Working Document to

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

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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 m^2 adjustable hatches	Thybron type 15	Injector F-15	Seaflex 7.5 m^2 adjustable hatches	0
Weight of trawl door (kg)	2200	1700	1970	2000	1700	+
Area trawl door (m^2)	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.

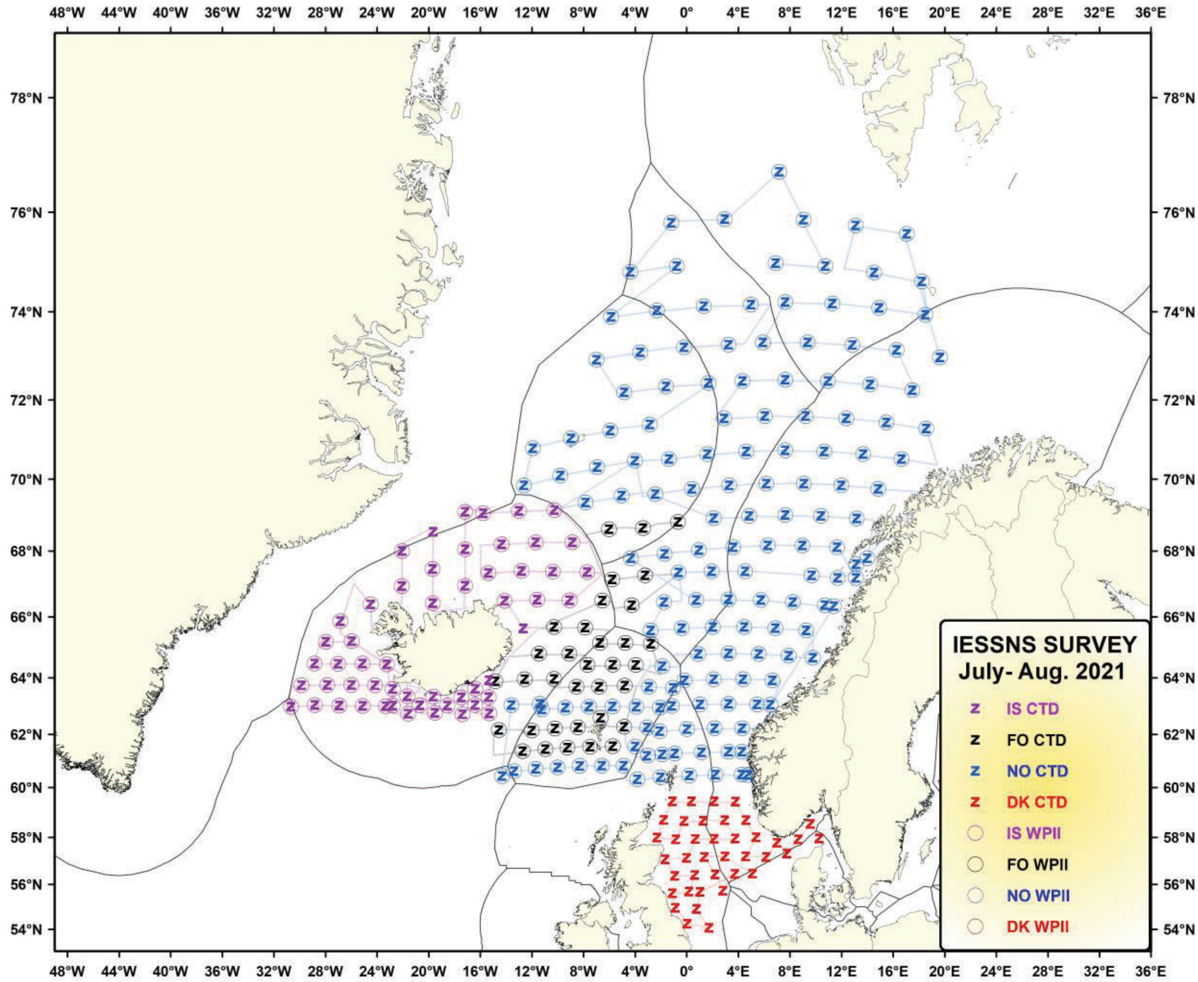


Figure 1. Fixed predetermined trawl stations (shown for CTD and WP2) included in the IESSNS from June 30th to August 3rd 2021. At each station a 30 min surface trawl haul, a CTD station (0-500 m) and WP2 plankton net samples (0-200 m depth) was performed. The colour codes, Árni Friðriksson (purple),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

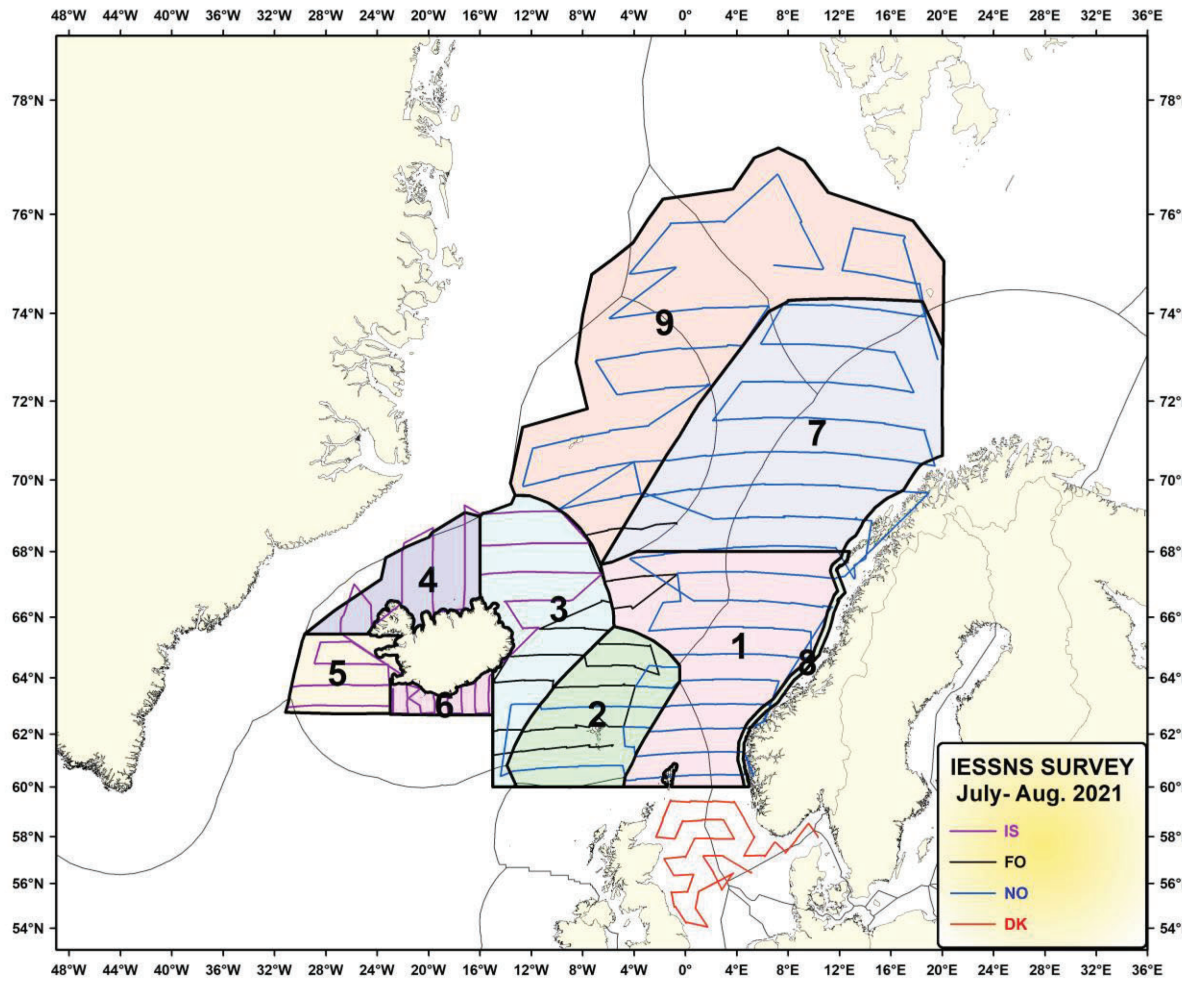


Figure 2. Permanent and dynamic strata used in StoX for IESSNS 2021. The dynamic strata are: 4 and 9.

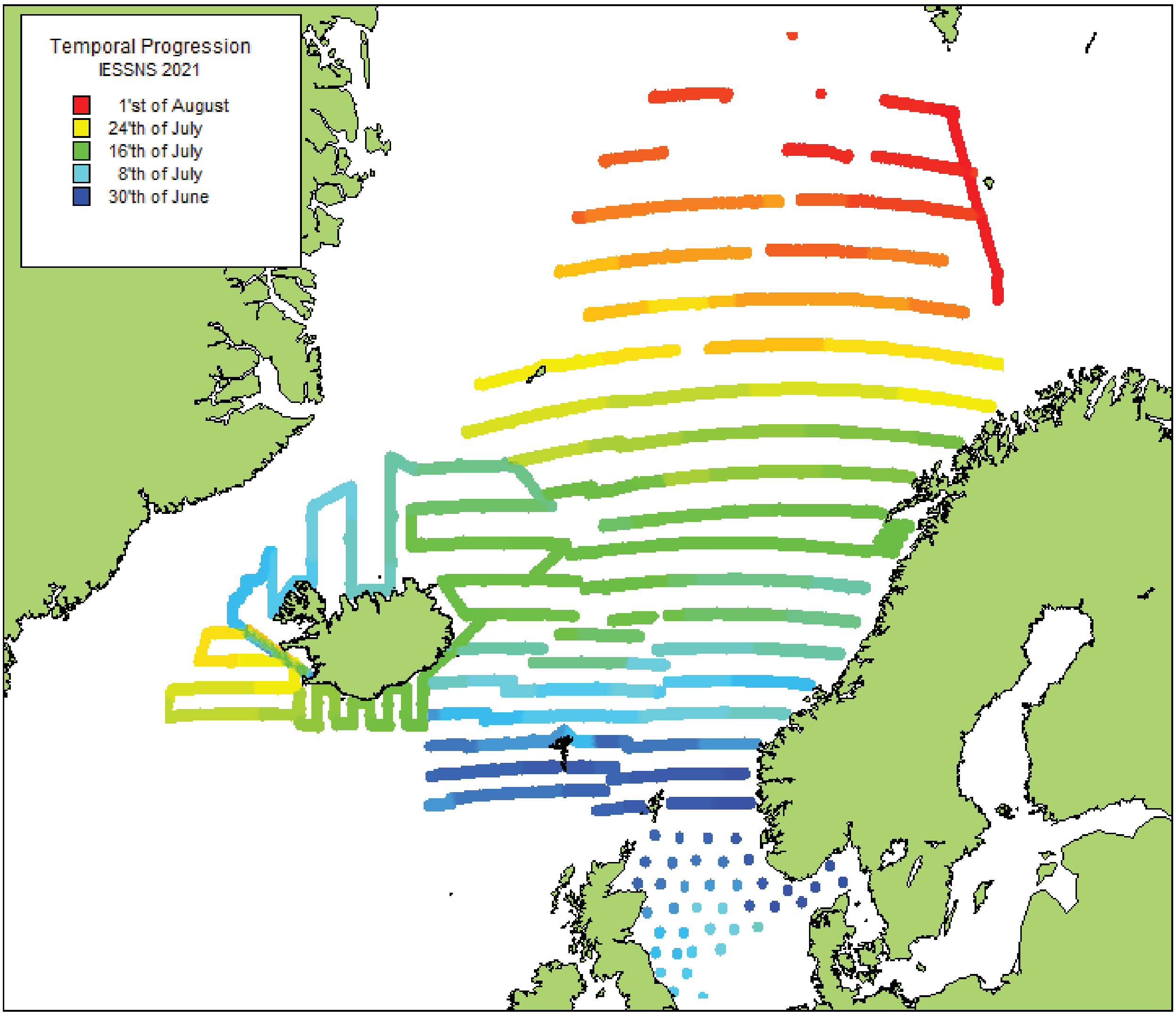


Figure 3. Temporal survey progression by vessel along the cruise tracks during IESSNS 2021: blue represents effective survey start (30th of June) progressing to red representing a five-week span (survey ended 3rd of August). As Ceton did not record acoustics, they have been represented by station positions.

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.

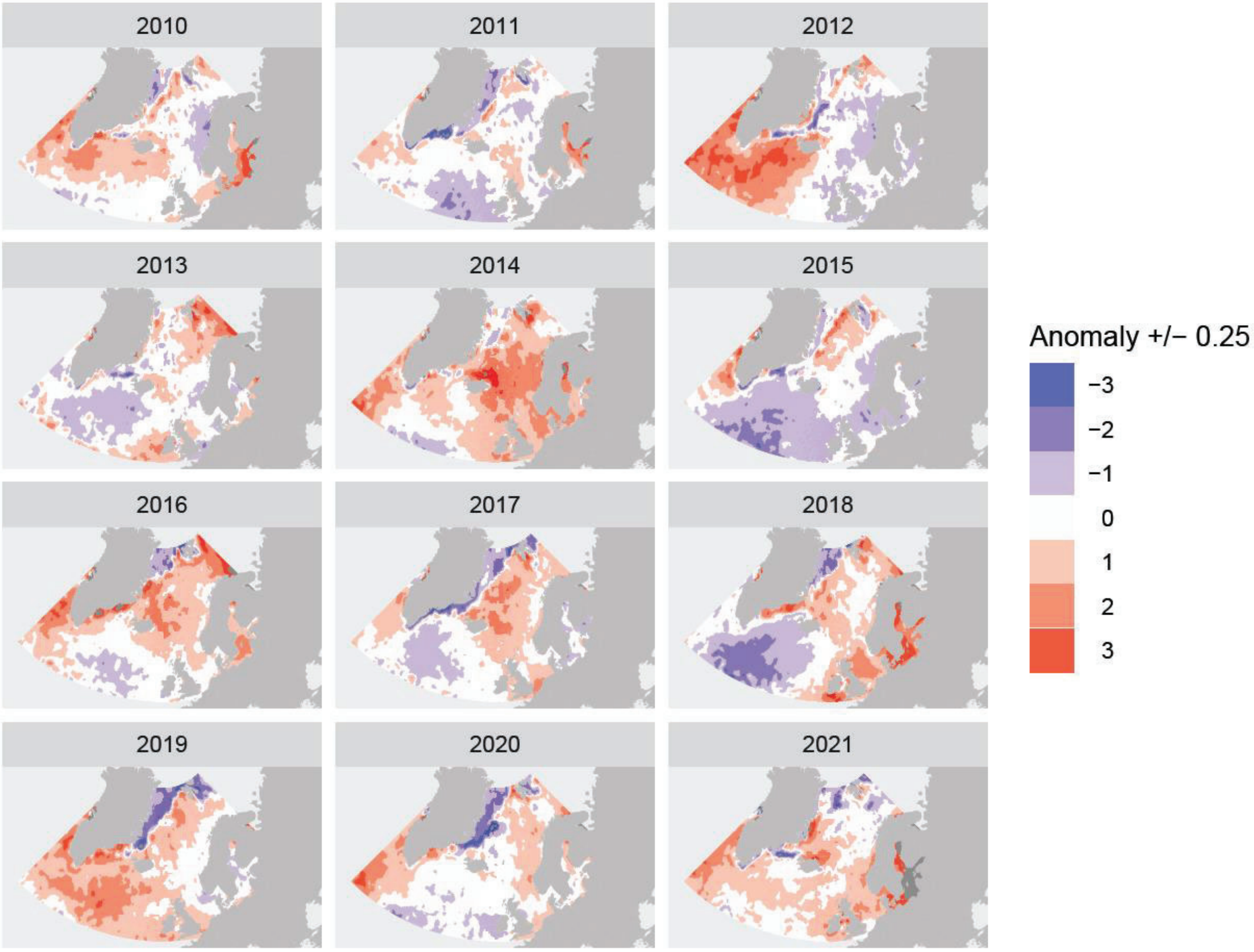


Figure 4. Annual sea surface temperature anomaly (-3 to +3°C) in Northeast Atlantic for the month of July from 2010 to 2021 showing warm and cold conditions in comparison to the average for July 1990-2010. Based on monthly averages of daily Optimum Interpolation Sea Surface Temperature (Ver. 2.1 NOAA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

