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INTERNATIONAL BLUE WHITING SPAWNING STOCK SURVEY (IBWSS) SPRING 2021

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Material and methods

Survey planning and Coordination

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

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

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

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

Sampling equipment

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

Biological sampling

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

Hydrographic sampling

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

Plankton sampling

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

Acoustic data processing

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

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

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

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

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

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

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

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

Acoustic data analysis

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

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

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

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

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

Estimate of relative sampling error

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

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

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

Results

Distribution of blue whiting

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

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

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

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

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

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

Stock size

The estimated total stock biomass of blue whiting for the 2021 international survey was 2.4 million tonnes, representing an abundance of 36.9×10^9 individuals (Table 4). Spawning stock was estimated at 2.3 million tonnes and 18.1×10^9 individuals (Table 5).

Stock composition

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

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

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

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

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

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

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

Hydrography

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

Mesopelagic fish

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

Concluding remarks

Main results

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

Interpretation of the results

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

Recommendations

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

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

Achievements

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

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

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

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

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

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

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

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

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

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

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

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

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

*Survey discarded.

Table 7. IBWSS survey effort time series.

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

* End of Russian participation.

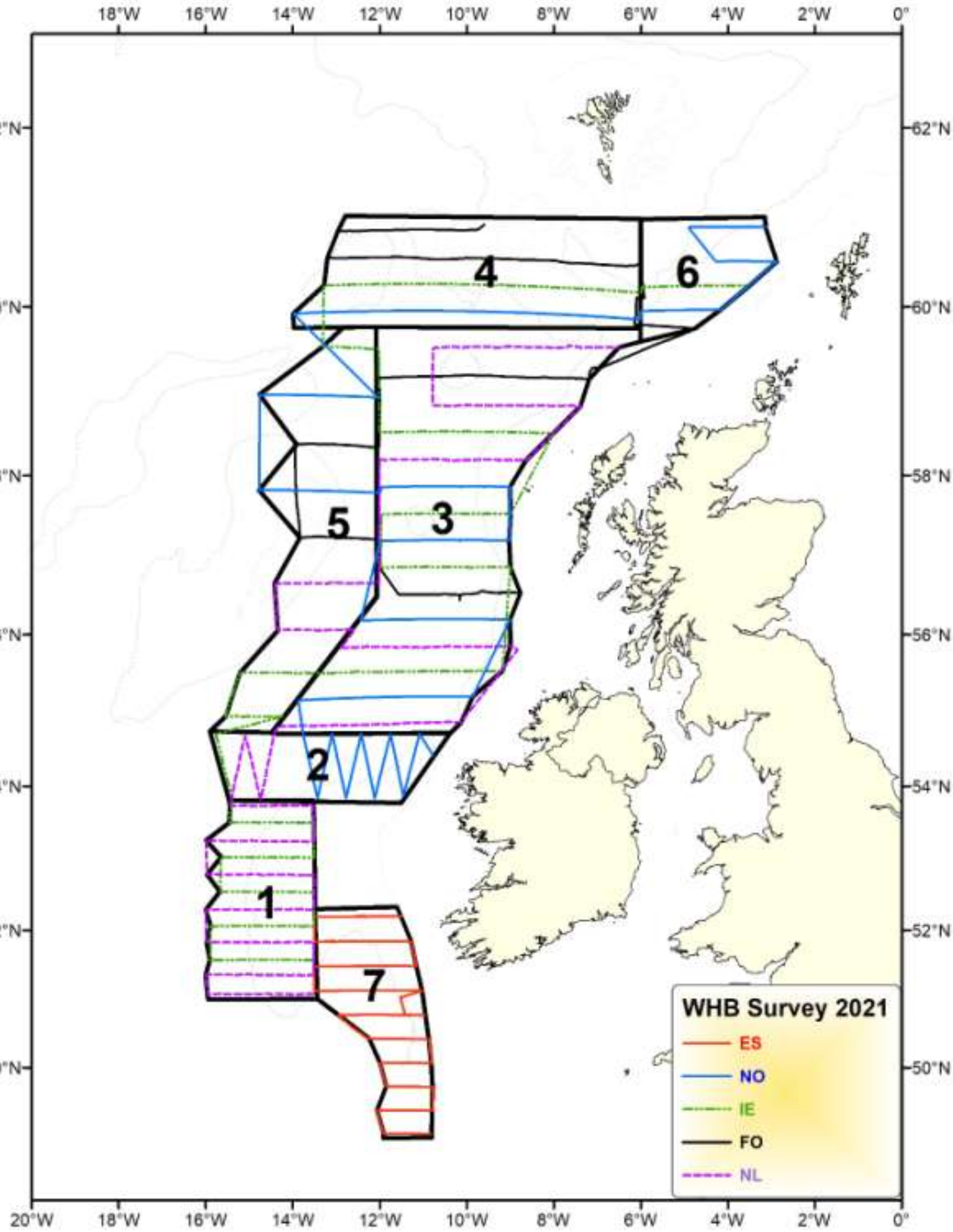


Figure 1. Strata and cruise tracks for the individual vessels (country) during the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021.

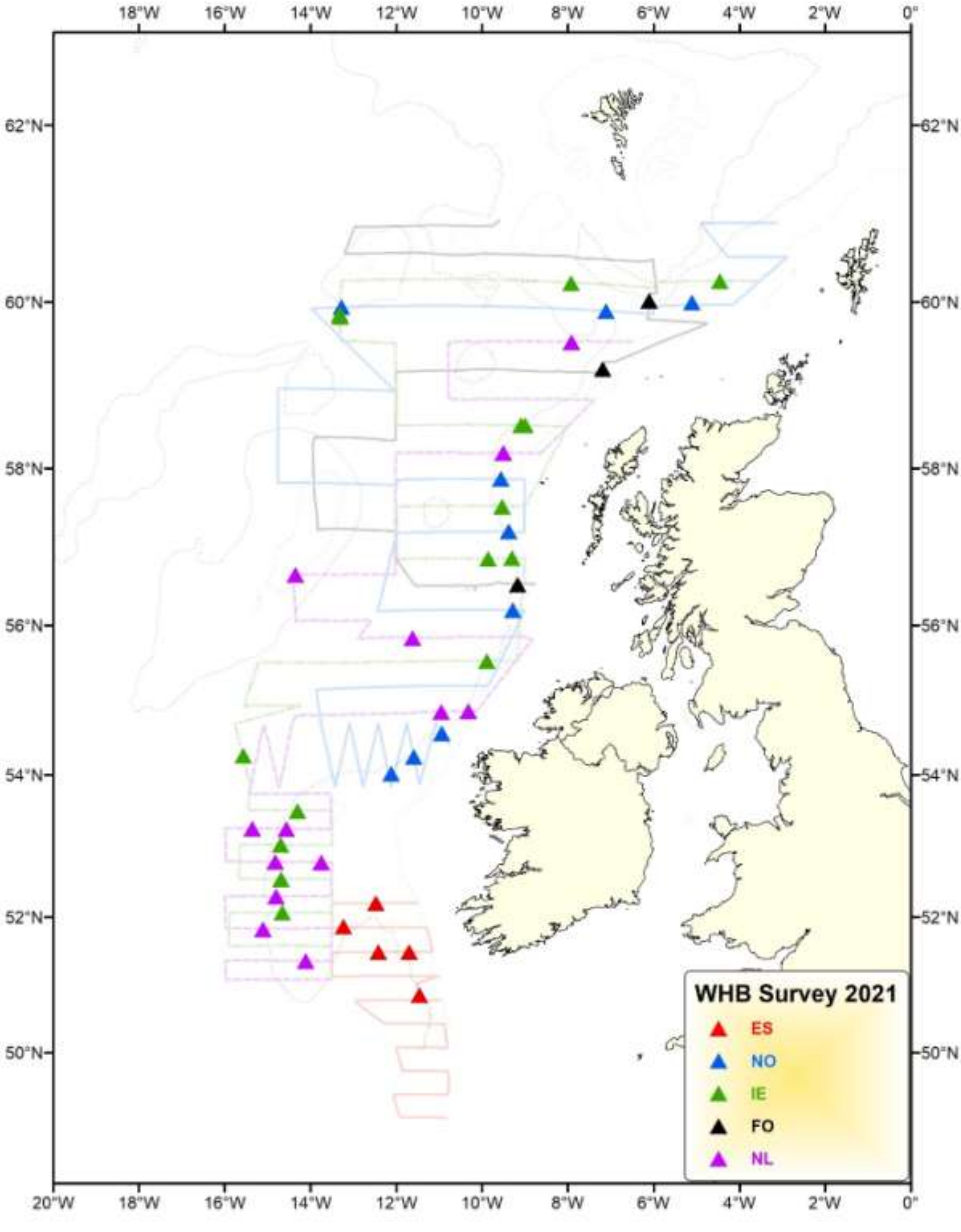


Figure 2. Vessel cruise tracks and trawl stations of the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021. ES: Spain (RV *Vizconde de Eza*); FO: Faroe Islands (RV *Jakúp Sverri*); IE: Ireland (RV *Celtic Explorer*); NL: Netherlands (RV *Tridens)*; NO: Norway (FV *Vendla*).

