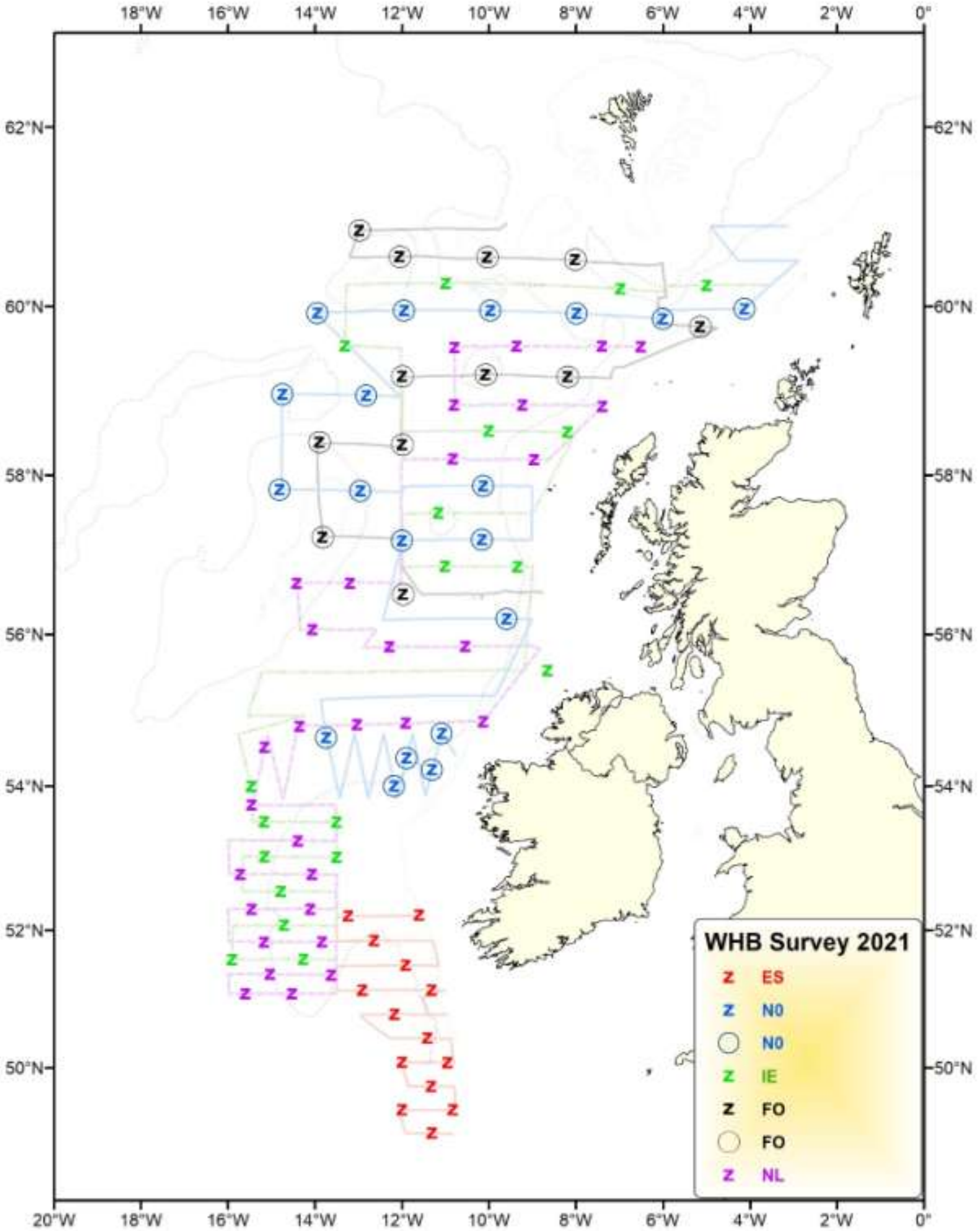


Figure 3. Vessel cruise tracks with hydrographic CTD stations (z) and WP2 plankton net samples (circles) during the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021. Colour coded by vessel.

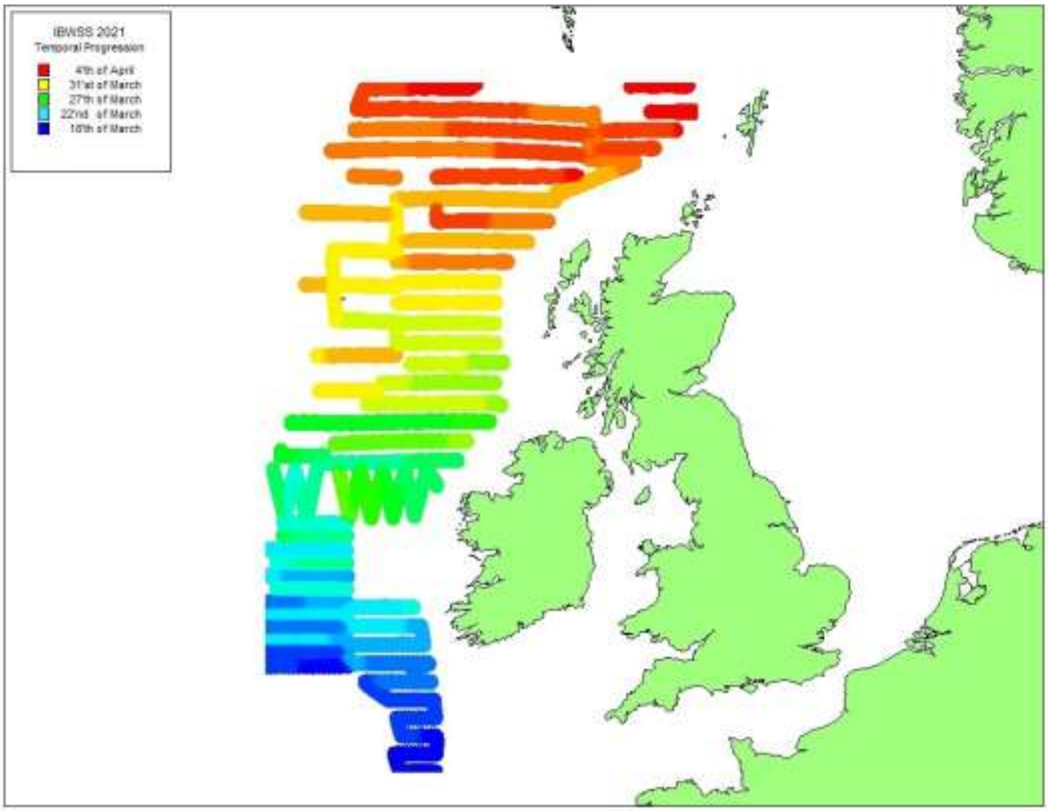


Figure 4. Temporal progression for the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021.

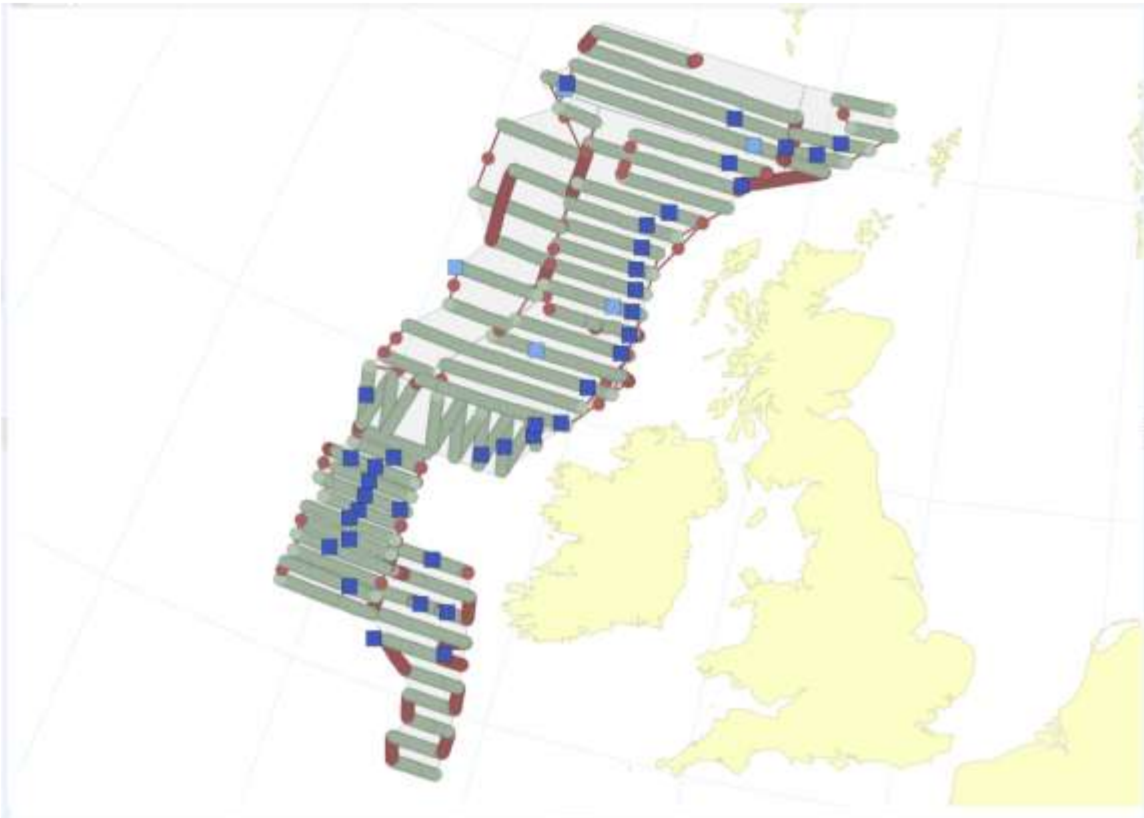


Figure 5. Tagged acoustic transects (green circles) with associated trawl stations containing blue whiting (dark blue squares) used in the StoX abundance estimation. IBWSS March-April 2021.

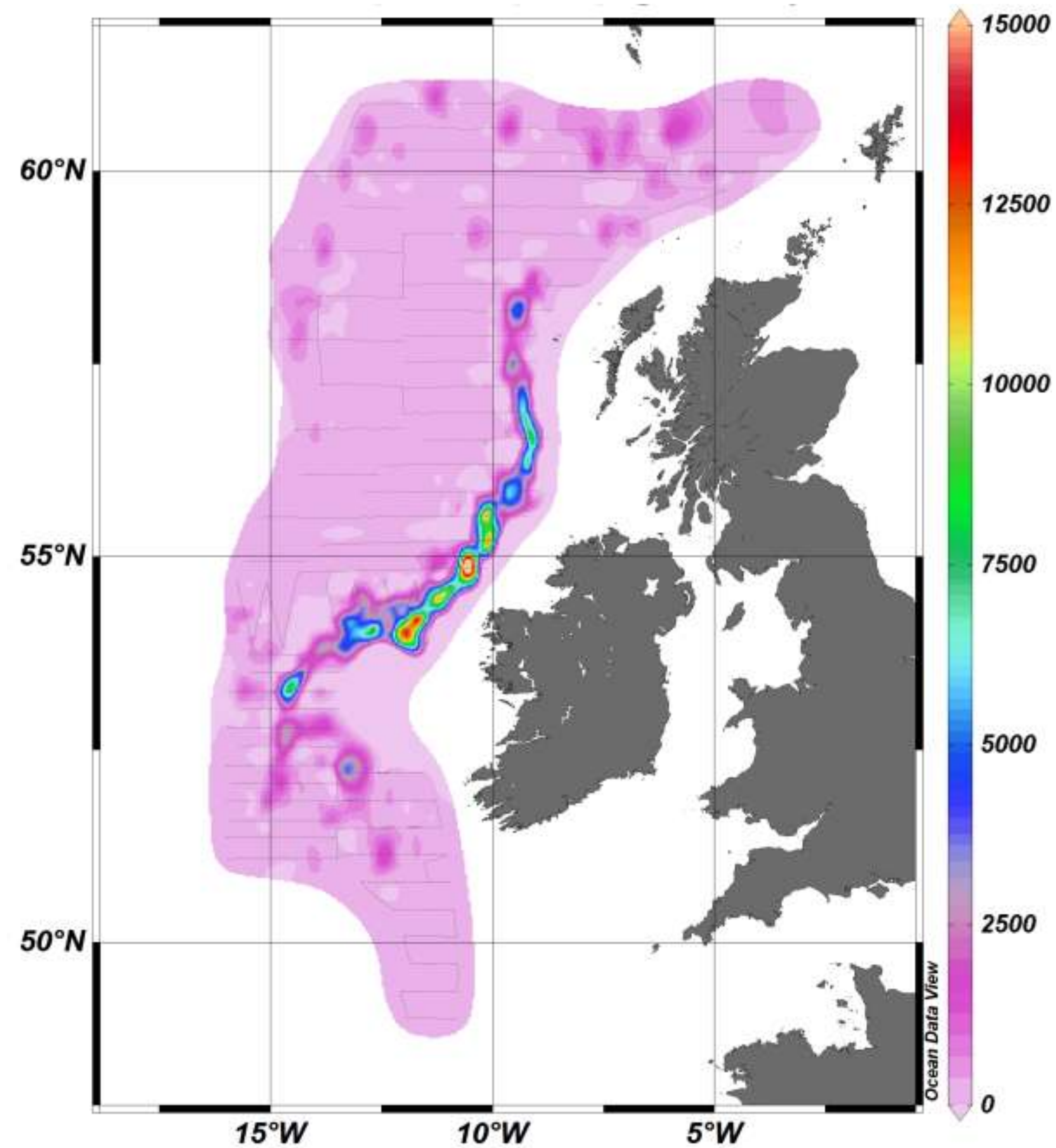


Figure 6. Acoustic density heat map (s_A m^2/nmi^2) of blue whiting during the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021.

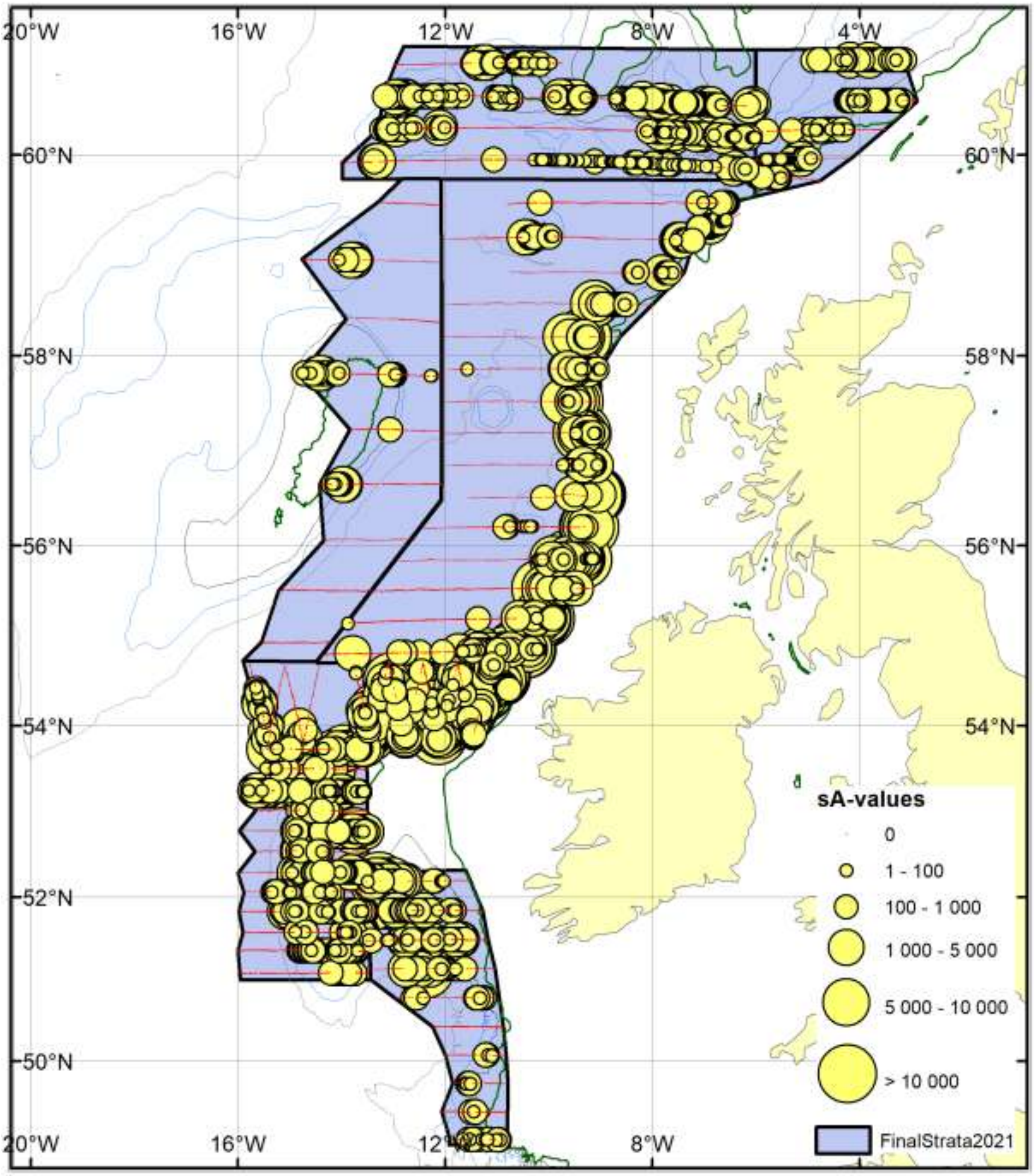
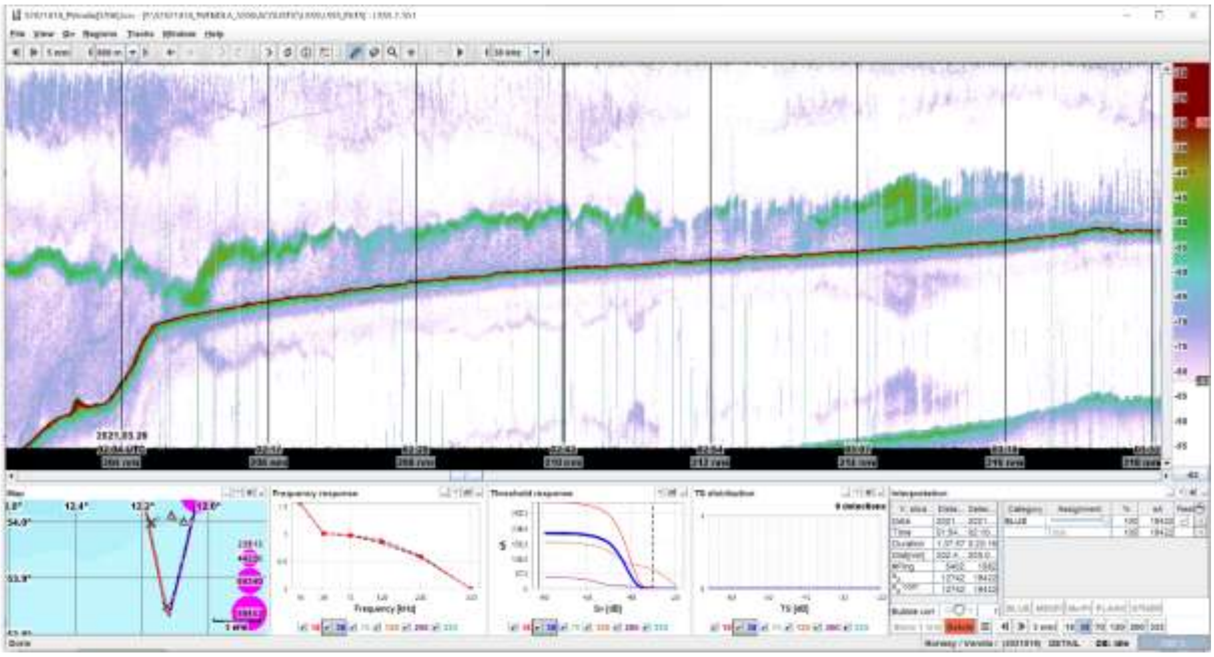
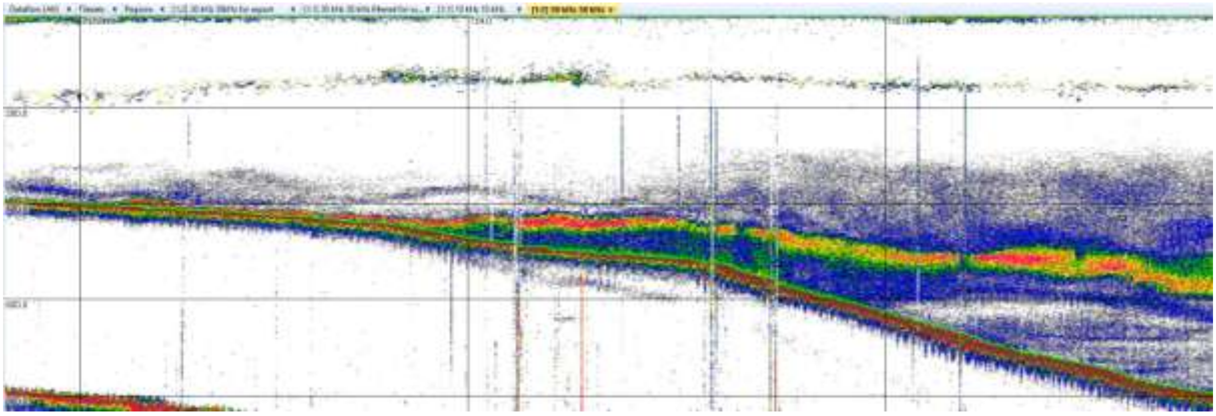


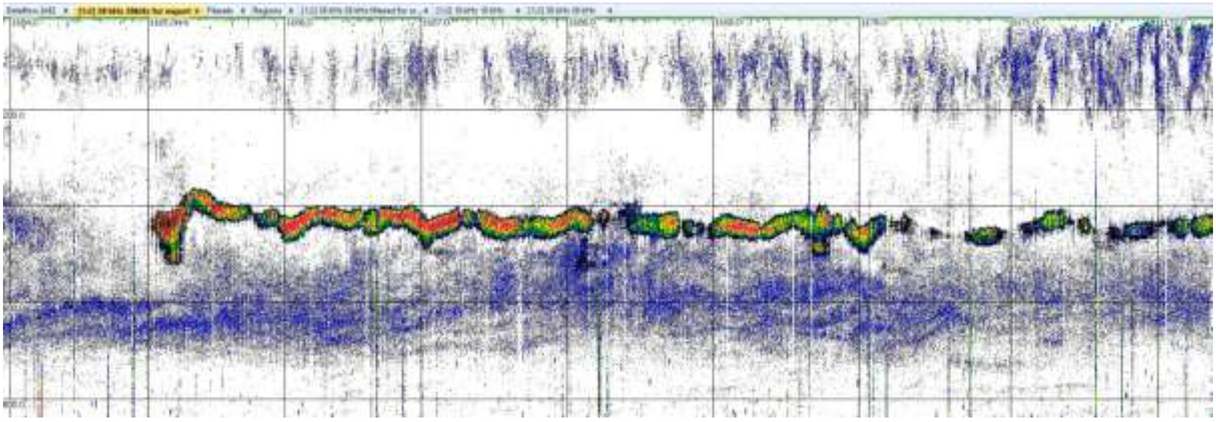
Figure 7. Map of proportional acoustic density (s_A m^2/nmi^2) of blue whiting by 1 nmi sampling unit. IBWSS March-April 2021.



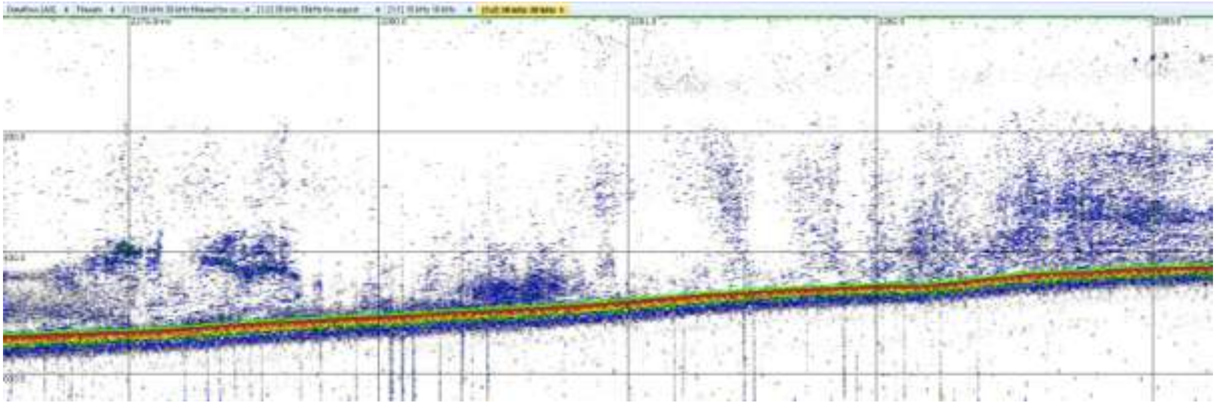
a) High density blue whiting per 1nmi log interval recorded on the northern slope of the Porcupine Bank area (Stratum 2) FV *Vendla*, Norway.



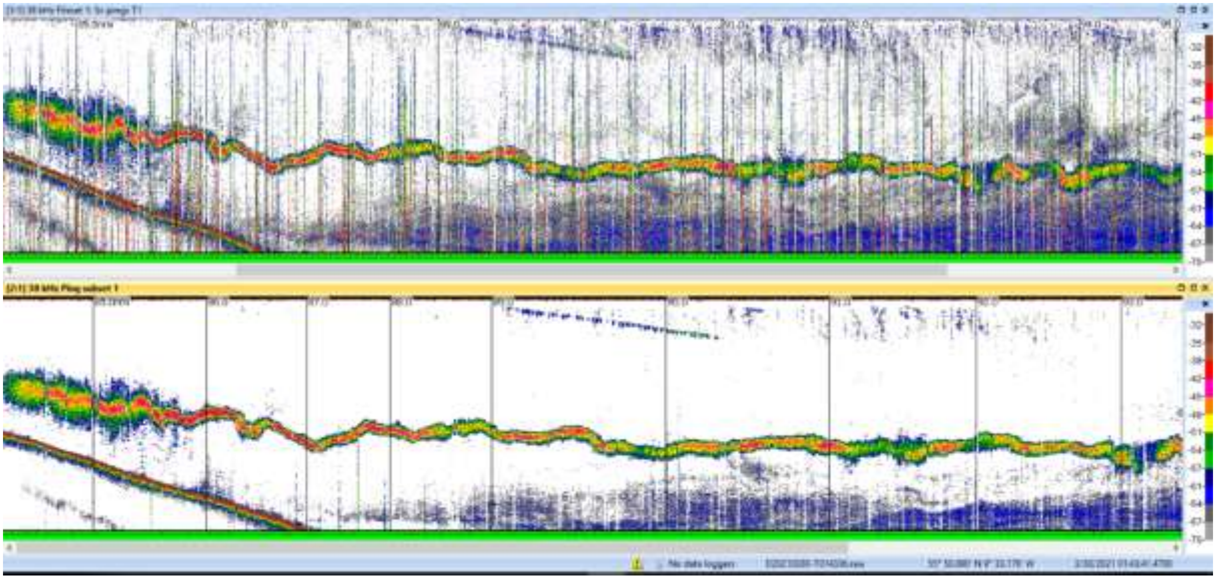
b) High density blue whiting layer per 1nmi log interval at 400- 600m recorded by the RV *Celtic Explorer* in the western Porcupine Bank area (strata 1).