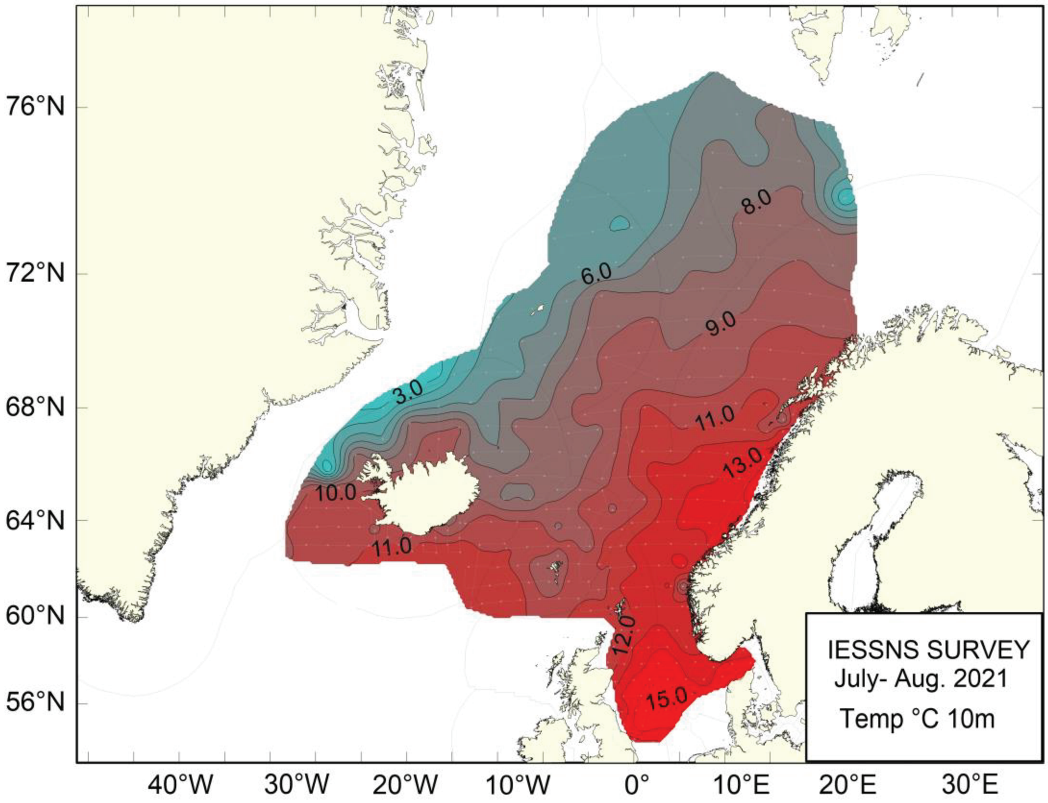


Figure 5. Temperature (°C) at 10 m depth in Nordic Seas and the North Sea in July-August 2021.

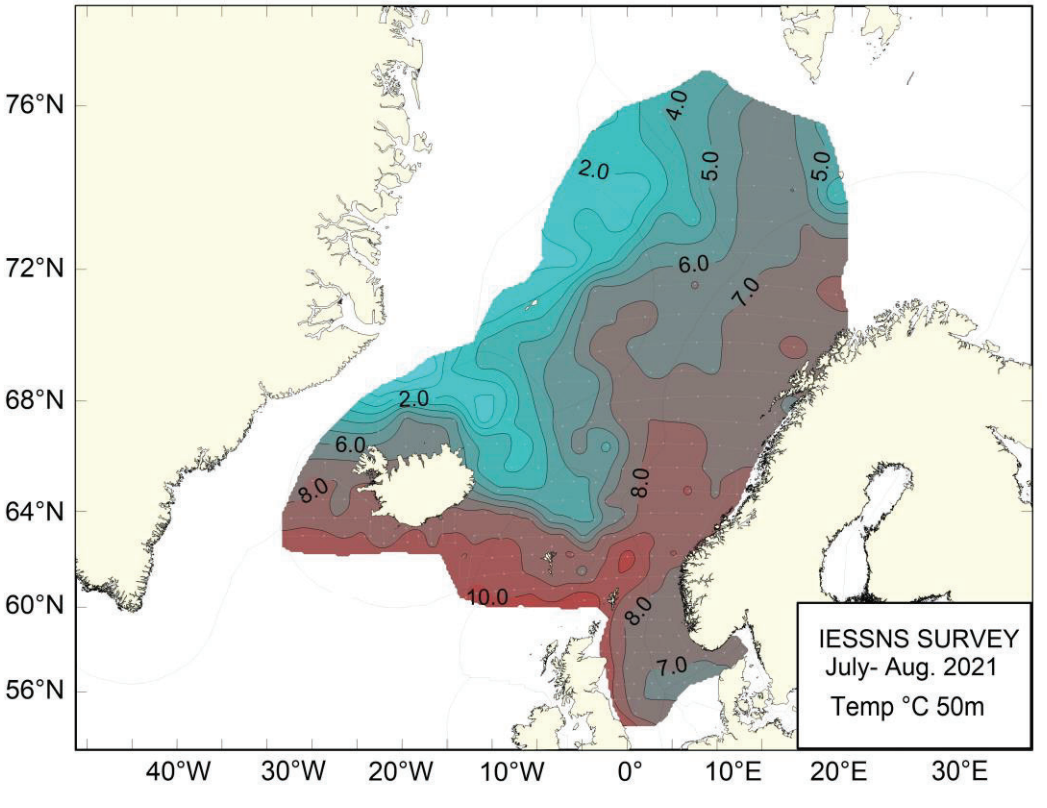


Figure 6. Temperature (°C) at 50 m depth Nordic Seas and the North Sea in July-August 2021.

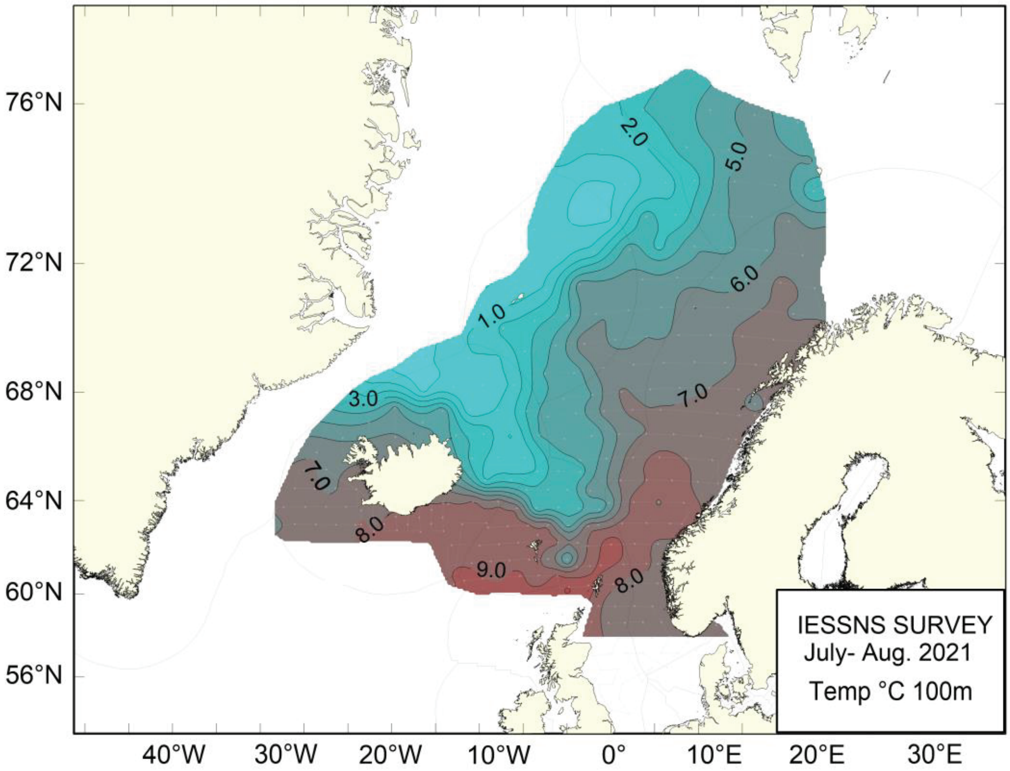


Figure 7. Temperature (°C) at 100 m depth in Nordic Seas and the North Sea in July-August 2021.

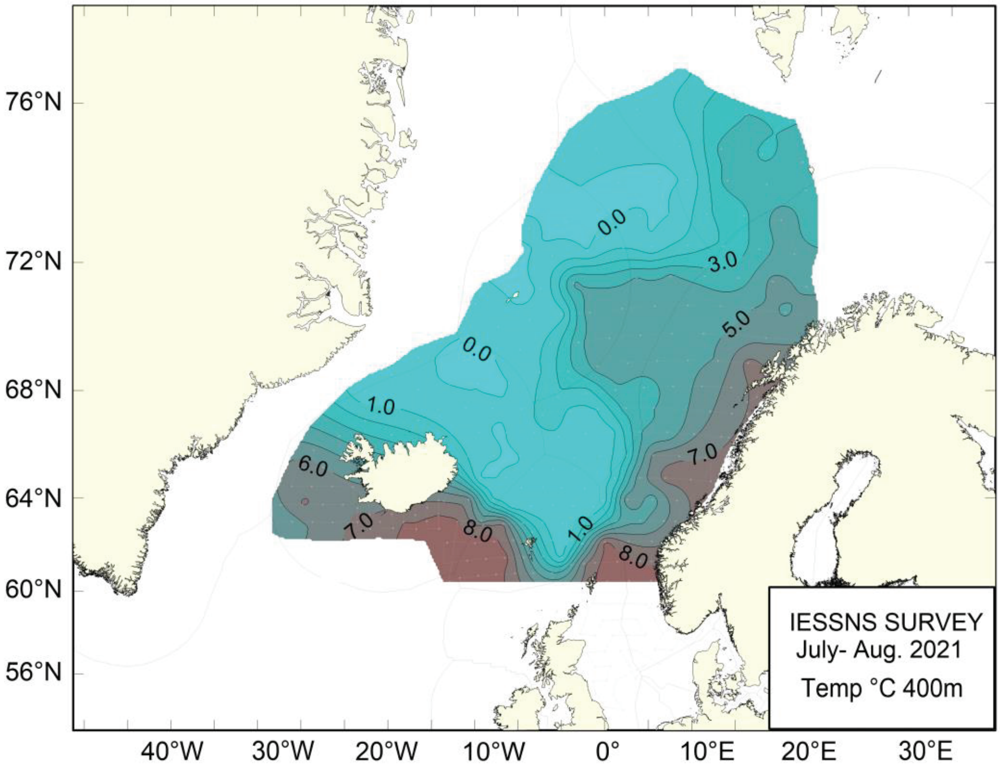


Figure 8. Temperature (°C) at 400 m depth in Nordic Seas and the North Sea in July-August 2021.

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.

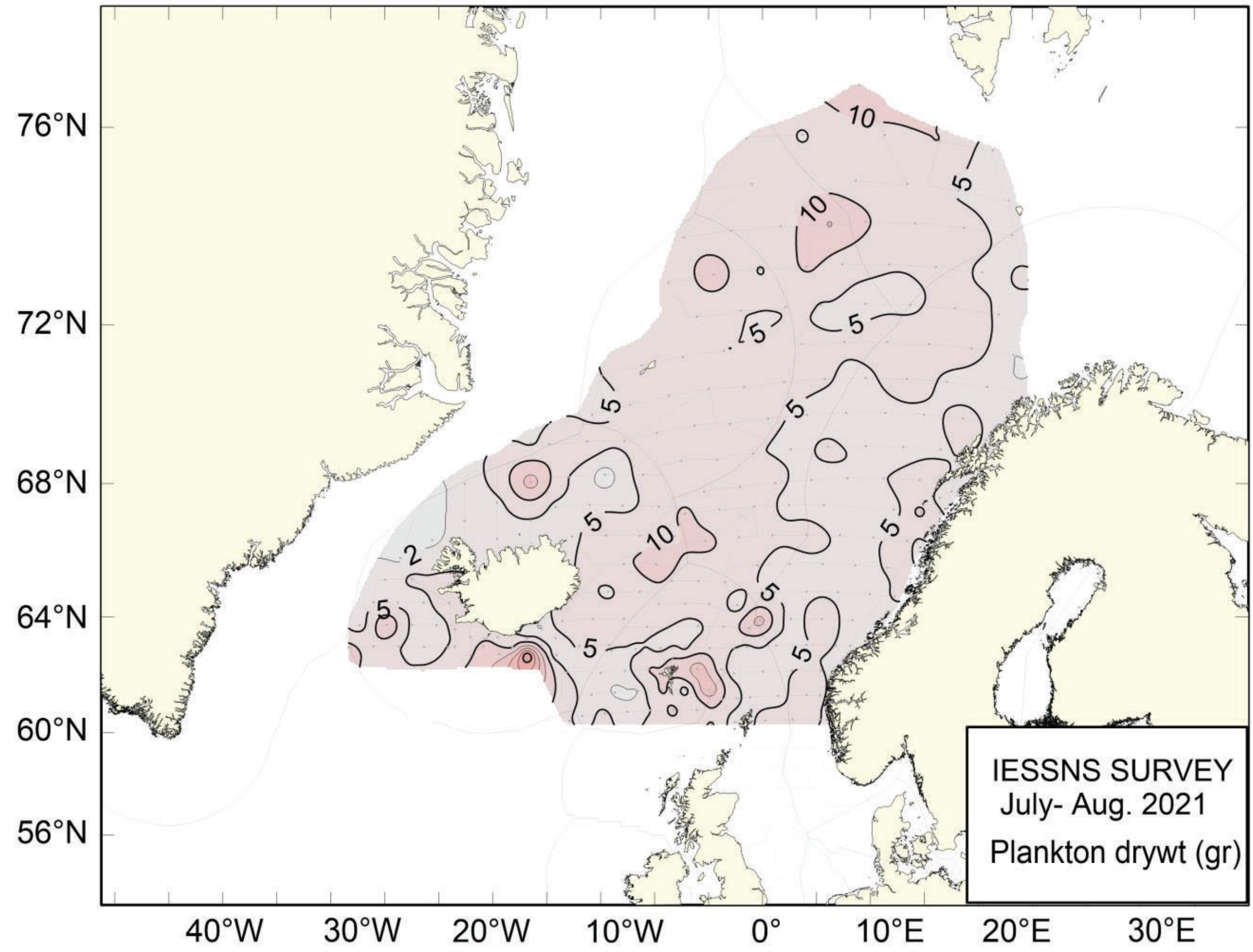


Figure 9a. Zooplankton biomass (g dw/m², 0-200 m) in Nordic Seas in July-August 2021.

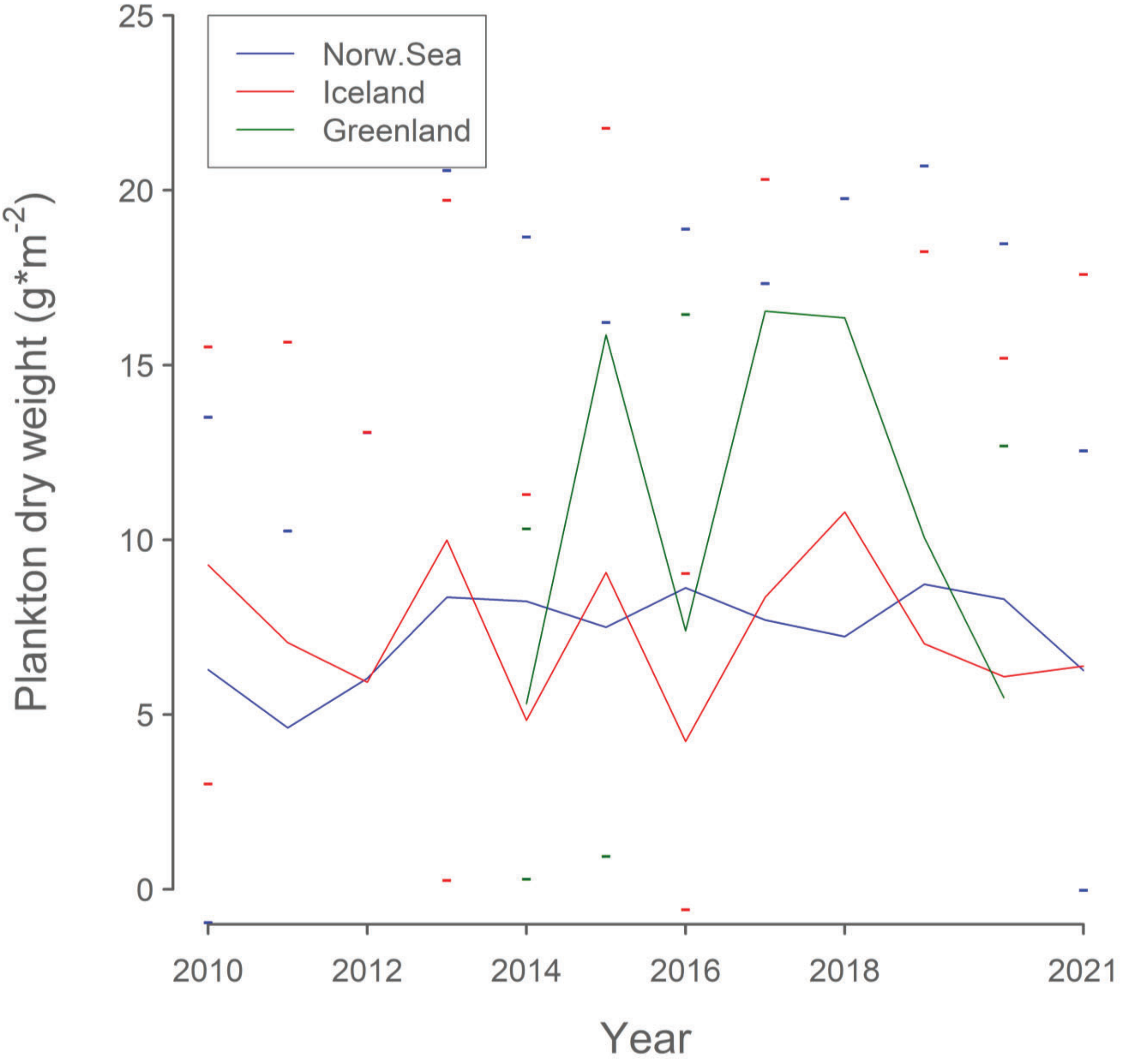


Figure 9b. Zooplankton biomass indices (g dw/m², 0-200 m). Time-series (2010-2021) of mean zooplankton biomass for three subareas within the survey range: Norwegian Sea (between 14°W-17°E & north of 61°N), Icelandic waters (14°W-30°W) and Greenlandic waters (2014-2020, west of 30°W).