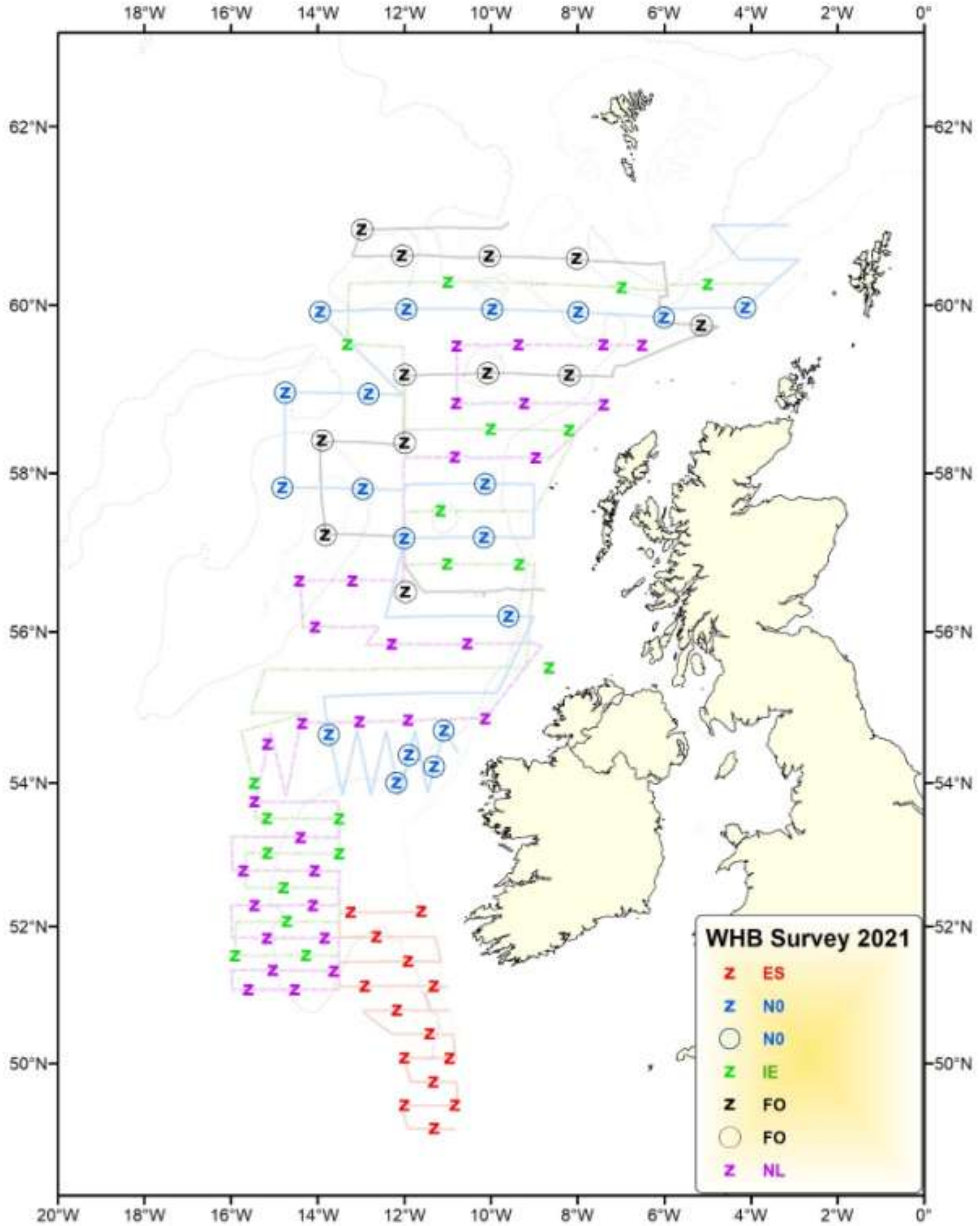


Figure 3. Vessel cruise tracks with hydrographic CTD stations (z) and WP2 plankton net samples (circles) during the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021. Colour coded by vessel.

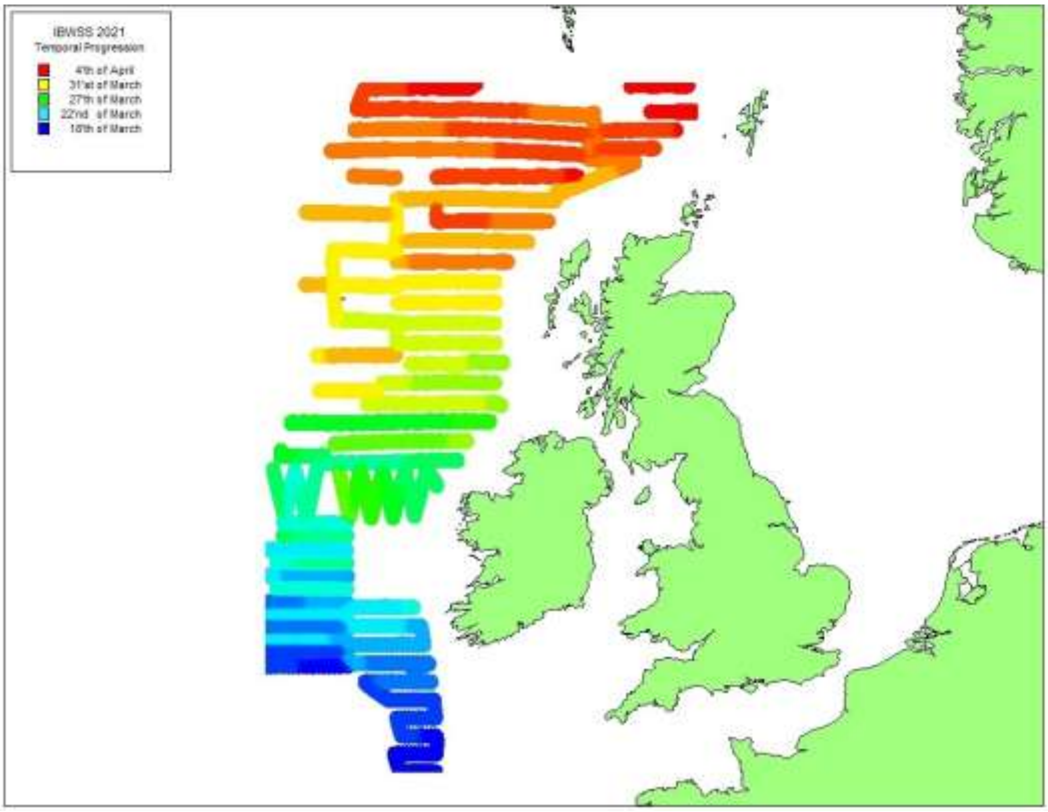


Figure 4. Temporal progression for the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021.

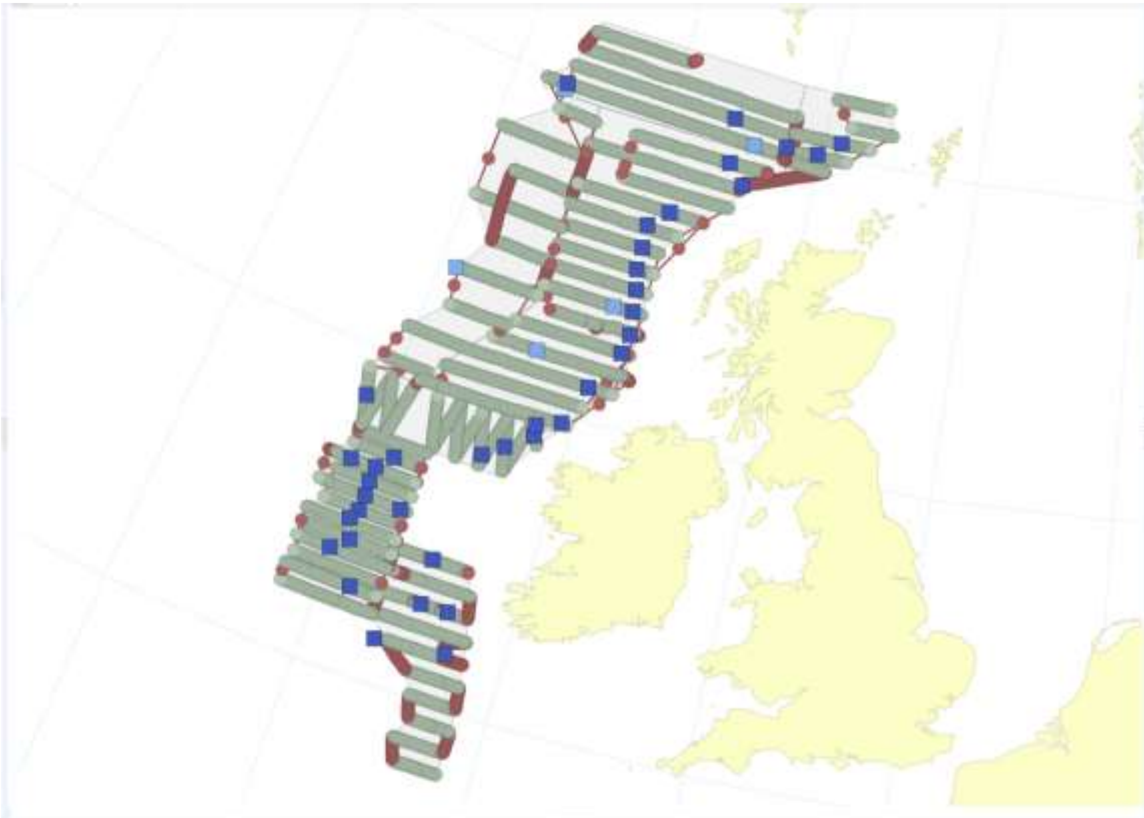


Figure 5. Tagged acoustic transects (green circles) with associated trawl stations containing blue whiting (dark blue squares) used in the StoX abundance estimation. IBWSS March-April 2021.