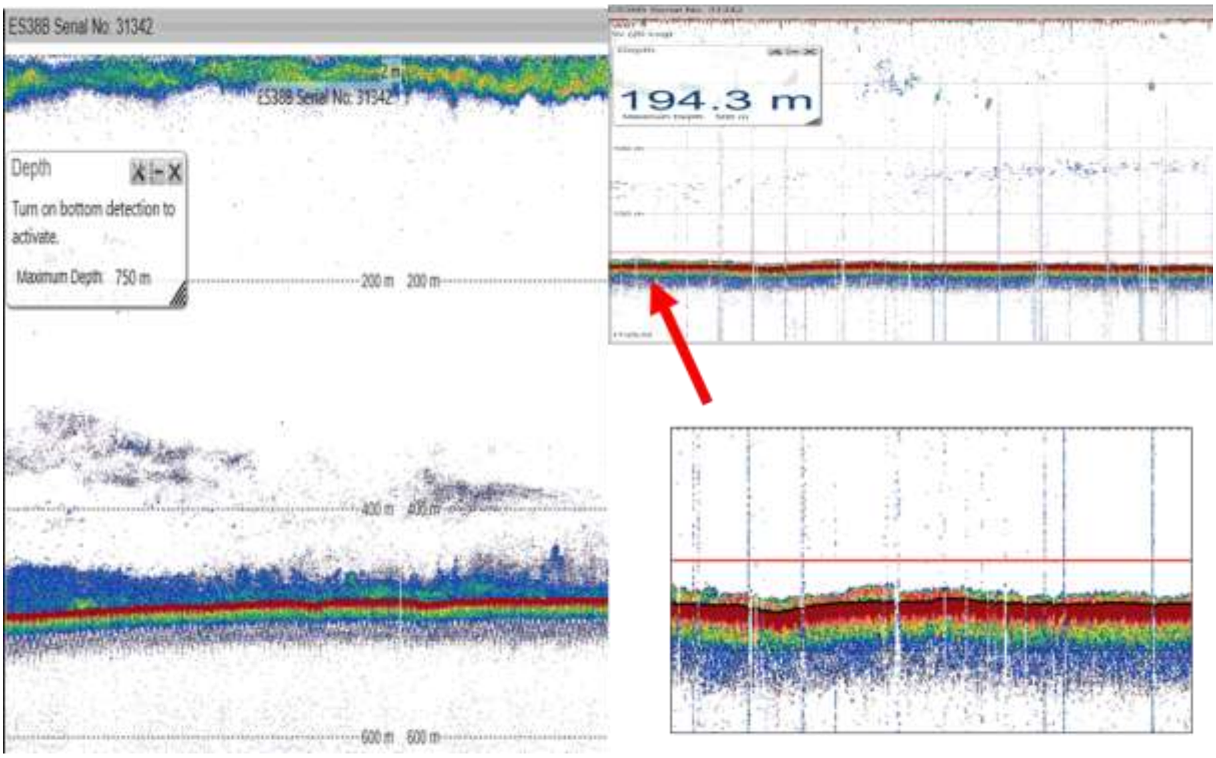
c) Single highest density blue whiting layer per 1nmi log interval (s_A value (73,312 m²/nmi²) observed during the survey recorded by the Celtic Explorer in the Rockall Trough area (Stratum 3) in 400 – 500 m.



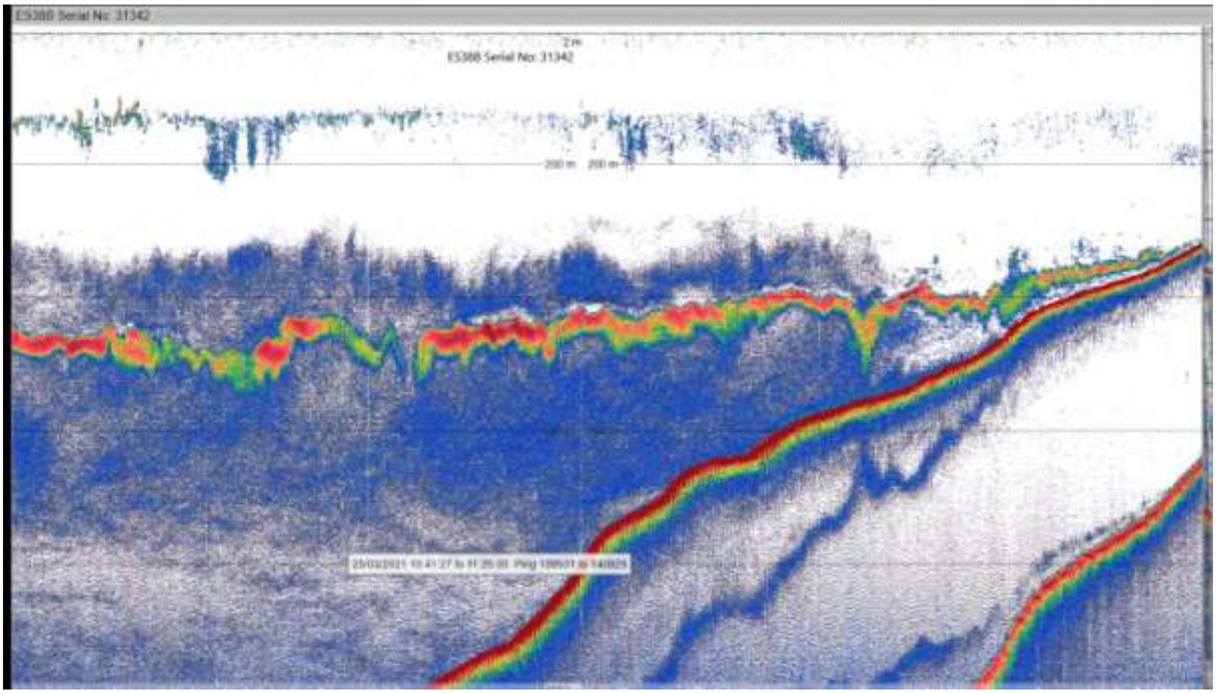
d) Weak scattering of predominantly juvenile blue whiting per 1 nmi log interval along the 400-500 m contour depth. This was an area that some of the fleet were fishing during the survey. Recorded by the RV *Celtic Explorer* in the Faroe – Shetland channel area (Stratum 6).



e) Blue whiting aggregations as observed by Tridens at the shelf edge (55.51N-9.00W). Above: without spike filtering. Below: after spike filtering. Test with spike filtering and removal of transmission loss, showed that there was no significant difference in NASC assigned to blue whiting before and after filtering (See annex 1). The weather conditions did not allow fishing.



f) Left: layer of blue whiting on Rockall Bank (*Tridens* – 19 March, haul1). Right: layer of grey gurnard on Rockall Bank (*Tridens* – 31 March, haul 11).



g) Blue whiting aggregations observed by *Tridens* at the edge of the continental shelf at 54.51N – 10.19W (25 March, haul 9).

Figure 8. Echograms of interest encountered during the IBWSS, March-April 2021. Vertical banding represents 1 nmi acoustic sampling intervals (EDSU). All echograms presented at 38 kHz.

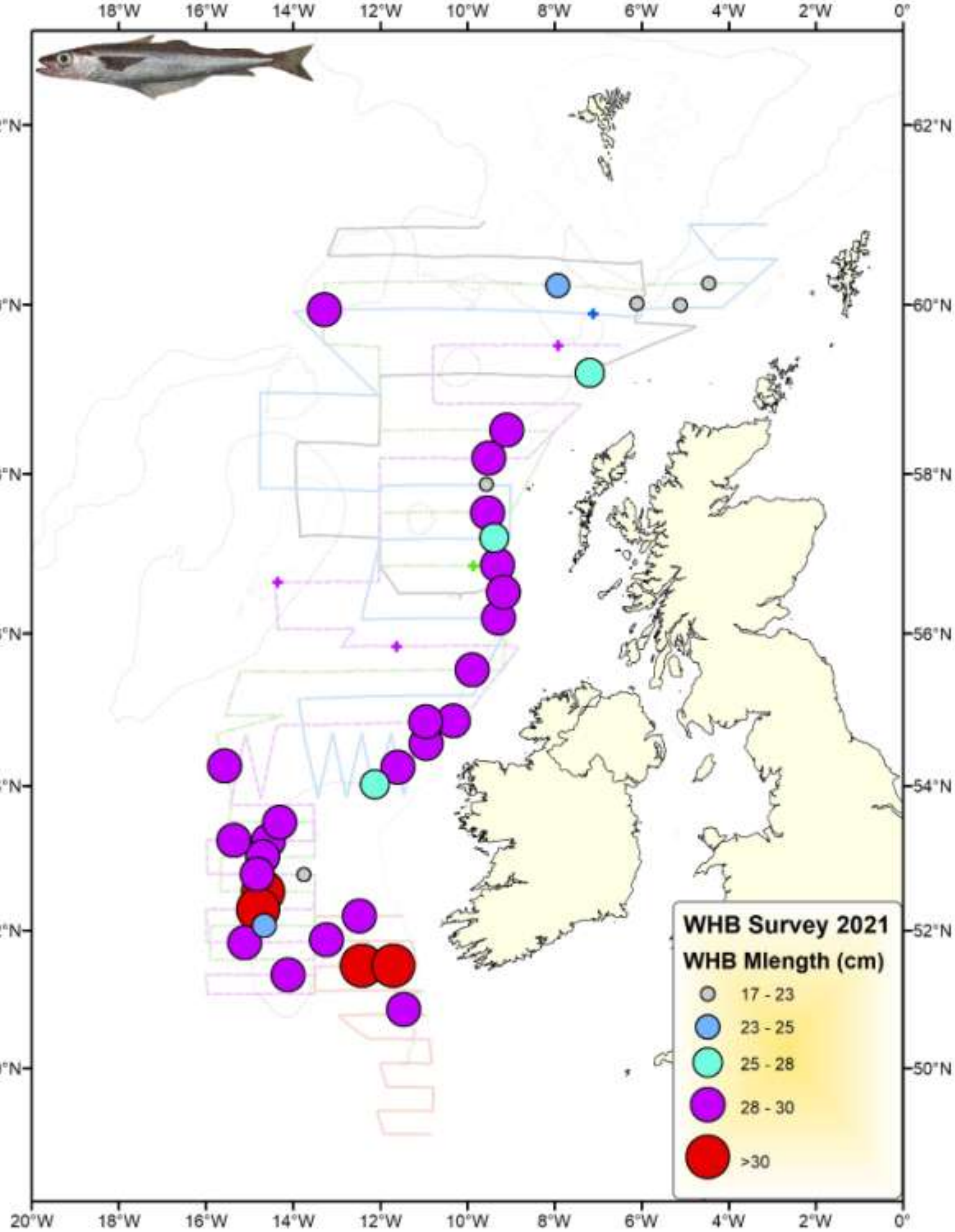


Figure 9. Combined mean length of blue whiting from trawl catches by vessel, IBWSS in March- April 2021. Crosses indicate hauls with zero blue whiting catches.

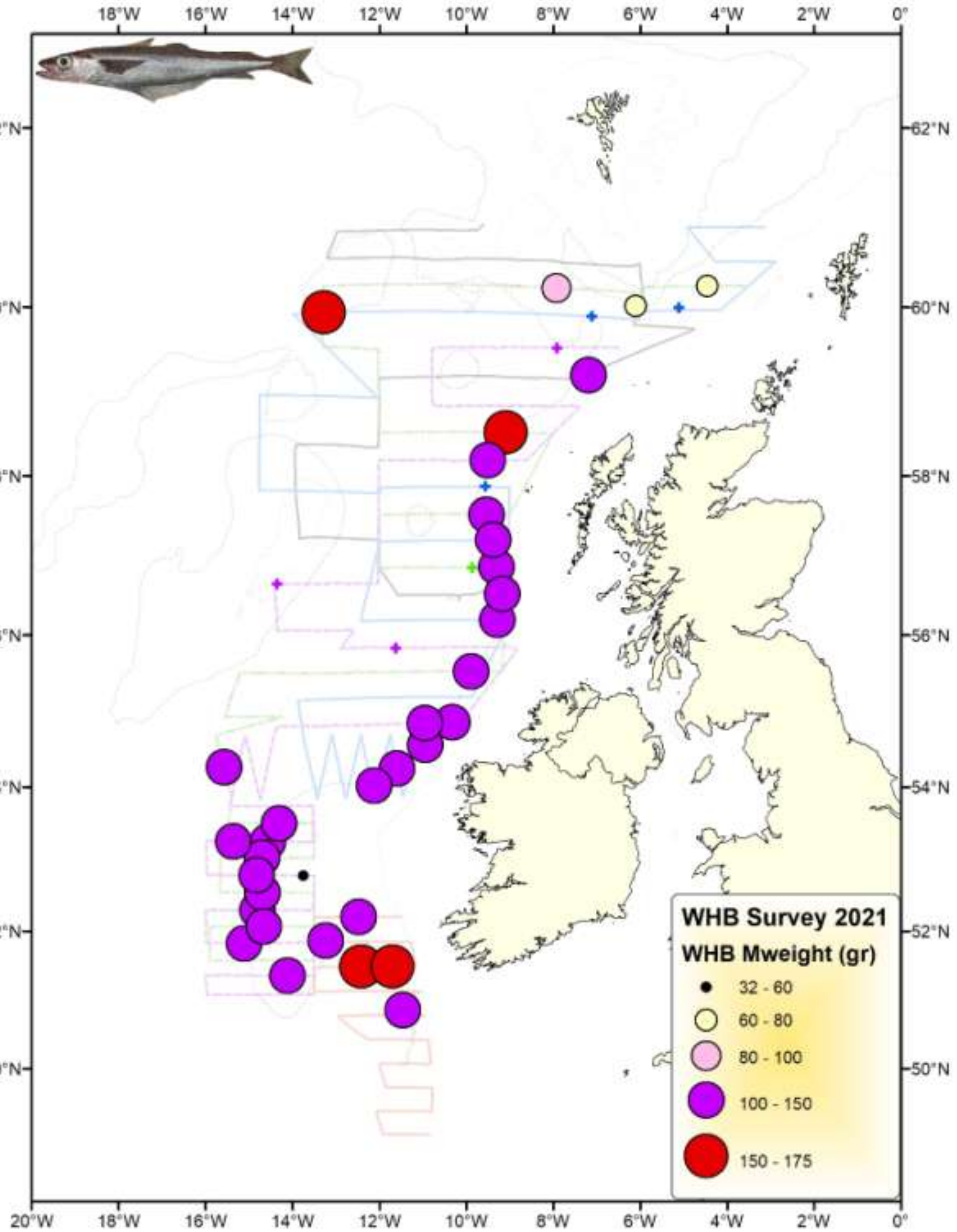


Figure 10. Combined mean weight of blue whiting from trawl catches, IBWSS March- April 2021. Crosses indicate hauls with zero blue whiting catches.

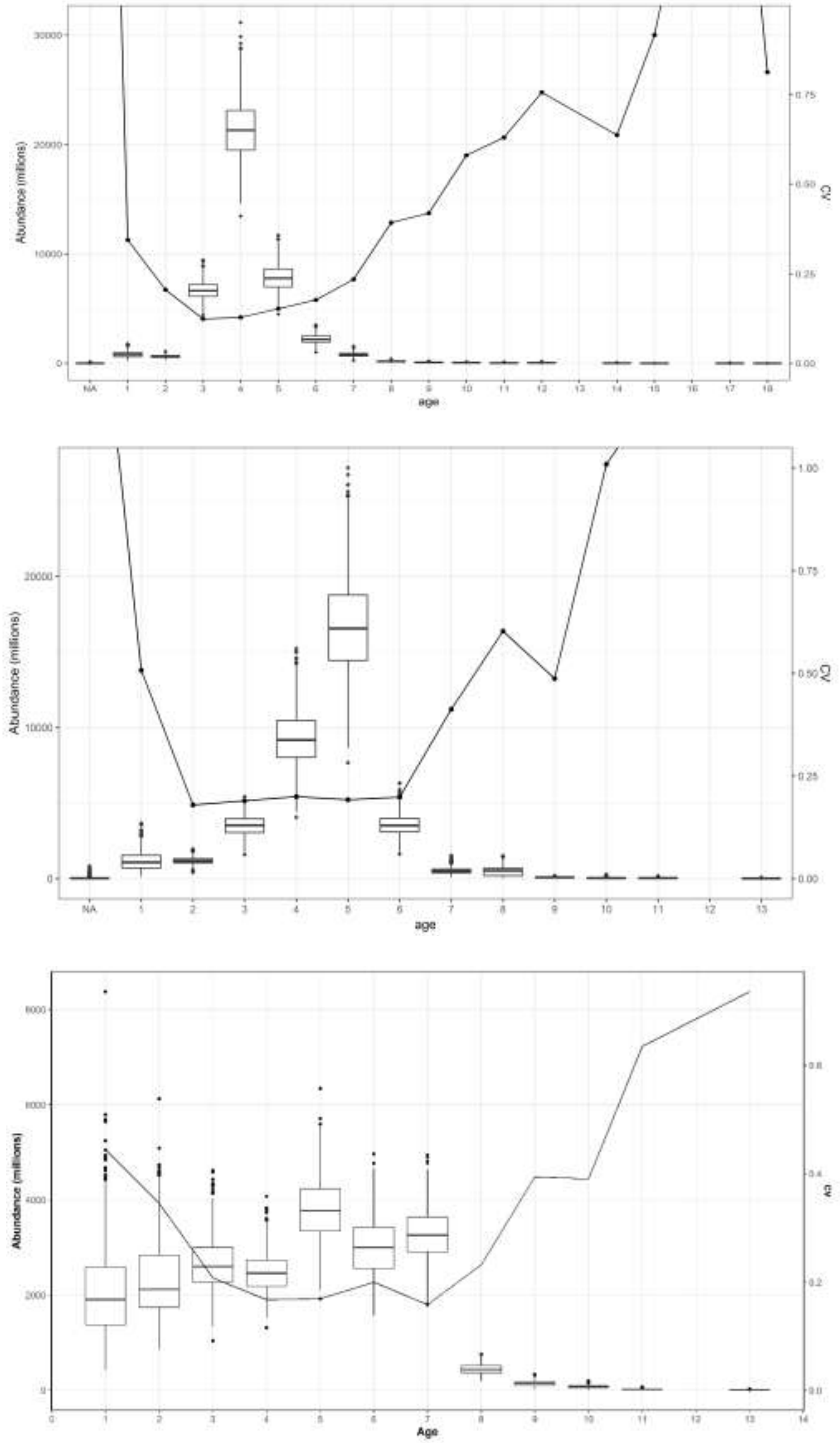


Figure 11. Blue whiting bootstrap abundance (millions) by age (left axis) and associated CVs (right axis) in 2018 (top panel), 2019 (middle panel) and 2021 (lower panel). From StoX.

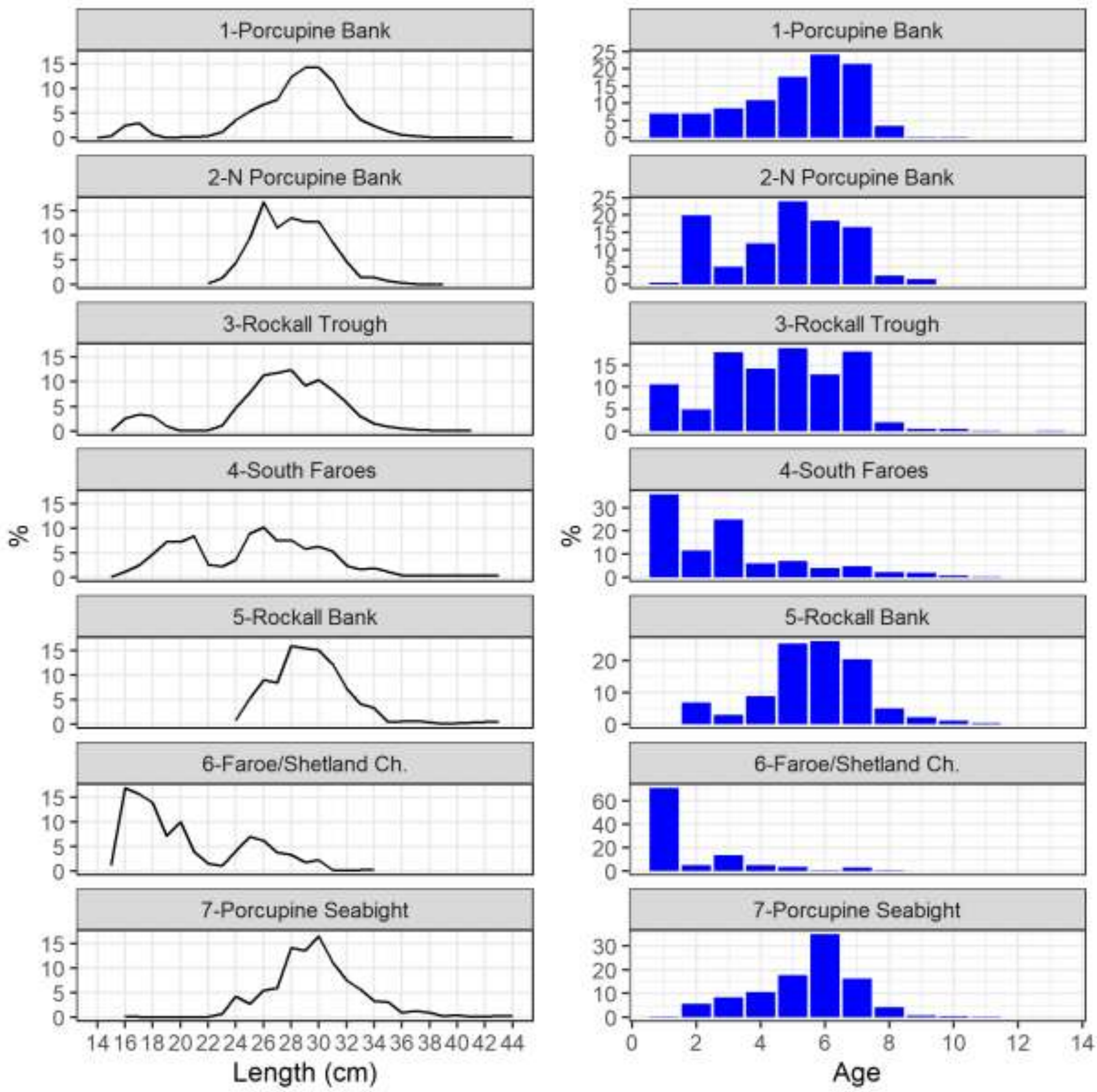


Figure 12. Length and age distribution (numbers) of blue whiting by survey strata. March-April 2021.

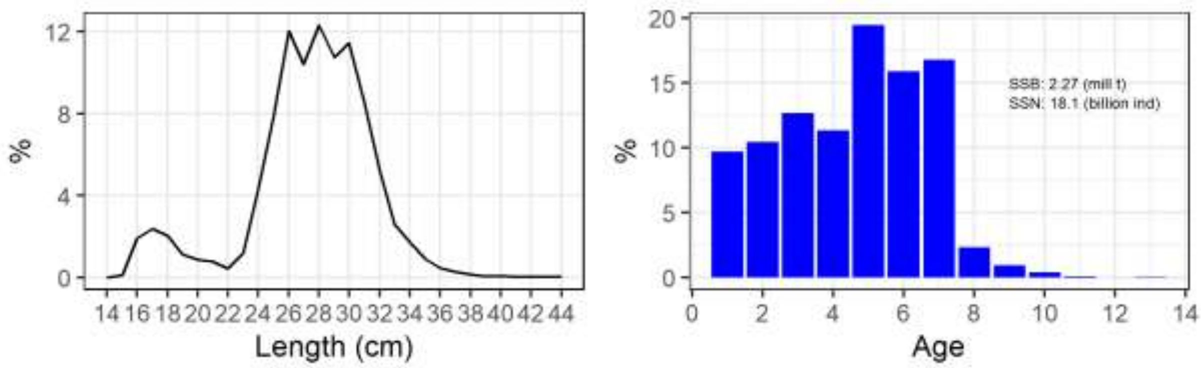


Figure 13. Length and age distribution (numbers) of total stock of blue whiting. March-April 2021.

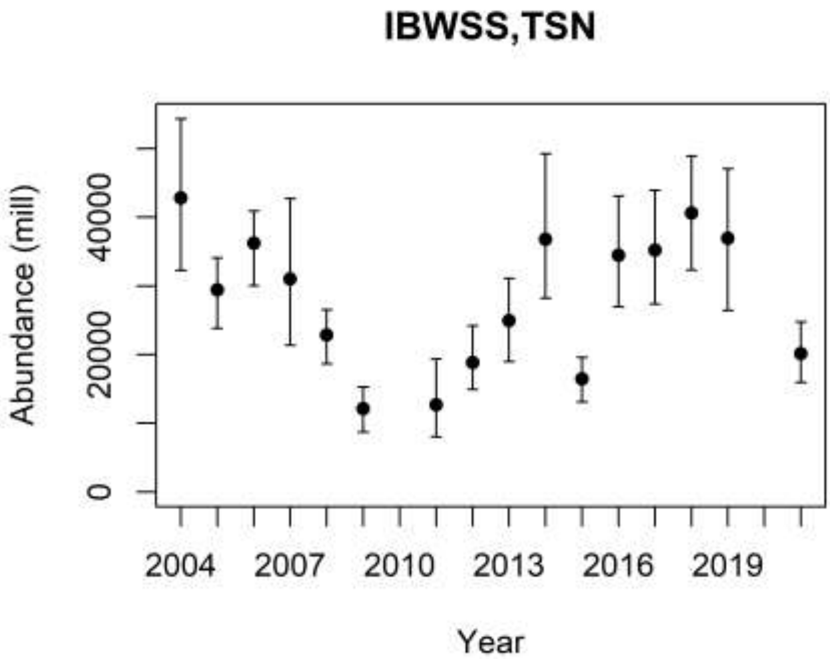


Figure 14. Time series of StoX survey indices of blue whiting abundance, 2004-2021, excluding 2010.