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.

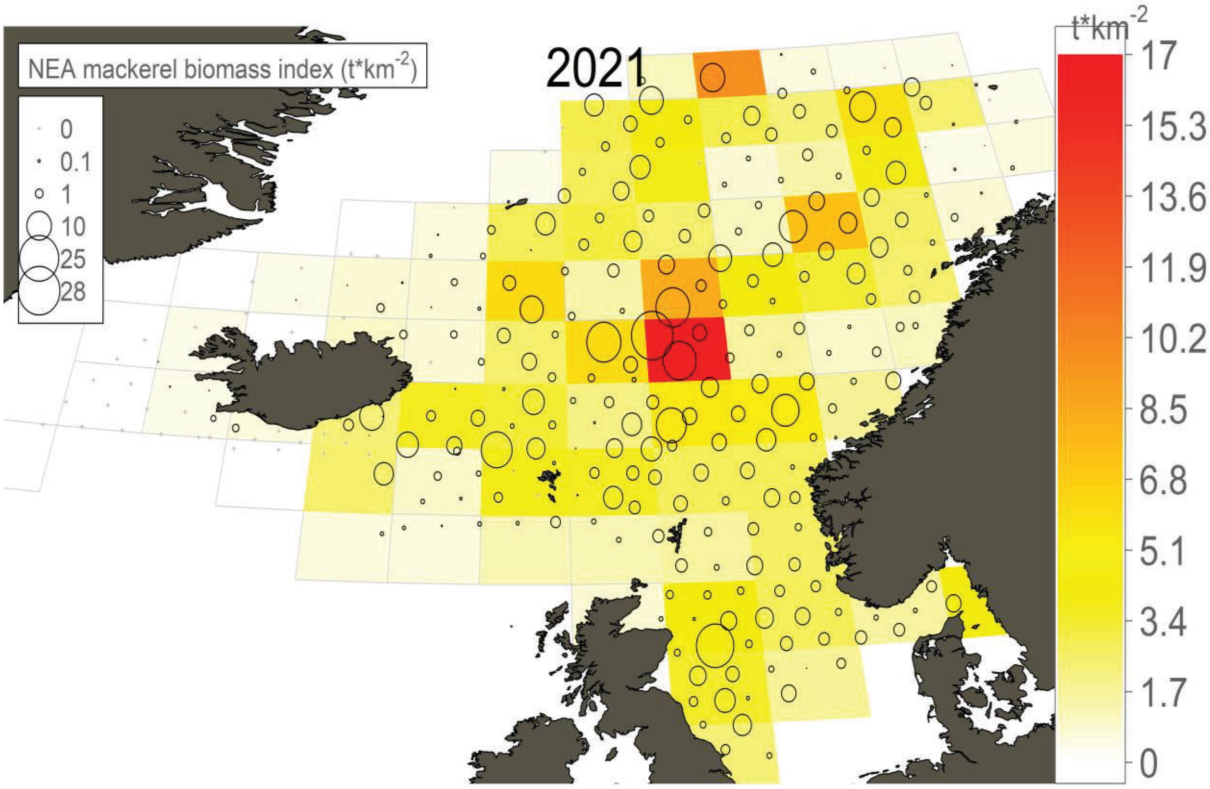


Figure 10. Mackerel catch rates by Multpelt 832 pelagic trawl haul at predetermined surface trawl stations (circle areas represent catch rates in kg/km^2) overlaid on mean catch rates per standardized rectangles (2° lat. x 4° lon.).

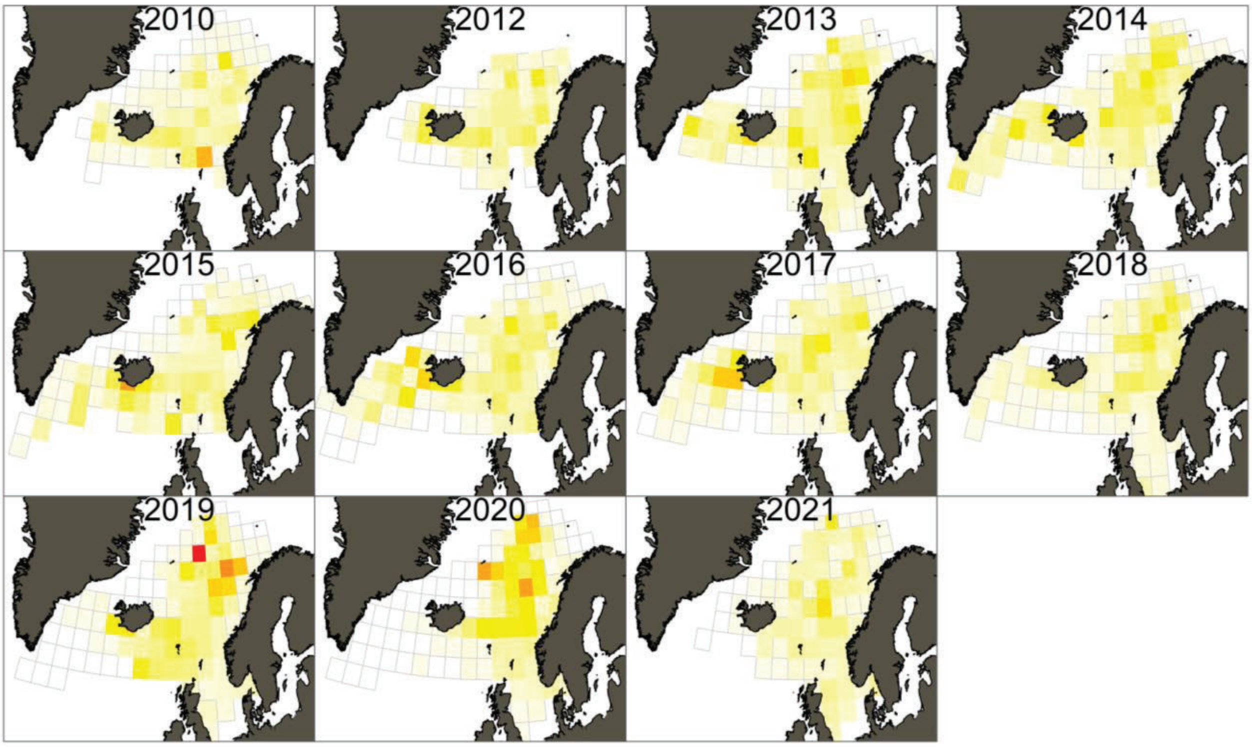


Figure 11. Annual distribution of mackerel proxied by the absolute distribution of mean mackerel catch rates per standardized rectangles (2° lat. x 4° lon.), from Multpelt 832 pelagic trawl hauls at predetermined surface trawl stations. Colour scale goes from white (= 0) to red (= maximum value for the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

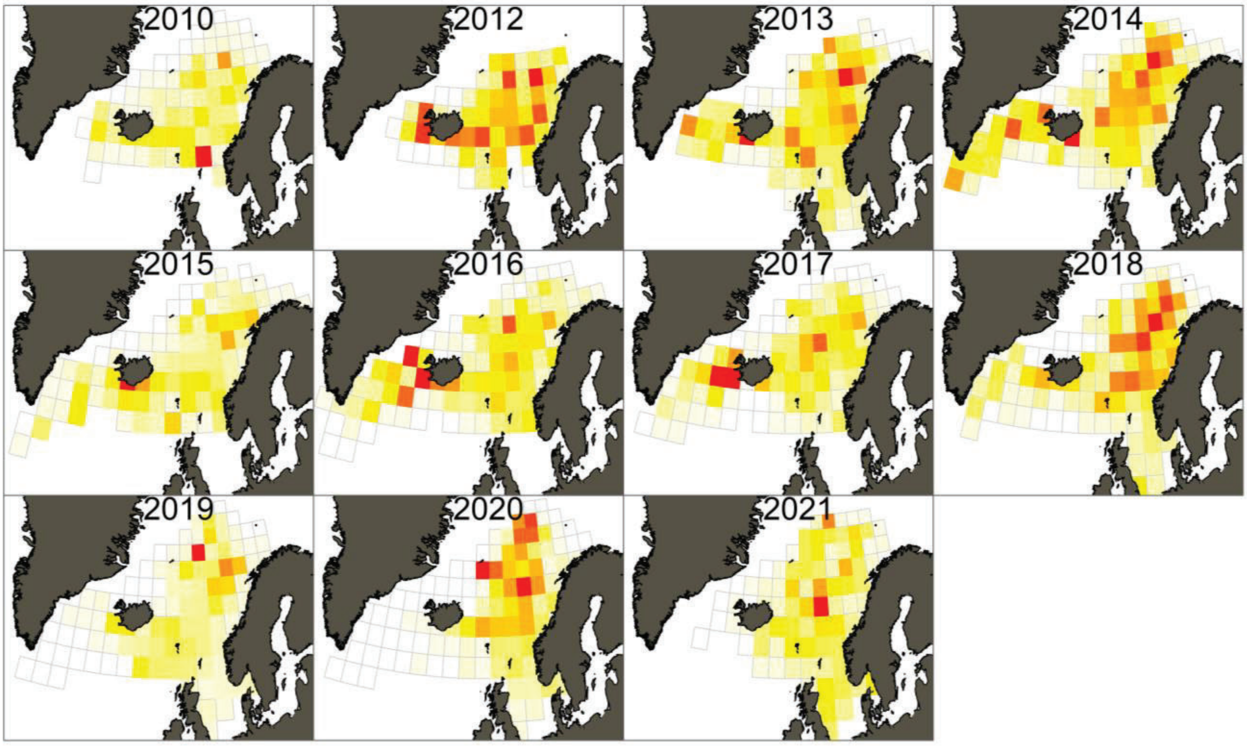


Figure 12. Annual distribution of mackerel proxied by the relative distribution of mean mackerel catch rates per standardized rectangles (2° lat. x 4° lon.), from Multpelt 832 pelagic trawl hauls at predetermined surface trawl stations. Colour scale goes from white (= 0) to red (= maximum value for the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

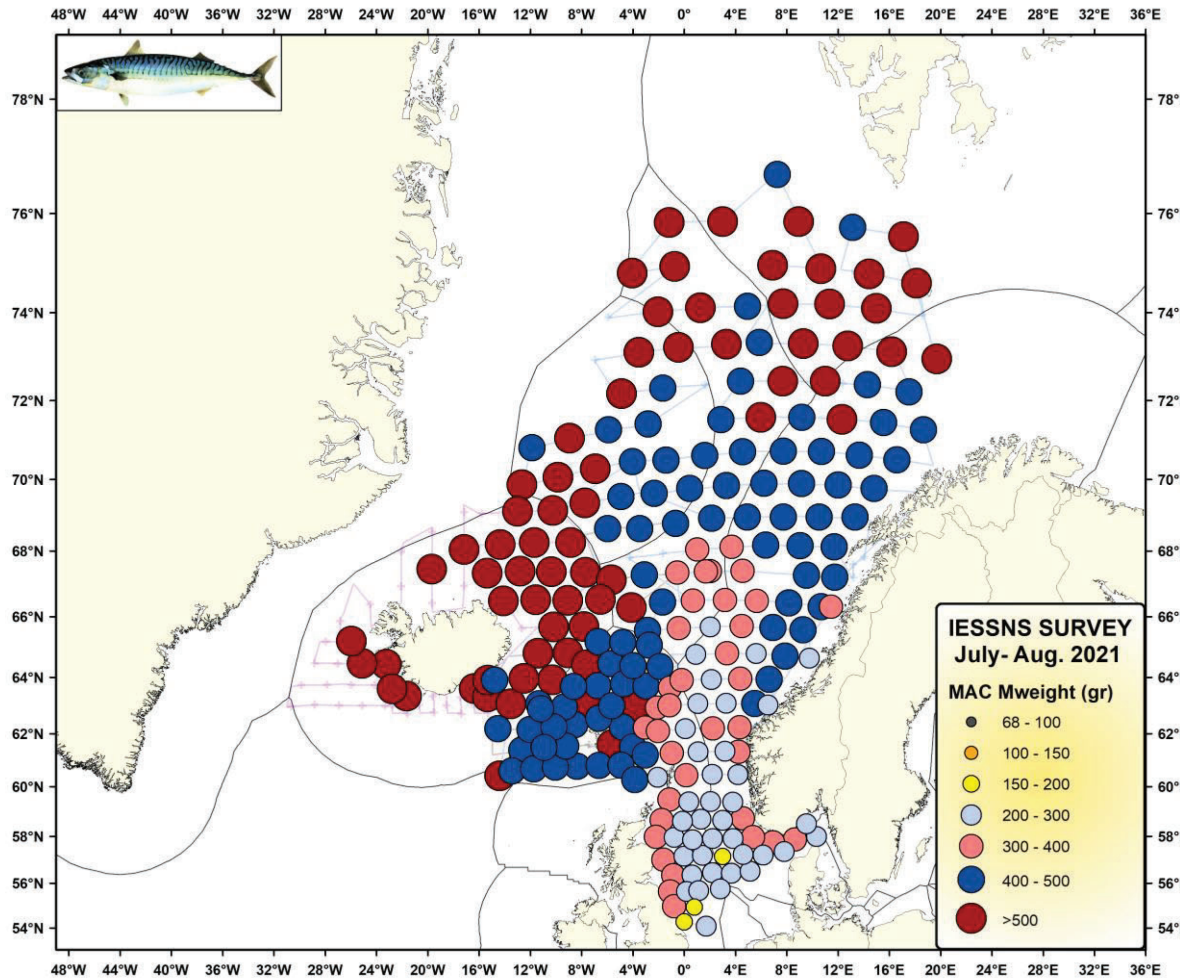


Figure 13. Average weight of mackerel at predetermined surface trawl stations during IESSNS 2021.

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.