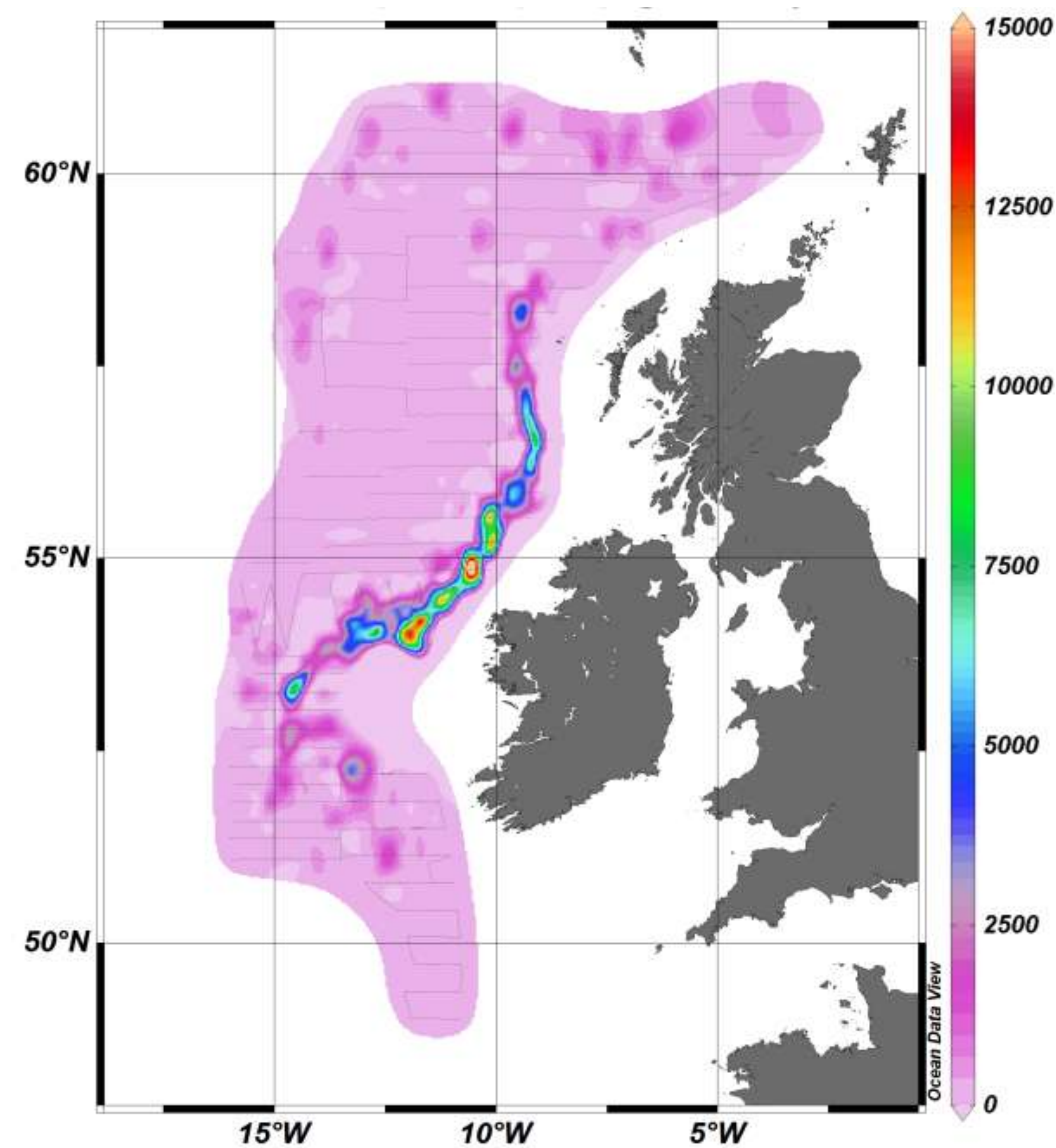


Figure 6. Acoustic density heat map (s_A m^2/nmi^2) of blue whiting during the International Blue Whiting Spawning Stock Survey (IBWSS) from March-April 2021.

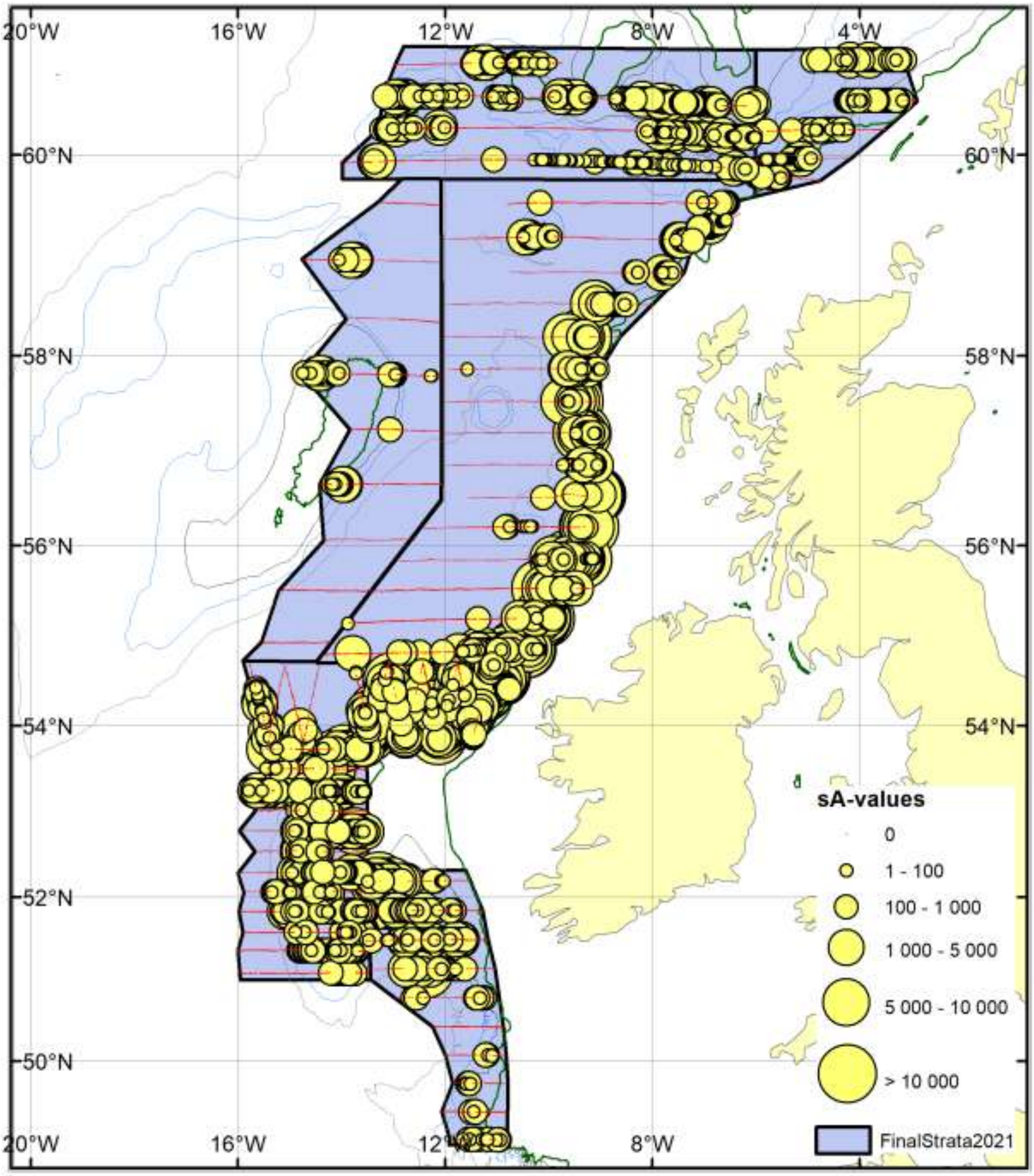
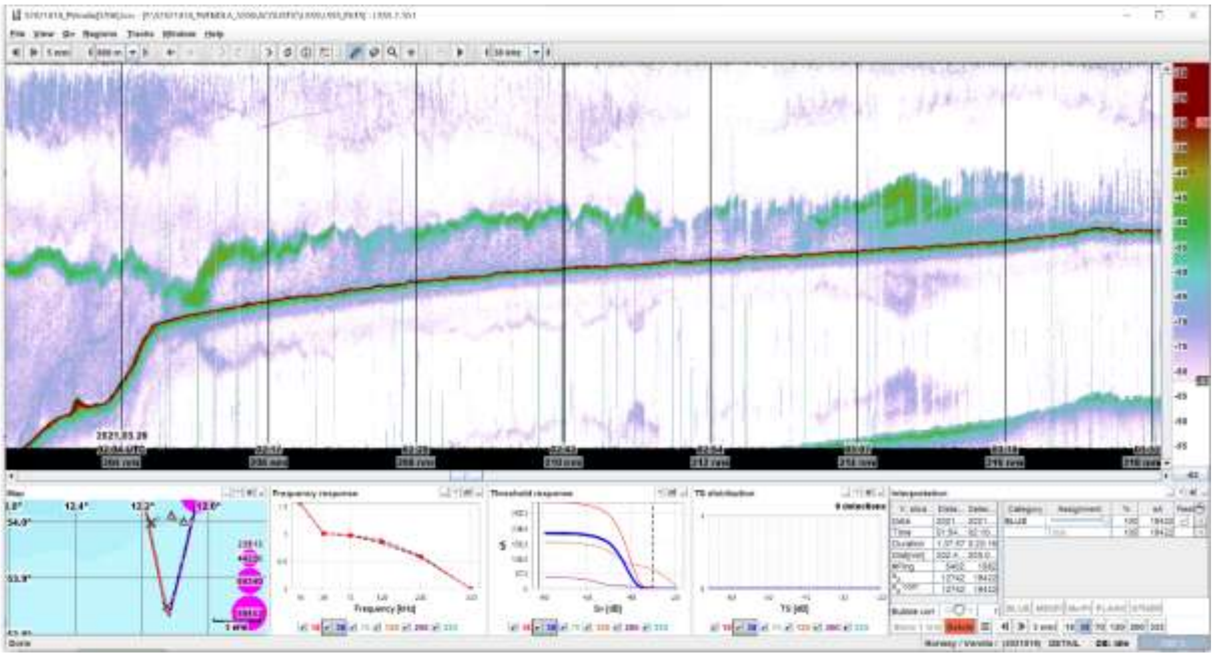
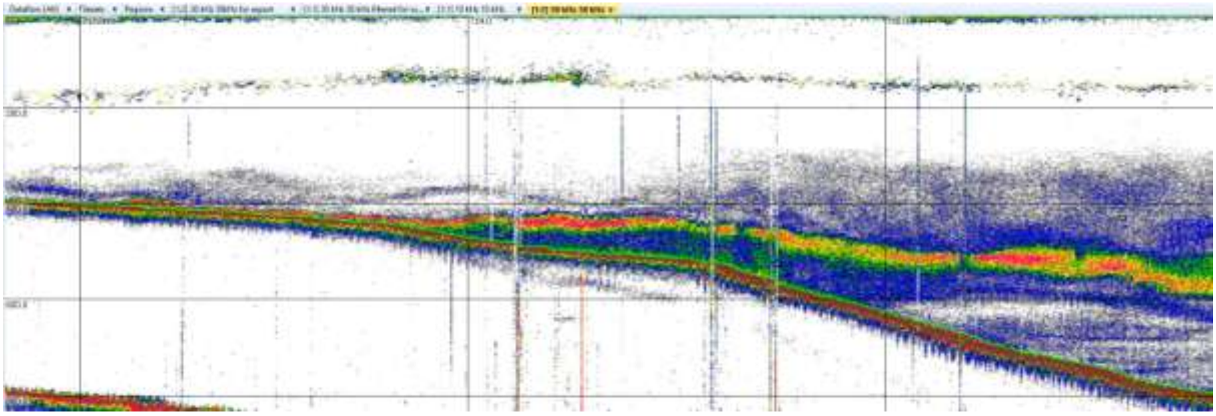


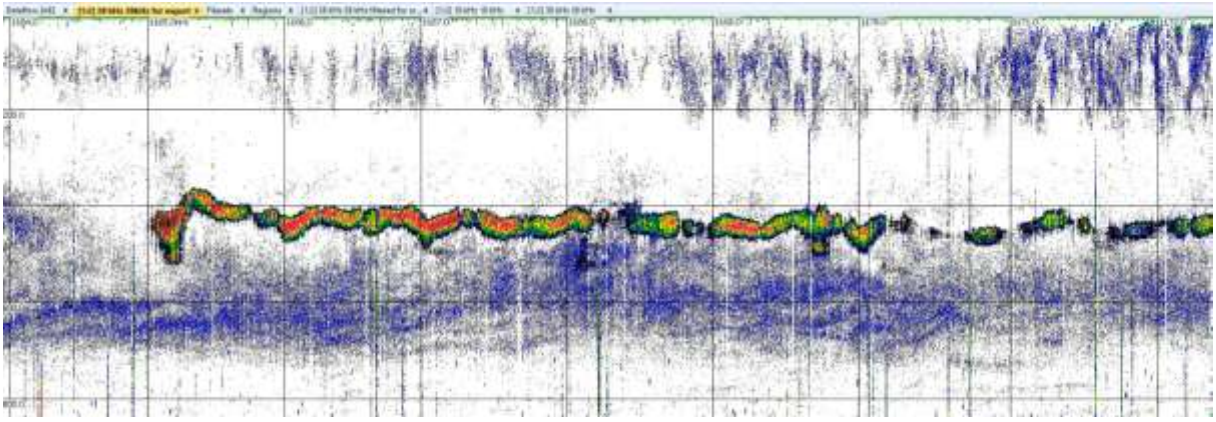
Figure 7. Map of proportional acoustic density (s_A m^2/nmi^2) of blue whiting by 1 nmi sampling unit. IBWSS March-April 2021.