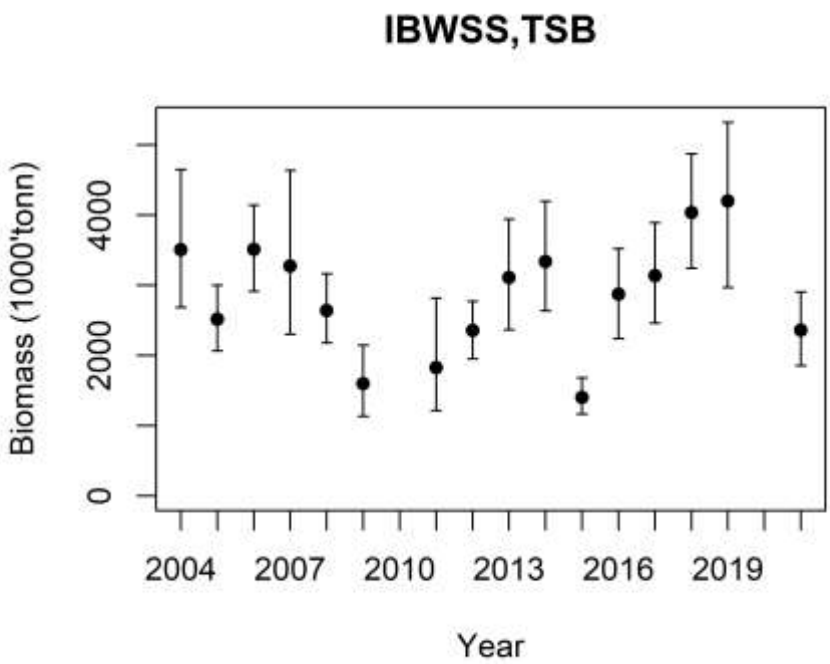


Figure 15. Time series of StoX survey indices of blue whiting biomass, 2004-2021, excluding 2010.

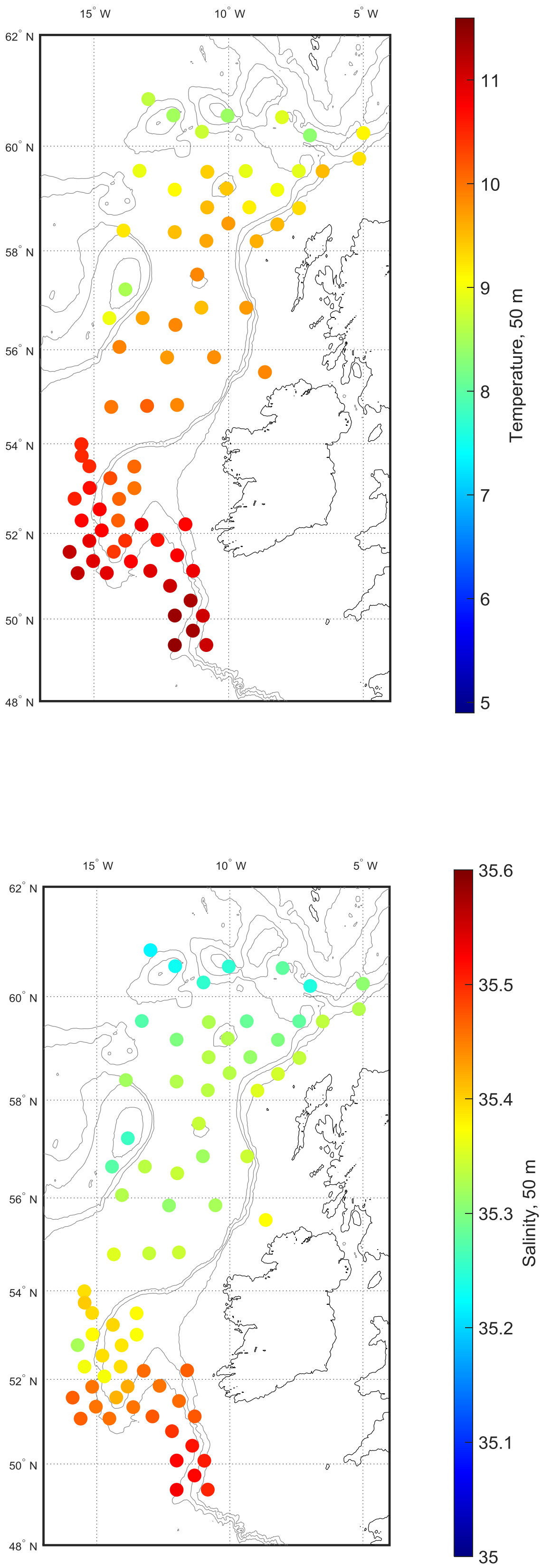


Figure 16. Horizontal temperature (top panel) and salinity (bottom panel) at 50 m subsurface as derived from vertical CTD casts. IBWSS March-April 2021.

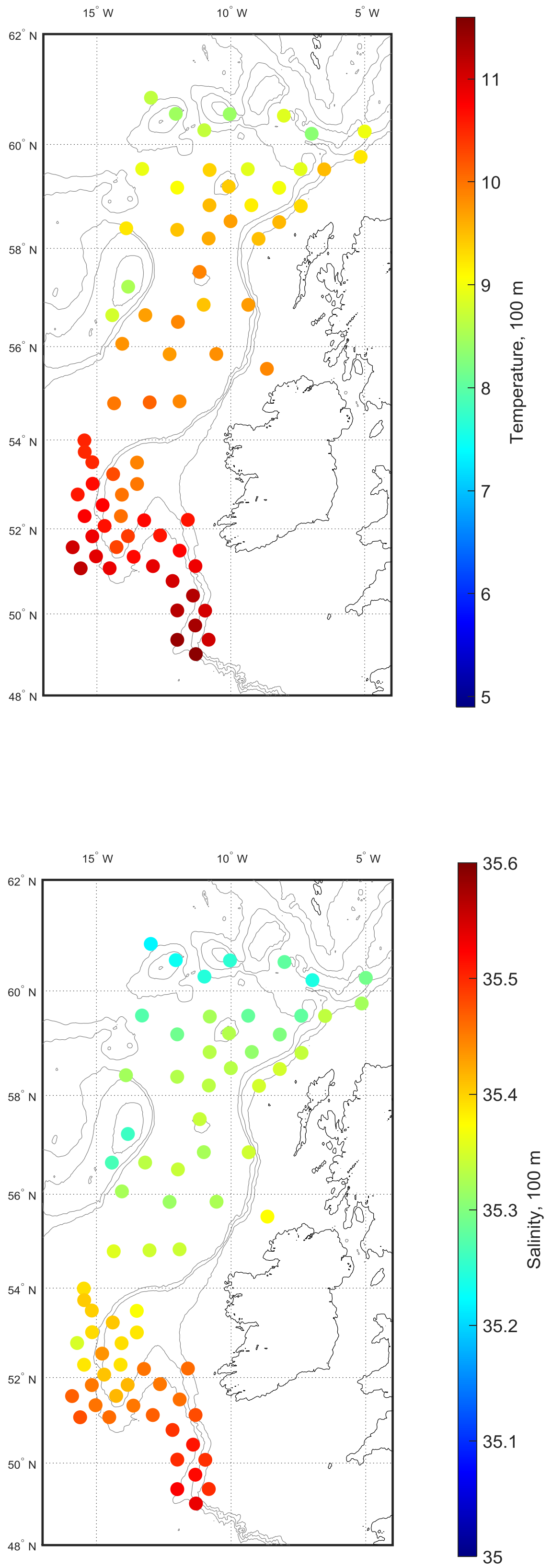


Figure 17. Horizontal temperature (top panel) and salinity (bottom panel) at 100 m subsurface as derived from vertical CTD casts. IBWSS March-April 2021.

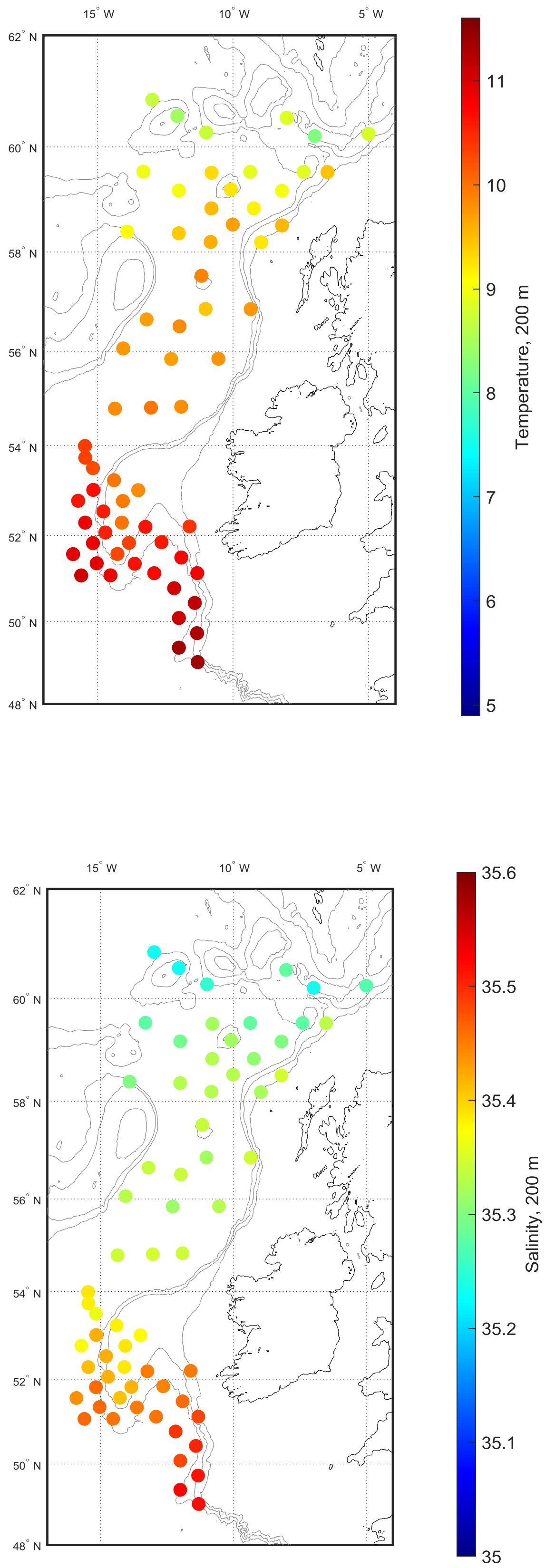


Figure 18. Horizontal temperature (top panel) and salinity (bottom panel) at 200 m subsurface as derived from vertical CTD casts. IBWSS March-April 2021.

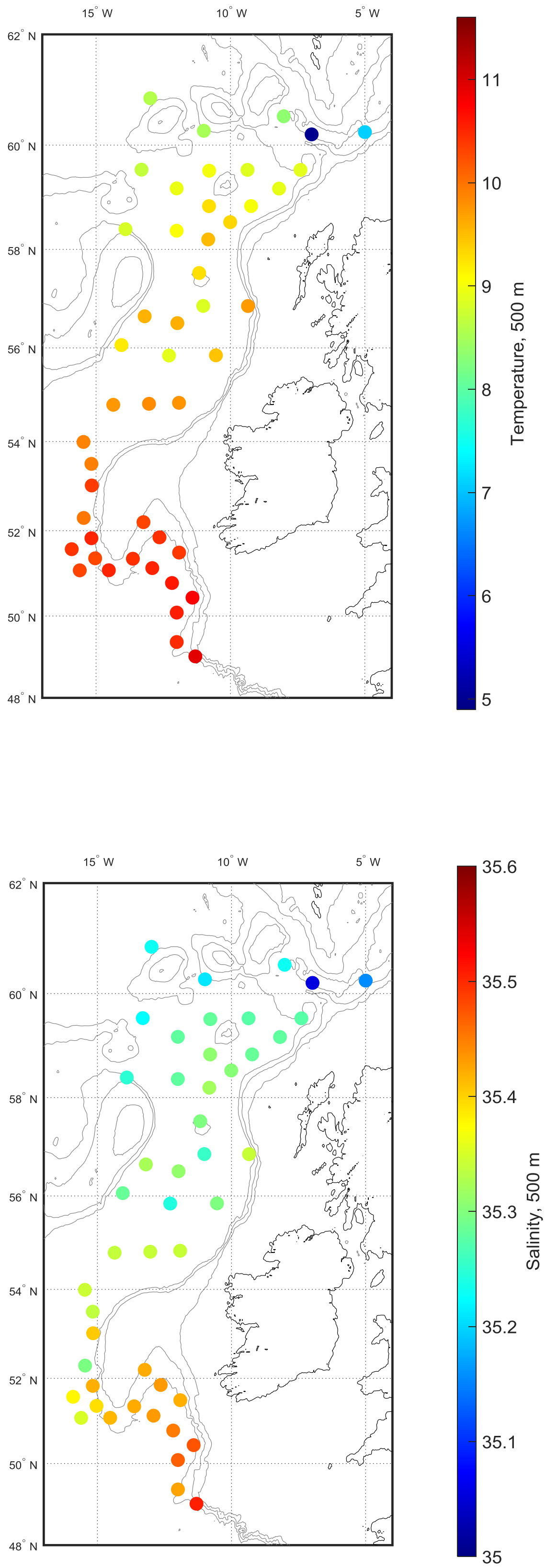


Figure 19. Horizontal temperature (top panel) and salinity (bottom panel) at 500 m subsurface as derived from vertical CTD casts. IBWSS March-April 2021.

Annex 1 – Bad data treatment on board RV Tridens

Part of this year's survey had to be conducted during adverse weather conditions where data quality deteriorated due to vessel motion, increased bubble entrainment and increased noise levels. These factors caused the signal degradation in the form of attenuations, spikes or dropouts. Concerns were especially raised in areas where dense and large aggregations of blue whiting were observed when the weather condition was adverse. Typically, Echoview and LSSS software have generic tools to address these issues, such as noise removal tools (Dunford correction, transient or impulse noise filter) or spike filters. However, such manipulations can come with a cost of data loss or possible additional bias. To understand the effects of this adverse weather condition, a data processing exercise was carried out on board Tridens during the Survey.

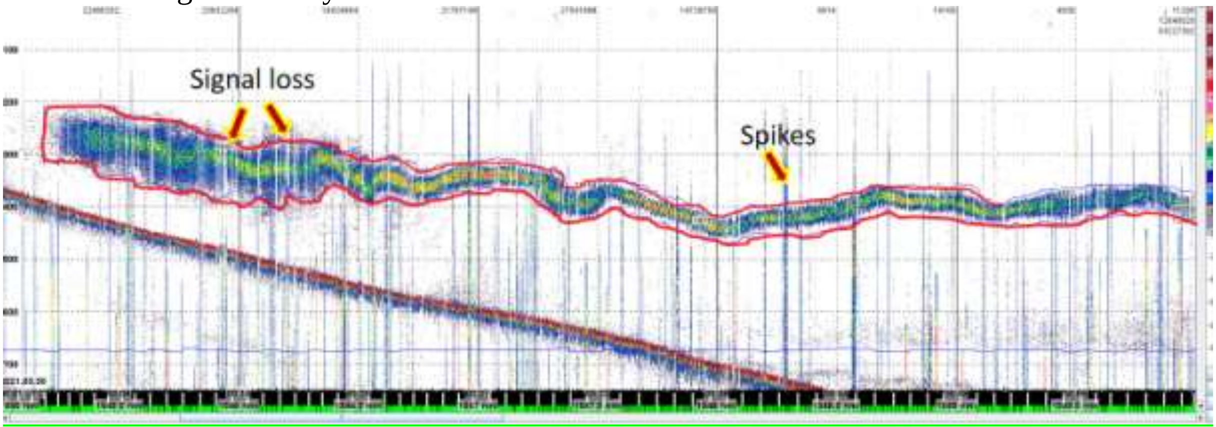


Figure 1 Dense-large aggregation of blue whiting encountered during a period of bad weather (2021 -03-30 early morning). Data contains both spike noise and transmission loss due to abrupt motion of the ship as well as bubble entrainment as a result of bad weather.

The exercise focused on a particular data set where the wind force was 7-8 Beaufort and swell height was greater than 2 m (March 30, 2021). During this time a large and dense aggregation was encountered along the transect where the acoustic recordings were subjected to signal degradation.

The effect of such signal degradation was investigated by using various methods including custom-written R-codes and postprocessing software: LSSS and Echoview. The main objective was to classify the recorded signals as "good pings" and "bad pings".

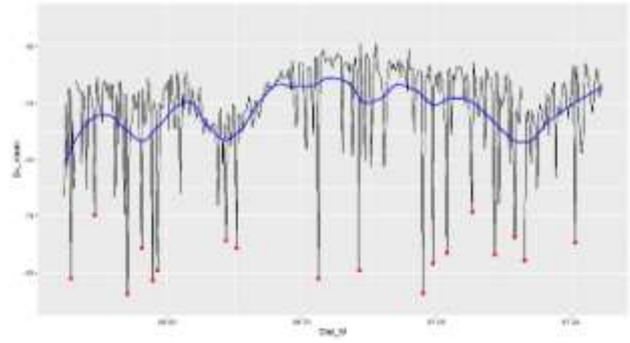
The stepwise processing procedure was as follows;

1- The aggregation was isolated by drawing a line around it.
2- Center of mass (CofMass) of the aggregation was determined per each ping (a function of Echoview that averages the sample depths weighted by sample Sv).
3- A horizontal line connecting the CofMass of each ping was created and a median smoothing filter (moving window of 21 pings) was applied.
4- A region from 5 meter above and below (10 meters in total) of this smoothed CofMass line was integrated per ping.
5- The integrated output values were grouped by 1000 consecutive pings.
6- For each of these 1000 pings a LOESS (local regression smoothing) curve was fitted based on mean Sv values. Using this fitted curve, expected values per each ping were calculated.
7- Standard deviation (SD) per each 1000 ping group was calculated.

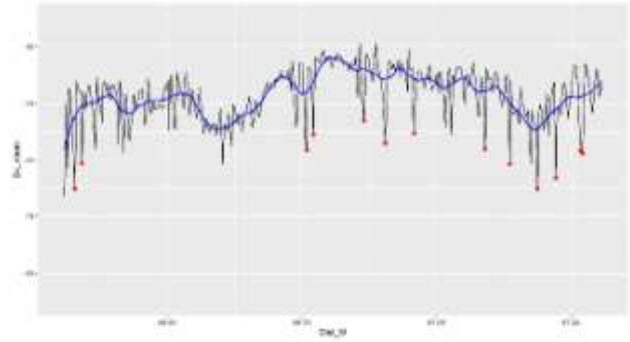
8- The predicted values were subtracted from the observed Sv values per each 1000 ping group and compared against the SD for detection of the outliers (“bad pings”).

9- For outlier-detection a stepwise approach was applied such that,

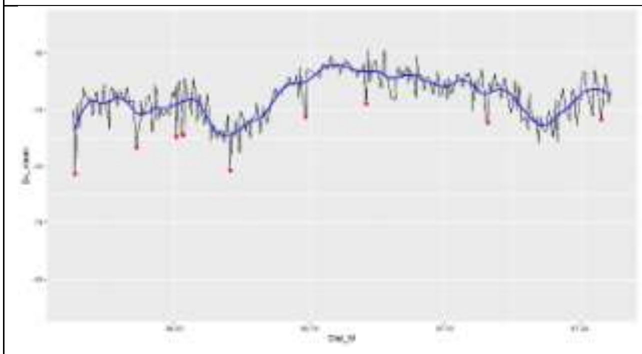
   a. 2*SD was used as a threshold. Values below -2*SD and above +2*SD standard deviations were identified as bad pings and removed from the data.
   b. After removal of bad pings, a new LOESS curve was fitted over the retained values. Again, a new standard deviation was calculated from these retained values and used as threshold for bad pings again.
   c. Same procedure repeated over the same 1000 ping group until no more bad pings were detectable. Then the same procedure was applied to the next ping group.



Step 1



Step 3



Step 5

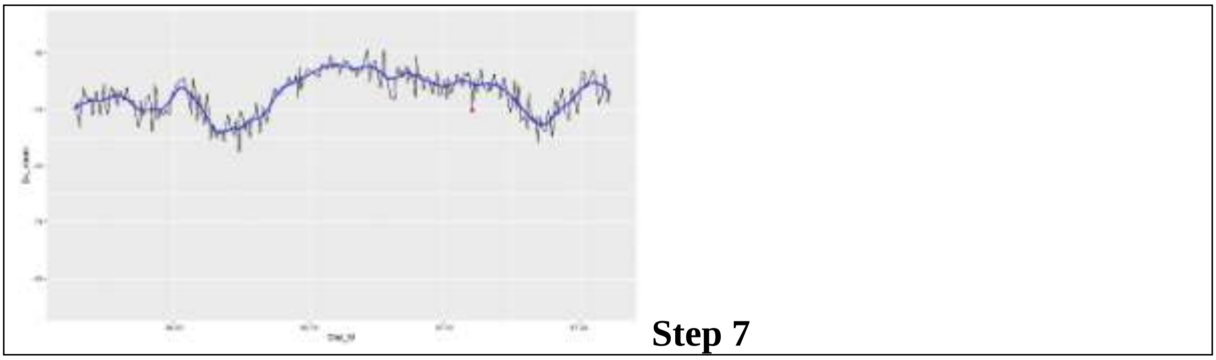


Figure 2 An example of bad ping detection for a group of 1000 pings. For this group, the procedure was finalized in 7 repetitive steps. The red dots indicate the bad pings (beyond SD threshold), the blue line is the fitted LOESS curve. The x axis is the time and the y axis is the mean Sv.

The identified bad-pings were handled in different ways by:

1- Removing all the bad pings
2- Assign bad pings with 0 values
3- Use of the mean value of the surrounding pings

In addition to this custom processing, both Echoview and LSSS has built-in spike filtering algorithms. These algorithms were also used to process separately as well. Results from these different methods were compared with non-cleaned values. The solution where all bad pings were removed resulted in a slightly higher mean Sv. And those where bad pings were assigned to "0" resulted in slightly lower values. However overall variation was less than 5% relative to the uncleaned echograms. Consequently, non-cleaned data was used for the survey calculations.

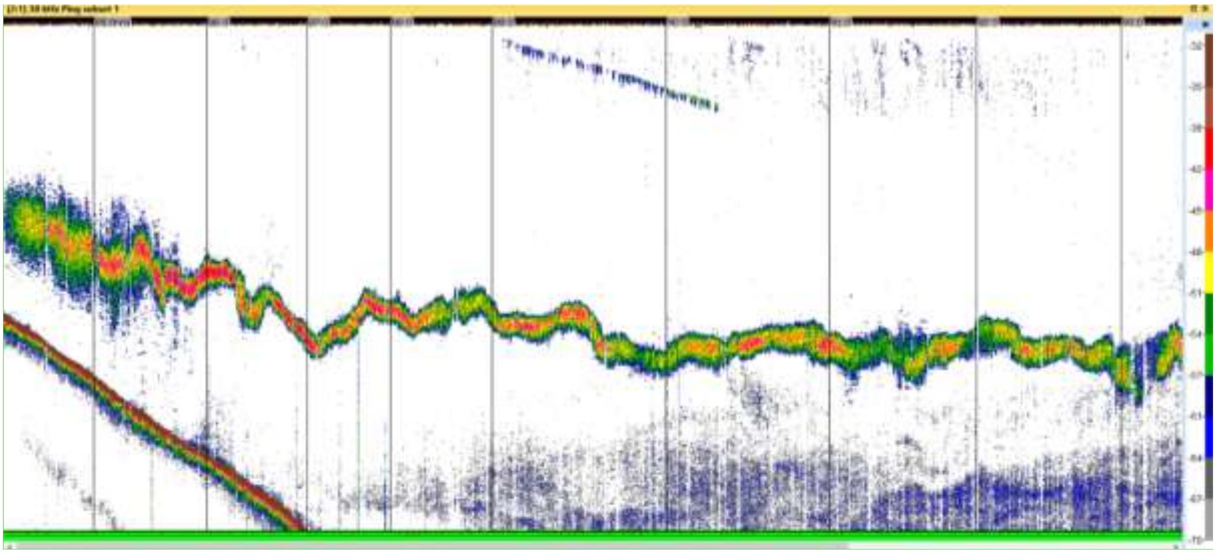


Figure 3 One of the processing solutions where all the identified bad pings were removed using the ping-subset function of Echoview. The resulting echogram looks similar to recordings in good weather.

Working Document to

Working Group on International Pelagic Surveys (WGIPS)
January 2022
and
Working Group on Widely Distributed Stocks (WGWIDE)
25 - 31 August 2021

INTERNATIONAL ECOSYSTEM SURVEY IN NORDIC SEA (IESNS) in April - May 2021

Post-cruise meeting on Teams, 15-18 June 2021

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RV Dr. Fridtjof Nansen

Susan Mærsk Lusseau[2], Matthias Kloppmann[3]
RV Dana

Sigurvin Bjarnason[4]
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Eydna í Homrum[5], Jan Arge Jacobsen[5], Leon Smith[5]
RV Jákup Sverri

Maxim Rybakov[6]
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Introduction

In April-May 2021, five research vessels; R/V Dana, Denmark (joined survey by Denmark, Germany, Ireland, The Netherlands, Sweden and UK. Due to the Covid19 situation in 2020 there was only participation from Denmark in the actual cruise), R/V Jakup Sverri, Faroe Islands, R/V Árni Friðriksson, Iceland, R/V Dr. Fridtjof Nansen, Norway and R/V Vilnyus, Russia participated in the International ecosystem survey in the Nordic Seas (IESNS). The aim of the survey was to cover the whole distribution area of the Norwegian Spring-spawning herring with the objective of estimating the total abundance of the herring stock, in addition to collect data on plankton and hydrographical conditions in the area. The survey was initiated by the Faroes, Iceland, Norway and Russia in 1995. Since 1997 also the EU participated (except 2002 and 2003) and from 2004 onwards it was more integrated into an ecosystem survey. This report represents analyses of data from this International survey in 2021 that are stored in the PGNAPES database and the ICES database and supported by national survey reports from each survey (Dana: Cruise Report R/V Dana Cruise 03/2021. International Ecosystem survey in the Nordic Seas (IESNS) in 2021, Árni Friðriksson: Report on Survey A9-2021, Bjarnason ,2021, Vilnyus: Rybakov PINRO 2021).

Material and methods

Coordination of the survey was done during the WGIPS meeting in January 2021 and by correspondence. Planning of the acoustic transects and hydrographic stations and plankton stations were carried out by using the survey planner function in the r-package Rstox version 1.11 (see https://www.hi.no/en/hi/forskning/projects/stox). The survey planner function generates the survey plan (transect lines) in a cartesian coordinate system and transforms the positions to the geographical coordinate system (longitude, latitude) using the azimuthal equal distance projection, which ensures that distances, and also equal coverage, if the method used is designed with this prerequisite, are preserved in the transformation. Figure 1 shows the planned acoustic transects and hydrographic and plankton stations in each stratum. Only parallel transects were used this year, however, because the transects follow great circles they appear bended in a Mercator projection. The participating vessels together with their effective survey periods are listed in the table below:

Vessel	Institute	Survey period
Dana	DTU Aqua - National Institute of Natural Resources, Denmark	01/5-27/5
Dr. Fridtjof Nansen	Institute of Marine Research, Bergen, Norway	29/4-28/5
Jákup Sverri	Faroe Marine Research Institute, Faroe Islands	29/4- 9/5
Árni Friðriksson	Marine and Freshwater Research Institute, Iceland	06/5-25/5
Vilnyus	Polar branch of VNIRO («PINRO»), Murmansk, Russia	28/4-25/5

Figure 2 shows the cruise tracks, Figure 3a the hydrographic and plankton stations and Figure 3b the pelagic trawl stations. Survey effort by each vessel is detailed in Table 1. Frequent contacts were maintained between the vessels during the course of the survey, primarily through electronic mail. The temporal progression of the survey is shown in Figure 4.