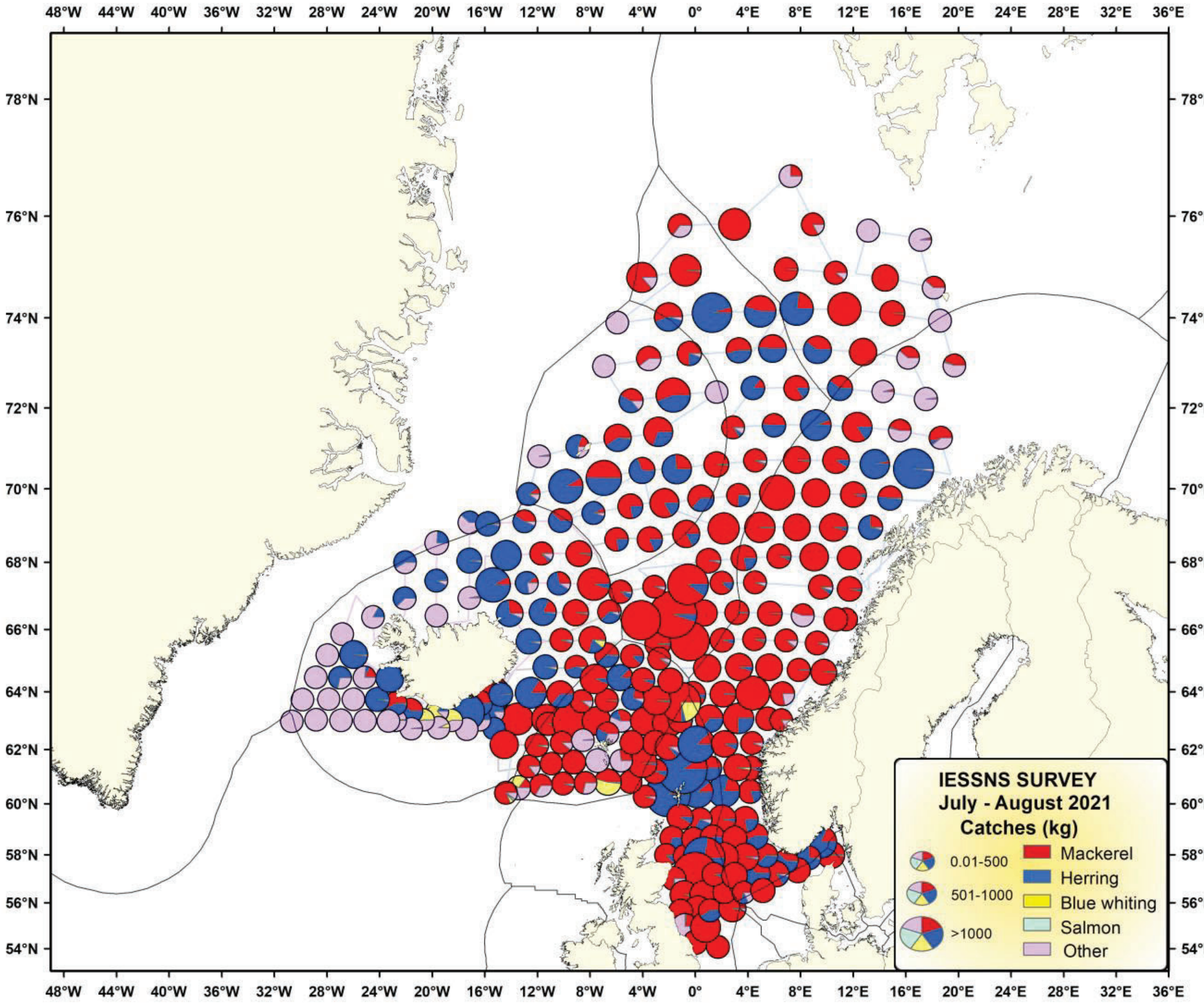


Figure 14. Distribution and spatial overlap between various pelagic fish species (mackerel, herring, blue whiting, salmon, and other (lumpfish)) in 2021 at all surface trawl stations. Vessel tracks are shown as continuous lines.

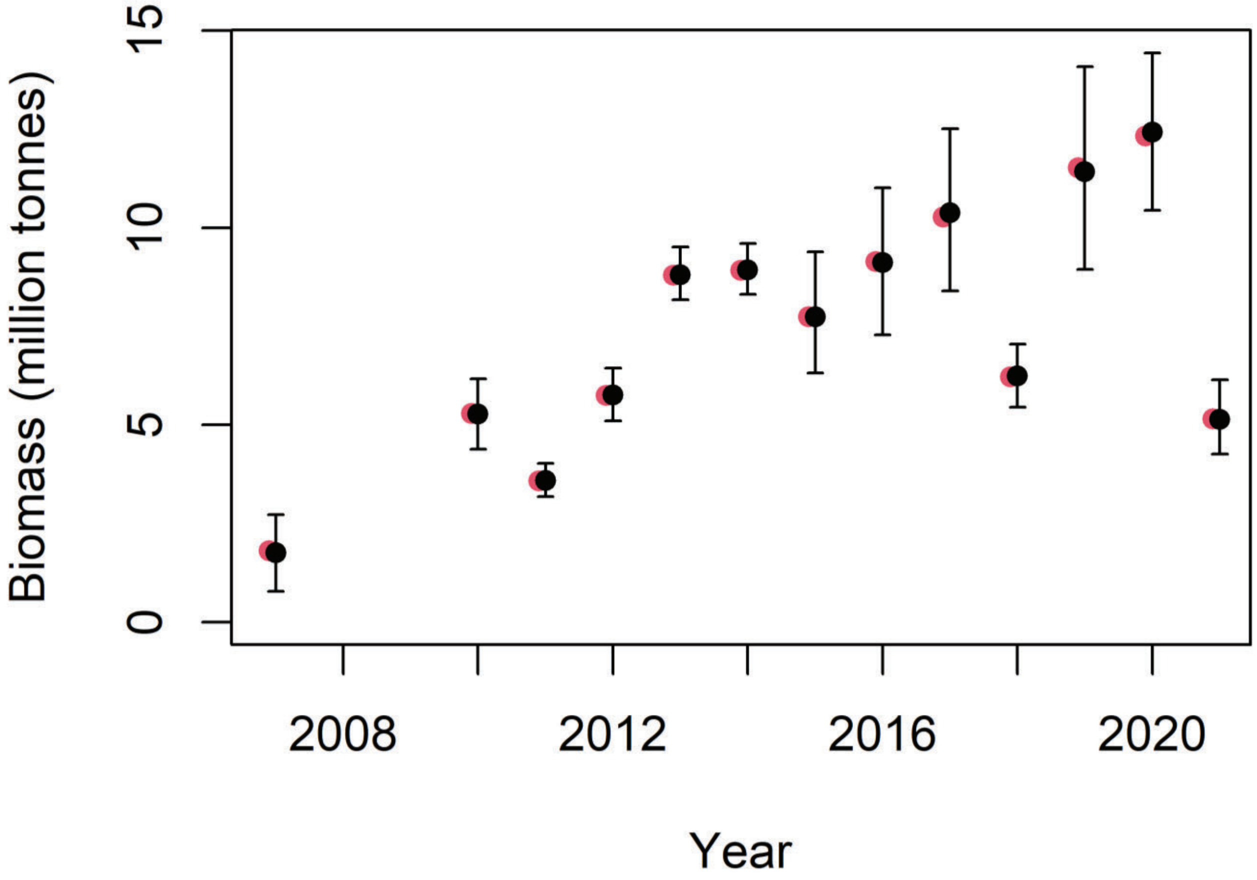
Swept area analyses from standardized pelagic trawling with Multpelt 832

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).



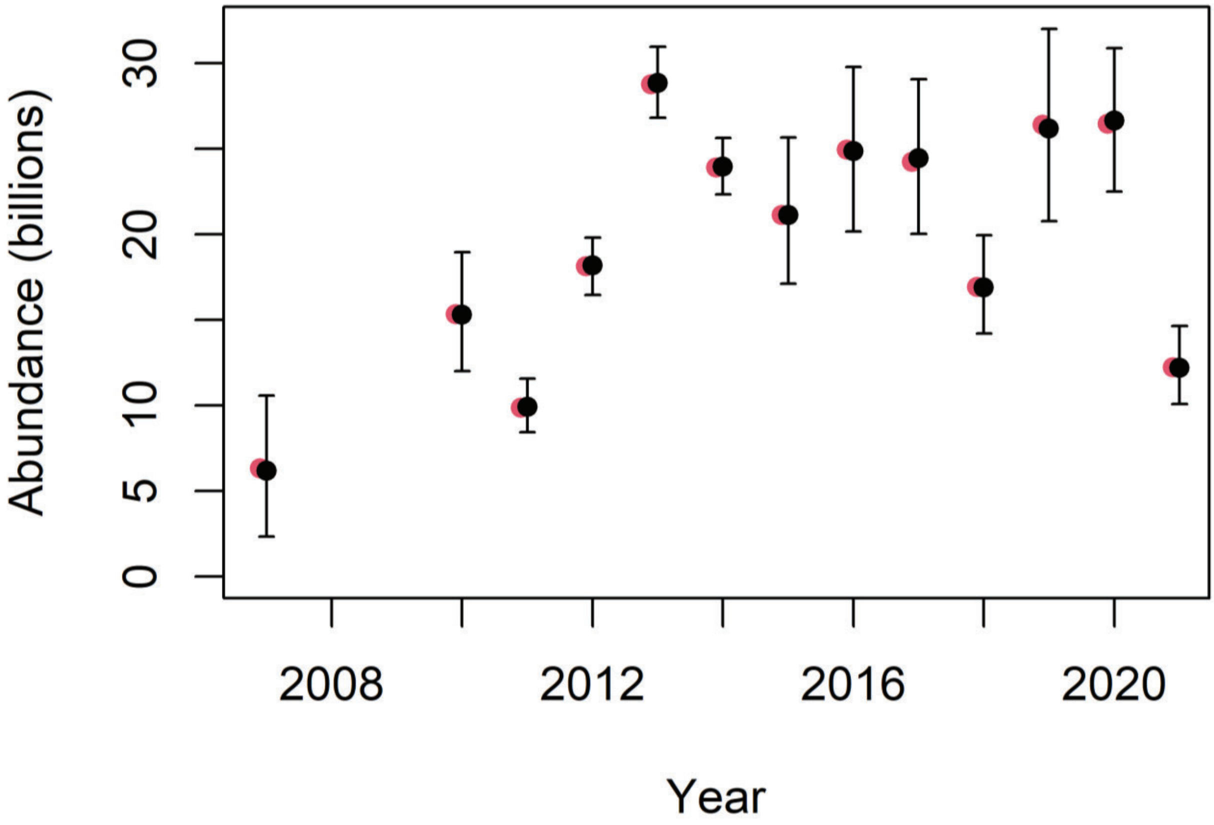


Figure 15. Estimated total stock biomass (upper panel) and total stock numbers (lower panel) of mackerel from StoX for the years 2007 and from 2010 to 2021. The red dots are baseline estimates, the black dots are mean of 1000 bootstrap replicates while the error bars represent 90 % confidence intervals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

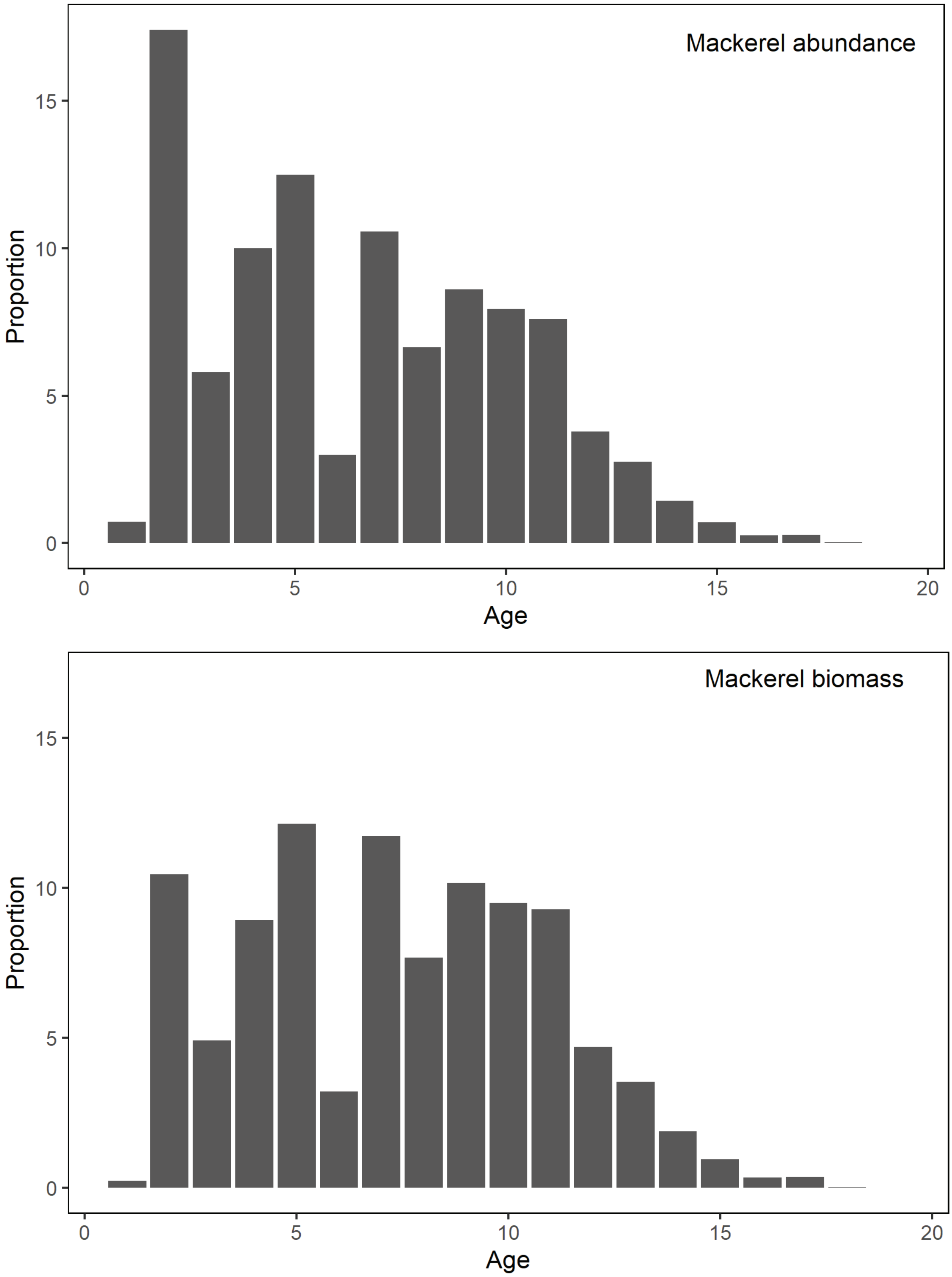


Figure 16. Age distribution in proportion represented as a) % in numbers and b) % in biomass of Northeast Atlantic mackerel in 2021.

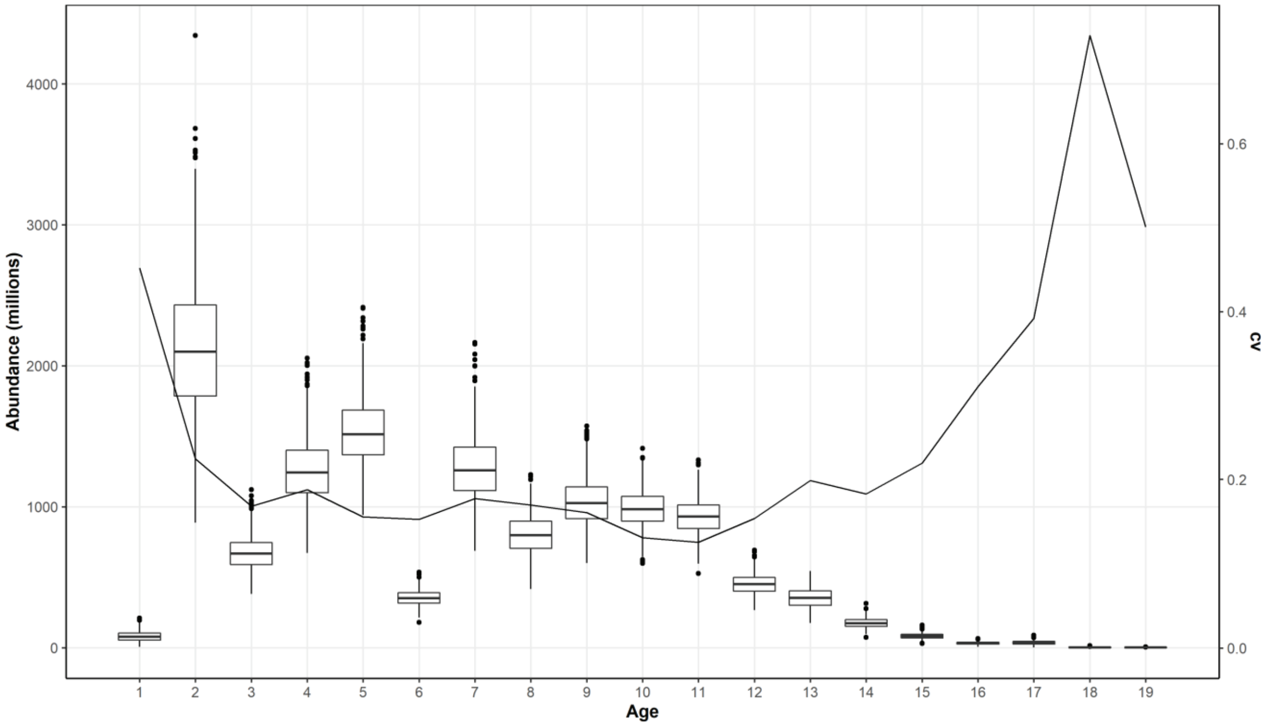


Figure 17. Number by age for mackerel in 2021. Boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 500 replicates using the StoX software.