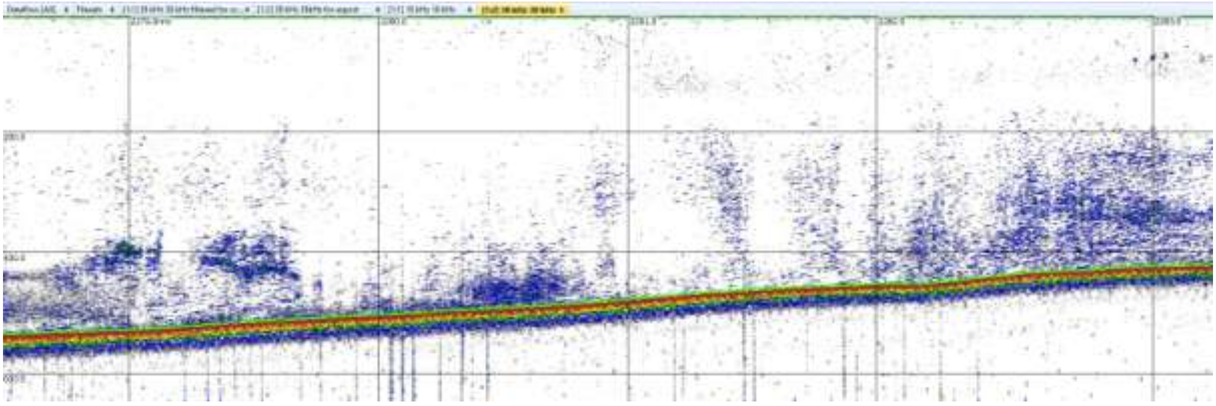
a) High density blue whiting per 1nmi log interval recorded on the northern slope of the Porcupine Bank area (Stratum 2) FV *Vendla*, Norway.



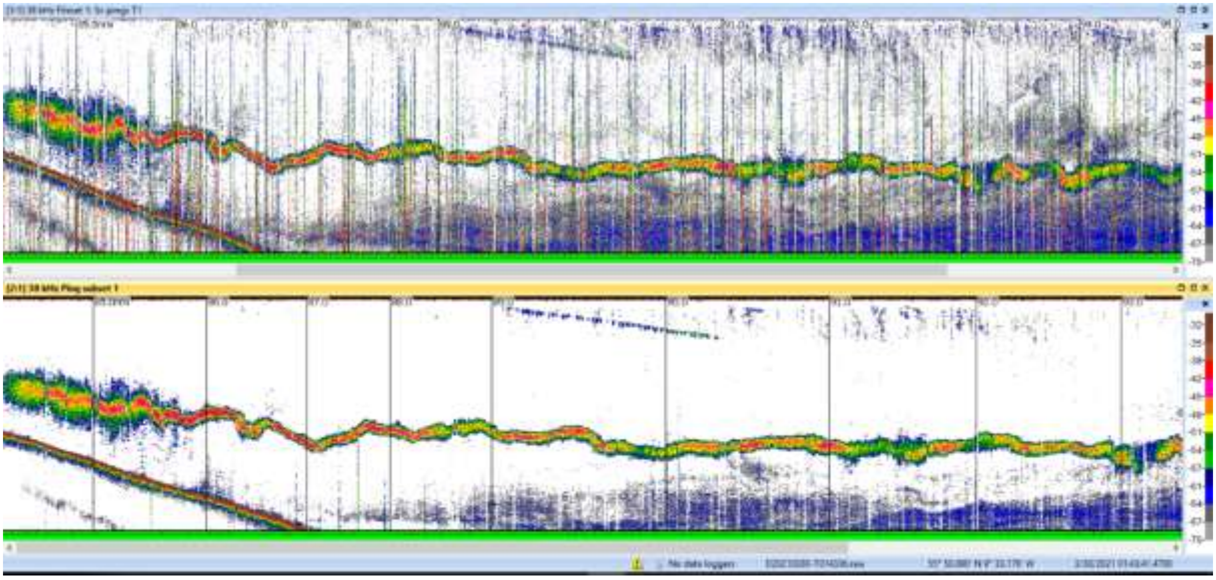
b) High density blue whiting layer per 1nmi log interval at 400- 600m recorded by the RV *Celtic Explorer* in the western Porcupine Bank area (strata 1).



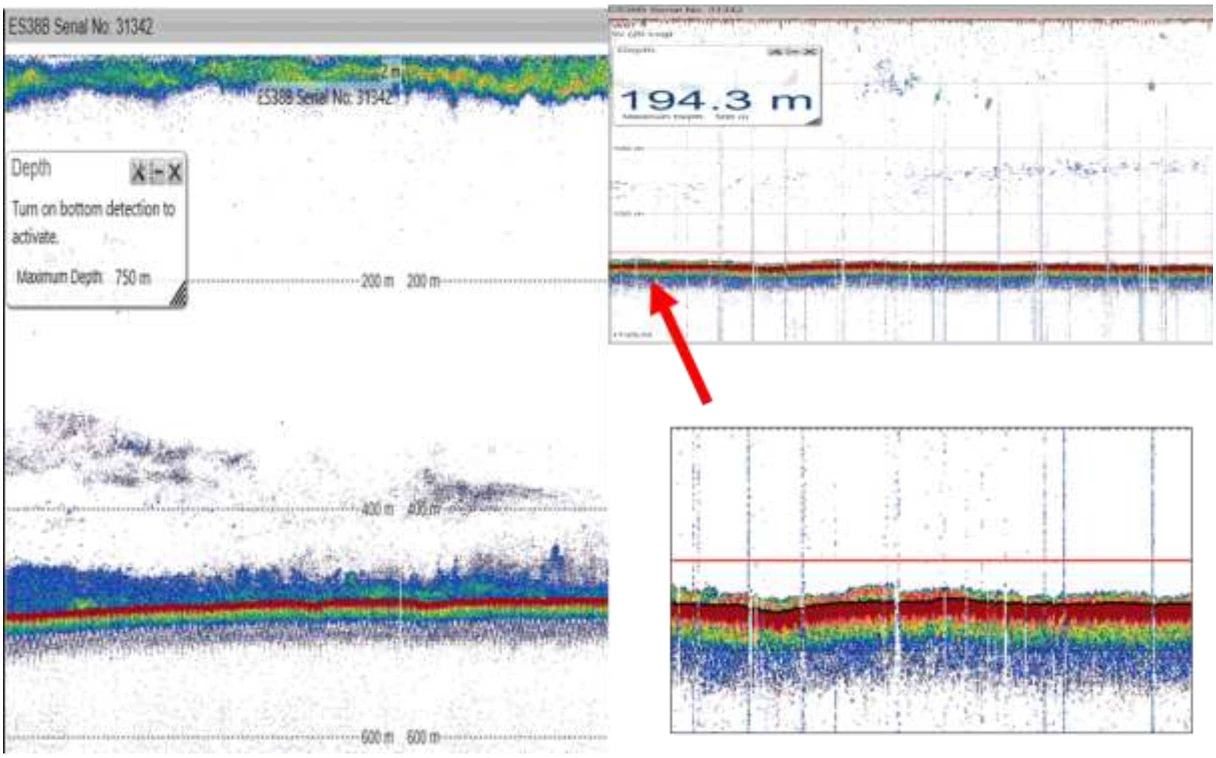
c) Single highest density blue whiting layer per 1nmi log interval (s_A value (73,312 m^2/nmi^2) observed during the survey recorded by the Celtic Explorer in the Rockall Trough area (Stratum 3) in 400 – 500 m.



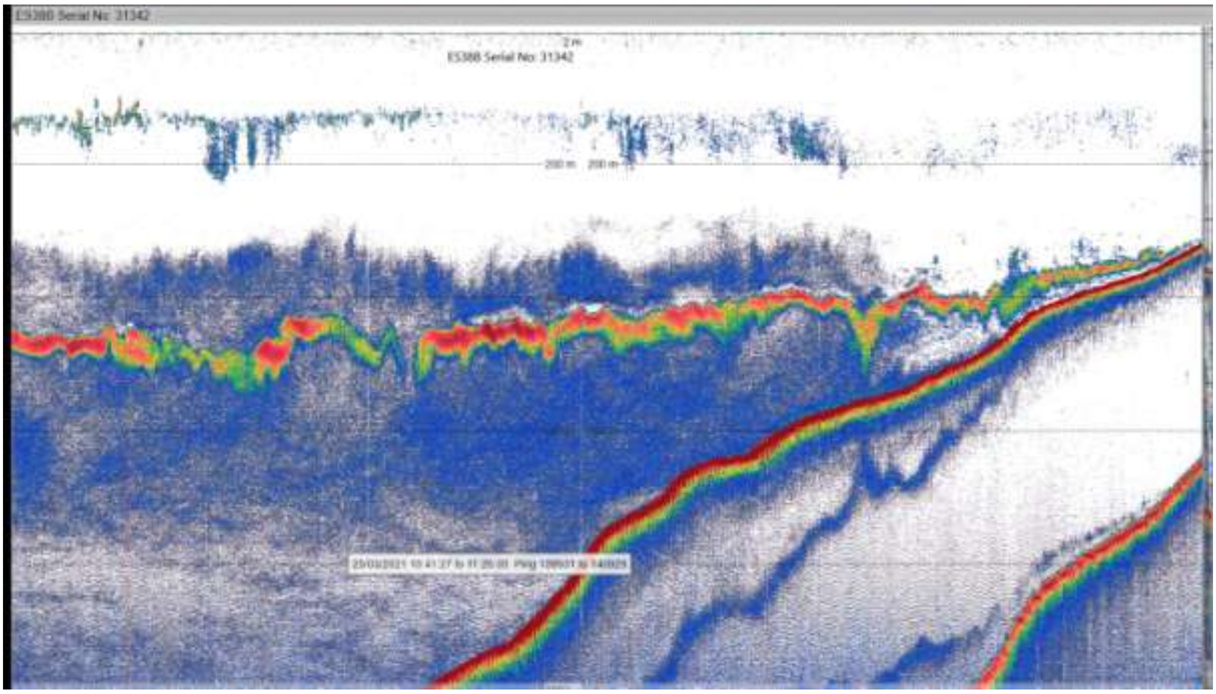
d) Weak scattering of predominantly juvenile blue whiting per 1 nmi log interval along the 400-500 m contour depth. This was an area that some of the fleet were fishing during the survey. Recorded by the RV *Celtic Explorer* in the Faroe – Shetland channel area (Stratum 6).