In general, the weather conditions did not affect the survey even if there were some days that were not favourable and prevented trawling, WP2 and Multinet sampling at some stations. The survey was based on scientific echosounders using 38 kHz frequency. Transducers were calibrated with the standard sphere calibration (Foote *et al.*, 1987) prior to the survey. Salient acoustic settings are summarized in the text table below.

Acoustic instruments and settings for the primary frequency (boldface).

	Dana	Dr. Fridtjof Nansen	Arni Friðriksson	Jákup Sverri	Vilnyus
Echo sounder	Simrad EK60	Simrad EK80	Simrad EK80	Simrad EK80	Simrad EK60
Frequency (kHz)	**38**	**38**, 18, 70, 120, 200, 333	**38**, 18, 70, 120, 200	18,**38**, 70, 120, 200, 333	**38**
Primary transducer	ES38BP	ES 38-7	ES38-7	ES38B	ES 38B
Transducer installation	Towed body	Drop keel	Drop keel	Drop keel	Hull
Transducer depth (m)	5 - 7	5.35	8	6-9	4.5
Upper integration limit (m)	10	15	15	15	10
Absorption coeff. (dB/km)	10.3	10.1	10.5	10.7	10.0
Pulse length (ms)	1.024	1.024	1.024	1.024	1.024
Band width (kHz)	2.425	2.43	2.425	3.06	2.425
Transmitter power (W)	2000	2000	2000	2000	2000
Angle sensitivity (dB)	21.9	21.9	18	21.9	21.9
2-way beam angle (dB)	-20.5	-20.7	-20.3	-20.4	-20.6
Sv Transducer gain (dB)					
Ts Transducer gain (dB)	25.45	27.02	27.05	26.96	26.02
s_A correction (dB)	-0.55	0.02	-0.02	-0.16	-0.67
3 dB beam width (dg)					
alongship:	6.89	6.29	6.42	6.55	6.97
athw. ship:	6.87	6.31	6.47	6.45	7.00
Maximum range (m)	500	500	500	500	500
Post processing software	LSSS	LSSS	LSSS	LSSS	LSSS

All participants used the same post-processing software (LSSS) and scrutinization was carried out according to an agreement at a PGNAPES scrutinizing workshop in Bergen in February 2009 (ICES 2009), and “Notes from acoustic Scrutinizing workshop in relation to the IESNS”, Reykjavík 3.-5. March 2015 (Annex 4 in ICES 2015). Generally, acoustic recordings were scrutinized on daily basis and species identified and partitioned using catch information, characteristic of the recordings, and frequency between integration on 38 kHz and on other frequencies by a scientist experienced in viewing echograms. Immediately after the 2021 survey an online meeting was held to standardise the scrutiny and to agree on particularly difficult scrutiny situations encountered. All vessels used a large or medium-sized pelagic trawl as the main tool for biological sampling. The salient properties of the trawls are as follows:

	Dana	**Dr. Fridtjof Nansen**	**Arni Friðriksson**	**Jákup Sverri**	**Vilnyus**
Circumference (m)		**624**	**832**	**832**	**500**
Vertical opening (m)	**20-35**	**25-35**	**20–35**	**45–55**	**50**
Mesh size in codend (mm)	**20/40**	**22**	**20/40**	**45**	**16**
Typical towing speed (kn)	**3.5-4.0**	**3.0–4.5**	**3.1–5.0**	**3.8–.4.9**	**2.9-4.6**

Catches from trawl hauls were sorted and weighed; fish were identified to species level, when possible, and other taxa to higher taxonomic levels. A subsample of herring, blue whiting and mackerel were sexed, aged, and measured for length and weight, and their maturity status was estimated using established methods. An additional sample of fish was measured for length. For the Norwegian, Icelandic and Faroese vessel, a smaller subsample of stomachs was sampled for further analyses on land. Salient biological sampling protocols for trawl catches are listed in the table below.

	Species	Dana	Dr. Fridtjof Nansen	Arni Friðriksson	Jákup Sverri	Vilnyus
Length measurements	Herring	200-300	100	300	200-300	300
	Blue whiting	200-300	100	50	100-200	0
	Mackerel	100-200	100	50	100-200	0
	Other fish sp.	50	30	30	100-150	100-300
Weighed, sexed and maturity determination	Herring	50	25-100	100	50-100*	50-100
	Blue whiting	50	25-100	50	50*	0
	Mackerel	50	25-100	50	50	0
	Other fish sp.	0	0	0	0*	25-50
Otoliths/scales collected	Herring	50	25-30	100	50-100	50-100
	Blue whiting	50	25-30	50	50	0
	Mackerel	0	25-30	50	50	0
	Other fish sp.	0	0	0	0	25-50
Stomach sampling	Herring	0	10	10	5	25
	Blue whiting	0	10	10	5	0
	Mackerel	0	10	10	5	0
	Other fish sp.	0	0	0	0	25

* Number of weighed individuals significantly higher.

Acoustic data were analysed using the StoX software package (version 3.1.0) which has been used for some years now for WGIPS coordinated surveys. A description of

StoX can be found in Johnsen et al. (2019) and here: https://www.hi.no/en/hi/forskning/projects/stox. Estimation of abundance from acoustic surveys with StoX is carried out according to the stratified transect design model developed by Jolly and Hampton (1990). This method requires pre-defined strata, and the survey area was therefore split into 5 strata with pre-defined acoustic transects. Within each stratum, parallel transects with equal distances were used. The distance between transects was based on available survey time, and the starting point of the first transect in each stratum was randomized. This approach allows for robust statistical analyses of uncertainty of the acoustic estimates. The strata and transects used in StoX are shown in Figure 2. Generally, and in accordance with most WGIPS coordinated surveys, all trawl stations within a given stratum with catches of the target species (either blue whiting or herring) were assigned to all transects within the stratum, and the length distributions were weighted equally within the stratum. However, due to uneven distribution of younger and older herring in Strata 1 and 3 (see Fig 12) adaptations were made as follows: In Stratum 1, all transects were split in two at 7°W and trawl stations east and west of 7°W were assigned to the respective transects east and west of 7°W; in Stratum 3 the first three transects were split at 5°W – west of 5°W the 5 closest trawl stations were assigned and east of 5°W the four closest trawl stations were assigned.

The following target strength (TS)-to-fish length (L) relationships were used:

Blue whiting: TS = 20 log(L) – 65.2 dB (ICES 2012)

Herring: TS = 20.0 log(L) – 71.9 dB (Foote et al. 1987)

The target strength for herring is the traditionally one used while this target strength for blue whiting was first applied in 2012 (ICES 2012).

The hydrographical and plankton stations by survey are shown in Figure 3a. Most vessels collected hydrographical data using a SBE 911 CTD. Maximum sampling depth was 1000 m. Zooplankton was sampled by a WPII on all vessels except the Russian vessel which used a Djedi net, according to the standard procedure for the surveys. Mesh sizes were 180 or 200 µm. The net was hauled vertically from 200 m to the surface or from the bottom whenever bottom depth was less than 200 m. All samples were split in two and one half was preserved in formalin while the other half was dried and weighed. The samples for dry weight were size fractionated before drying by sieving the samples through 2000 µm and 1000 µm sieves, giving the size fractions 180/200 – 1000 µm, 1000 – 2000 µm, and > 2000 µm. Data are presented as g total dry weight per m^2. For the zooplankton distribution map, all stations are presented. For the time series, stations in the Norwegian Sea delimited to east of 14°W and west of 20°E have been included. The zooplankton data were interpolated using objective analysis utilizing a Gaussian correlation function to obtain a time-series for four different areas. The results are given as inter-annual indexes of zooplankton abundance in May. This method was introduced at WGINOR in 2015 (ICES, 2016) and the results match the former used average index. It has been noted that the Djedy net applied by the Russian vessel in the Barents Sea seems to be less effective in catching zooplankton in comparison to WP2

WPII net applied by other vessels in an overlapping area. Thus, the biomass estimates for the Barents Sea are not directly comparable to the other areas but are comparable among years within the Barents Sea. The Russian data from the Barents Sea are not included in the 2021 report.

Results and Discussion

Hydrography

The temperature distributions in the ocean, averaged over selected depth intervals; 0-50 m, 50-200 m, and 200-500 m, are shown in Figures 5-7. The temperatures in the surface layer (0-50 m) ranged from below 0°C in the Greenland Sea to 9-10°C in the southern part of the Norwegian Sea (Figure 5). The Arctic front was encountered below south of 65°N east of Iceland extending eastwards towards about 2° W where it turned north-eastwards to 65°N and then almost straight northwards. This front was well-defined at 200-500 m depth while shallower it was unclear. Further to west at about 8° W another front runs northward to Jan Mayen, the Jan Mayen Front, that was most distinct in the upper 200 m. The warmer North Atlantic water formed a broad tongue that stretched far northwards along the Norwegian coast with temperatures 5-6 °C to the Bear Island at 74.5° N in the surface layer.

Relative to the 25 year long-term mean, from 1995 to 2019, the temperatures at 0-50 m were below mean in the southern and eastern parts of the Norwegian Sea and in the Lofoten Basin (Figure 5). Below 50 m depth, the patterns were more fragmented but at 200-500 m depth the Norwegian Basin was in general colder than the long-term mean, probably due to increased influence of Arctic water at this depth (Figure 7). Largest negative temperature anomalies were between Iceland and Faroe Islands due to a more southern located Iceland-Faroe front compared to the long-term mean. This was found for all depths and the temperatures in this region were in some locations 2-3 °C lower than the mean (Figures 5-7). Warmest region relative to the long-term mean was in the eastern Greenland Sea and particular in the upper 200 m with temperatures 2 °C higher than the mean.

The temperature, salinity and potential density in the upper 800 m at the Svinøy section in 6-8 May 2021 are shown in Figure 8. Atlantic water is lying over the colder and fresher intermediate/deep layer and reach down to 500 m at the shelf edge and shallower westward. The warmest water, above 8 °C, is located near the shelf edge where the core of the inflowing Atlantic Water is located. Westward, temperature and salinity are reduced due to mixing with colder and less saline water. Compared to 30 years long-term mean, from 1978 to 2007, the temperatures in 2021 near the shelf edge were higher than the mean at 50-400 m depth and lower the mean below this depth. Further westward, the temperatures were both lower and higher than the mean due to meandering or eddies. The pattern of salinity anomaly follows in general the pattern of temperature anomaly. The increased influence of Arctic water observed at 200-500 m (Figures 6-7) can also be observed in the western part of the section at 200-400 m depth with temperature and salinity anomalies lower than the long-term mean (Figure 8).

Two main features of the circulation in the Norwegian Sea, where the herring stock is grazing, are the Norwegian Atlantic Current (NWAC) and the East Icelandic Current (EIC). The NWAC with its offshoots forms the northern limb of the North Atlantic current system and carries relatively warm and salty water from the North Atlantic into the Nordic Seas. The EIC, on the other hand, carries Arctic waters. To a large extent this water derives from the East Greenland Current, but to a varying extent, some of its waters may also have been formed in the Iceland and Greenland Seas. The EIC flows into the southwestern Norwegian Sea where its waters subduct under the Atlantic waters to form an intermediate Arctic layer. While such a layer has long been known in the area north of the Faroes and in the Faroe-Shetland Channel, it is in the last four decades a similar layer has been observed all over the Norwegian Sea. Also, in periods this layer has been less well-defined.

This circulation pattern creates a water mass structure with warm Atlantic Water in the eastern part of the area and more Arctic conditions in the western part. The NWAC is rather narrow in the southern Norwegian Sea, but when meeting the Vøring Plateau off Mid Norway it is deflected westward. The western branch of the NWAC reaches the area of Jan Mayen at about 71°N. Further northward in the Lofoten Basin the lateral extent of the Atlantic water gradually narrows again, apparently under topographic influence of the mid-ocean ridge. It has been shown that atmospheric forcing largely controls the distribution of the water masses in the Nordic Seas. Hence, the lateral extent of the NWAC, and consequently the position of the Arctic Front, that separates the warm North Atlantic waters from the cold Arctic waters, is correlated with the large-scale distribution of the atmospheric sea level pressure. The local air-sea heat flux in addition influence the upper layer and it is found that it can explain about half of the year-to-year variability of the ocean heat content in the Norwegian Sea.

Zooplankton

The zooplankton biomass (g dry weight m^{-2}) in the upper 200 m is shown in Figure 9. Sampling stations were evenly spread over the area, covering Atlantic water, Arctic water, and the Arctic frontal zone. The highest zooplankton biomasses were not concentrated in a specific area but spread over several locations in the sampling area. High biomasses were found east/northeast of Jan Mayen (i.e. in northwestern parts of the Norwegian Sea), north of Faeroe Islands, in the Lofoten/Vesterålen area at the Norwegian coast, and in the northernmost sampled area towards the Bear Island at the entrance to the Barents Sea. Lower biomasses were found in the most central parts of the Norwegian Sea.

Figure 10 shows the zooplankton indices for the sampling area (delimited to east of 14°W and west of 20°E). To examine regional biomass difference, the area was divided into 4 sub-areas 1) the Norwegian Sea Basin (covering the southern Norwegian Sea), 2) the Lofoten Basin (covering the northern Norwegian Sea, 3) the Jan Mayen Arctic front, and 4) East of Iceland. The mean index of sub-area 1 and 2 is also given, called the Norwegian Sea index, and this index cover large parts of the Norwegian Sea. The zooplankton biomass index for the Norwegian Sea was in 2021 8.0 g dry weight m^{-2}, which is at similar level as in previous years, but with a small decrease. The same situation was observed in all sub-areas. Highest biomass (12.3 g dry weight m^{-2}) was observed in the sub-area "Northeast of Iceland".

The zooplankton biomass indices for the Norwegian Sea in May have been estimated since 1995. For the period 1995-2002 the plankton biomass was relatively high (mean 11.5 g), with fluctuations between years. From 2003-2006, the index decreased continuously and has been at lower levels since then, with a mean of 7.9 g for the period 2003-2021. There has been an increasing trend during the low-biomass period. This general pattern applies more or less to all the different sub-areas within the Norwegian Sea. The zooplankton biomass at the Jan Mayen Arctic front was high until 2007 but has since then been at the same level as the Norwegian Sea. The zooplankton biomass East of Iceland was in general higher compared with the other sub-areas until 2015.

The reasons for the changes in zooplankton biomass are not obvious. It is worth noting that the period with lower zooplankton biomass coincides with higher-than-average heat content in the Norwegian Sea (ICES, 2020) and reduced inflow of Arctic water into the southwestern Norwegian Sea (Kristiansen et al., 2019). Timing effects, such as match/mismatch with the phytoplankton bloom, can also affect the zooplankton abundance. The high biomass of pelagic fish feeding on zooplankton has been suggested to be one of the main causes for the reduction in zooplankton biomass. However, carnivorous zooplankton and not pelagic fish may be the main predators of zooplankton in the Norwegian Sea (Skjoldal *et al.*, 2004), and we do not have good data on the development of the carnivorous zooplankton stocks.

Norwegian spring-spawning herring

Survey coverage in the Norwegian Sea was considered adequate in 2021. The zero-line was believed to be reached for adult NSS herring in most of the areas. It is recommended that the results from IESNS 2021 can be used for assessment purpose. The herring was primarily distributed in the south-western area (Figure 11). In the westernmost area old herring dominated, but in general, the 2016-year-class was the most abundant year class throughout the survey area. It is a commonly observed pattern that the older fish are distributed in the southwest while the younger fish are found closer to the nursery areas in the Barents Sea (Figure 12).

Five year old herring (year class 2016) dominated both in terms of number (53%) and biomass (46 %) on basis of the StoX bootstrap estimates for the Norwegian Sea (Table 2). This year class as 5 year old is as large as the 2004 year class was at same age (Figure 13), and this puts the magnitude of the 2016 year class into perspective as a large year class. There was a slight decrease in abundance of the 2016 year class from last year, which is not expected for young herring. However, the decrease was small and within the uncertainty estimates of abundance of 4 year old herring last year and 5 year old herring this year. The 2004 year class, which has dominated the stock together with the 2002 year class, still contributes significantly to the biomass of older age-groups (see paragraph on issues with age determination below). Herring aged 12-18 years old thus comprised 13% of the numbers and 21% of the biomass. Uncertainty estimates for number at age based on bootstrapping within StoX are shown in Figure 14 and Table 2. The relative standard error (CV) of the total biomass estimate is 15 % and 16 % for the total numbers estimate, and the relative standard error for the dominating age groups is around 20 % (Figure 14 and Table 5).

The total estimate of herring in the Norwegian Sea from the 2021 survey was 23 billion in number and the biomass was 5.1 million tonnes. The biomass estimate is 0.90 million tonnes (21 %) higher than the 2020 survey estimate while the estimated number is 2% higher in 2021. The biomass estimate decreased significantly from 2009 to 2012 and has since then been rather stable at 4.2 to 5.9 million tonnes with similar confidence interval (Figure 16), with the lowest abundance occurring in 2017. The 2016 year class now appears to be fully recruited, distributed widely in the feeding area and more dominant than the older year classes.

The Barents Sea was also covered adequately in 2021. The results based on bootstrap are shown in Table 4 and Figure 15. The estimated total abundance (125 million) and biomass (4.3 thousand tonnes) of herring in the Barents Sea was the lowest observed in the time series that started in 1991. The 3 year olds (2018 year class) was the most abundant year class in the Barents Sea.

In the last 6 years, there have been concerns regarding age reading of herring, because the age distributions from the different participants have showed differences – particularly older specimens appear to have uncertain ages. A scale and otolith exchange has been ongoing for some period, where scales and otoliths for the same fish have been sampled. As a follow-up on that work, a new exchange and following workshop are currently being planned and sampling of exchange material has started. The survey group emphasizes the necessity of having this workshop before next year’s survey takes place.

With respect to age-reading concerns in the recent years, the comparison between the nations in this year's survey could not been done fully since the cruise tracks of the Norwegian vessel did not cover strata 1 and 3. However, in strata 2 and 4 there was overlap between the Norwegian vessel and the Danish vessel and the age distributions from those strata seem to be relatively similar between the two vessels (Figure 17). In stratum 1 there was overlap between the Icelandic and Faroese vessel and the difference in age distributions mainly reflected differences in the length distribution.

Recently, concerns have been raised by the survey groups for the International ecosystem surveys in the Nordic Seas (IESNS and IESSNS) on mixing issues between Norwegian spring-spawning herring and other herring stocks (e.g. Icelandic summer-spawning, Faroese autumn-spawning, Norwegian summer-spawning and North Sea type autumn-spawning herring) occurring in some of the fringe regions in the Norwegian Sea. Until now, fixed cut lines have been used by the survey group to exclude herring of presumed other types than NSS herring, however this simple procedure is thought to introduce some contamination of the stock indices of the target NSS herring. WGIPS noted in their 2019 report that the separation of different herring stock components is an issue in several of the surveys coordinated in WGIPS and the needs for development of standardized stock splitting methods was also noted in the WKSIDAC (ICES 2017).

In the IESNS 2021 survey, all herring in Stratum 1 was allocated to NSSH. This year there were only minor issues with mixing, because only limited amounts of herring of autumn spawning type were caught.

Blue whiting

The spatial distribution of blue whiting in 2021 was similar to the years before, with the highest abundance estimates in the southern and eastern part of the Norwegian Sea, along the Norwegian continental slope. The main concentrations were observed in connections with the continental slopes off Norway and along the Scotland – Iceland ridge (Figure 18). Blue whiting was distributed similar as last year. The largest fish were found in the western and northern part of the survey area (Figure 19). It should be noted that the spatial survey design was not intended to cover the whole blue whiting stock during this period.

The total biomass index of blue whiting registered during the IESNS survey in 2021 was 0.85 million tonnes, which is a 118 % increase from the biomass estimate in 2020 (0.39). The abundance index for 2021 was 13.9 billion, which is 184 % higher than in 2020 (4.9). Age 1 is totally dominating the acoustic estimate (50 % of the biomass and 74% by number). Uncertainty estimates for numbers at age based on bootstrapping with StoX are shown in Figure 20 and Table 3. The relative standard error (CV) of total biomass estimate is 14 % and 14 % also for total numbers (Table

3). The 2021 estimate of one-year old blue whiting was the highest in the IESNS time series (from 2008). The survey group compared age and length distributions by vessel and strata (Figure 21 and 22) and no clear differences were found compared to earlier years.

Mackerel

Trawl catches of mackerel are shown in Figure 23. Mackerel was present in the southern and eastern part of the Norwegian Sea (as far north as 68°N) in the beginning of May. No further quantitative information can be drawn from these data as this survey is not designed to monitor mackerel.

Pink Salmon

Pink salmon is a relatively new species in the Nordic Seas and was caught in the IESNS surveys since 2017 – and only every other year, when the odd-year spawning component conducts oceanic migrations. This is in accordance with observations of spawning pink salmon in particularly northern Norwegian rivers in later years. In 2021 a total of 91 pink salmon were caught during the survey. The distribution area was mainly on and off the Norwegian shelf and north off the Faroe Plateau.

General recommendations and comments

Recommendation	Addressed to
1. Continue the methodological research in distinguishing between Herring and blue whiting in the interpretation of echograms.	WGIPS
2. It is recommended that a workshop based on the ongoing otolith and scale exchange will take place before next year's IESNS survey.	WGBIOP, WGWIDE
3. It is recommended that the WGIPS meeting in 2021 includes a workshop on how to deal with stock components of herring in the IESNS-survey.	WGIPS

Next year's post-cruise meeting

We will aim for next meeting in 14-16 June 2022. The final decision will be made at the next WGIPS meeting.

Concluding remarks

- The sea temperature in 2021 was generally below the long-term mean (1995-2019) in the Norwegian Sea, but the pattern was more fragmented 50-200 m.
- The 2021 index of meso-zooplankton biomass in the Norwegian Sea and adjoining waters decreased marginally from last year.

- The total biomass estimate of NSSH in herring in the Norwegian Sea was 5.1 million tonnes, which is a 21 % increase from the 2020 survey estimate. The estimate of total number of NSSH was 23 billion, which is 2 % higher than in the 2020 survey. The survey followed the pre-planned protocol and the survey group recommends using the abundance estimates in the analytical assessment.
- The 2016 year class of NSSH dominated in the survey indices both in numbers (53%) and biomass (46%), and it is on the same level as the strong 2004 year class at the same age (in the 2009 survey). In numbers, the estimate of the 2016 year class decreased from age four to age five. This is not the usual pattern for NSS herring, but the decrease was small and within the uncertainty estimates of abundance of four year old herring in 2020 and five year old herring in 2021.
- The estimated total abundance and biomass of herring in the Barents Sea was the lowest observed in the time series that started in 1991.
- The biomass of blue whiting measured in the 2021 survey increased by 118 % from last year's survey and 184 % in terms of numbers. Age 1 (2020 year class) is the dominating year class (50 % of the biomass and 74% by number), and this year's estimate of one year olds is the highest in the time series.

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Tables

Table 1. Survey effort by vessel for the International ecosystem survey in the Nordic Seas in May - June 2021.

Vessel	Effective survey period	Effective acoustic cruise track (nm)	Trawl stations	Ctd stations	Aged fish (HER)	Length fish (HER)	Plankton stations
Dana	01/05-27/05	2056	20	35	476	1537	35
Jákup Sverri	29/4-9/5	1334	16	22	361	1547	21
Árni Fridriksson	8/5-23/5	2980	22	38	1531	5537	34
Dr. Fridtjof Nansen	29/4-28/5	4518	37	47	362	1149	45
Vilnyus	29/4-21/5	3540	58	50	151	362	50
Total		**14428**	**153**	**192**	**2881**	**10132**	**185**

Table 2. IESNS 2021 in the Norwegian Sea. Estimates of abundance, mean weight and mean length of Norwegian spring-spawning herring. The estimates are mean of 1000 bootstrap replicates in Stox.

	Age in years (year class)																			Number	Biomass	Mean
Length	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Unknown			weight
(cm)	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003		(10^6)	(10^6 kg)	(g)
15-16																						
16-17																						
17-18																			8.4	8.4	0.3	31.5
18-19																			4.2	4.2	0.2	40.0
19-20																			66.8	66.8	2.9	43.6
20-21			270.1	16.4																286.5	15.3	53.4
21-22			318.4																0.2	318.6	19.5	61.4
22-23			236.4	2.3															0.1	238.8	16.6	73.4
23-24			147.5	49.5															0.7	197.7	16.1	90.6
24-25			9.5	155.8																165.4	16.8	110.6
25-26		23.1	5.6	156.9	12.0														0.2	197.8	24.2	123.4
26-27	14.9	10.5	34.8	91.6	158.6															310.3	41.8	136.6
27-28			42.1	171.9	389.2	6.0	5.9													615.1	92.0	152.0
28-29			31.6	232.3	1138.6	5.3	14.2													1 422.0	231.6	163.9
29-30			12.8	258.4	2834.1	13.6	59.8	13.5	12.8			2.9								3 207.8	570.5	178.3
30-31				91.2	3052.8	93.4	116.3	87.0	40.8	32.1	3.6									3 517.2	685.8	195.7
31-32				40.6	2619.6	126.1	108.4	168.9	22.6		31.4	21.3								3 138.9	688.2	218.5
32-33				10.3	1431.7	264.5	199.8	181.6	38.7	29.8	45.9									2 202.4	517.3	235.2
33-34				12.6	221.4	107.0	311.6	616.5	19.7	32.0	4.2	5.3								1 330.4	343.7	259.9
34-35					47.9	55.0	175.0	622.0	104.6	54.6	4.4	1.1								1 064.7	298.0	281.7
35-36						27.3	44.3	300.6	150.7	103.5	51.3	66.5	45.8	52.0	34.8	2.3	12.2			891.2	269.5	304.6
36-37							15.9	41.6	88.1	163.3	226.6	189.5	178.3	201.8	160.9	95.8	6.5			1 368.3	450.6	332.1
37-38								7.1	20.0	120.2	97.1	159.8	141.7	269.5	324.2	248.3	38.9	5.8		1 432.6	496.3	349.0
38-39									2.8	15.3	11.9	15.3	65.0	72.8	189.4	182.2	76.7	2.8		634.2	235.1	373.7
39-40													11.5	19.2	42.8	37.6	42.1	5.6		158.8	61.6	388.9
40-41																	6.1		2.7	8.8	2.3	387.8
TSN(mill)	14.9	33.6	1108.8	1289.9	11906.0	698.2	1051.1	2038.8	500.8	550.8	476.4	461.7	442.3	615.3	752.1	566.1	182.4	14.2		22 983.8		
cv (TSN)	1.20	1.22	0.50	0.19	0.20	0.22	0.21	0.19	0.20	0.25	0.25	0.26	0.30	0.30	0.31	0.31	0.35	0.64		0.16		
TSB(1000 t)	2.0	3.7	82.2	196.7	2 329.5	163.8	259.5	546.2	140.9	166.2	148.2	150.7	149.9	212.0	267.7	201.8	66.2	5.5		5 096.3		
cv (TSB)	1.20	1.22	0.45	0.18	0.20	0.21	0.20	0.19	0.20	0.25	0.26	0.27	0.31	0.30	0.31	0.31	0.35	0.64		0.15		
Mean length(cm)	26.0	25.3	23.5	27.3	29.9	32.0	32.7	33.7	34.7	35.6	35.9	36.2	36.6	36.7	37.1	37.2	37.9	37.7				
Mean weight(g)	137.0	110.3	98.3	157.7	195.2	237.1	256.5	276.4	295.3	312.7	325.6	334.6	342.7	347.9	359.0	359.1	363.9	382.0				

Table 3. IESNS 2021 in the Norwegian Sea. Estimates of abundance, mean weight and mean length of blue whiting. The estimates are mean of 1000 bootstrap replicates in Stox.