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

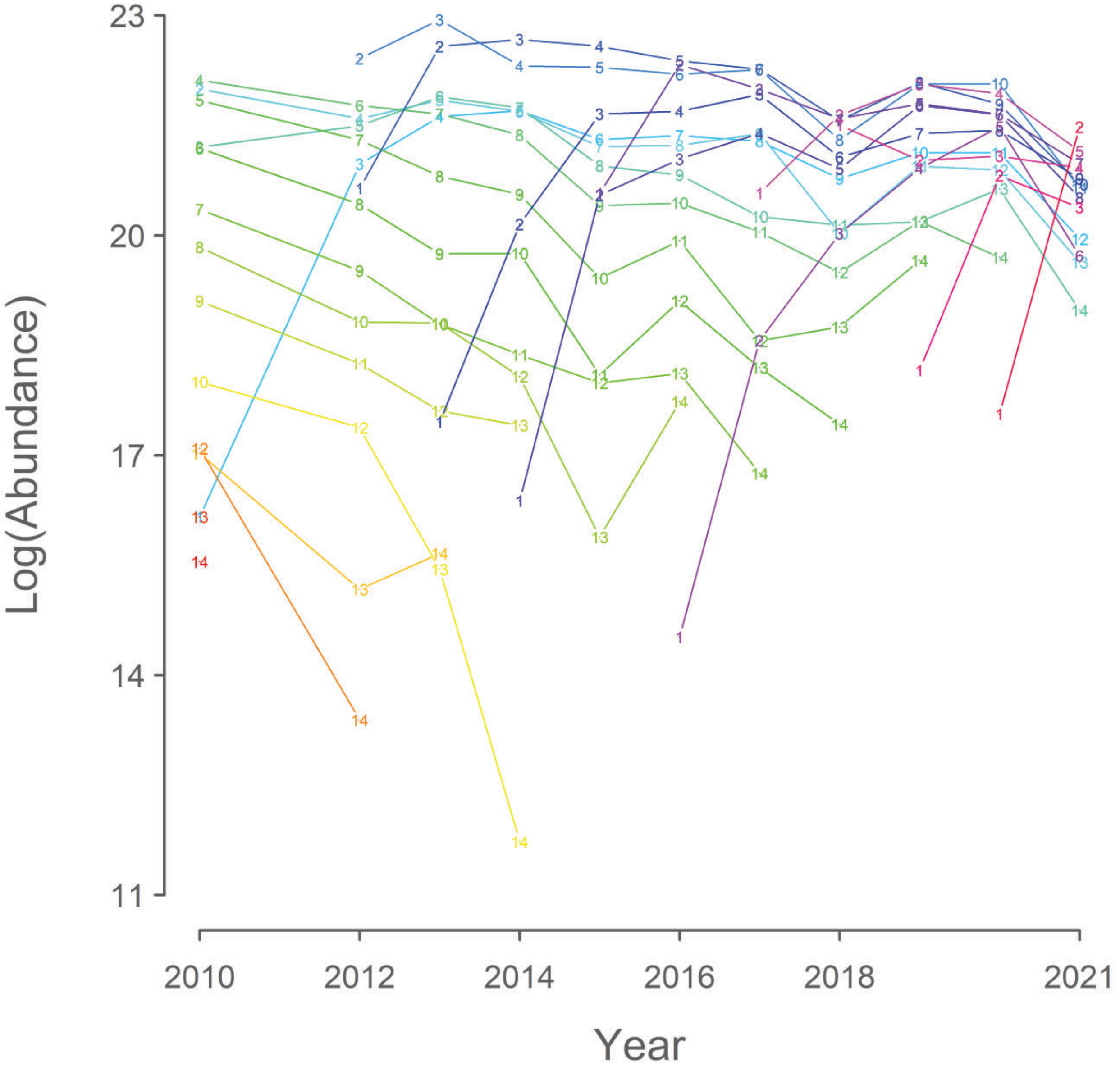


Figure 18. Catch curves in 2021. Each cohort of mackerel is marked by a uniquely coloured line that connects the estimates indicated by the respective ages.

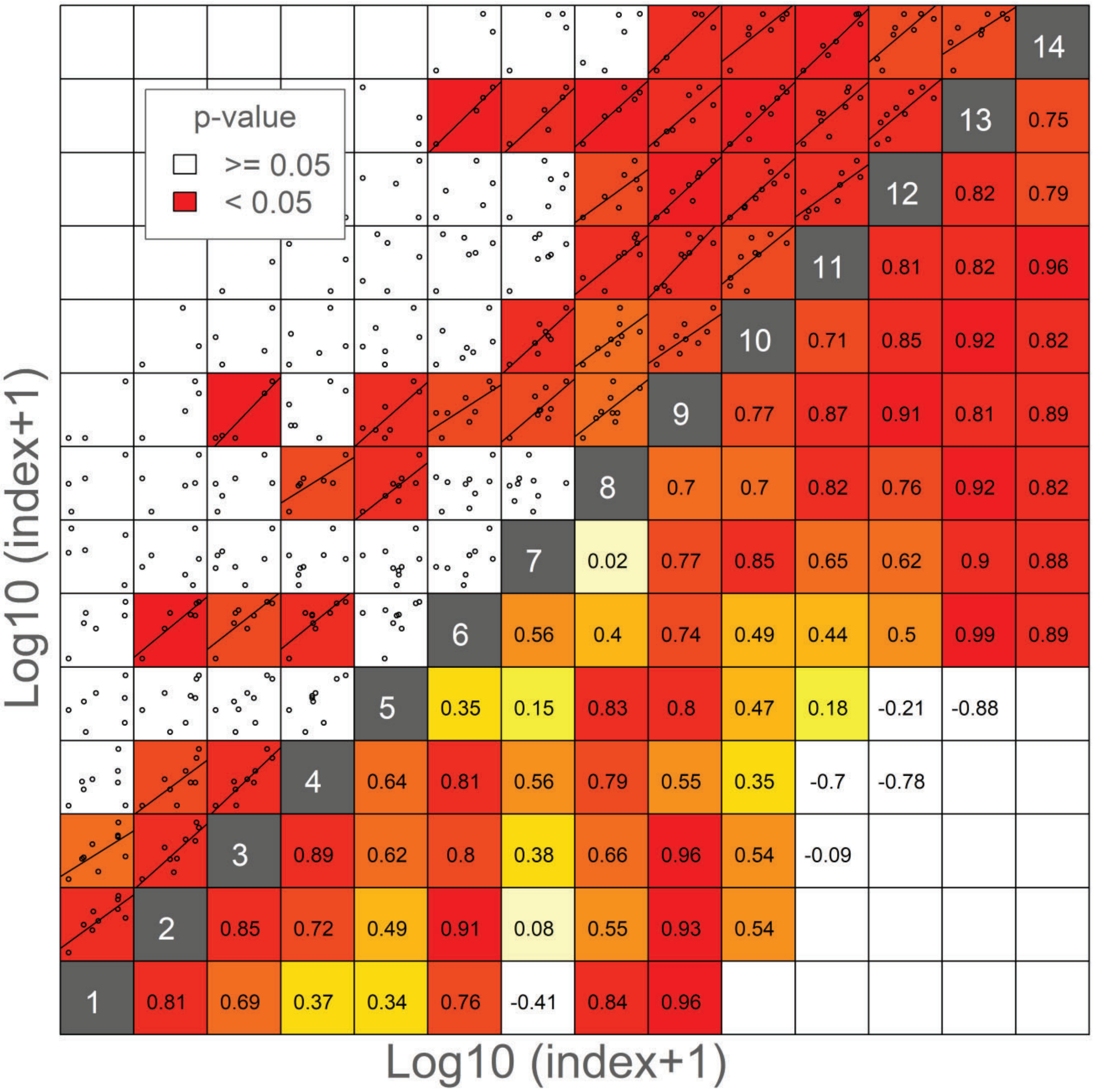


Figure 19. Internal consistency of the of mackerel density index from 2012 to 2021. Ages indicated by white numbers in grey diagonal cells. Statistically significant positive correlations (*p<0.05*) are indicated by regression lines and red cells in upper left half. Correlation coefficients (r) are given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

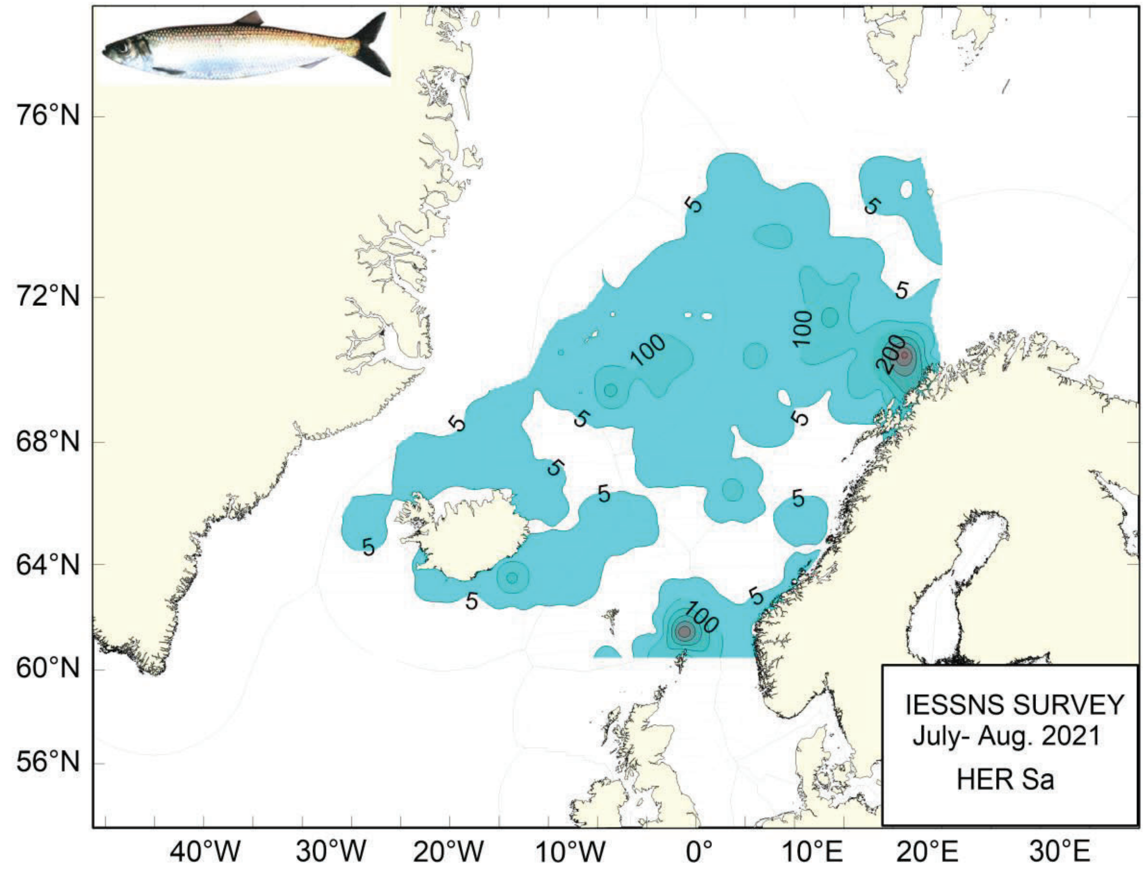


Figure 20a. The sA/Nautical Area Scattering Coefficient (NASC) values of herring along the cruise tracks in 2021 presented as contour lines. Values north of 62ºN, and east of 14ºW, are considered to be Norwegian spring-spawning herring. South and west of this area the herring observed are other stocks,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

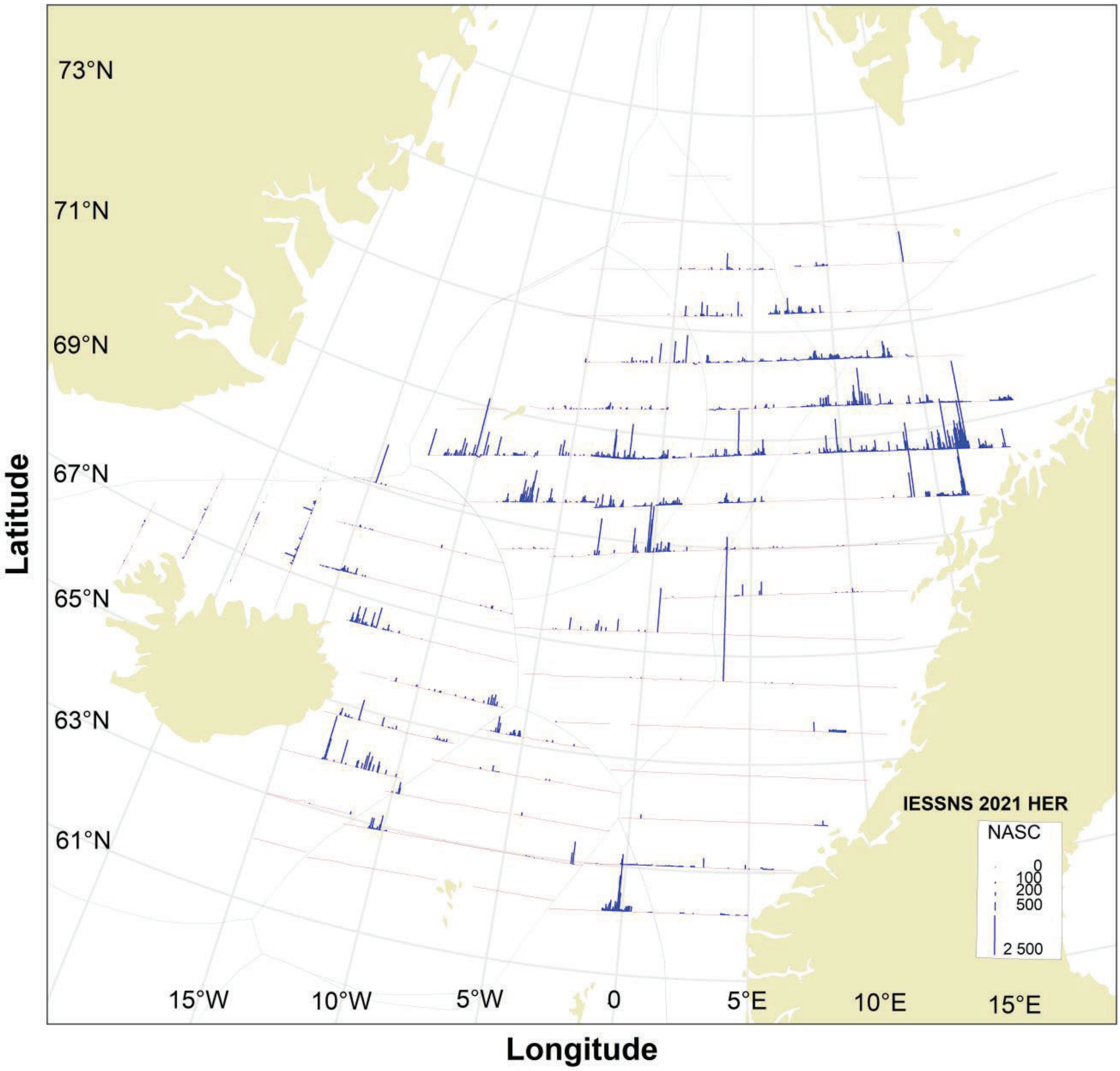


Figure 20b. The sA/Nautical Area Scattering Coefficient (NASC) values of Norwegian spring-spawning herring along the cruise tracks in 2021, presented as bar plot.