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



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



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

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

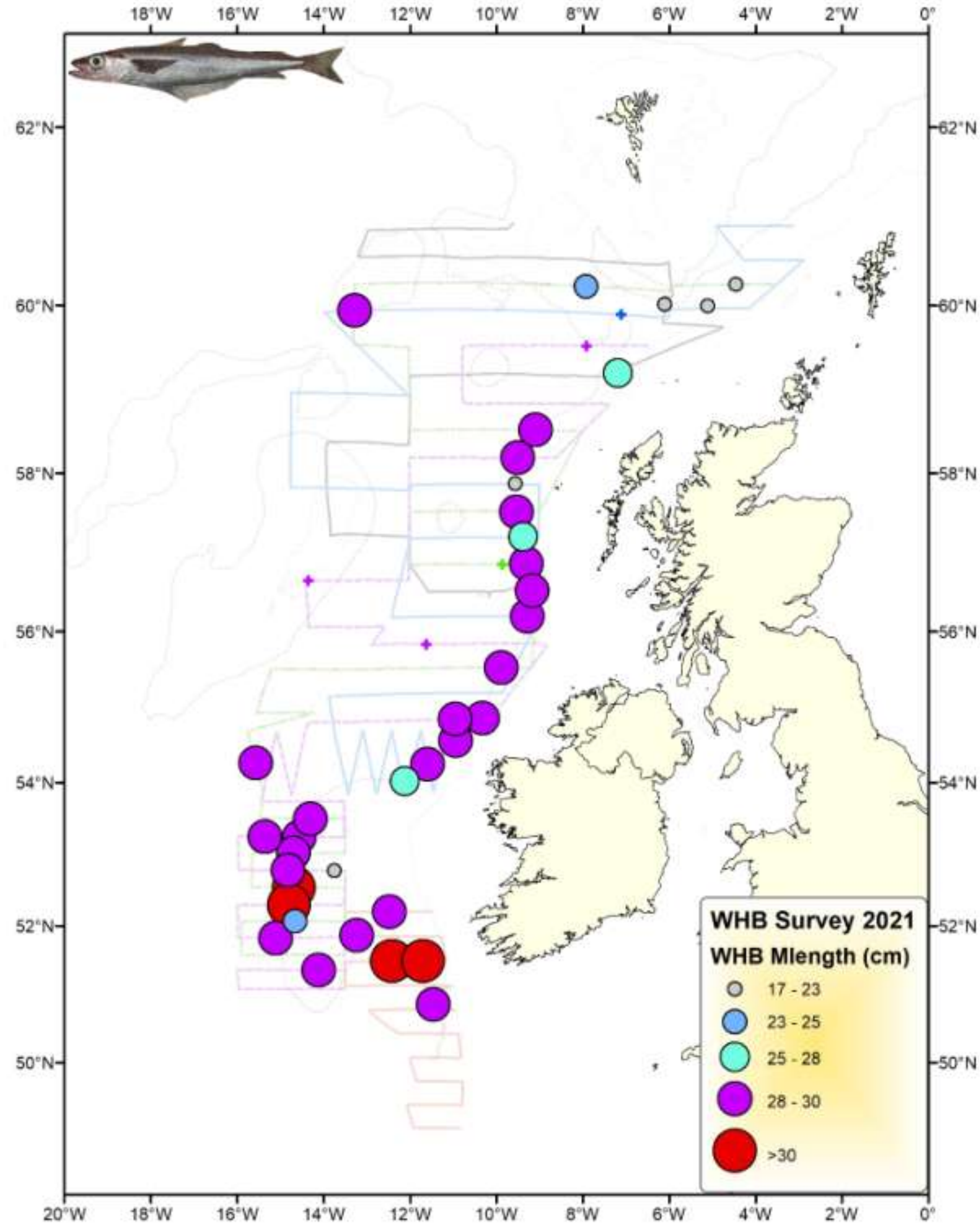


Figure 9. Combined mean length of blue whiting from trawl catches by vessel, IBWSS in March- April 2021. Crosses indicate hauls with zero blue whiting catches.

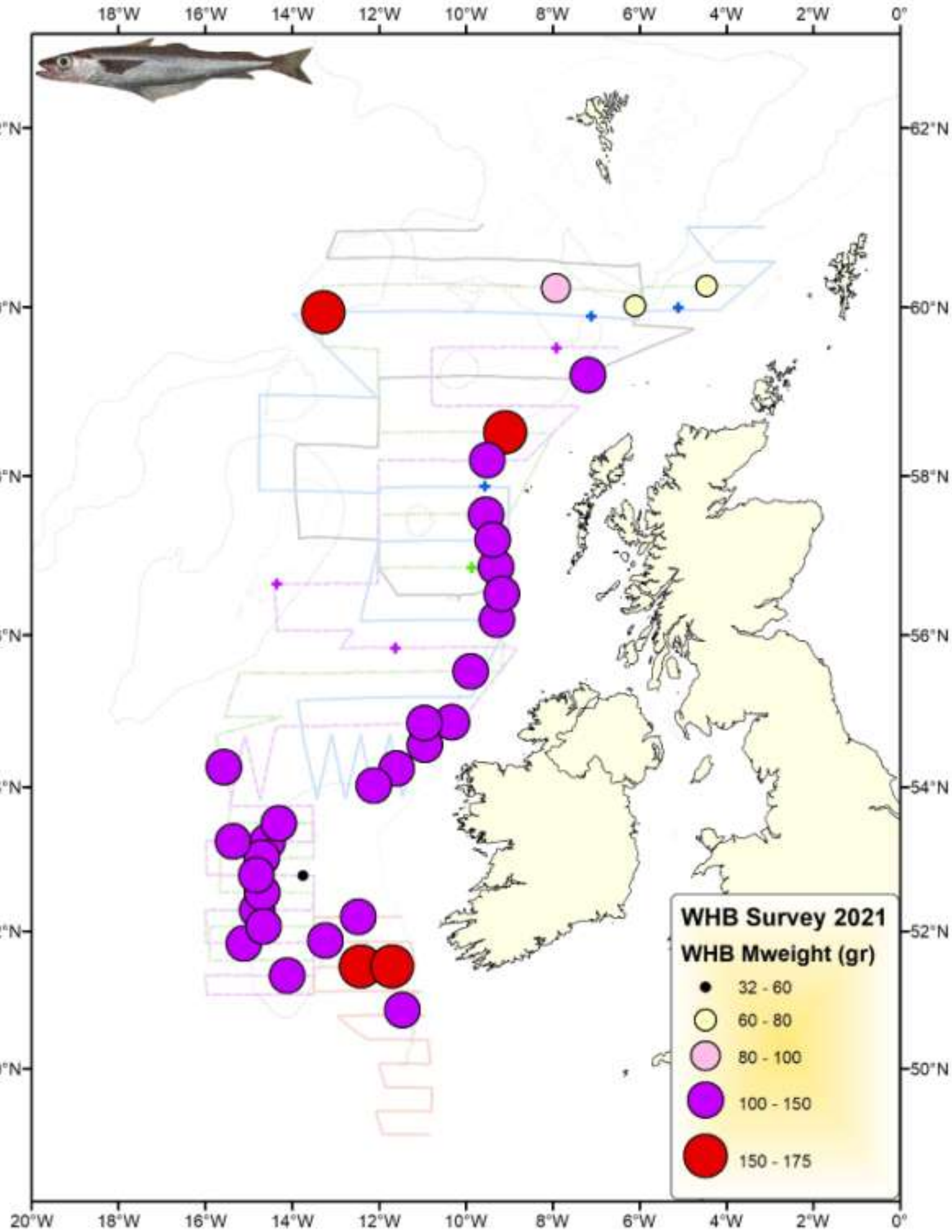


Figure 10. Combined mean weight of blue whiting from trawl catches, IBWSS March- April 2021. Crosses indicate hauls with zero blue whiting catches.