	Age in years (year class)											Number	Biomass	Mean
Length	1	2	3	4	5	6	7	8	9	10	Unknown			weight
(cm)	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011		(10^6)	(10^6 kg)	(g)
15-16														
16-17	67.8	6.7									0.3	74.8	1.8	24.1
17-18	888.9	13.9										902.9	26.3	29.7
18-19	2344.4	65.7										2 410.1	81.6	34.5
19-20	3056.6	65.1										3 121.7	124.7	40.3
20-21	2457.7	32.4	10.0									2 500.2	117.2	47.0
21-22	1048.4	143.0	3.7									1 195.2	63.8	53.6
22-23	331.6	191.2	61.6									584.4	36.0	62.0
23-24	55.4	348.1	43.6									447.1	32.2	73.5
24-25	5.6	319.8	91.0	3.0								419.3	33.9	82.6
25-26	4.4	139.4	201.4	9.6	2.5							357.4	34.3	96.9
26-27		145.4	150.9	46.3		35.1		10.4				388.1	42.0	109.7
27-28		27.9	147.3	36.4	4.8	1.6	18.3					236.4	27.6	118.6
28-29	2.8	2.0	64.8	45.4	11.4	43.0	16.4	10.1				195.7	26.3	135.9
29-30			43.7	83.8	77.8	5.3	14.4					225.0	35.3	159.2
30-31			2.8	23.2	66.9	126.6	44.4	6.7		12.3		282.9	48.4	173.0
31-32				35.6	45.5	134.7	34.3	29.5	8.3			287.9	55.6	195.2
32-33			11.5	18.9	19.5	49.1	24.1	11.5				134.5	28.2	210.9
33-34					18.2	13.9	9.6	8.3	7.0		0.1	57.1	13.1	233.4
34-35					2.2	12.7	27.5				0.2	42.5	10.0	242.0
35-36					10.1						0.3	10.3	2.4	235.1
36-37						11.9						11.9	3.4	283.0
37-38														
38-39						7.8					1.3	9.1	2.9	316.4
39-40											5.3	5.3	1.4	462.0
> 40											3.8	3.8	2.8	732.0
TSN(mill)	10264	1500	832	302	259	442	189	77	15	12		13 903.3		
cv (TSN)	0.17	0.23	0.25	0.32	0.38	0.46	0.40	0.66	0.77	1.21		0.14		
TSB(1000 t)	424.9	110.1	86.8	45.3	47.2	79.1	34.1	13.6	3.4	2.1		851.2		
cv (TSB)	0.16	0.22	0.26	0.33	0.39	0.46	0.41	0.66	0.76	1.21		0.14		
Mean length(cm)	19.3	23.1	25.7	28.2	30.0	30.6	30.4	30.3	31.8	30.0				
Mean weight(g)	43	77	106	147	179	184	178	179	223	175				

Table 4. IESNS 2021 in the Barents Sea. Estimates of abundance, mean weight and mean length of Norwegian spring-spawning herring. The estimates are mean of 1000 bootstrap replicates in Stox.

Length	Age in years (year class)					Number	Biomass	Mean weight
	1	2	3	4	5			
(cm)	2020	2019	2018	2017	2016	(10^6)	(10^3 kg)	(g)
9-10	7.1					7.1	32	4.6
10-11	8.5					8.5	49	5.8
11-12	2.8					2.8	25	9.0
12-13	2.8					2.8	31	11.0
13-14								
14-15								
15-16								
16-17		1.7				1.7	50	29.0
17-18			5.7			5.7	187	32.9
18-19			18.8			18.8	733	39.0
19-20			29.2			29.2	1291	44.3
20-21			23.1			23.1	1165	50.4
21-22			5.2	1.4		6.6	378	57.4
22-23			2.6	0.7		3.3	208	62.9
23-24			1.9			1.9	131	68.0
24-25				0.2		0.2	20	92.0
25-26								
26-27					0.2	0.2	20	92.0
27-28								
28-29								
29-30								
TSN(mill)	21.2	1.7	86.5	2.3	0.2	125.1		
cv (TSN)	0.81	0.84	0.37	0.58	0.78	0.36		
TSB(t)	138.3	50.5	3 974.7	137.8	20.1	4 321.4		
cv (TSB)	0.81	0.84	0.37	0.53	0.78	0.37		
Mean length(cm)	10.1	16.0	19.3	22.2	26.0			
Mean weight(g)	7	29	47	68	92			

Figures

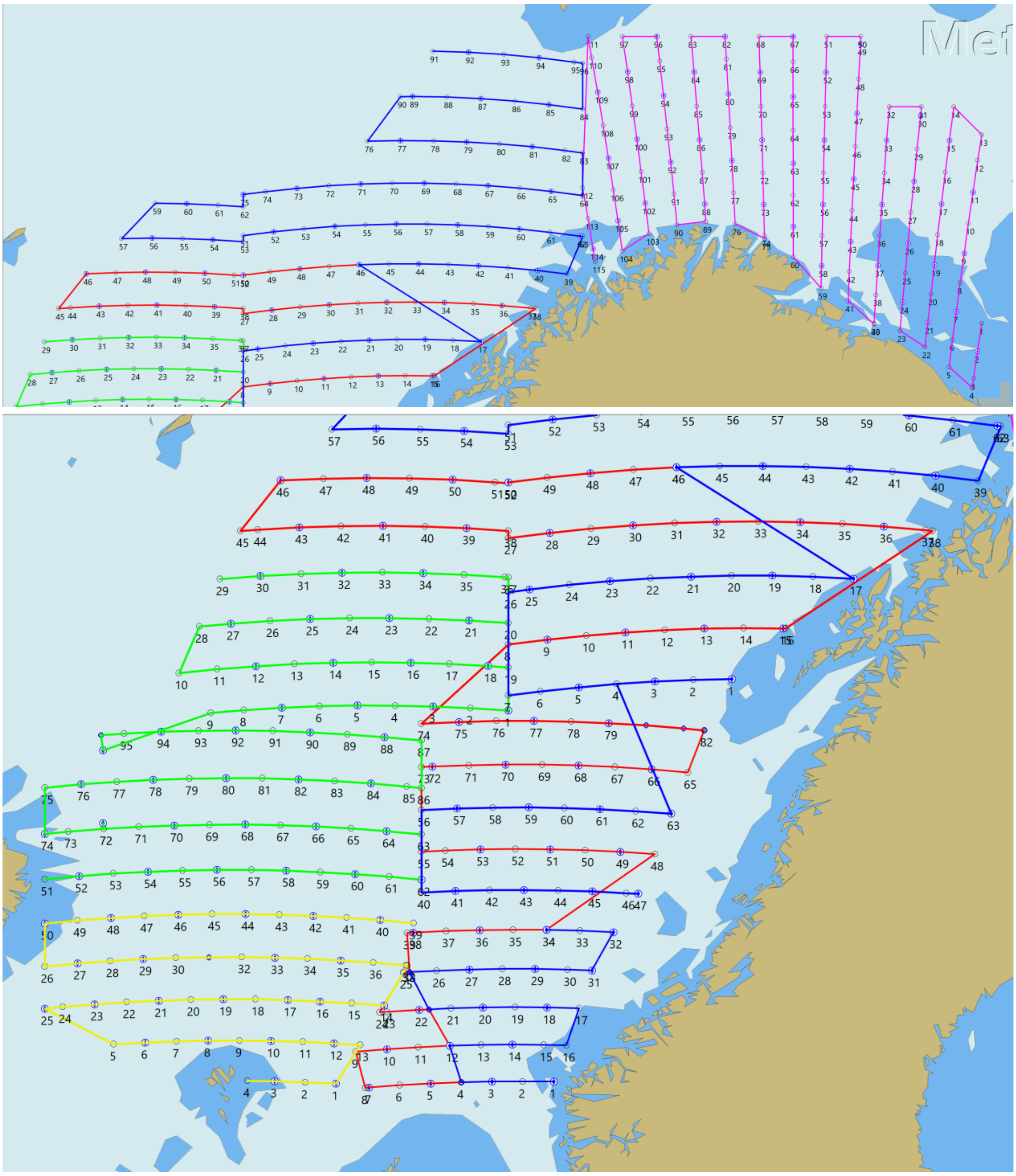


Figure 1. The pre-planned strata and transects for the IESNS survey in 2021 (red: EU, dark blue: Norway, yellow: Faroes Islands, violet: Russia, green: Iceland). Hydrographic stations and plankton stations are shown as blue circles with diamonds. All the transects have numbered waypoints for each 30 nautical mile and at the ends.

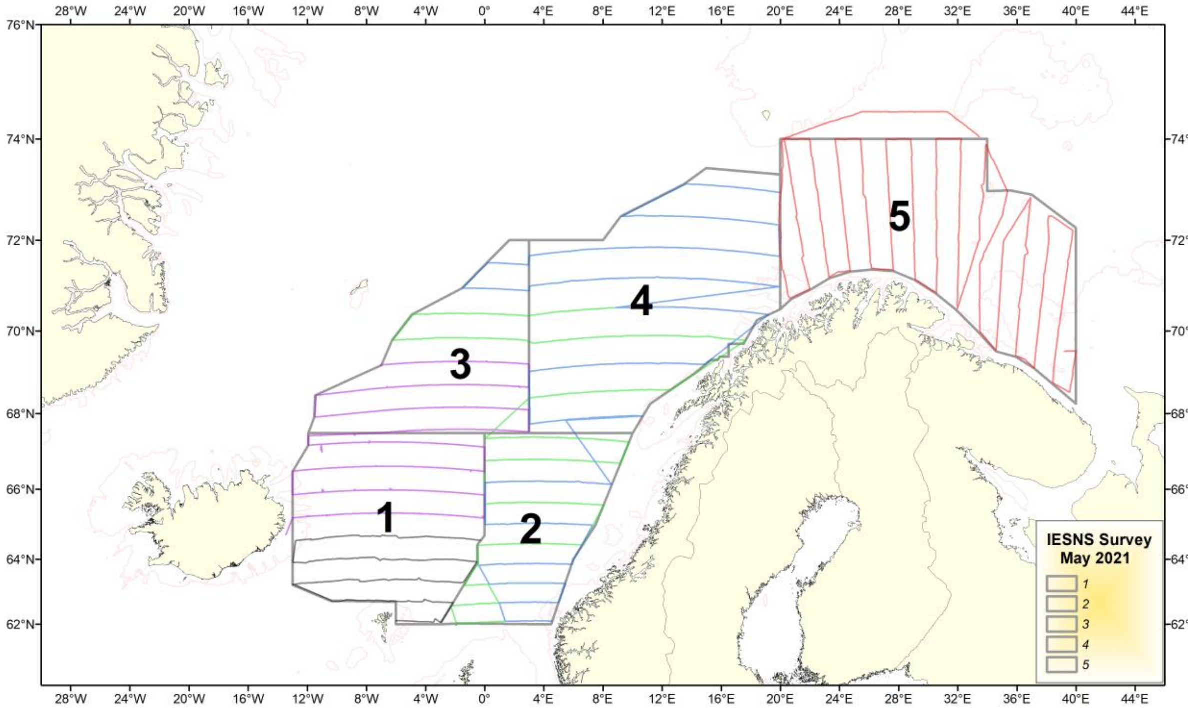


Figure 2. Cruise tracks and strata (with numbers) for the IESNS survey in May 2021.

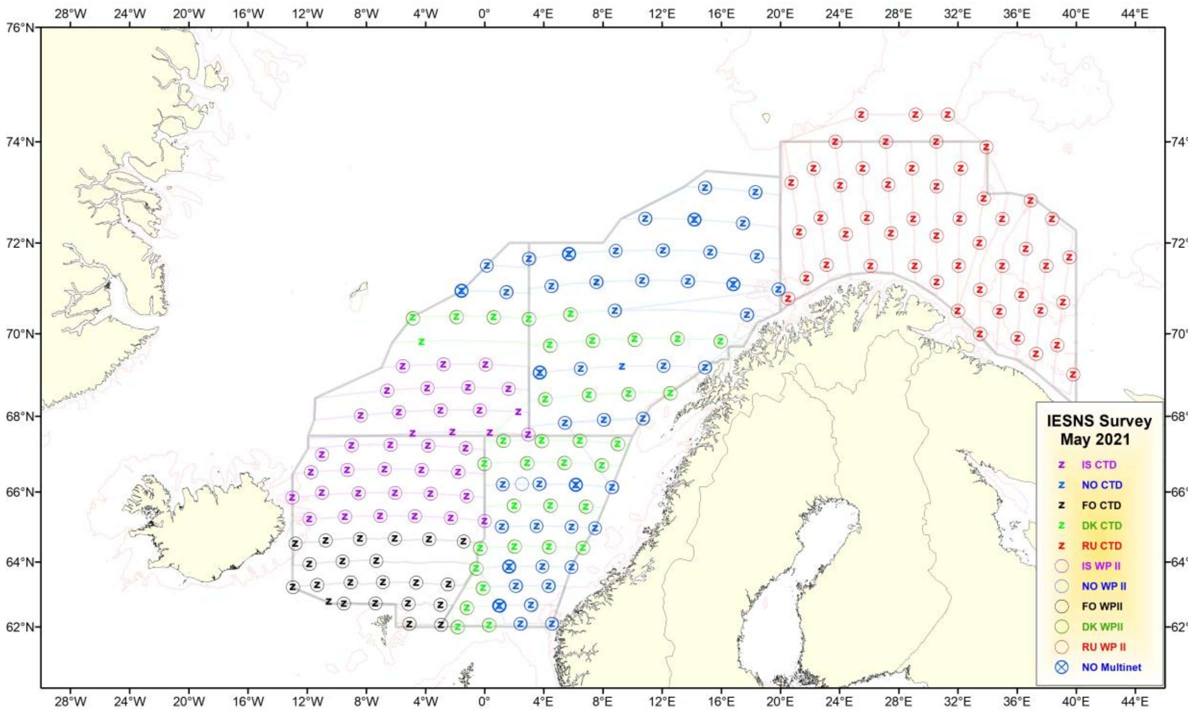


Figure 3a. IESNS survey in May 2021: location of hydrographic and plankton stations. The strata are shown.

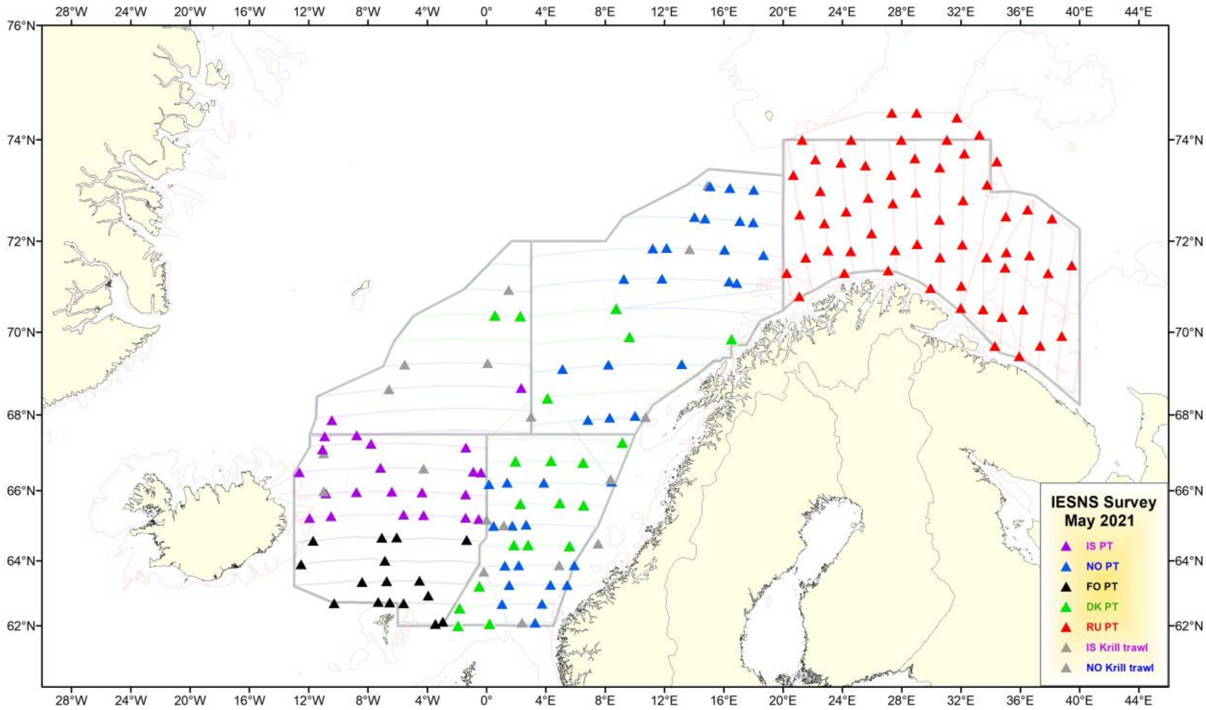


Figure 3b. IESNS survey in May 2021: location of pelagic trawl stations. The strata are shown.

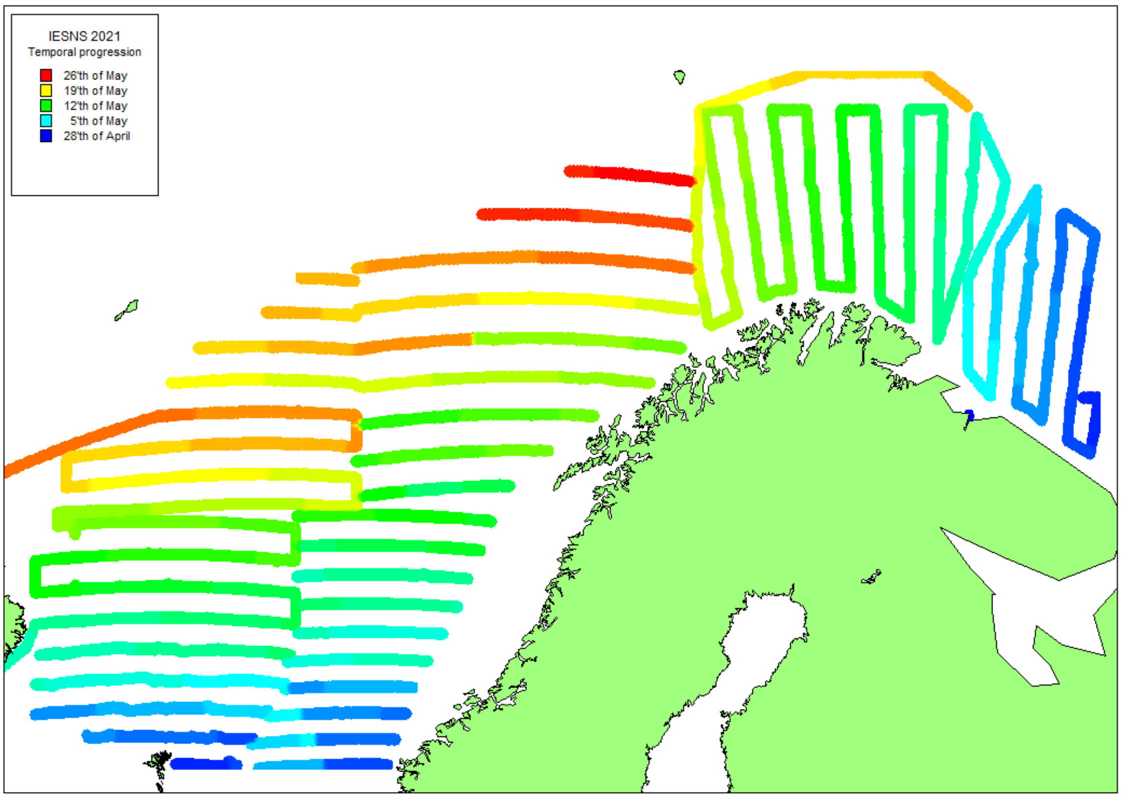


Figure 4. Temporal progression IESNS in May 2021.

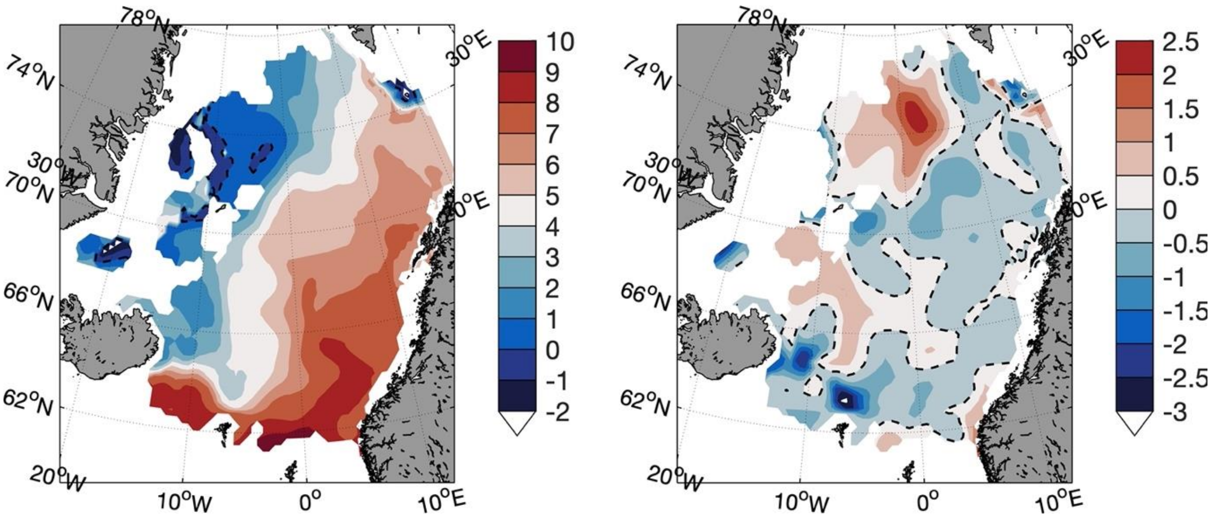


Figure 5. Temperature (left) and temperature anomaly (right) averaged over 0-50 m depth in May 2021. Anomaly is relative to the 1995-2019 mean.

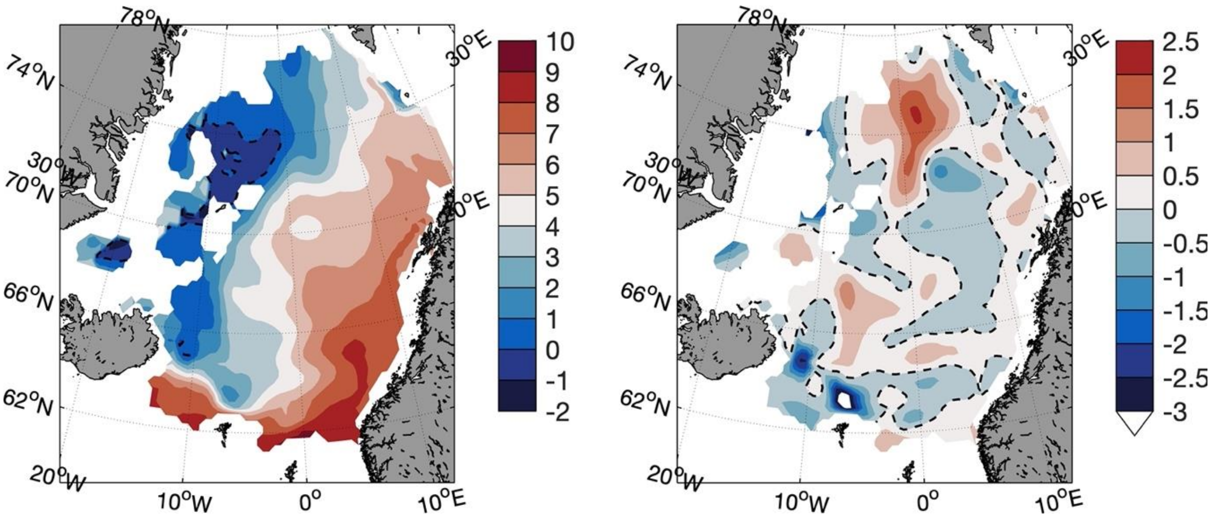


Figure 6. Same as above but averaged over 50-200 m depth.

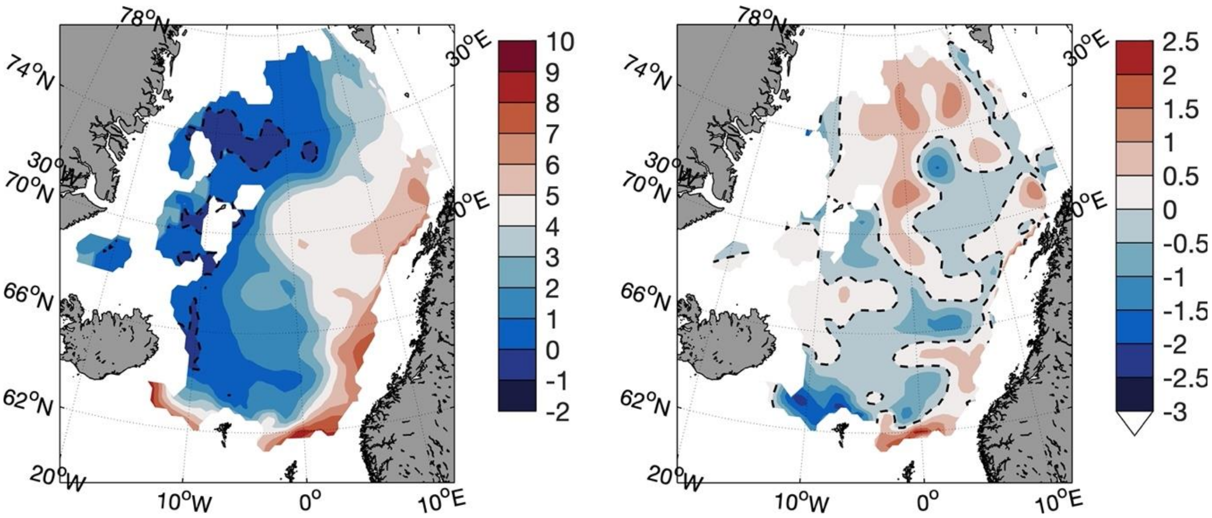


Figure 7. Same as above but averaged over 200-500 m depth.