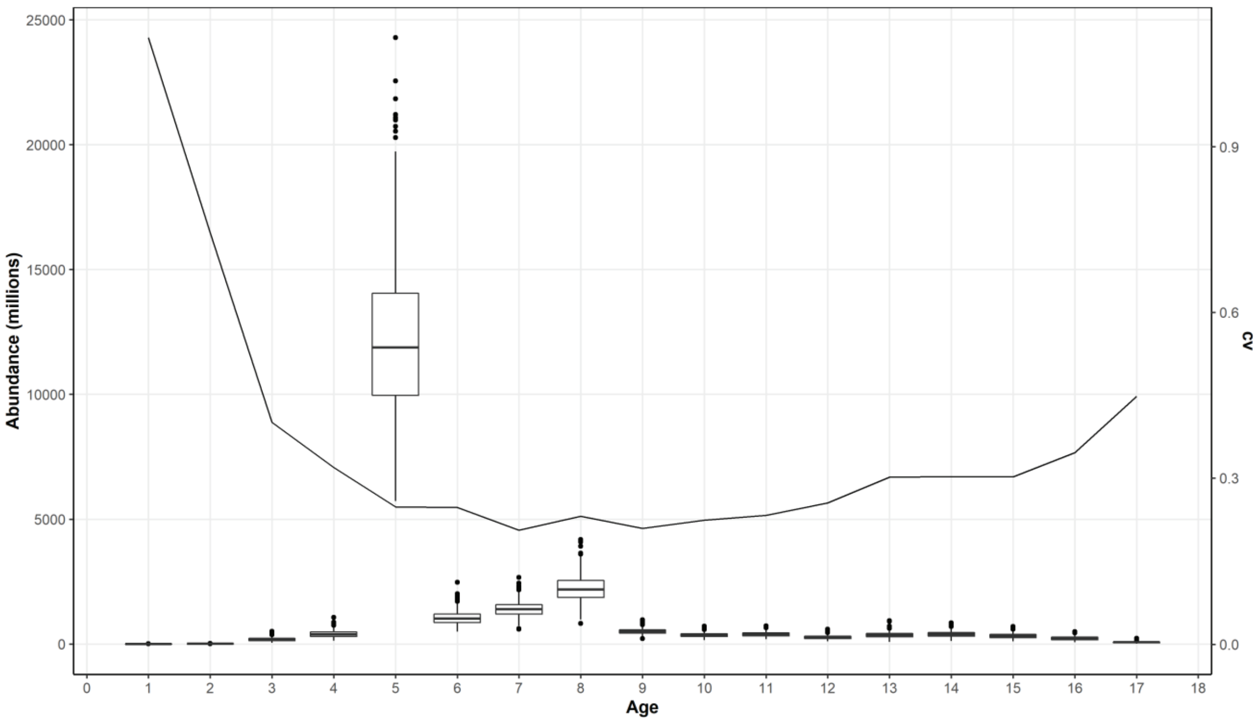


Figure 21. Abundance by age for Norwegian spring-spawning herring during IESSNS 2021. Boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 500 replicates using the StoX software.

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

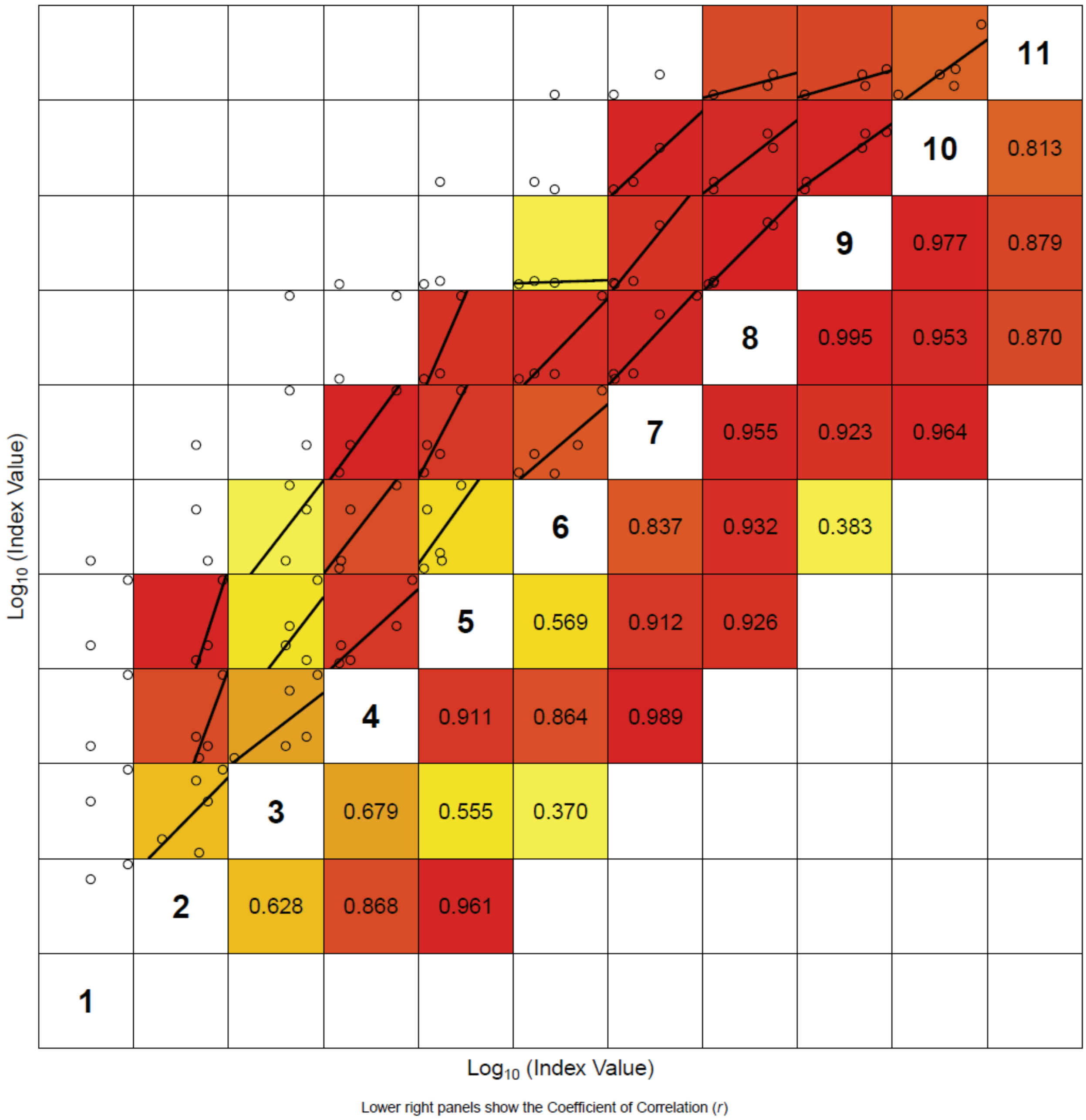


Figure 22. Internal consistency for Norwegian spring-spawning herring within the IESSNS 2021. The upper left part of the plots shows the relationship between log index-at-age within a cohort. Linear regression line shows the best fit to the log-transformed indices. The lower-right part of the plots shows 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 (sA-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.

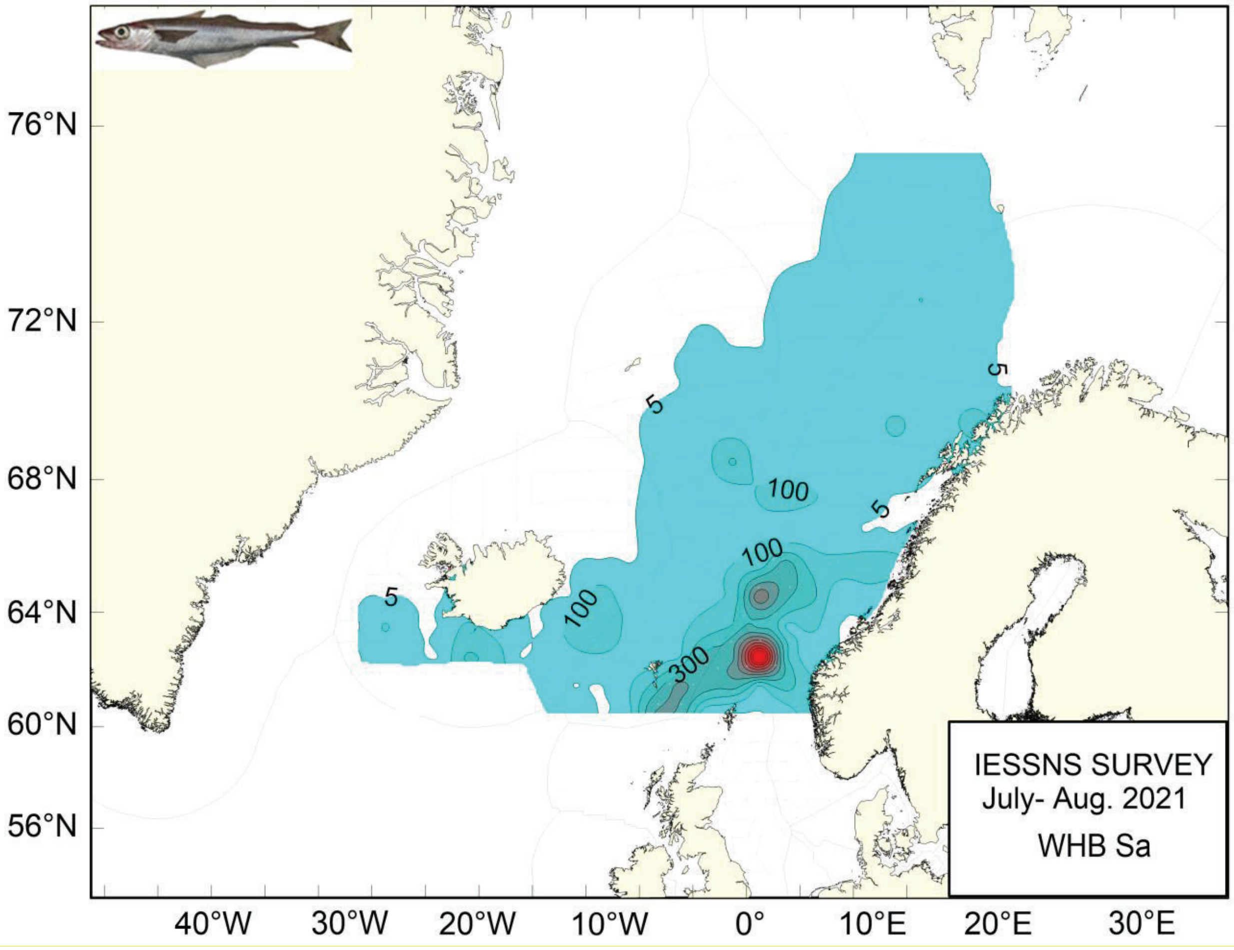


Figure 23a. The sA/Nautical Area Scattering Coefficient (NASC) values of blue whiting along the cruise tracks in IESSNS 2021. Presented as contour lines.

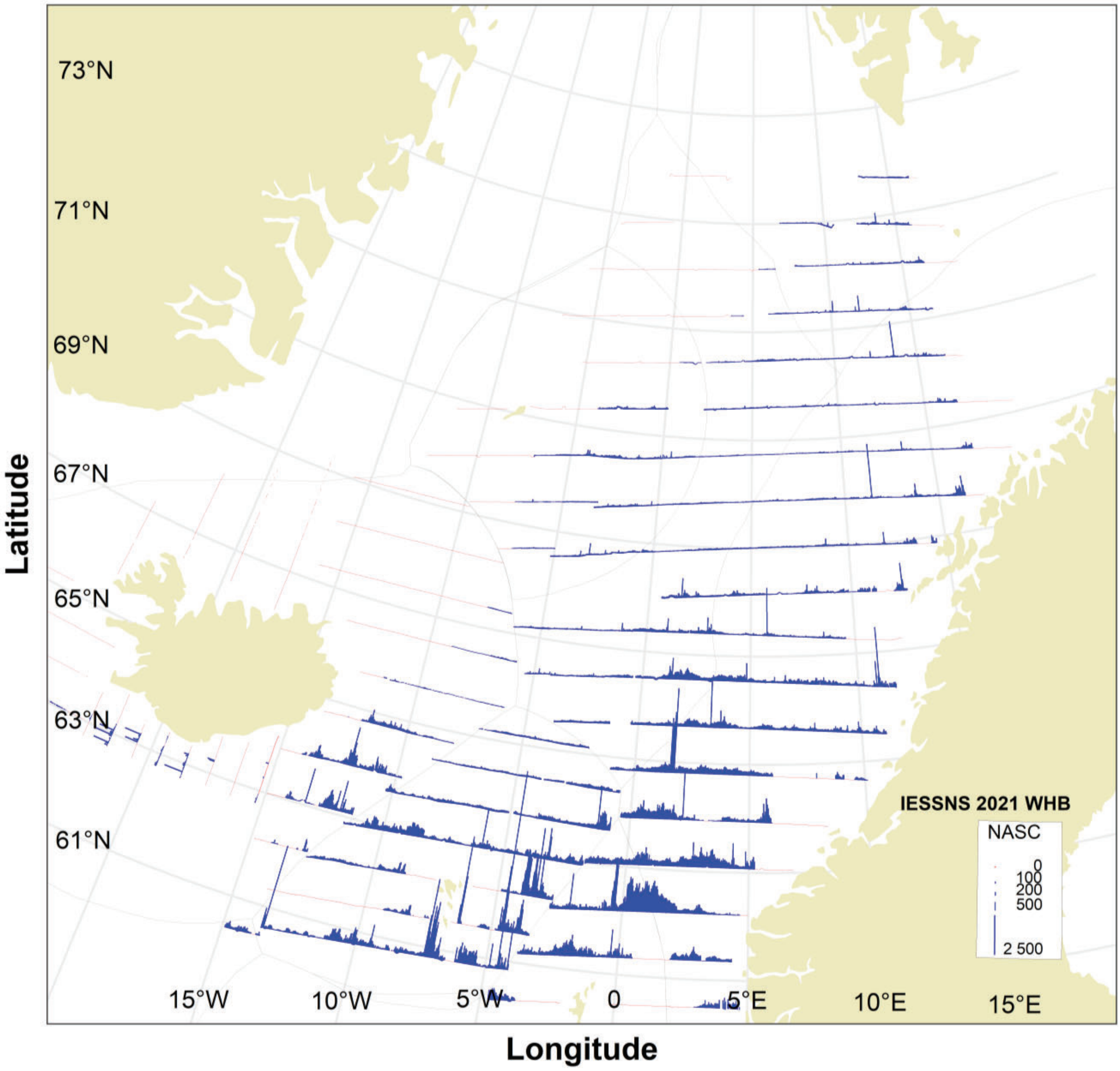


Figure 23b. The sA/Nautical Area Scattering Coefficient (NASC) values of blue whiting along the cruise tracks in IESSNS 2021. Presented as bar plot.

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

	Age in years (year class)											Number	Biomass	Mean
Length	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			

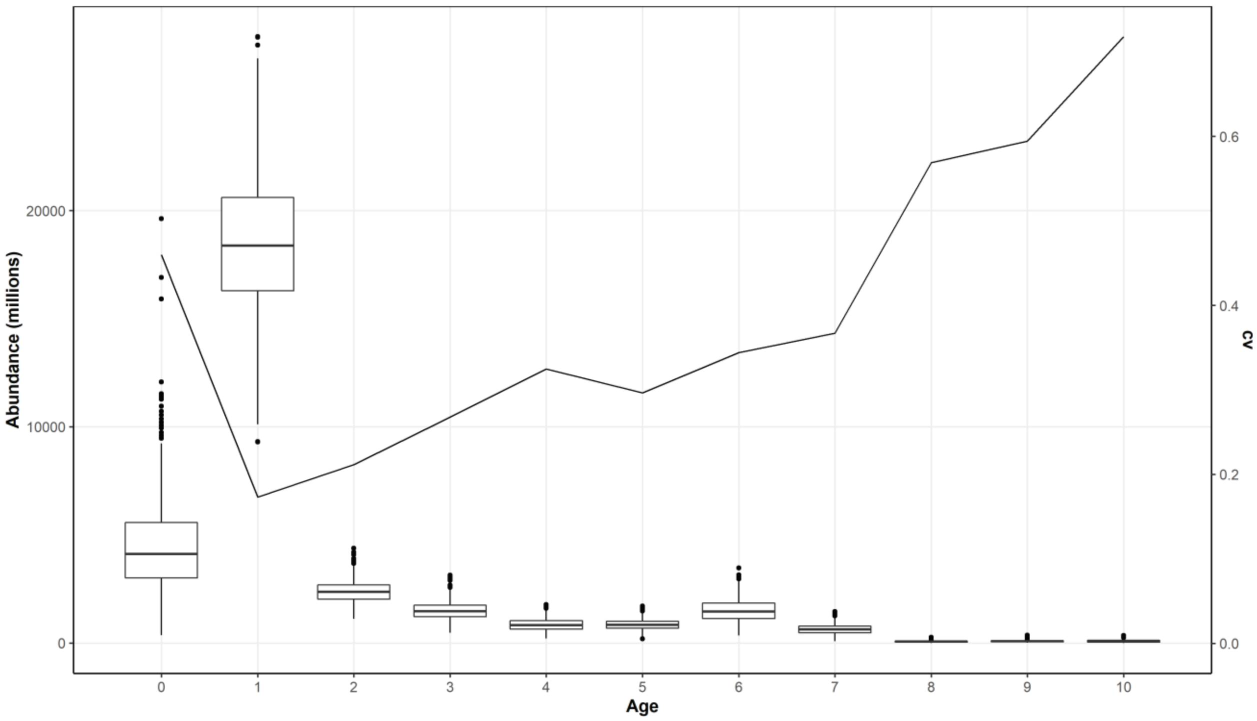


Figure 24. Number by age with uncertainty for blue whiting during IESSNS 2021. Boxplot of abundance and relative standard error (CV) obtained by bootstrapping with 1000 replicates using the StoX software.