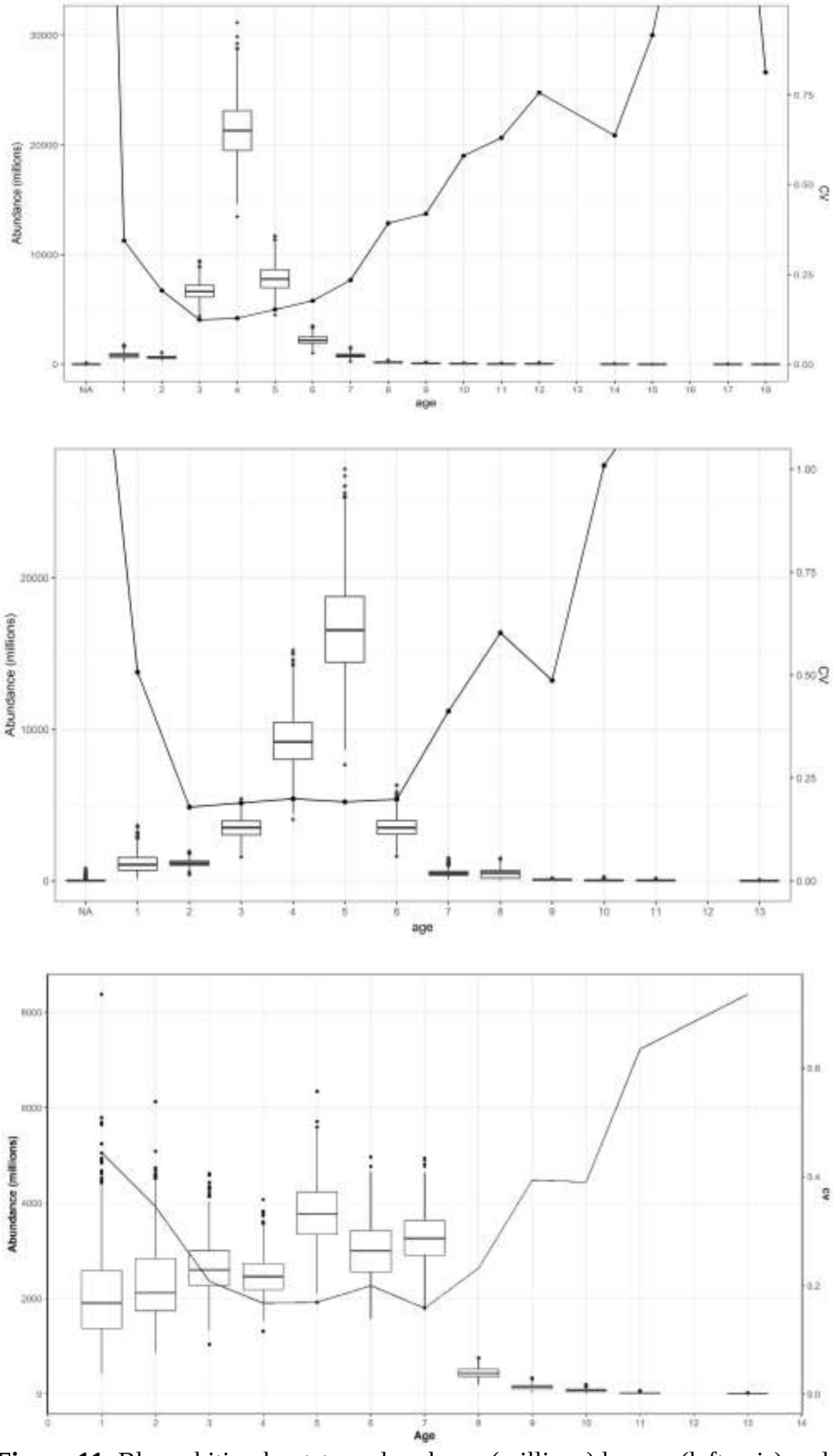


Figure 11. Blue whiting bootstrap abundance (millions) by age (left axis) and associated CVs (right axis) in 2018 (top panel), 2019 (middle panel) and 2021 (lower panel). From StoX.

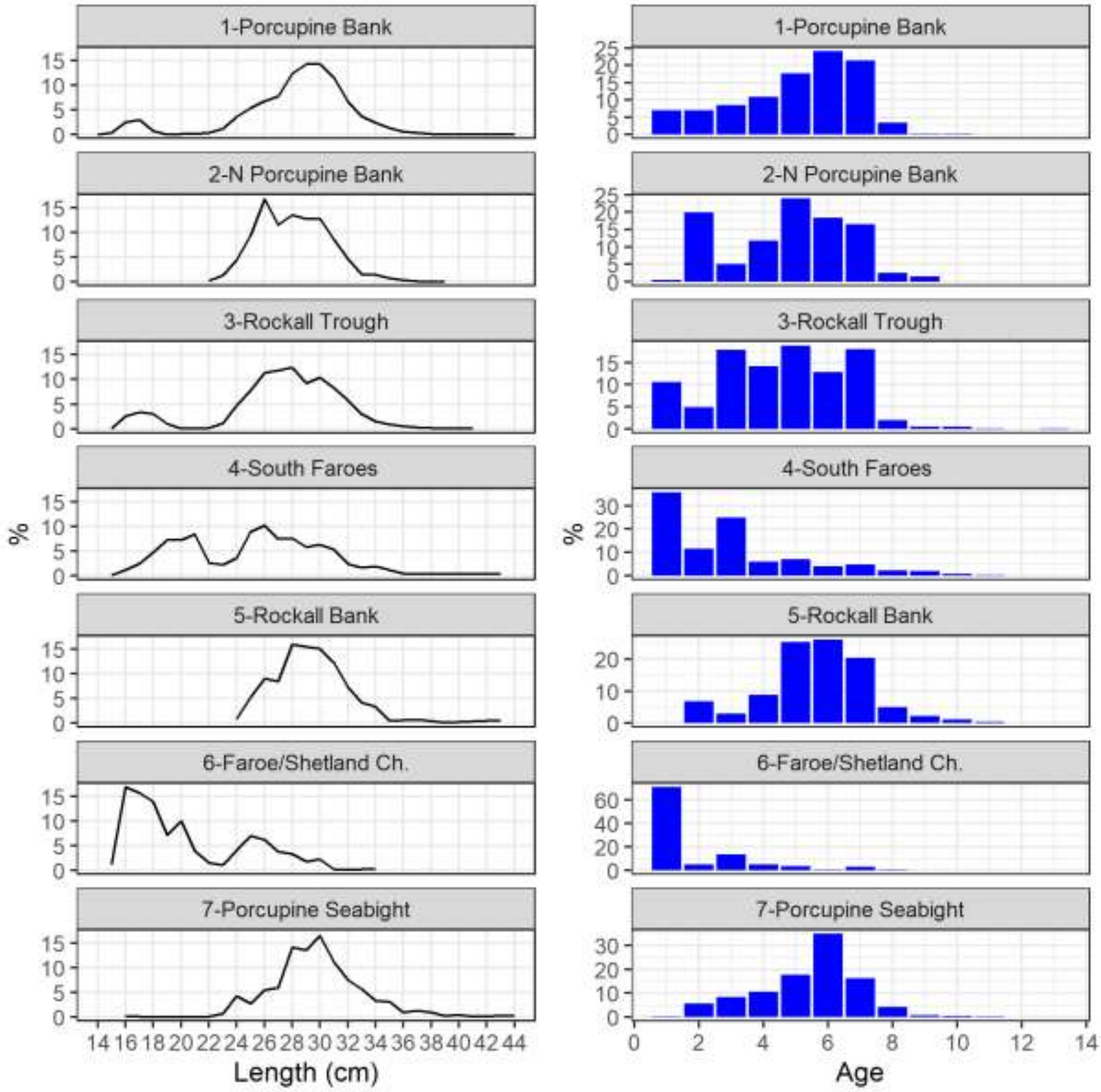


Figure 12. Length and age distribution (numbers) of blue whiting by survey strata. March-April 2021.

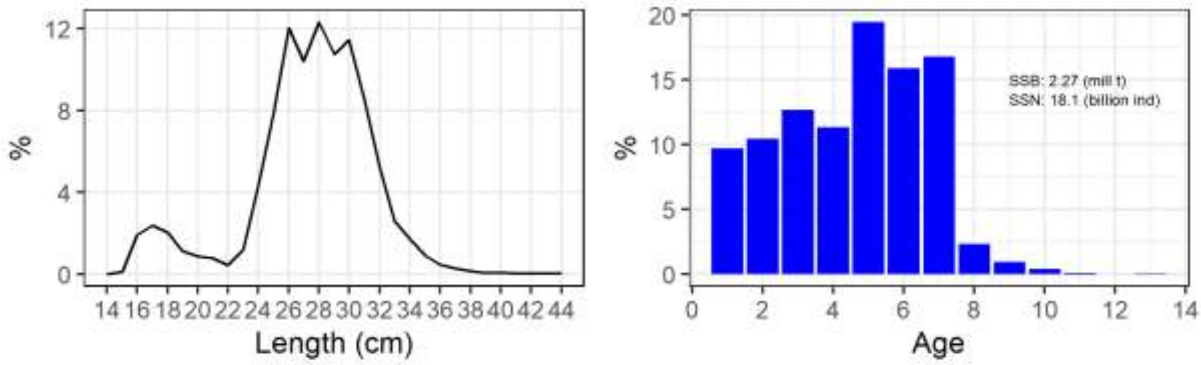


Figure 13. Length and age distribution (numbers) of total stock of blue whiting. March-April 2021.

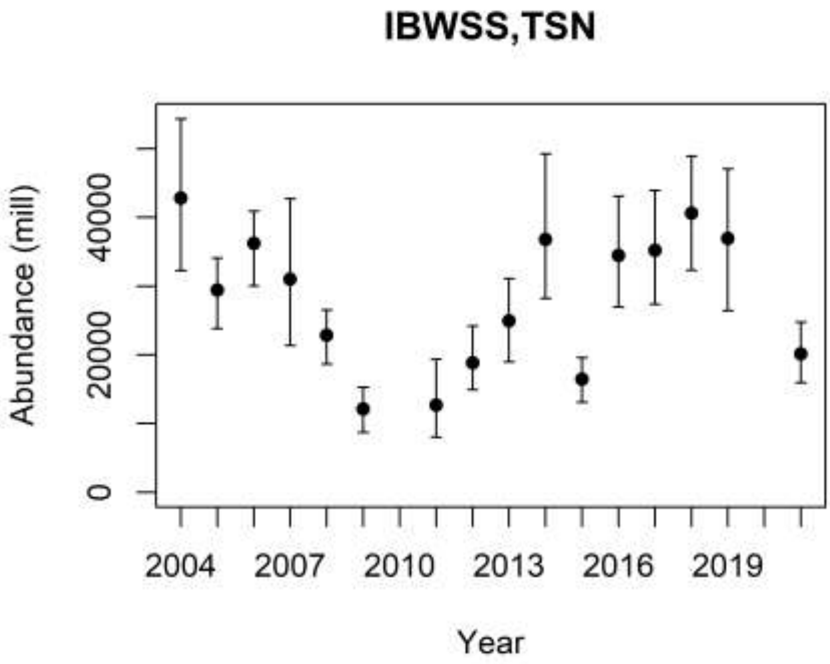


Figure 14. Time series of StoX survey indices of blue whiting abundance, 2004-2021, excluding 2010.

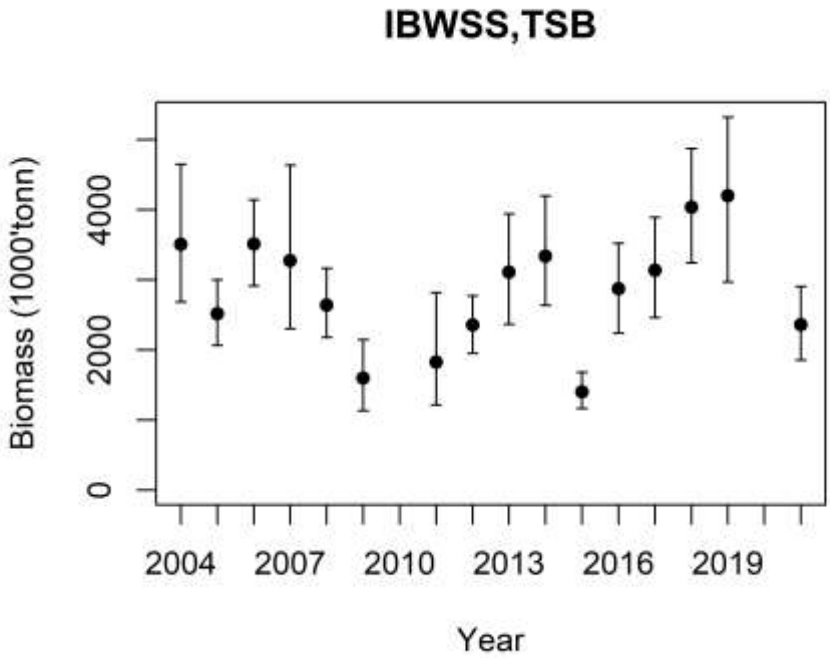


Figure 15. Time series of StoX survey indices of blue whiting biomass, 2004-2021, excluding 2010.