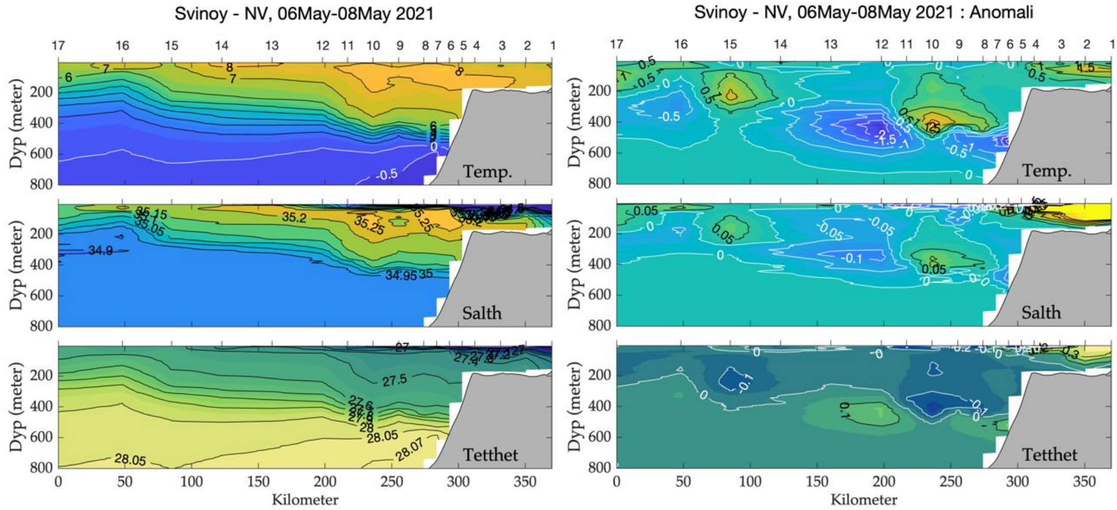


Figure 8. Temperature, salinity and potential density (sigma-t) (left figures) and anomalies (right figures) in the Svinøy section, 6-8 May 2021. Anomalies are relative to 30 years long-term mean (1978-2007).

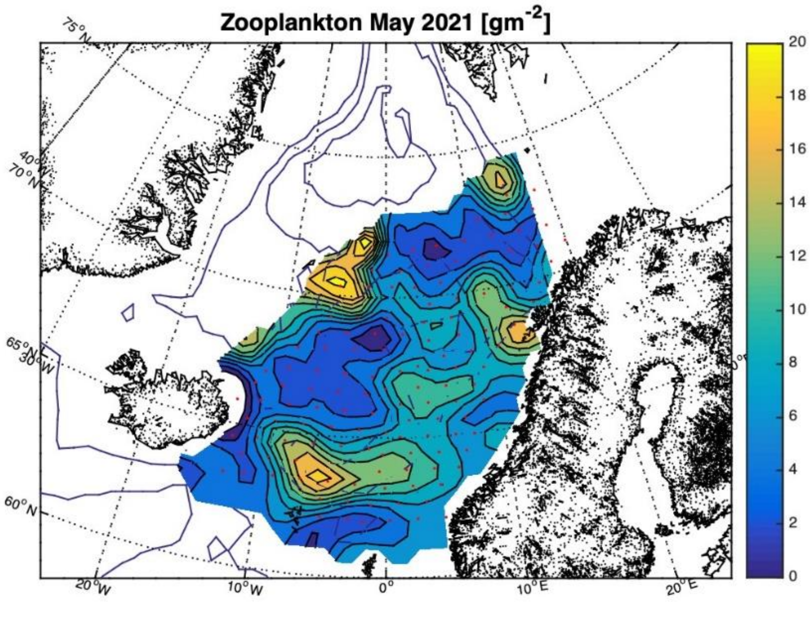


Figure 9. Representation of zooplankton biomass (g dry weight m^{-2}; at 0-200 m depth) in May 2021.

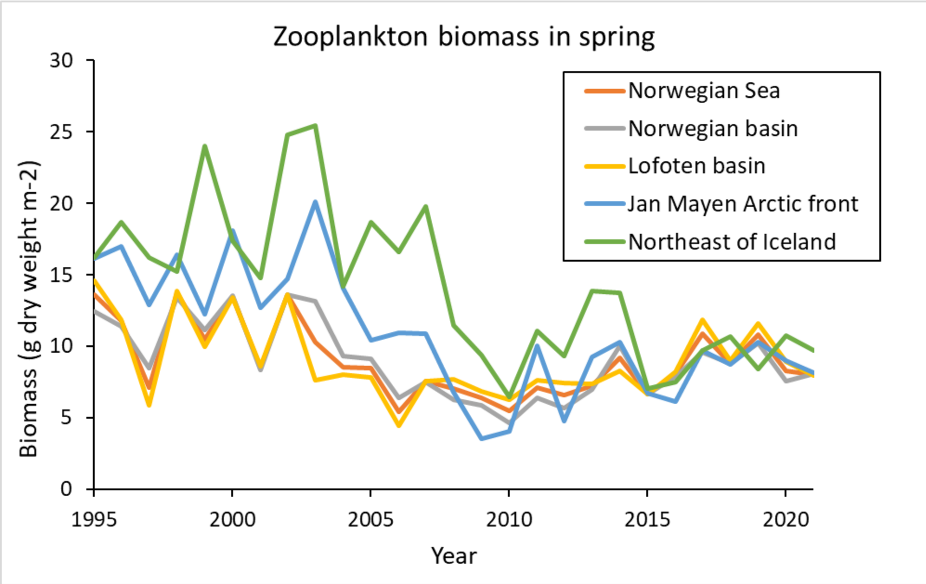
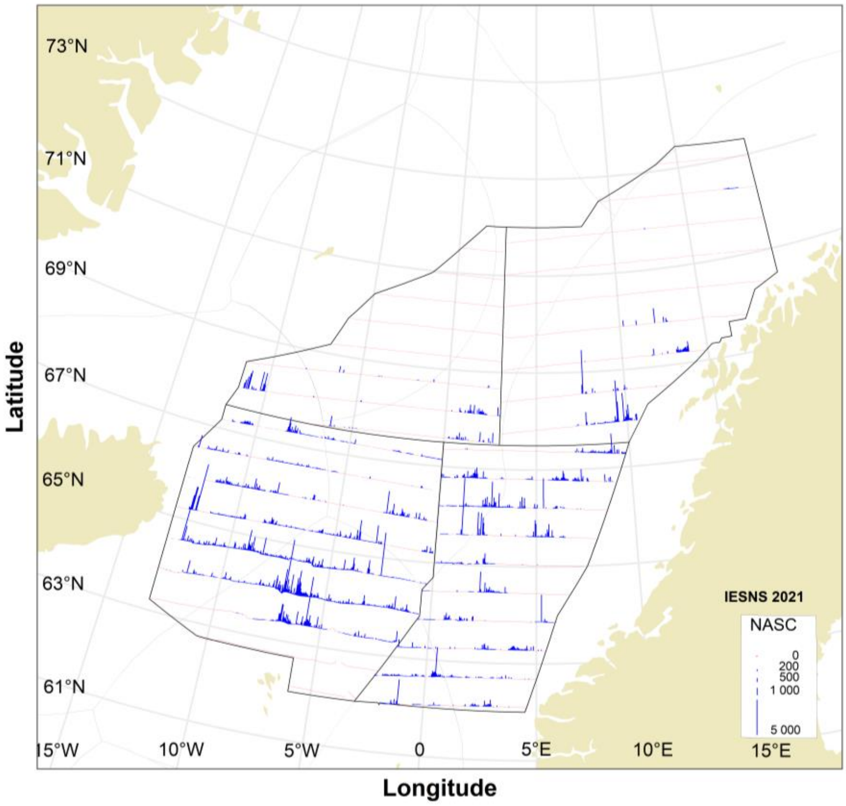


Figure 10. Indices of zooplankton biomass (g dry weight m^{-2}) sampled by WP2 in May in the Norwegian Sea and adjacent waters from 1995-2021.

(a)



(b)

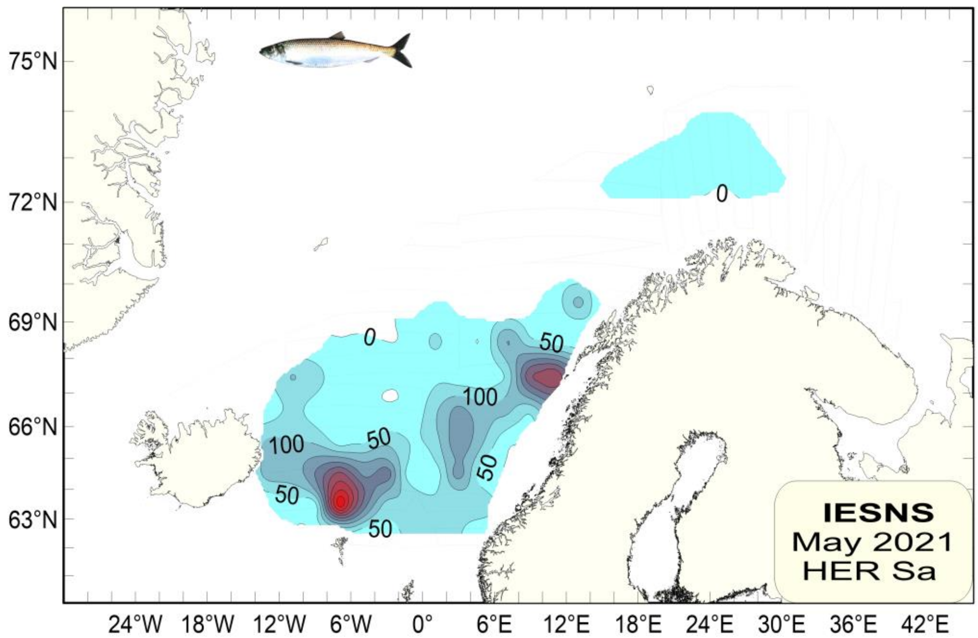


Figure 11. Distribution of Norwegian spring-spawning herring as measured during the IESNS survey in May 2021 in terms of NASC values (m^2/nm^2) averaged for every 1 nautical mile and (b) represented by a contour plot. Note that

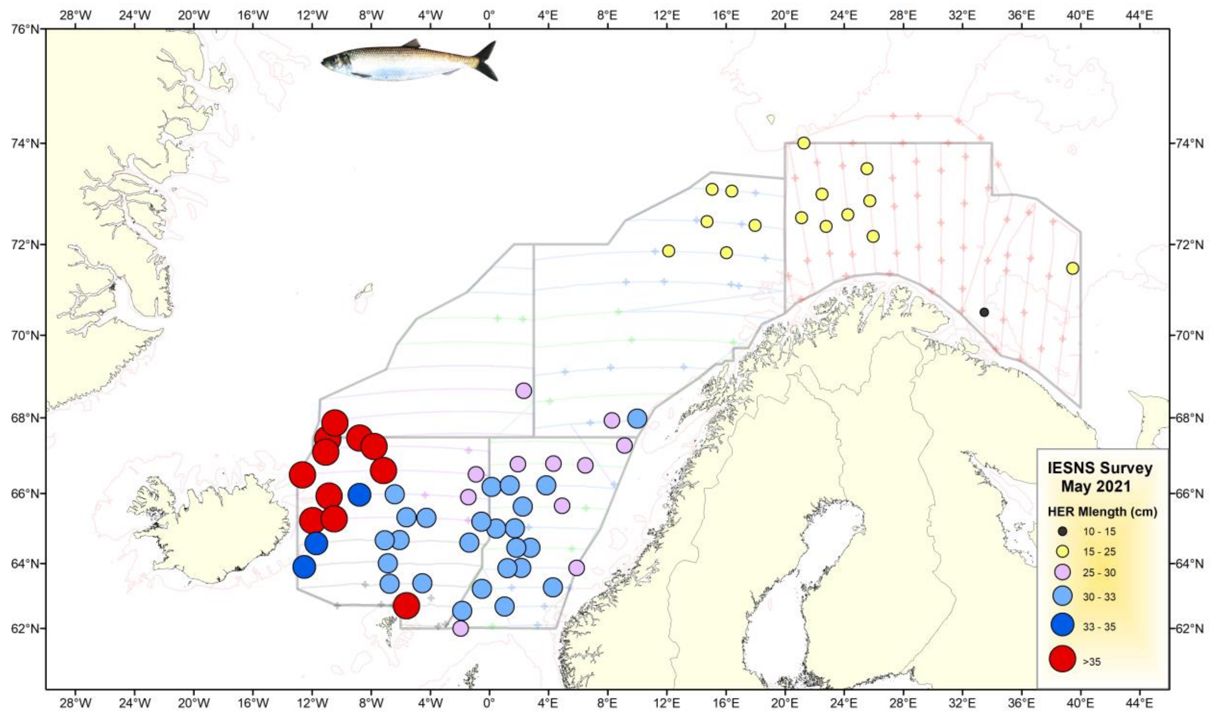


Figure 12. Mean length of Norwegian spring-spawning herring in all hauls in May 2021. The strata are shown.

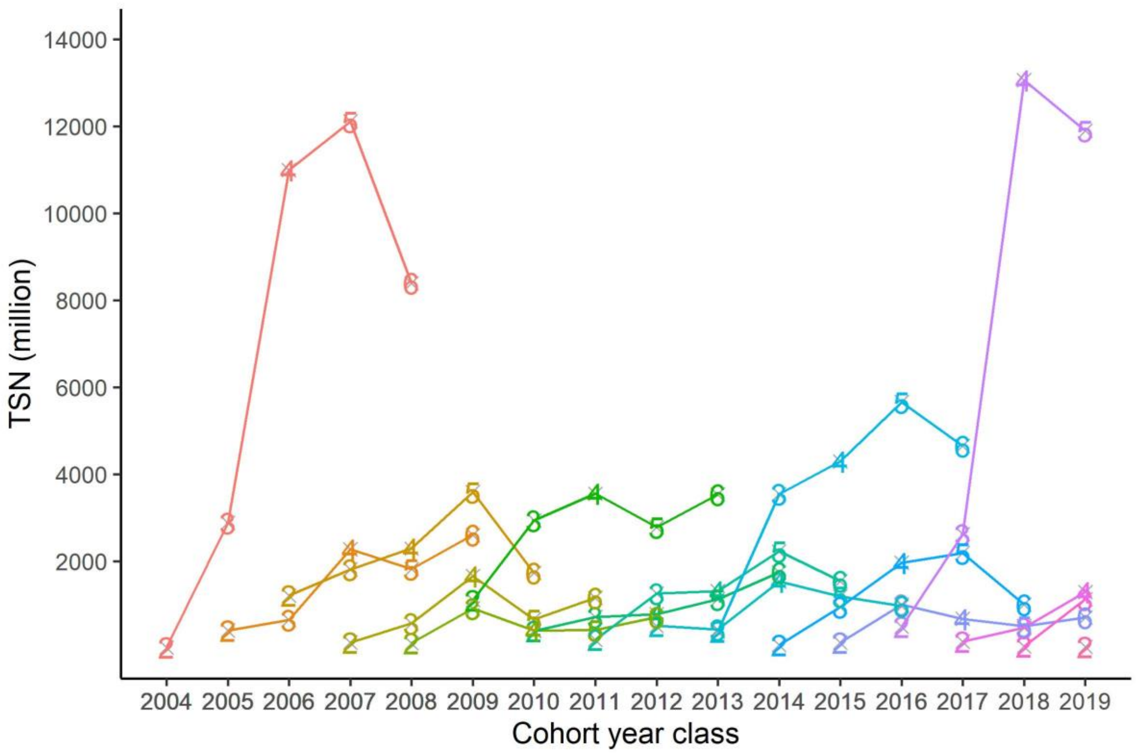


Figure 13. Tracking of the Total Stock Number at age (TSN, in millions) of Norwegian spring-spawning herring for each cohort since 2004 from age 2 to age 6. From 2008, stock is estimated using the StoX software. Prior to 2008, stock was estimated using BEAM.

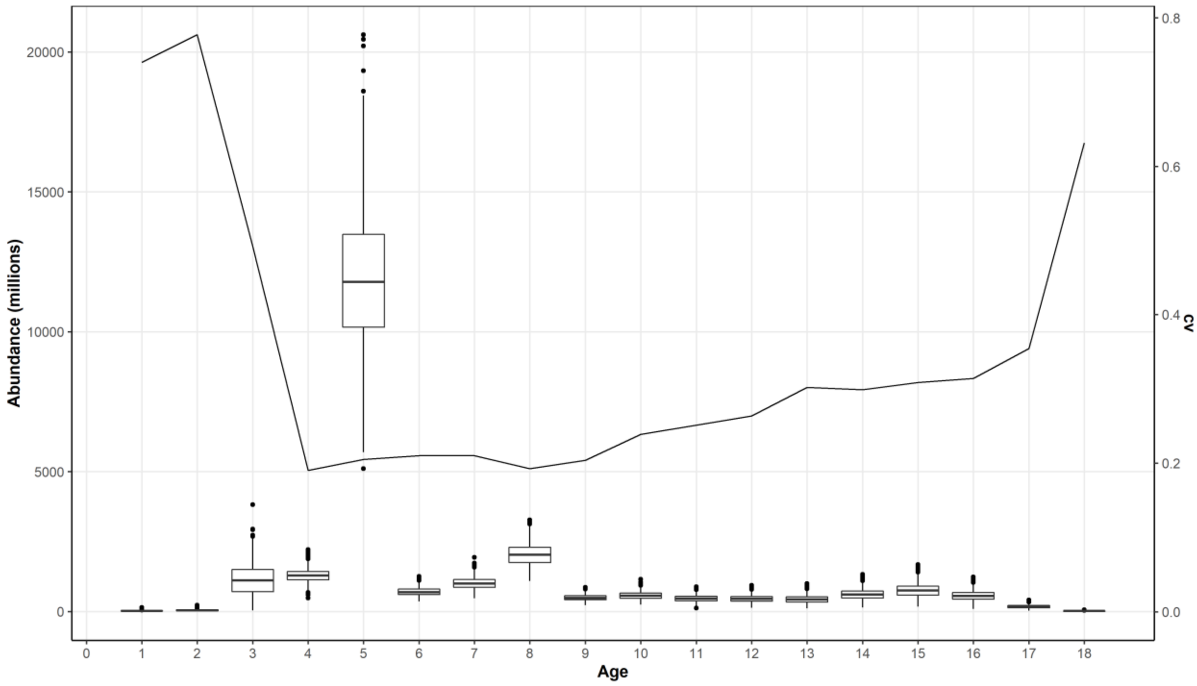


Figure 14. Norwegian spring-spawning herring in the Norwegian Sea: R boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 1000 replicates using the StoX software.

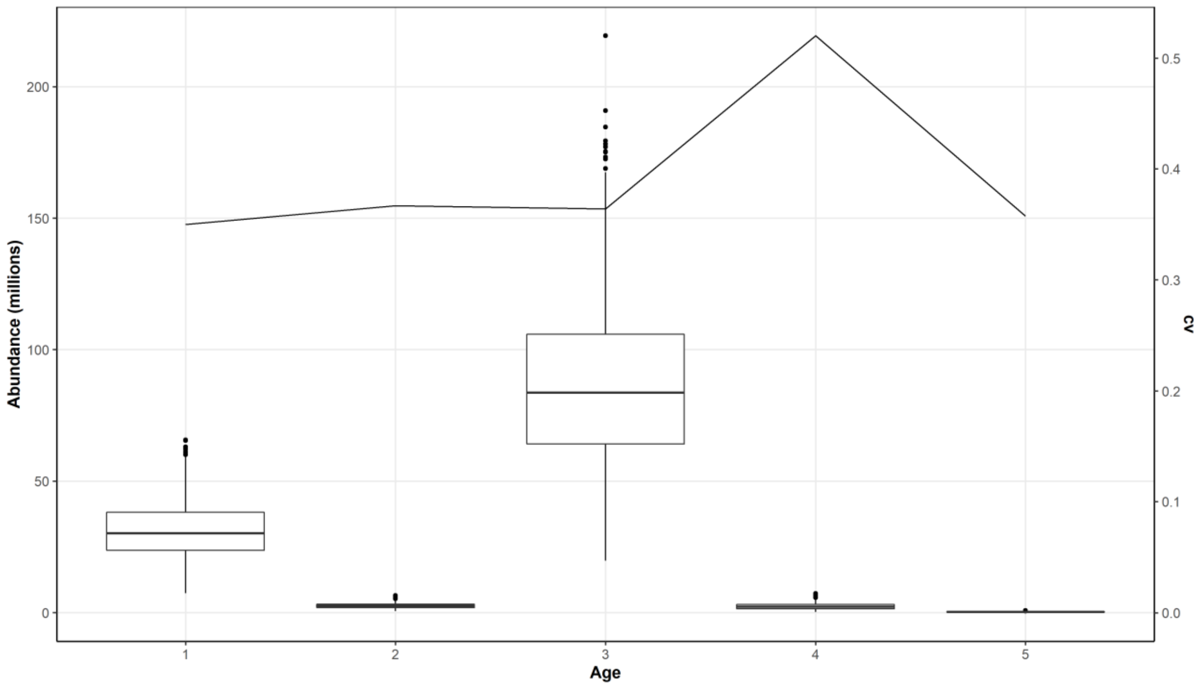


Figure 15. Norwegian spring-spawning herring in the Barents Sea: R boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 1000 replicates using the StoX software.

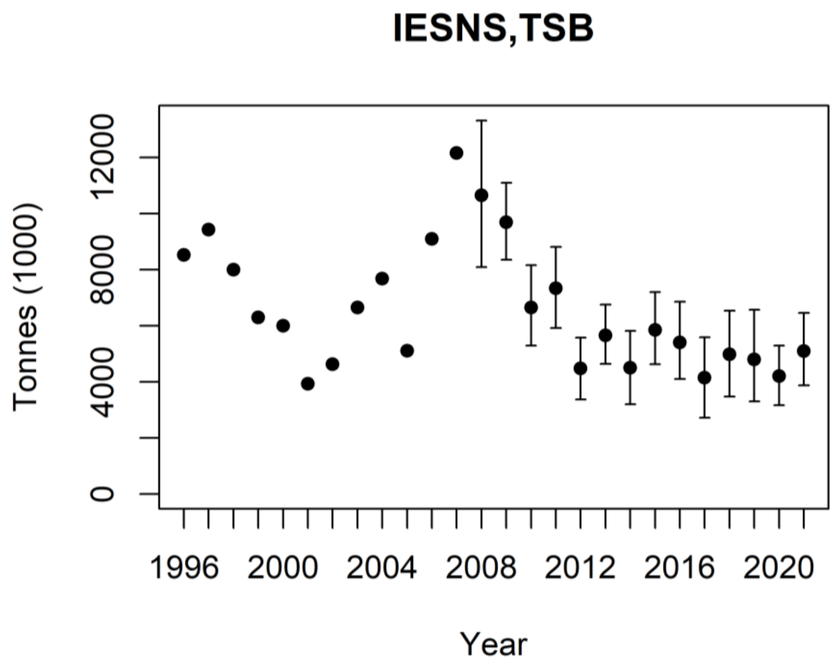


Figure 16. Biomass estimates of Norwegian-spring spawning herring in the IESNS survey (Barents Sea, east of 20°E, is excluded) from 1996 to 2021 as estimated using BEAM (1996-2007; calculated on basis of rectangles) and as estimated with the software StoX (2008-2021; bootstrap means with 90% confidence interval; calculated on basis of standard stratified transect design).

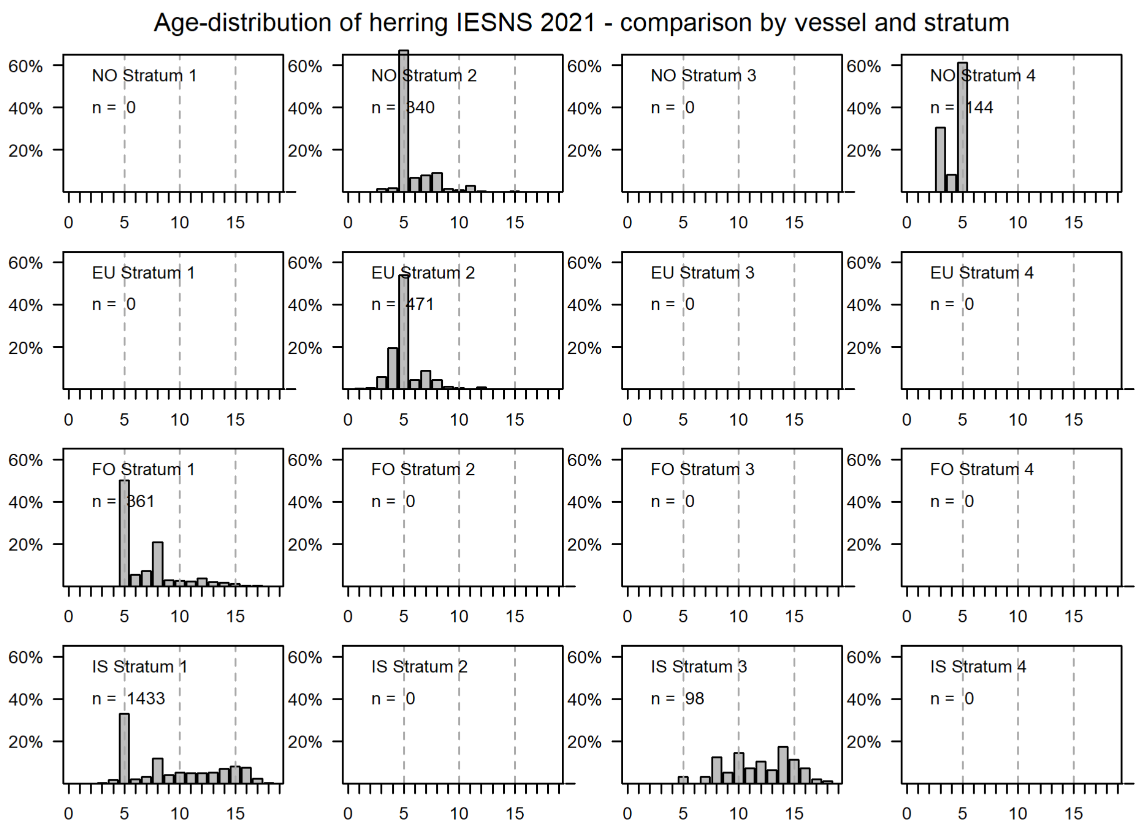
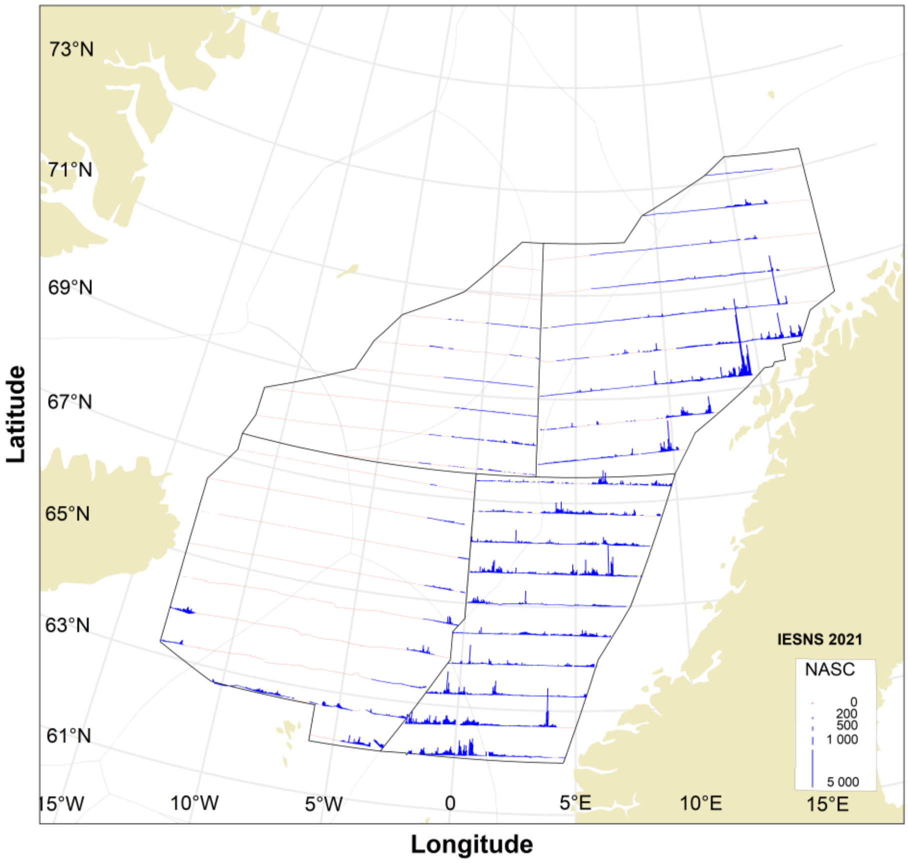


Figure 17. Comparison of the age distributions of NSS-herring by stratum and country in IESNS 2021 (Barents Sea not included). The strata are shown in Figure 3.