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

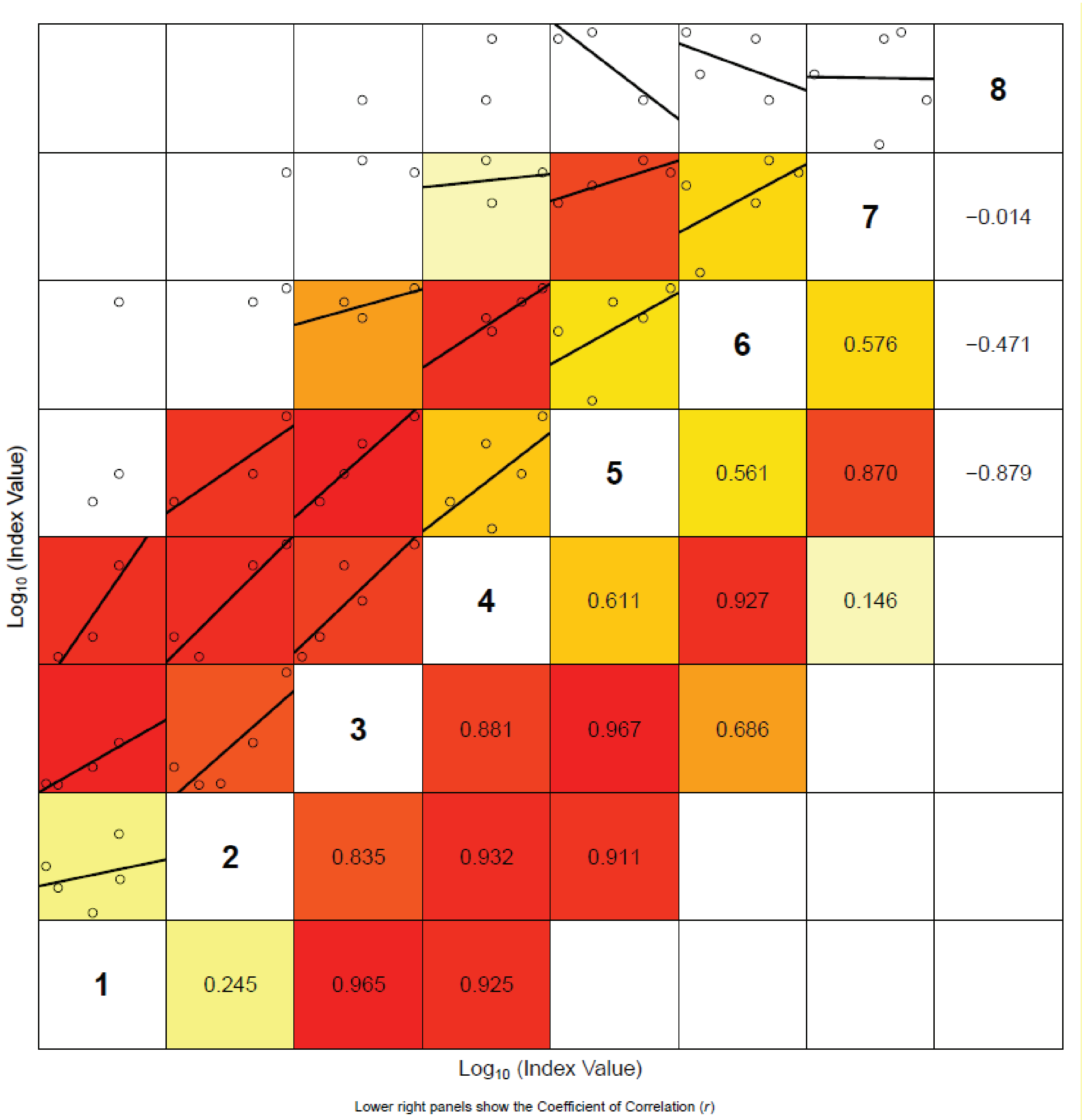


Figure 25. Internal consistency for blue whiting within the IESSNS. The upper left part of the plots shows the relationship between log index-at-age within a cohort. Linear regression line shows the best fit to the log-transformed indices. The lower-right part of the plots shows the correlation coefficient (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).

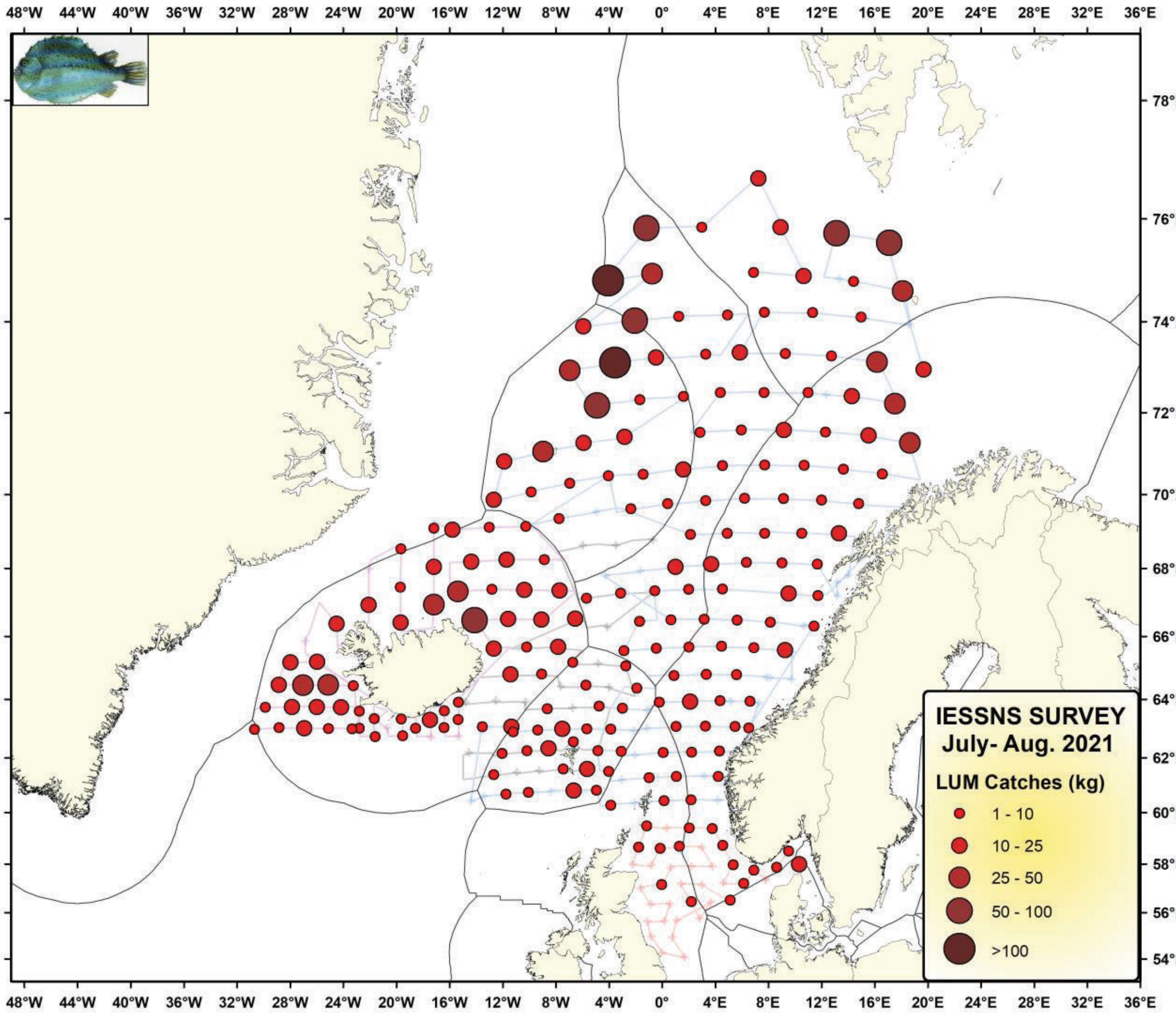


Figure 26. Lumpfish catches at surface trawl stations during IESSNS 2021.

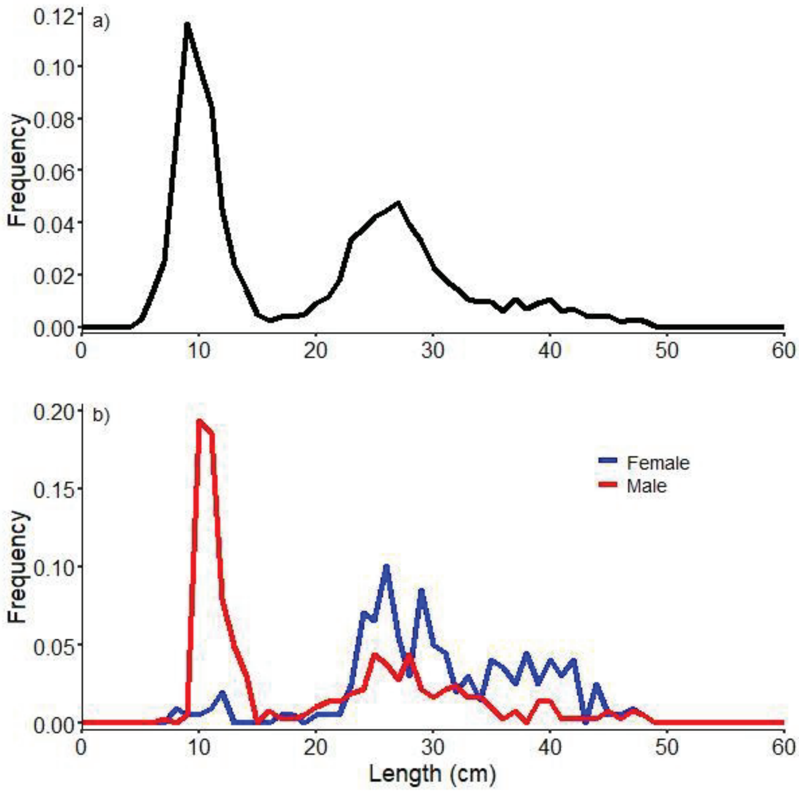


Figure 27. Length distribution of a) all lumpfish caught during the survey and b) length distribution of fish in which sex was determined.

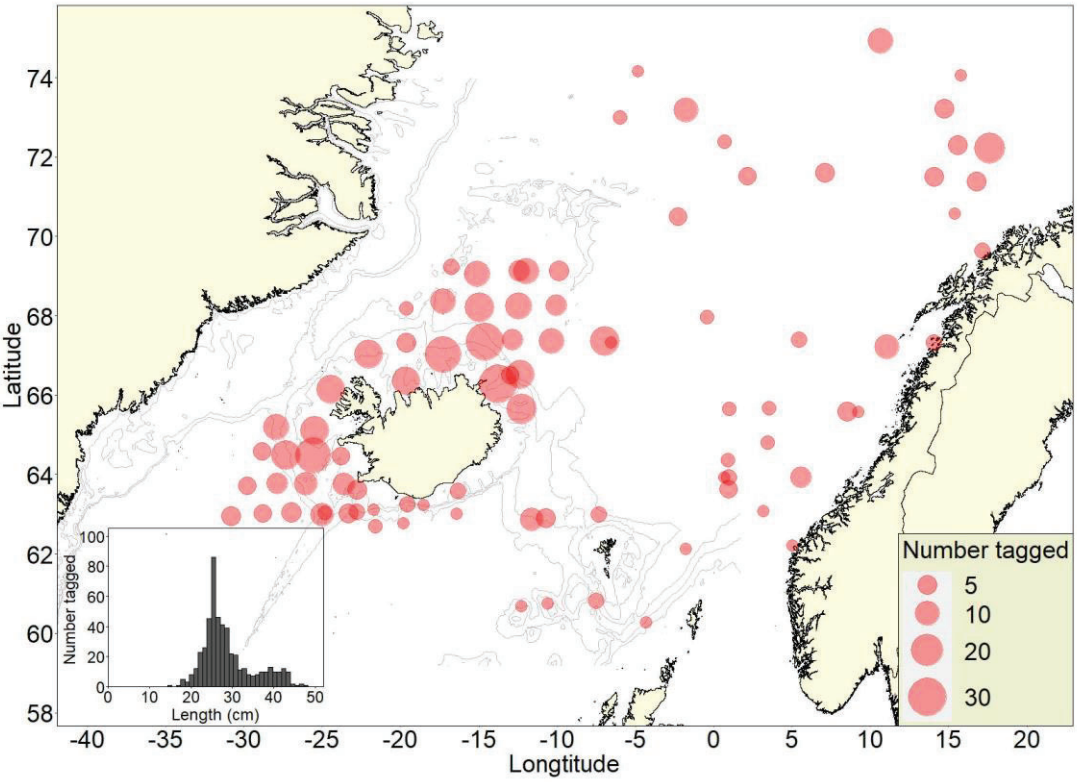


Figure 28. Number tagged, and release location, of lumpfish. Insert shows the length distribution of the tagged fish.

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)

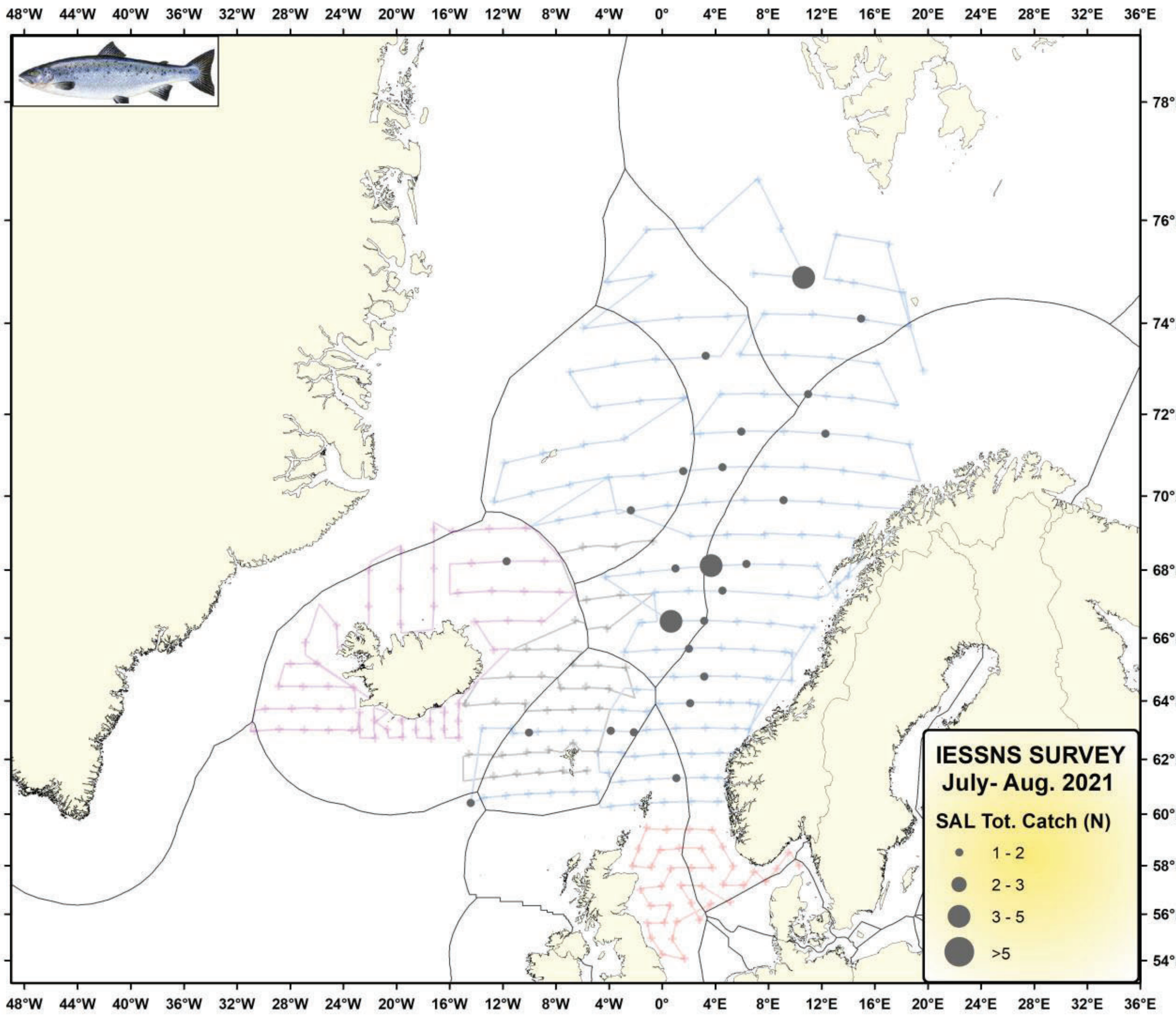


Figure 29. Catches of salmon at surface trawl stations during IESSNS 2021.