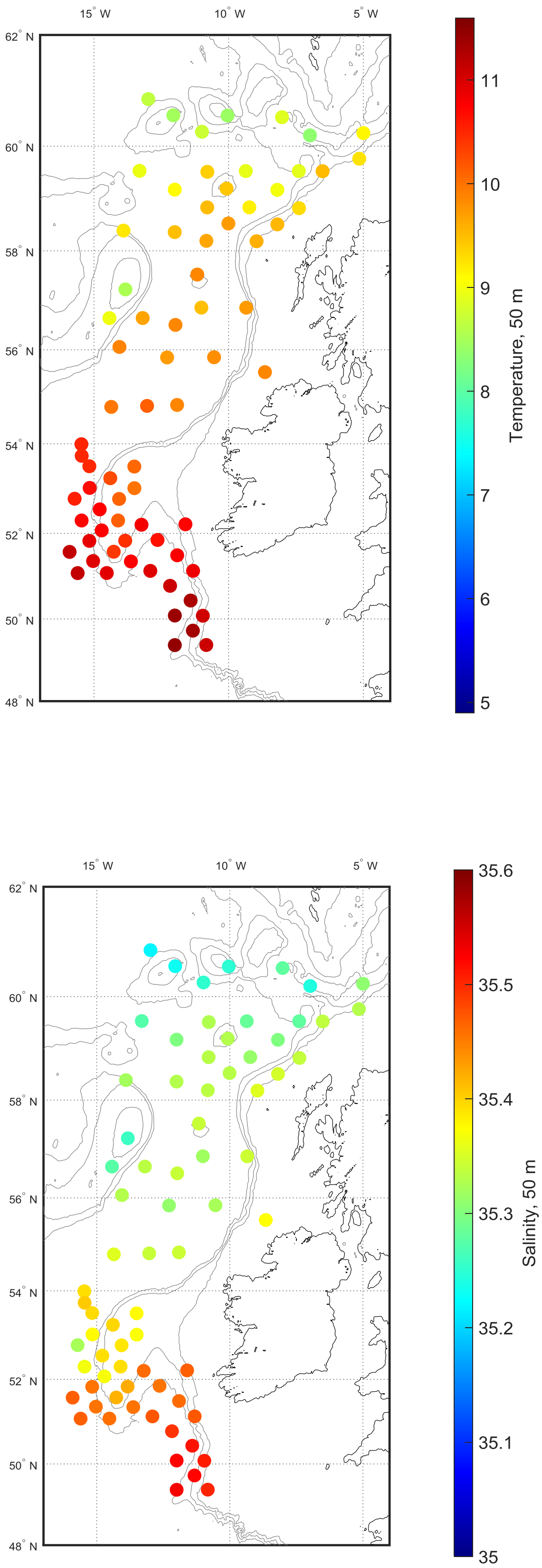


Figure 16. Horizontal temperature (top panel) and salinity (bottom panel) at 50 m subsurface as derived from vertical CTD casts. IBWSS March-April 2021.

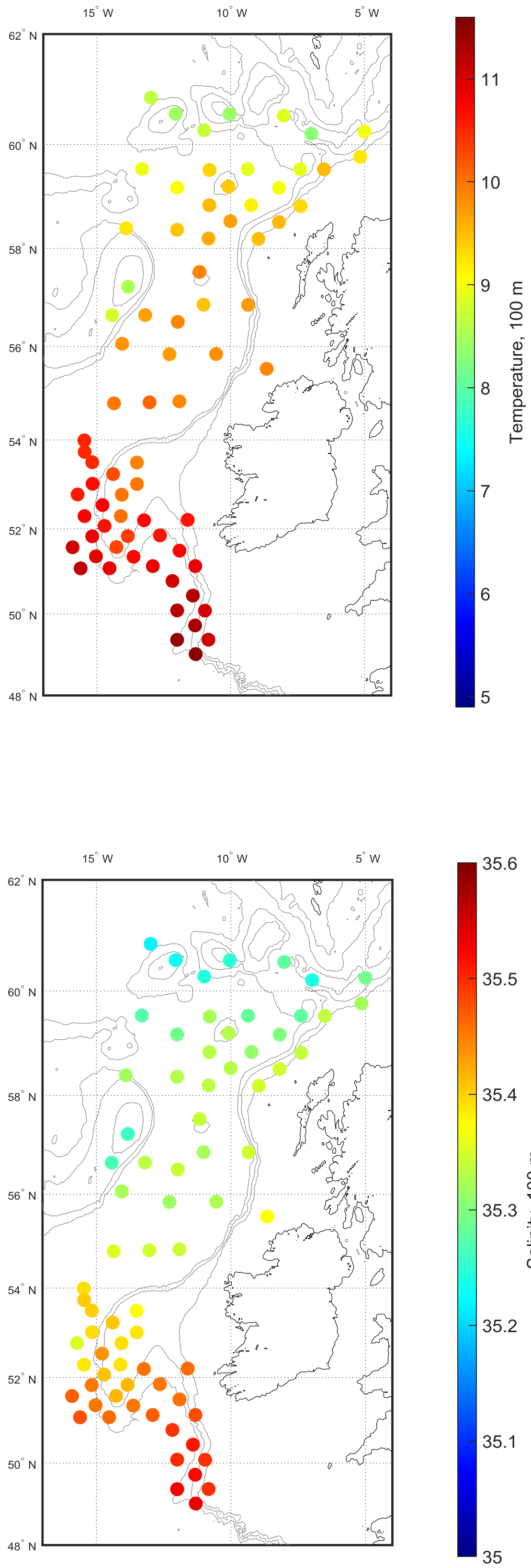


Figure 17. Horizontal temperature (top panel) and salinity (bottom panel) at 100 m subsurface as derived from vertical CTD casts. IBWSS March-April 2021.

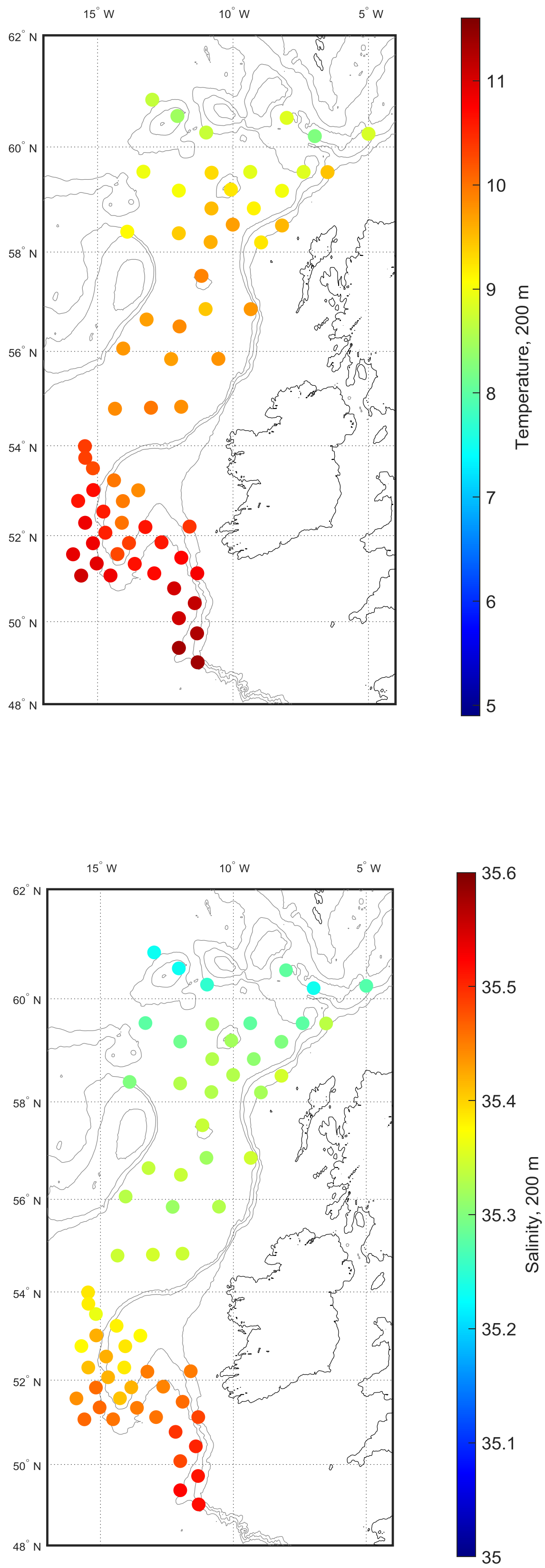


Figure 18. Horizontal temperature (top panel) and salinity (bottom panel) at 200 m subsurface as derived from vertical CTD casts. IBWSS March-April 2021.