(a)



(b)

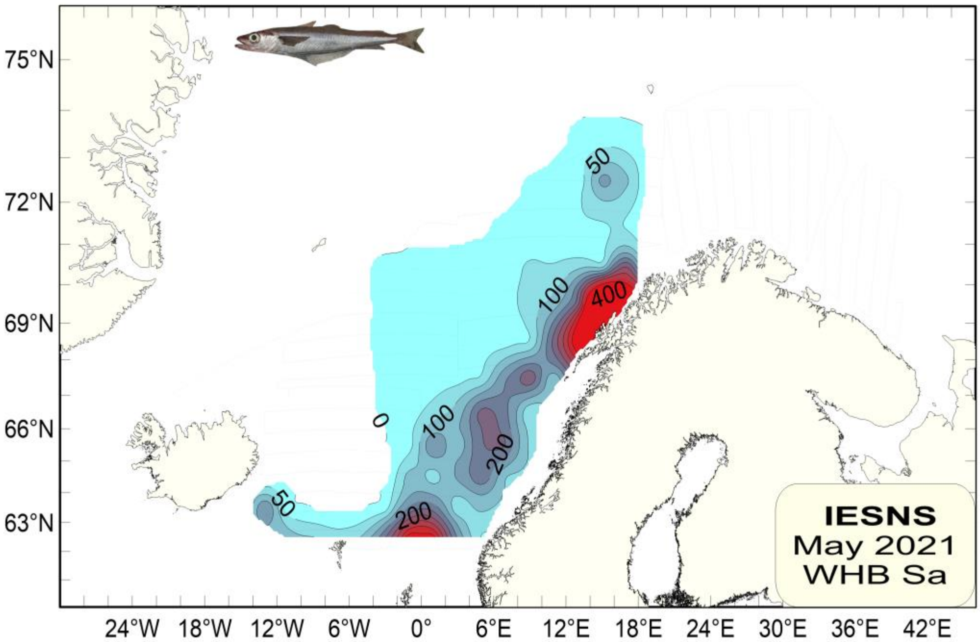


Figure 18. Distribution of blue whiting as measured during the IESNS survey in May 2021 in terms of NASC values (m^2/nm^2) (a) averaged for every 1 nautical mile and (b) represented by a contour plot.

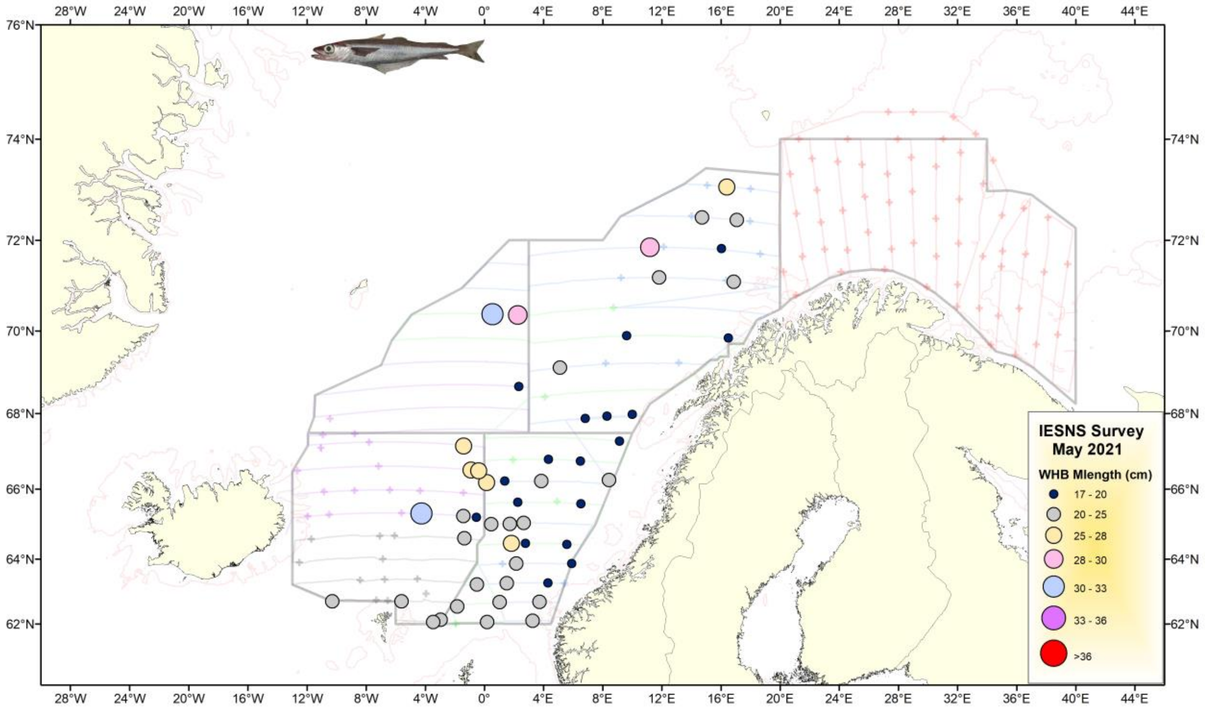


Figure 19. Mean length of blue whiting in all hauls in IESNS 2021. The strata are shown.

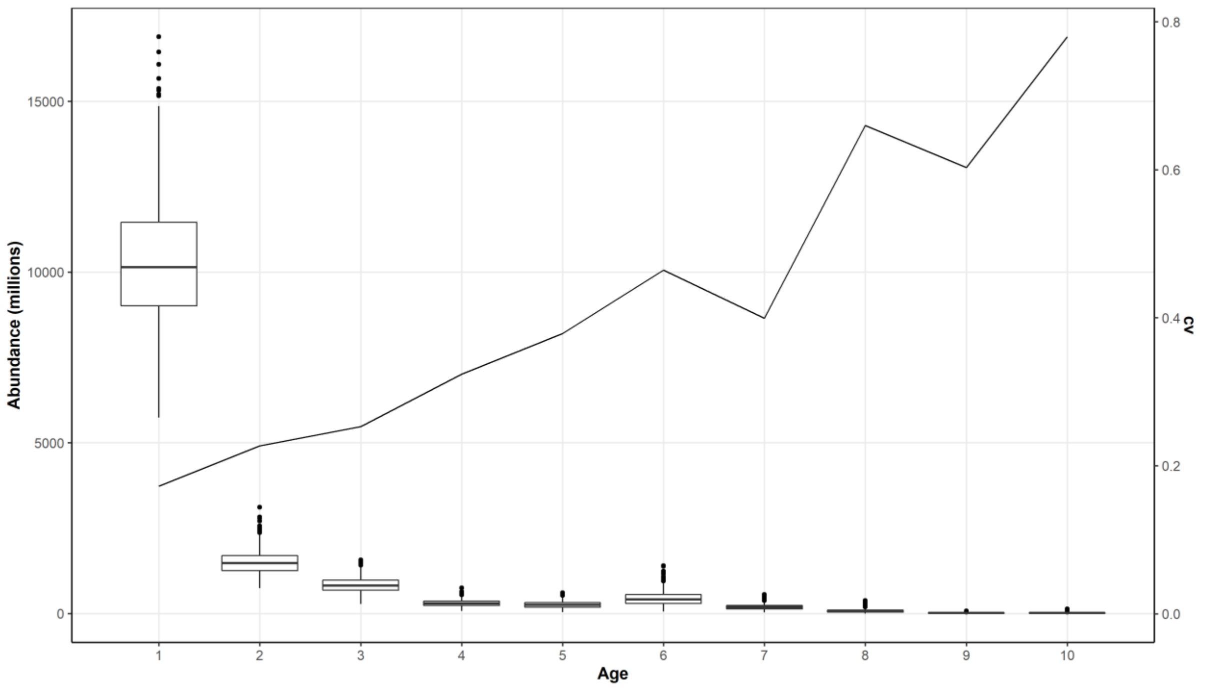


Figure 20. Blue whiting in the Norwegian Sea: R boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 1000 replicates using the StoX software.

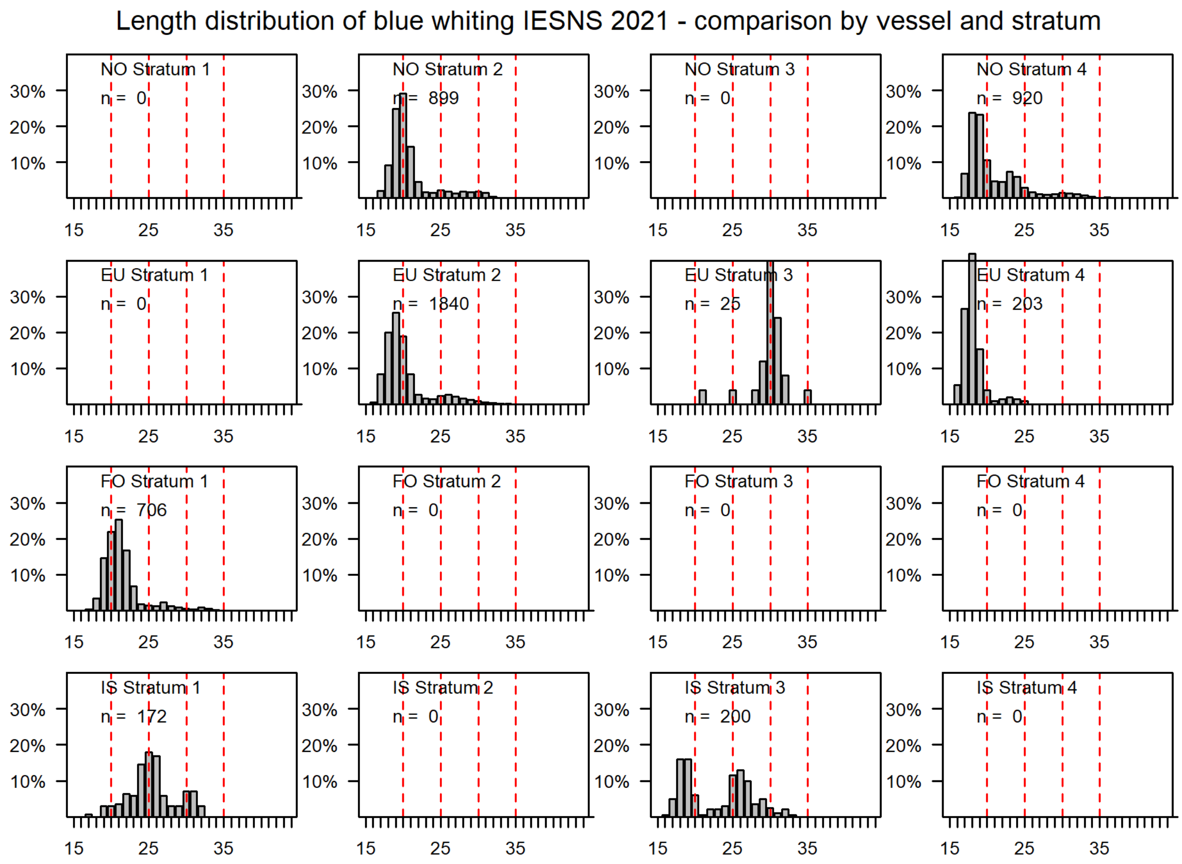


Figure 21. Comparison of the length distributions of blue whiting by stratum and country in IESNS 2021 (Barents Sea not included). The strata are shown in Figure 3.

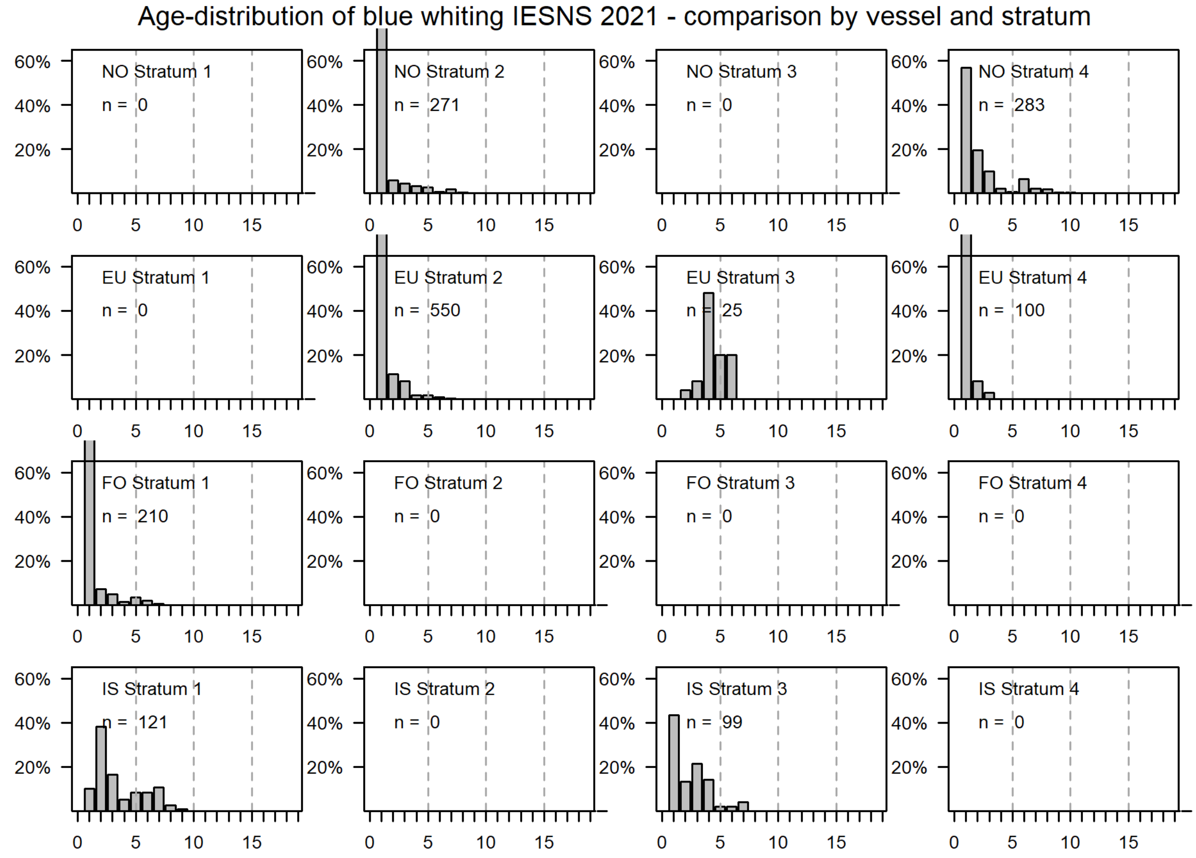


Figure 22. Comparison of the age distributions of blue whiting by stratum and country in IESNS 2021 (Barents Sea not included). The strata are shown in Figure 3.

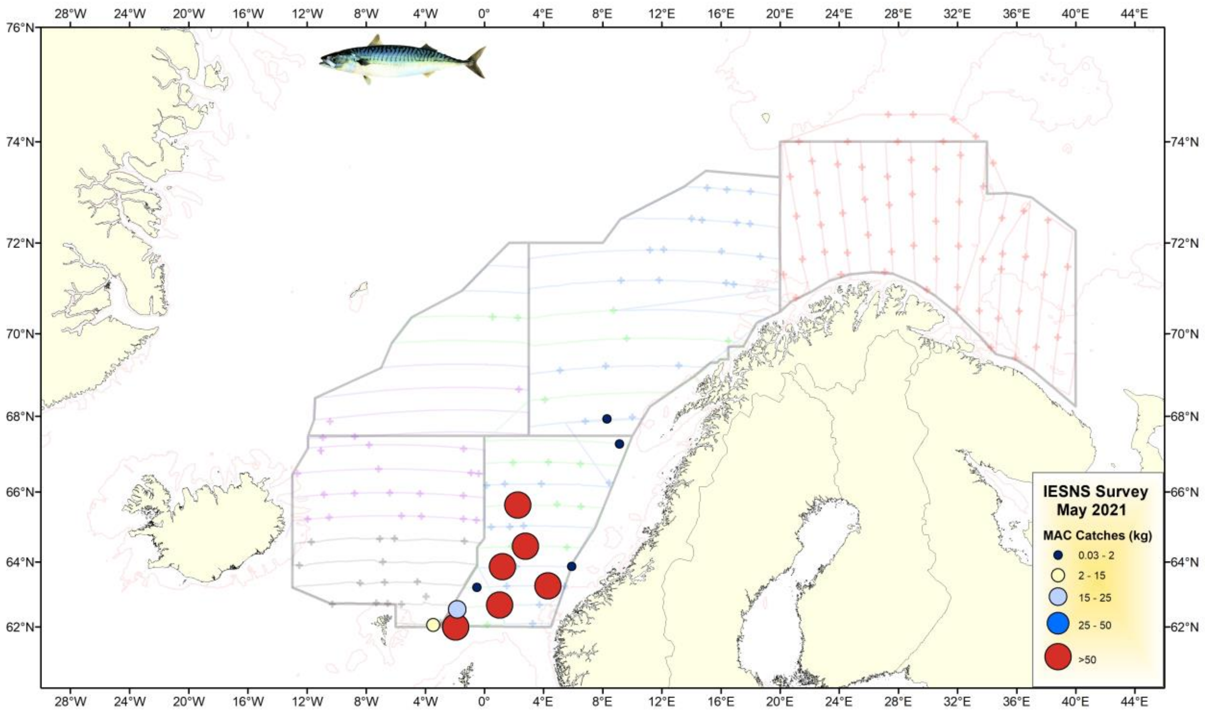


Figure 23. Pelagic trawl catches of mackerel in IESNS 2021. The strata are shown.

2021 mackerel egg exploratory survey (0321H)

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Introduction

WGMEGS, the ICES working group tasked with coordinating the triennial Mackerel and Horse mackerel egg surveys (MEGS) has since 2007 been observing and reporting on the offshore westwards and northwards expansion of mackerel spawning. During this period it had been noted that although the proportion of spawning taking place in these northern and western areas had indeed been small (in comparison to the total annual egg production) it had nevertheless been increasing with every survey. The results from the recent triennial MEGS surveys in 2016 and 2019 provided clear evidence that this was no longer the case demonstrating a significant and unprecedented shift with emphasis moving away from the traditional spawning hotspot areas of Biscay and the Celtic Sea and instead over a large swathe of open ocean often well away from the continental shelf. During the last 2 triennial surveys some of the highest spawning densities were observed to the west and Northwest of Scotland and importantly very close to the northern and north-western survey boundary (see figures 1 and 2).

During the last NEA mackerel benchmark in 2017 (ICES,2017) and as part of the WGMEGS survey review process a commitment was made to undertake exploratory icthyoplankton surveys within the mackerel spawning boundary regions in the North and Northwest and where the MEGS surveys have hitherto struggled to delineate a hard spawning boundary. During 2017 and 2018 exploratory surveys undertaken by Ireland and Scotland and utilising Gulf 7 samplers successfully mapped and delineated a mackerel spawning boundary within the offshore areas of Hatton Bank/South Iceland Basin and the Scotland-Faroe-Iceland Ridge (ICES,2018). The results from these surveys played a useful role in informing the survey planning process ahead of the 2019 MEGS triennial survey but left the Norwegian Sea/Shelf as an area that still provided a level of uncertainty and especially with recent MEGS survey results providing compelling evidence (ICES,2021) that mackerel appear to be favouring the North-eastern route as they head North towards their summer feeding grounds. This survey aims to conclude this exploratory objective by surveying mackerel spawning activity up and along the Norwegian Shelf and during the month when the highest mackerel spawning densities are likely to be encountered within this region. An additional objective included completion of several icthyoplankton transects undertaken within the Northern North Sea area and that will feed directly into the North Sea Mackerel Egg Survey (NSMEGS) dataset. In contrast to the previous exploratory surveys in 2017 and 2018, trawling was scheduled during this survey with midwater trawl deployments being planned within both the North Sea and Norwegian Sea areas. Information on adult mackerel being requested for both batch fecundity and spawning fraction estimation for the NSMEGS (south of 62N) as well as contribute to ongoing research taking place at the Institute of Marine Research (IMR) in Bergen.

Survey

Survey methodology

The 76m Scottish pelagic fishing trawler, *Altaire*, was chartered to undertake survey 0321H, from 7th to the 22nd June 2021. The samples were collected and analysed in accordance with the WGMEGS sampling at sea manual (ICES, 2019). Double oblique deployments were conducted at every sampled station and these were taken to within 10m of the bottom or to a maximum depth of 200m, whichever is shallower. Scotland utilises a Gulf VII plankton sampler which is towed at a speed of 4 knots and uses a 250 µm plankton net. Valeport replica electronic flowmeters and a RBR Duo CTD attached to the sampler, monitored volume as well as recording depth, temperature and salinity during each deployment. Real-time sampler depth was monitored using a ScanMar depth sensor, also attached to the sampler. Whilst completing transects for the NSMEGS component (south of 62N) half degree longitude station spacing was retained thereby ensuring consistency between NSMEGS participants. During the exploratory plankton survey component (North of 62N) the nominal station spacing was increased to one degree of longitude. This is consistent with the previous exploratory surveys undertaken and maximises the geographical area that can be completed. Survey protocols for sample treatment as well as data work up for all stations presented within this working document are as per the WGMEGS at sea protocols for surveying in the North Sea. On retrieval the plankton net was washed down in seawater with the plankton being fixed in 4% buffered formalin. All samples were analysed within 36 hours of being fixed, with all eggs being extracted and retained for analysis. All mackerel eggs were subsequently identified, counted and their development stage determined.

Survey summary

Altaire departed from Peterhead at around mid-afternoon on the 7th June in near perfect weather conditions and headed North towards the survey starting point on the East side of Muckle Flugga, Shetland. After completion of the flowmeter calibrations Altaire headed East to commence surveying on the 60.75N transect. Whilst still awaiting final clearance for permission to survey within the Norwegian EEZ, Altaire was able to complete an additional partial transect at 59.75N during the 9th June, however with the permit being issued Altaire was then able to continue surveying back on to the 60.75N transect heading eastwards towards the Norwegian coast before turning North and then west on the 61.75N transect towards Tampen and to the North of Shetland. This concluded the NSMEGS component and from here the station spacing increased to 1 degree of longitude with double alternate transect spacing employed on the Northwards outbound survey plan. Following this plan and with weather conditions being generally calm although largely overcast Altaire was able to make excellent progress completing transects at 63.45N, 65.45N, 67.45N before completion of a the final outbound transect at 68.15N on the 16th June. During the inbound track Altaire proceeded south interlacing to complete the transects ‘missed’ during the outbound route North. As regards the geographic extent of the transect to the west, the intention was to survey at least as far west as the 1000m isobath, which was achieved and in several cases the transects were extended even further west and out over 2000m(figure 3). After completion of a survey track of almost 2900 nm Altaire finally returned back to Peterhead in the early hours of the 22nd June.

Temperature

Surface temperatures encountered during the survey (taken at 5m depth) ranged from 9 degrees Celsius in the northernmost latitudes surveyed to almost 14 degrees further south and within the North Sea area over towards the Norwegian Coast. A period of relatively settled weather experienced prior to as well as during the survey period almost certainly contributed to the stratification observed throughout the survey with temperature profiles recording an average drop in temperature of approximately 3 degrees Celsius when comparing surface temperatures with those recorded at 50m depth. Figures 4 – 6 provide heat plots for 5, 20 and 50m temperatures recorded in Celsius during the survey.

Results

Egg Abundance

87 Gulf deployments were made in total with 9 flowmeter calibration runs and a further 78 plankton deployments. These yielded 5123 mackerel eggs of all stages, of which 1671 were recently spawned stage 1 eggs. Mackerel eggs were recorded from every deployment with stage 1 eggs being recorded on all but 2 of the stations completed. The numbers of mackerel eggs extracted from the Gulf VII samples were standardised and the stage 1 data presented as numbers /m^2/day (see figure 7). Egg counts across the entire surveyed area were low to moderate with the highest egg counts generally being encountered within the southern half (south of 66N) of the survey area and reducing gradually as the survey proceeded Northwards until counts were entirely down to single figures on transects West of Lofoten and with even the surface temperatures cooled to levels approaching the perceived temperature threshold for spawning in mackerel.