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.

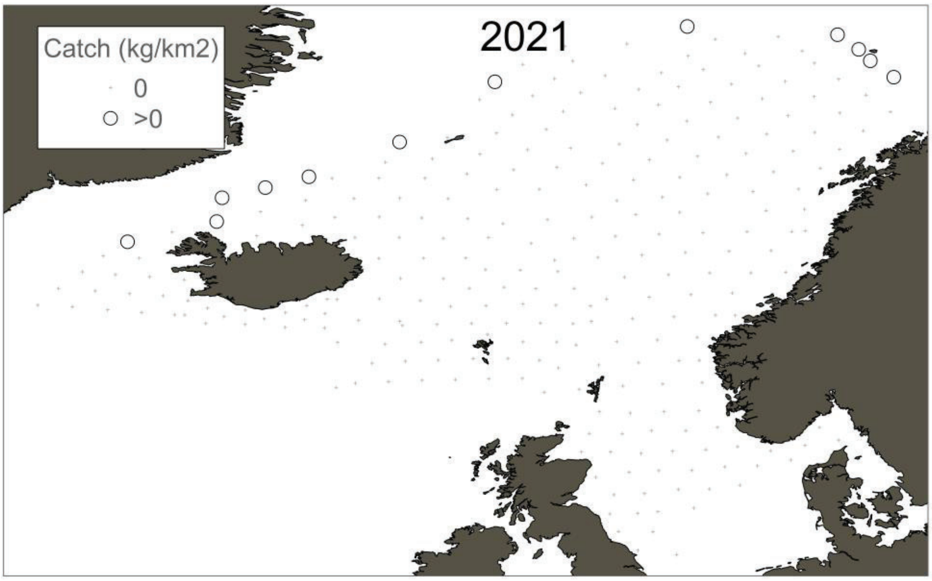


Figure 30. Presence of capelin in surface trawl stations.

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)

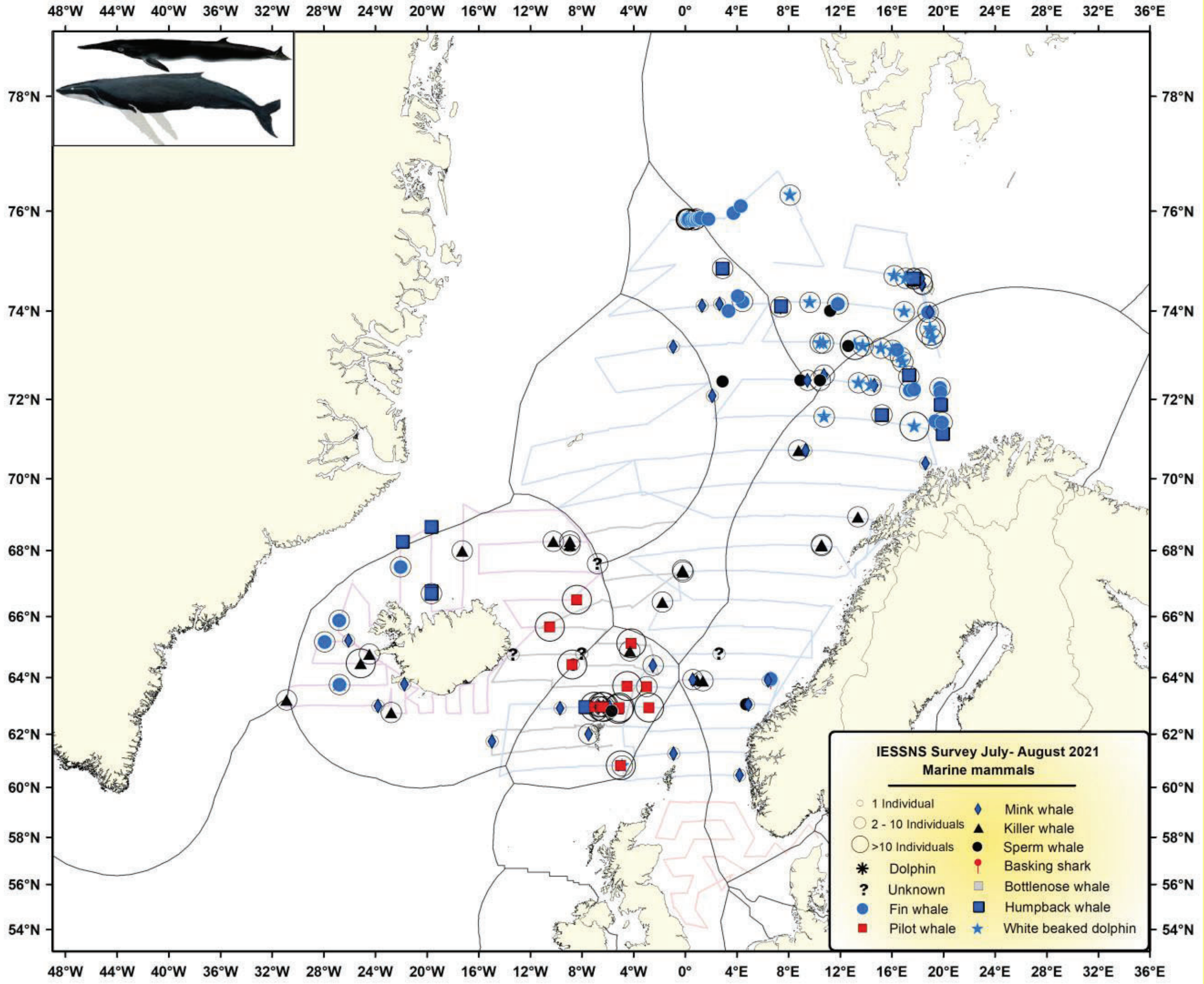


Figure 31. Overview of all marine mammals sighted during IESSNS 2021.

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

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8 Acknowledgements

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9 References

Bachiller E, Utne KR, Jansen T, Huse G. 2018. Bioenergetics modelling of the annual consumption of zooplankton by pelagic fish feeding in the Northeast Atlantic. PLOS ONE 13(1): e0190345. doi.org/10.1371/journal.pone.0190345.

Banzon, V., Smith, T. M., Chin, T. M., Liu, C., and Hankins, W., 2016. A long-term record of blended satellite and in situ sea-surface temperature for climate monitoring, modelling and environmental studies. Earth System Science Data. 8, 165–176, doi:10.5194/essd-8-165-2016.

Foote, K. G., 1987. Fish target strengths for use in echo integrator surveys. Journal of the Acoustical Society of America. 82: 981-987.

Gilbey; J., Utne K.A., Wennevik V. et al. 2021. The early marine distribution of Atlantic salmon in the North-East Atlantic: A genetically informed stocks-specific synthesis. Fish and Fisheries:2021;00:1.-33. DOI:10.1111/faf.12587.

ICES. 2012. Report of the International Bottom Trawl Survey Working Group (IBTSWG), 27–30 March 2012, Lorient, France. ICES CM 2012/SSGESST:03. 323 pp.

ICES 2013a. Report of the Workshop on Northeast Atlantic Mackerel monitoring and methodologies including science and industry involvement (WKNAMMM), 25–28 February 2013, ICES Headquarters, Copenhagen and Hirtshals, Denmark. ICES CM 2013/SSGESST:18. 33 pp.

ICES. 2013b. Report of the Working Group on Improving Use of Survey Data for Assessment and Advice (WGISDAA), 19-21 March 2013, Marine Institute, Dublin, Ireland. ICES CM 2013/SSGESST:07.22 pp.

ICES 2014a. Manual for international pelagic surveys (IPS). Working document of Working Group of International Surveys (WGIPS), Version 1.02 [available at ICES WGIPS sharepoint] 98 pp.

ICES 2014b. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 17–21 February 2014, Copenhagen, Denmark. ICES CM 2014/ACOM: 43. 341 pp

ICES. 2017. Report of the Benchmark Workshop on Widely Distributed Stocks (WKWIDE), 30 January-3 February 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:36. 196 pp.

Jansen, T., Post, S., Kristiansen, T., Oskarsson, G.J., Boje, J., MacKenzie, B.R., Broberg, M., Siegstad, H., 2016. Ocean warming expands habitat of a rich natural resource and benefits a national economy. Ecol. Appl. 26: 2021–2032. doi:10.1002/eap.1384

Johnsen, E., Totland, A., Skålevik, Å., Holmin, A.J., Dingsør, G.E., Fuglebakk, E., Handegard, N.O. 2019. StoX: An open source software for marine survey analyses. Methods Ecol Evol. 2019; 10:1523–1528.

Jolly, G. M., and I. Hampton. 1990. A stratified random transect design for acoustic surveys of fish stocks. Canadian Journal of Fisheries and Aquaculture Science. 47: 1282-1291.

Løviknes; S.., Jensen, K.H., Krafft, B.A., Nøttestad, L. 2021. Feeding hotspots and distribution of fin and humpback whales in the Norwegian Sea from 2013 to 2018. Frontiers in Marine Science 8:632720. doi.org/10.3389/fmars.2021.632720

Nikolioudakis, N., Skaug, H. J., Olafsdottir, A. H., Jansen, T., Jacobsen, J. A., and Enberg, K. 2019. Drivers of the summer-distribution of Northeast Atlantic mackerel (Scomber scombrus) in the Nordic Seas from 2011 to 2017; a Bayesian hierarchical modelling approach. ICES Journal of Marine Science. 76(2): 530-548. doi:10.1093/icesjms/fsy085

Nøttestad, L., Utne, K.R., Óskarsson, G. J., Jónsson, S. Þ., Jacobsen, J. A., Tangen, Ø., Anthonypillai, V., Aanes, S., Vølstad, J.H., Bernasconi, M., Debes, H., Smith, L., Sveinbjörnsson, S., Holst, J.C., Jansen, T. and Slotte, A. 2016. Quantifying changes in abundance, biomass and spatial distribution of Northeast Atlantic (NEA) mackerel (*Scomber scombrus*) in the Nordic Seas from 2007 to 2014. ICES Journal of Marine Science. 73(2): 359-373. doi:10.1093/icesjms/fsv218.

Ólafsdóttir, A., Utne, K.R., Jansen, T., Jacobsen, J.A., Nøttestad, L., Óskarsson, G.J., Slotte, A., Melle, W. 2019. Geographical expansion of Northeast Atlantic mackerel (Scomber scombrus) in the Nordic Seas from 2007 - 2014 was primarily driven by stock size and constrained by temperature. Deep-Sea Research Part II. 159, 152-168.

Rosen, S., Jørgensen, T., Hammersland-White, Darren, Holst, J.C. 2013. Canadian Journal of Fisheries and Aquatic Sciences. 70(10):1456-1467. doi.org/10.1139/cjfas-2013-0124.

Salthaug, A., Aanes, S., Johnsen, E., Utne, K. R., Nøttestad, L., and Slotte, A. 2017. Estimating Northeast Atlantic mackerel abundance from IESSNS with StoX. Working Document (WD) for WGIPS 2017 and WKWIDE 2017. 103 pp.

Utne K., Diaz Pauli, B., Haugland, M. et al. 2021. Starving at sea? Poor feeding opportunities for salmon post-smolts in the Northeast Atlantic Ocean. ICES Journal of Marine Science (in press).

Valdemarsen, J.W., J.A. Jacobsen, G.J. Óskarsson, K.R. Utne, H.A. Einarsson, S. Sveinbjörnsson, L. Smith, K. Zachariassen and L. Nøttestad 2014. Swept area estimation of the North East Atlantic mackerel stock using a standardized surface trawling technique. Working Document (WD) to ICES WKPELA. 14 pp.

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

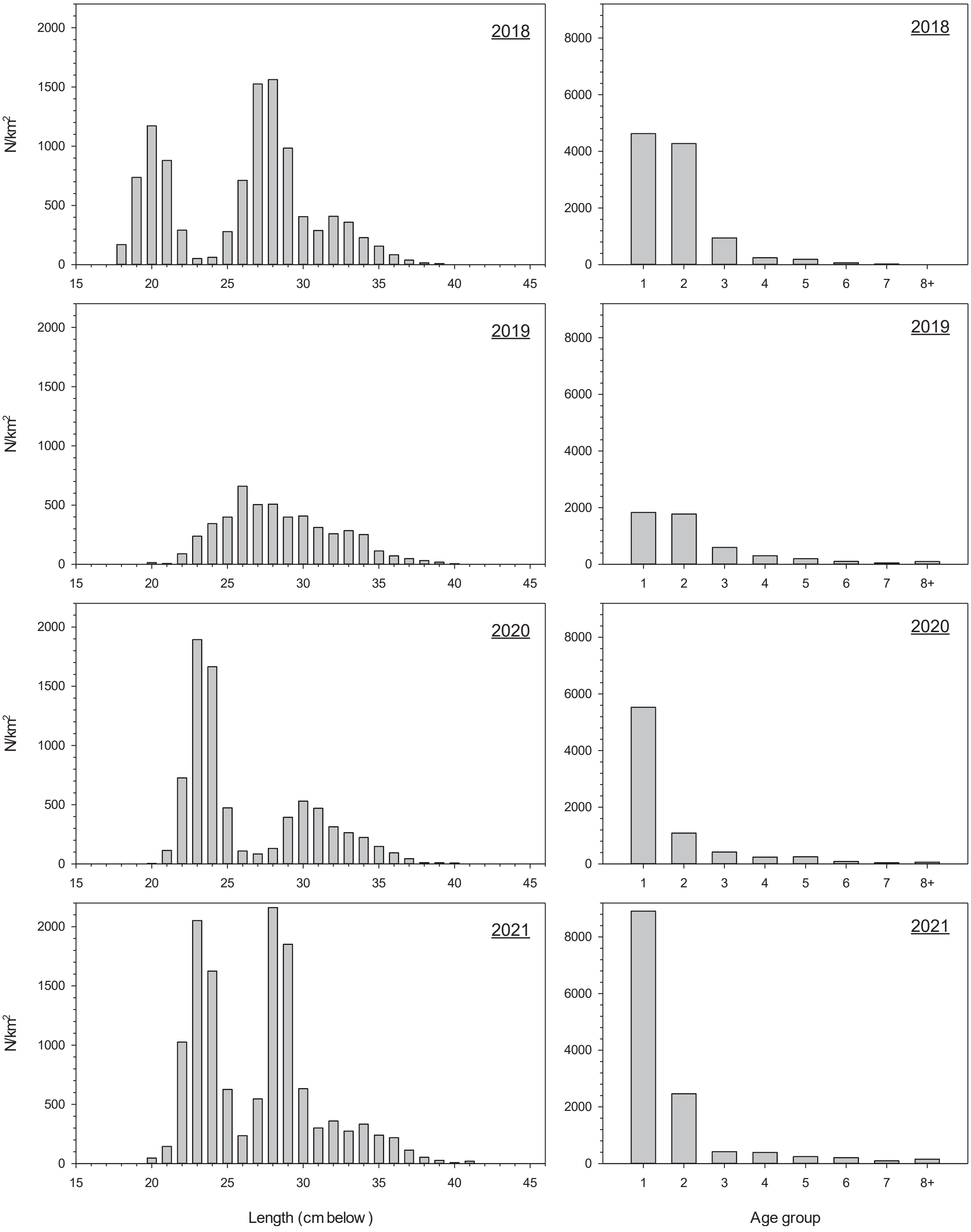

Fig. A1. Comparison of length and age distribution of mackerel in the North Sea 2018, 2019, 2020 and 2021.

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’)