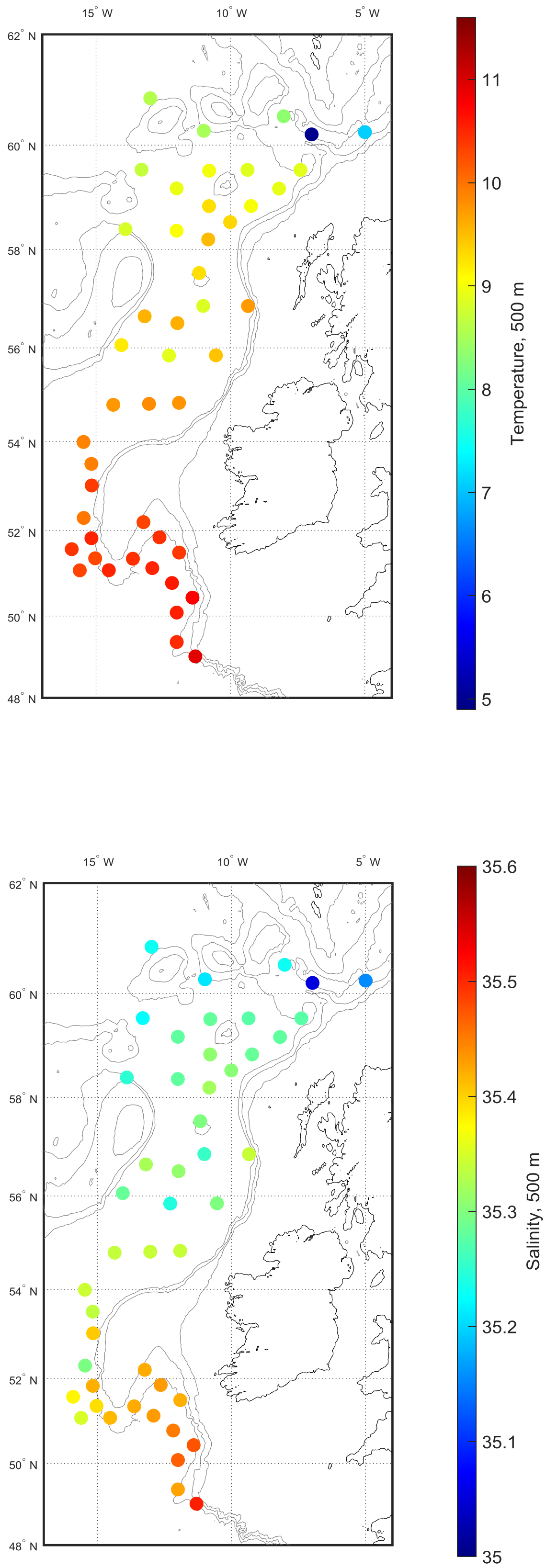


Figure 19. Horizontal temperature (top panel) and salinity (bottom panel) at 500 m subsurface as derived from vertical CTD casts. IBWSS March-April 2021.

Annex 1 – Bad data treatment on board RV Tridens

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

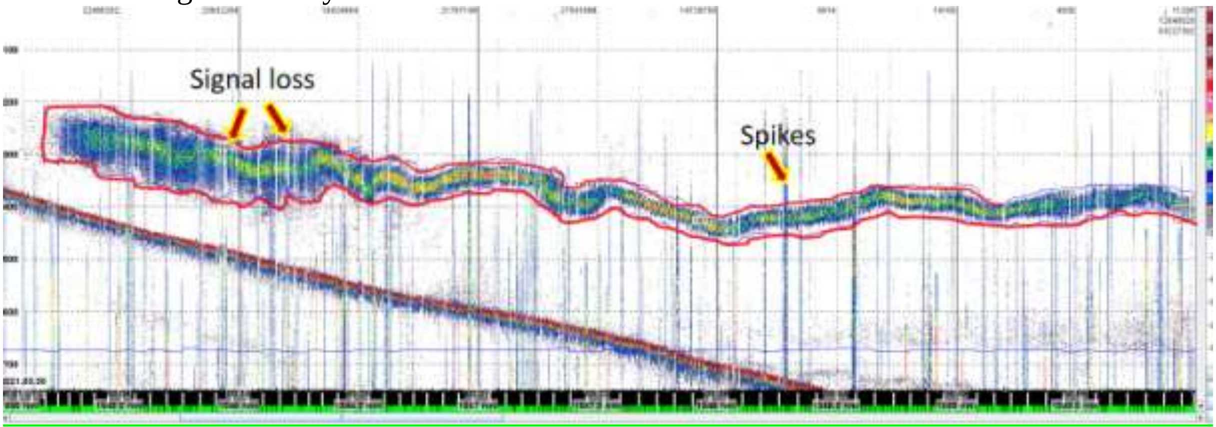


Figure 1 Dense-large aggregation of blue whiting encountered during a period of bad weather (2021 -03-30 early morning). Data contains both spike noise and transmission loss due to abrupt motion of the ship as well as bubble entrainment as a result of bad weather.

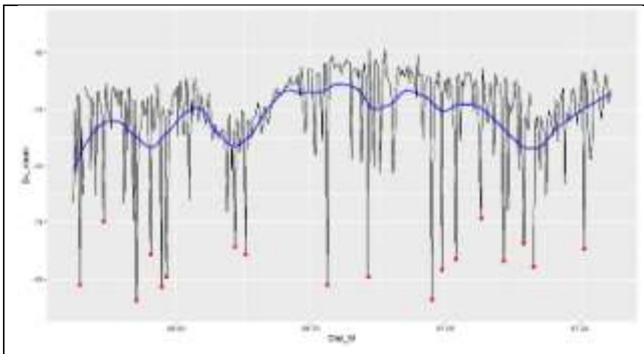
The exercise focused on a particular data set where the wind force was 7-8 Beaufort and swell height was greater than 2 m (March 30, 2021). During this time a large and dense aggregation was encountered along the transect where the acoustic recordings were subjected to signal degradation.

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

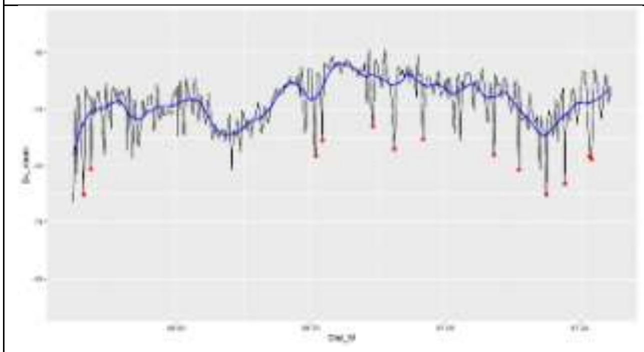
The stepwise processing procedure was as follows;

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

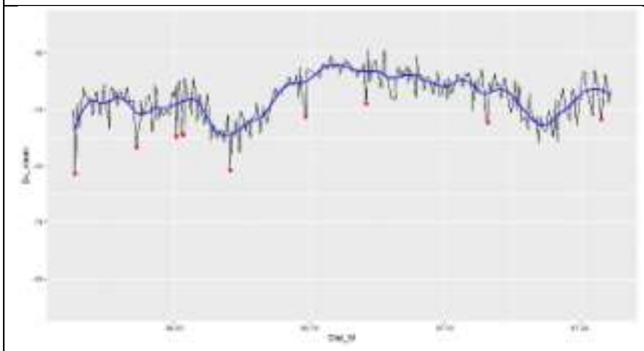
8- The predicted values were subtracted from the observed Sv values per each 1000 ping group and compared against the SD for detection of the outliers (“bad pings”).
9- For outlier-detection a stepwise approach was applied such that,
    a. 2*SD was used as a threshold. Values below -2*SD and above +2*SD standard deviations were identified as bad pings and removed from the data.
    b. After removal of bad pings, a new LOESS curve was fitted over the retained values. Again, a new standard deviation was calculated from these retained values and used as threshold for bad pings again.
    c. Same procedure repeated over the same 1000 ping group until no more bad pings were detectable. Then the same procedure was applied to the next ping group.



Step 1



Step 3



Step 5

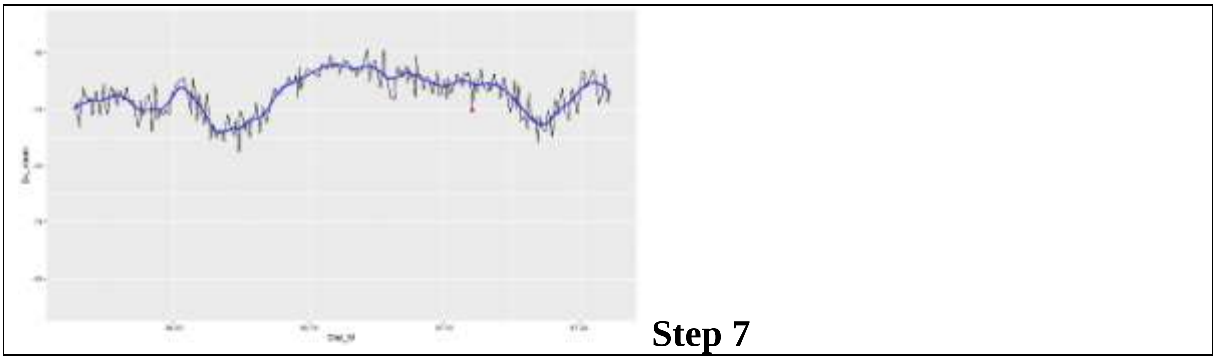


Figure 2 An example of bad ping detection for a group of 1000 pings. For this group, the procedure was finalized in 7 repetitive steps. The red dots indicate the bad pings (beyond SD threshold), the blue line is the fitted LOESS curve. The x axis is the time and the y axis is the mean Sv.

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

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

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

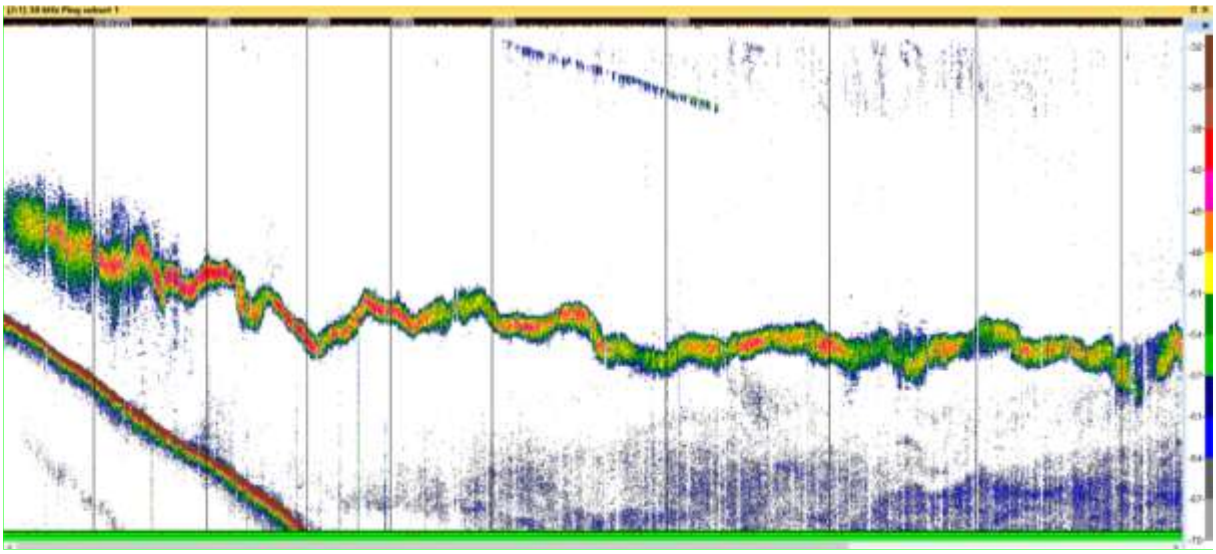


Figure 3 One of the processing solutions where all the identified bad pings were removed using the ping-subset function of Echoview. The resulting echogram looks similar to recordings in good weather.