Trawling

The vessel's own midwater trawl was deployed 5 times (fig. 8) during the survey, and was successful in catching mackerel on two of those occasions. All trawl deployments were towed for approximately 1 hour. An attempt was made to collect adult fish for fecundity analysis as part of the NSMEGS, however the night-time deployment at Tampen was unsuccessful. Further North it became clear that within a well stratified water column with relatively warm surface layer that Altaire's unfloated net would struggle to get close enough to the surface to be effective and unsurprisingly the trawls undertaken close to the Norwegian Coast at 63.75N and again at 66.75N were unsuccessful. Even with the trawl headline at 25 – 30m from the surface (*shallowest that net could operate*) the sub 7.5 Celcius temperature recorded on the trawl headline sensor appeared to be too cold for mackerel. As an alternative method 3 sessions with rod and line were also tried at the surface but also with no success. The last two trawl deployments were undertaken on the inbound track and towards the western edge of transects at 64.75N 4E (AE03/04) and also 62.75N 1.25E (AE03/05) respectively and where stratification was less defined resulting in the layer of warm water extending deeper and importantly within reach of the midwater trawl. Trawl AE03/04 yielded 19 mackerel whereas AE03/05 was successful in catching approximately 180kgs mackerel of which 104 randomly selected fish were sampled. Length, sex, maturity (*Walsh scale*) and age (*otoliths removed for ageing back in the lab*) were determined for each of the 123 mackerel sampled. In addition 60 ovary samples were collected for colleagues in IMR Bergen in order to progress current ongoing collaborative research being undertaken into spawning fish within the Northern region.

The sampled adults sampled ranged from between 28 and 41cm in length with the overwhelming majority within the length range 32 – 35cm. This translated into an age profile that spanned from ages 2 - 15 but where where over 80% of those sampled were between ages 2 – 5 with age 4 being the most prevalent year class. Unsurprisingly, of the 123 mackerel sampled almost 60% were found to be maturity stage 5 (*partially spent*) while almost 20% were stage 6 (*spent*). Perhaps more surprisingly almost 15% were stage 4 (*spawning*) (see figs. 9-11).

Additional Sampling IESNS – Faroe Islands

17 additional plankton samples were collected for WGMEGS by the Faeroe Islands during the IESNS survey and within the of region extending from the east side of Iceland across to the north of Shetland. This survey took place between April 29th and 8th May. These samples were collected using a vertically deployed WP2 net that is deployed to a depth of 50m. The samples from these deployments have yet to be processed but the results will be available prior to WGMEGS in 2022 and incorporated into the WG report.

Conclusions/Discussion

The exploratory egg survey successfully completed the transects allocated to it within the North Sea area south of 62Nn with 29 stations being incorporated into the NSMEGS dataset. As regards the exploratory objective this has also been completed successfully with Altaire delivering a comprehensive snapshot of mackerel spawning within the area of the Norwegian Sea and during the period when as has already been stated mackerel spawning activity would expect to be at its peak. Despite completing the most northerly transect at 68.25N the survey was unable to find a hard spawning boundary albeit the numbers being encountered were very low within these high latitudes. This contrasts markedly with the previous exploratory surveys undertaken further West around Hatton Bank and North to Iceland during 2017 and 2018 and that were able to reaffirm the existence of a cold water barrier stretching from the East coast of Iceland across to the Faroe/Shetland and demonstrating very little if any mackerel spawning taking place in June at latitudes North of the Faroe Islands. The situation up and along the Norwegian Sea is very different with the influence of the Norwegian Current keeping sea surface temperatures (within the surface layers in anycase) within a range that is tolerable for spawning mackerel. Nevertheless, the spawning levels observed in the sampled stations North of 62 degrees are overall very low with an estimated contribution to the overall total annual egg production (TAEP) of around 2%. Looking ahead to the

2022 survey, there is no immediate requirement for WGMEGS to significantly extend the survey coverage in this region much beyond what was undertaken in 2019.

An additional and secondary objective was to assess the existence (or otherwise) of a boundary between the North Sea and the western area component. The results from this survey highlight clearly that no boundary currently exists with continuous spawning taking place from the southern North Sea right up to and almost certainly beyond Lofoten in the North. Historically, a mismatch in timing and location of peak spawning may well have helped to preserve some degree of spatial separation between the components but on the evidence of this survey it is no longer there.

All the information gathered from these exploratory egg surveys as well as the additional samples received from the various Nordic surveys since 2017 are invaluable and provide a unique opportunity not available during the triennial survey year to map the distribution of spawning mackerel within the northern boundary regions. Knowledge gleaned is crucial during the planning and execution of the triennial survey in 2022.

Special thanks to Aril Slotte for assistance/advice provided during the permit application process and also to Eydna í Homrum and Sólva Eliasen for the collection of additional WP2 samples during the IESNS surveys.

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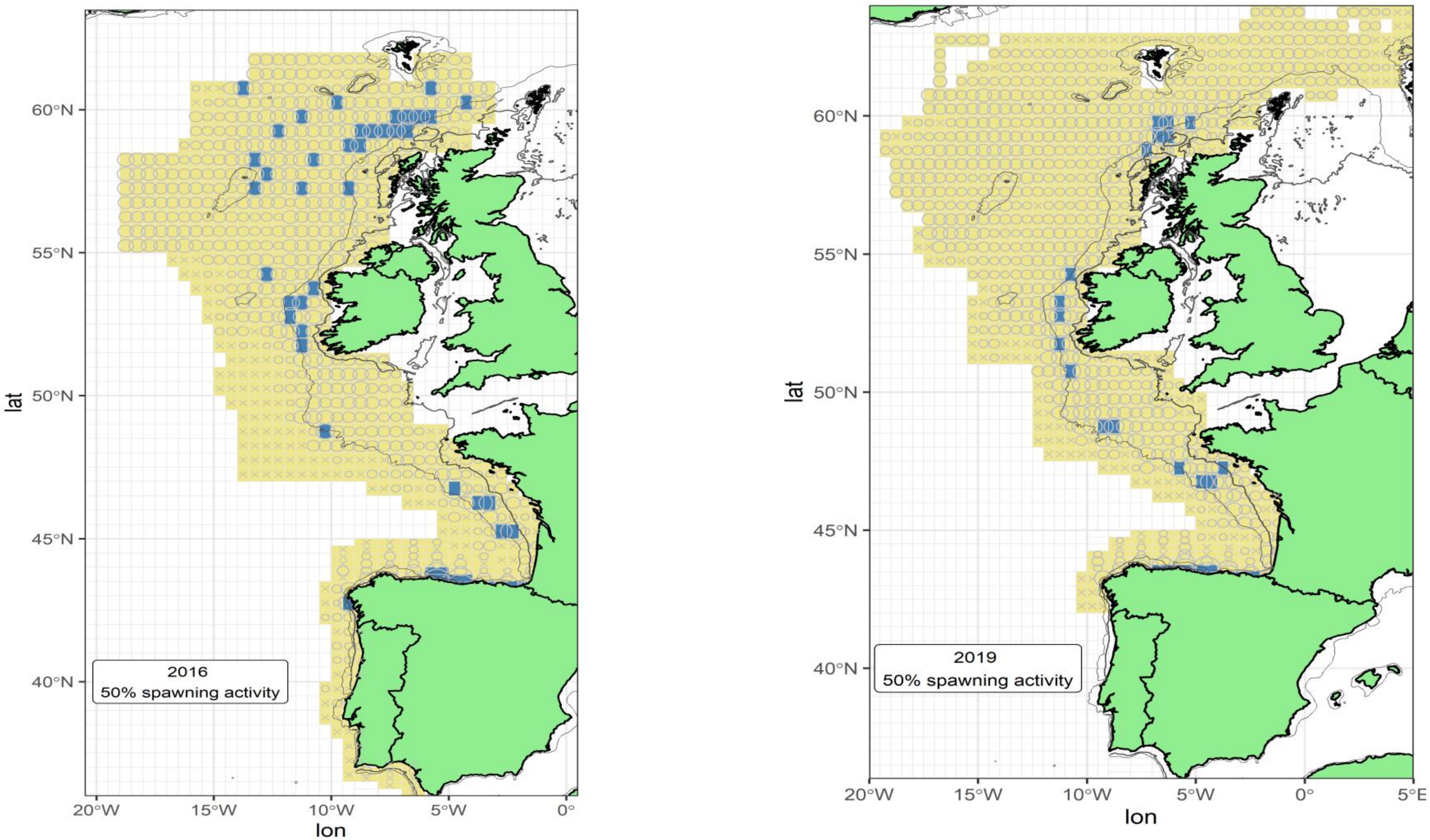


Figures 1 and 2: Mean egg production (stage 1 eggs/m2/day) by half ICES rectangle for all MEGS stations sampled in 2016 and 2019. Egg production values are square root transformed. (Crosses denote locations where sampling was undertaken but where no spawning was recorded). Area in yellow denotes the maximum geographical survey extent for the western survey area. Area/stations capturing 50% of spawning activity within that year are overlaid in blue.

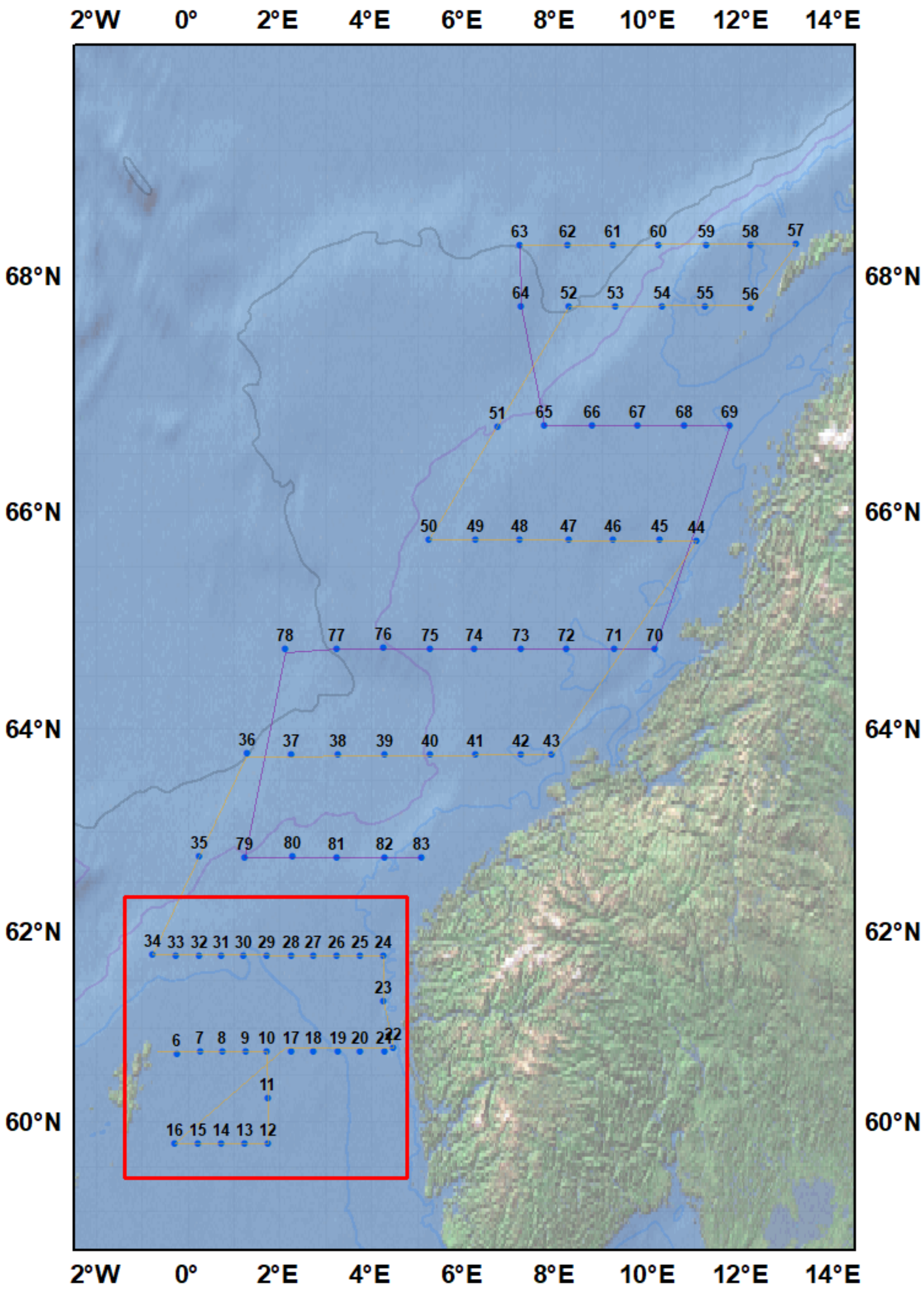
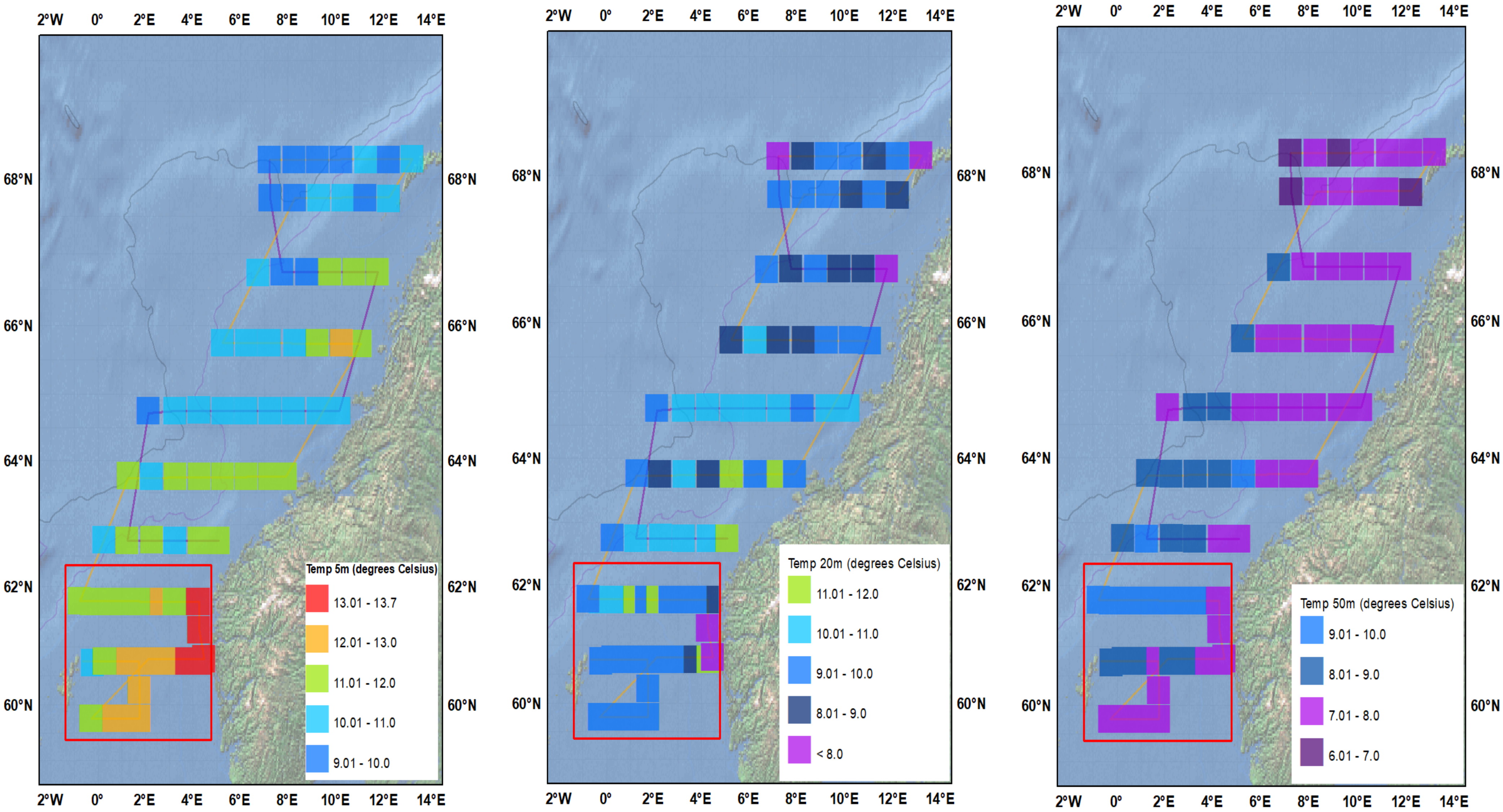


Figure 3: Survey track and stations for 0321H egg survey. Outbound track – orange and inbound track – purple. Red outline denotes 29 icthyoplankton stations undertaken south of 62N and contributing to NSMEGS. Isobaths at 200, 1000 and 2000m are also included for reference.



Figures 4 - 6: Survey 0321H temperatures recorded during Gulf VII deployments at 5m, 20m and 50m

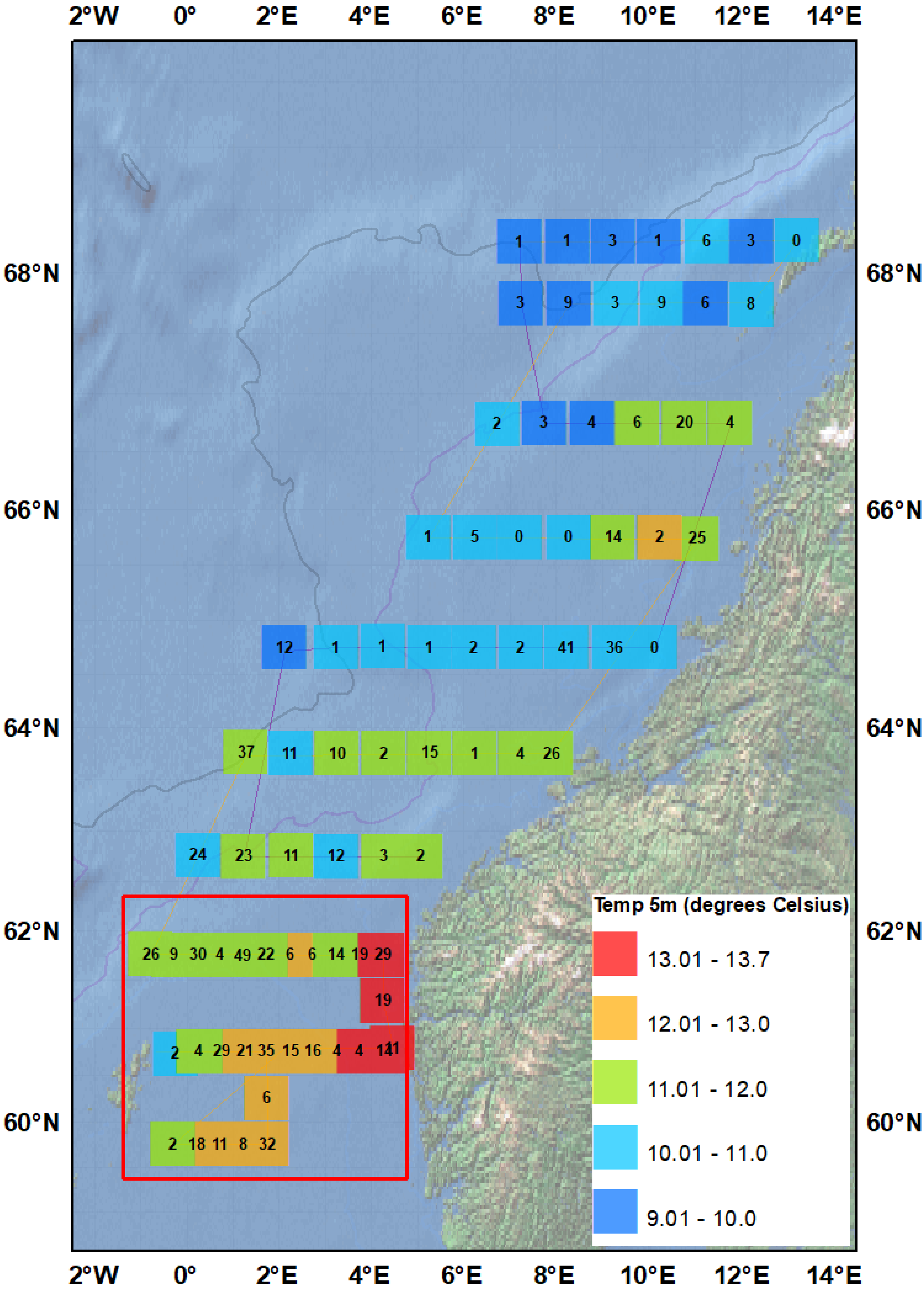


Figure 7: Mackerel stage 1 egg counts/m^2/day survey 0321H, for all stations sampled. The coloured squares represent the surface temperature in degrees Celsius at 5m depth during the icthyoplankton deployments.

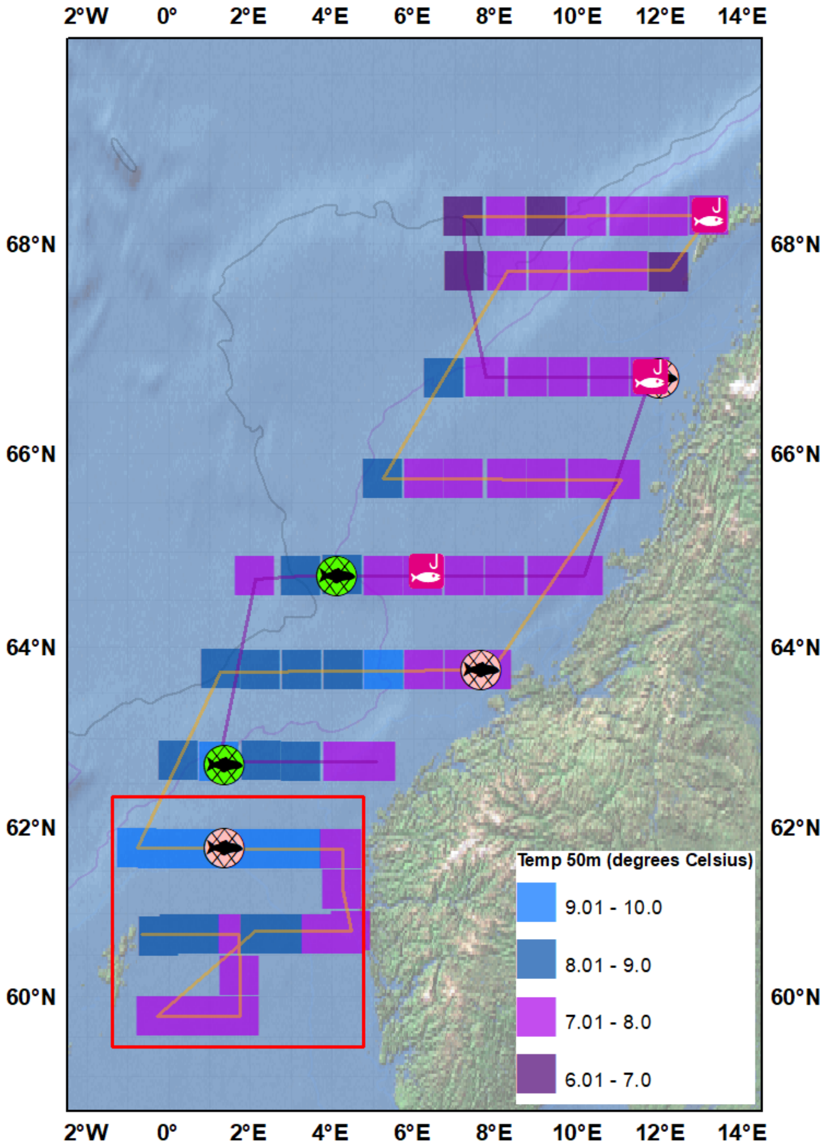
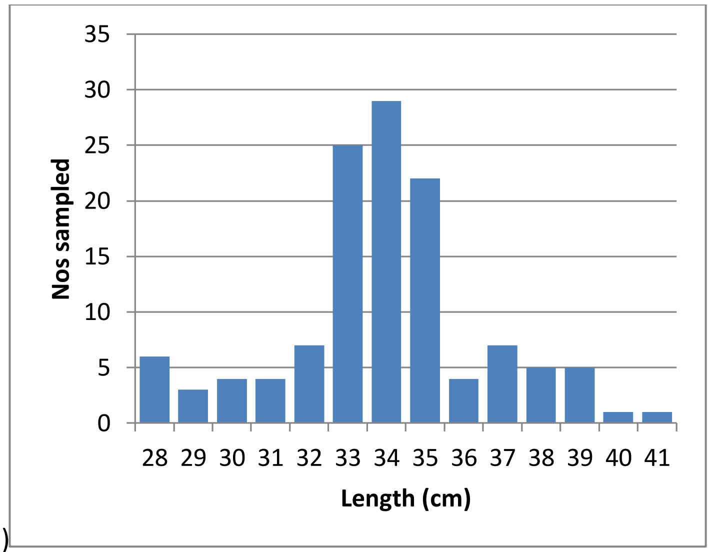


Figure 8: 0321H Trawl deployment. Red fish icons denote unsuccessful deployments, green fish icons denote deployments where mackerel were caught. Rod and line deployment locations (unsuccessful) are also presented. Temp profile at 50m is also underlaid for reference.



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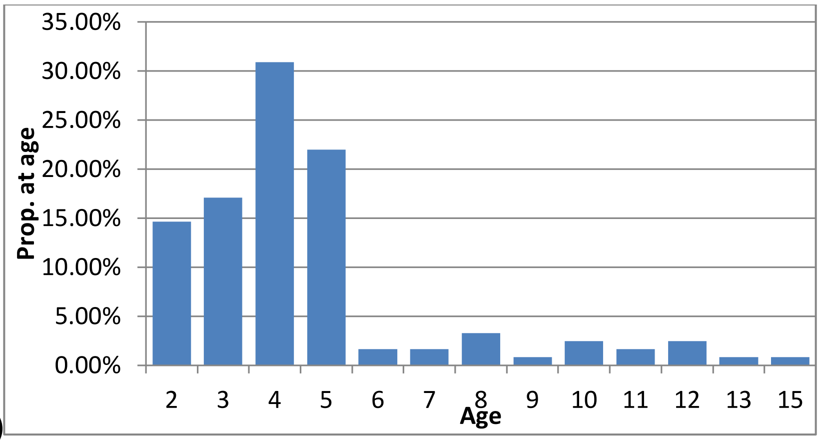

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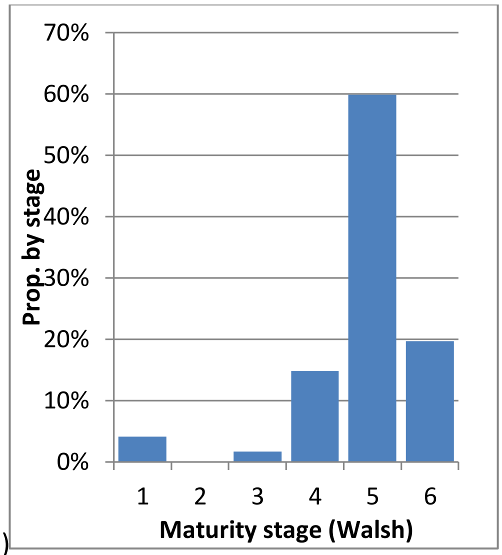

3)

Figures 9- 11: Histograms presenting summarised biological parameters of adult mackerel sampled during survey 0321H. From the top - 1) length(cms), 2) age profile by proportion of total sampled and also 3) maturity profile also as a proportion of total sampled. Combined total of 123 mackerel sampled from trawl deployments AE03/04 and AE03/05.