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Survey report

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

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

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Summary

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

Survey participants 12-26.02.2019:

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Erling Kåre Stenevik	Cruise leader
Lage Drivenes	Instrument/Acoustics
Jori Neteland-Kyte	Instrument /Acoustics
Ørjan Sørensen	Biology
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Christine Djønne	Biology
Lea Marie Hellenbrecht	Biology
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MS *Vendla*	
Are Salthaug	Cruise leader and Survey coordinator
Jarle Kristiansen	Instrument/Acoustics
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Valantine Anthonypillai	Biology
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Introduction

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

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

Material and methods

Survey design

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

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

Biological sampling

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

Additional data collection

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

Acoustic data processing

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

Abundance estimation methods

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

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

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

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

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

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

Variance by stratum is estimated as:

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

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

The global variance is estimated as

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

The global relative standard error of NASC

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

where N is number of strata.

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

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

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

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

Where

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

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

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

Sonar data and analyses

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

Results and discussion

Survey coverage

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

Estimates of abundance

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

Spatial distribution of the stock

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

Geographical variation in temperatures experienced by the herring

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

Quality of the survey

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

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Tables

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

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

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

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

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

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

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

Figures

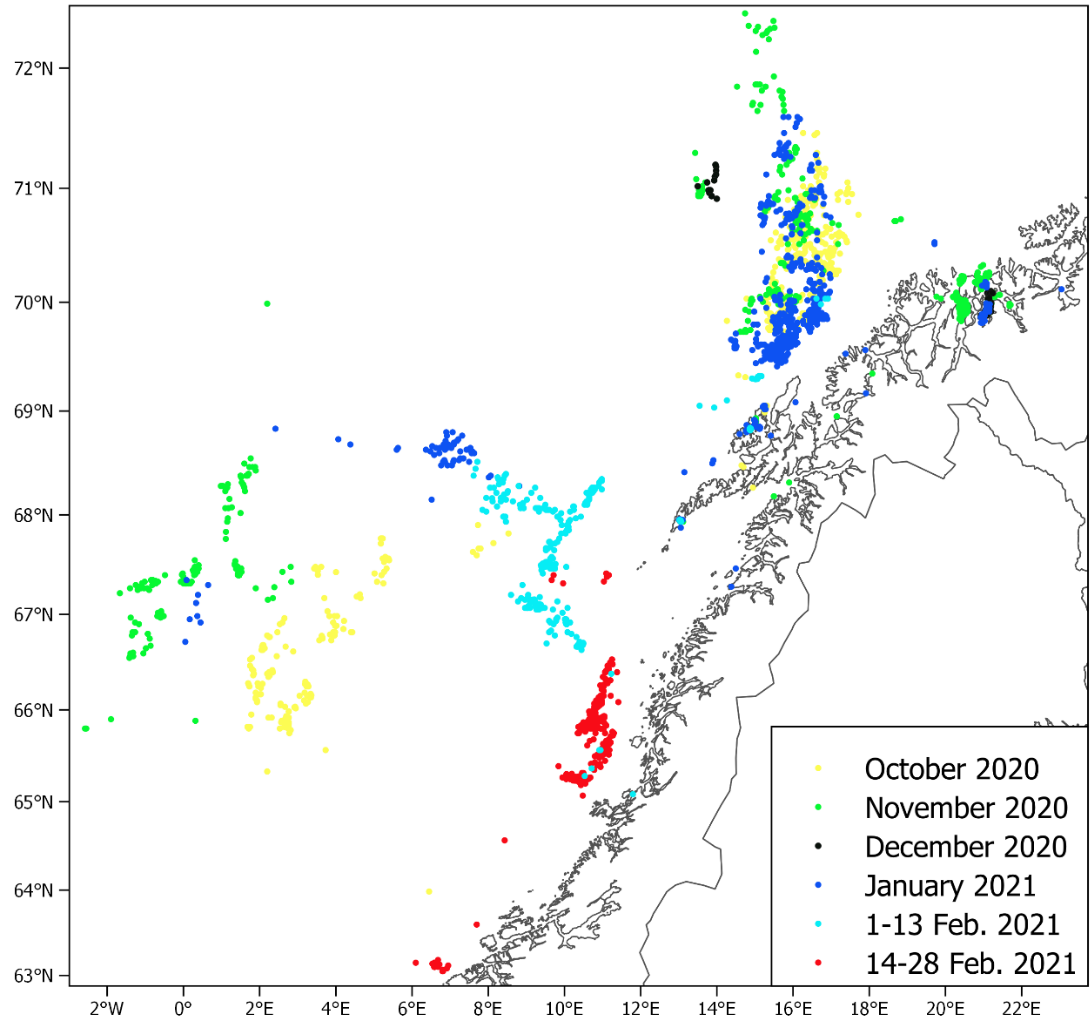

Figure 1. Distribution of commercial catches of Norwegian spring-spawning herring from October 2020 until February 2021, based on electronic logbooks. Each point represent one catch, only catches larger than 10 tons are shown.

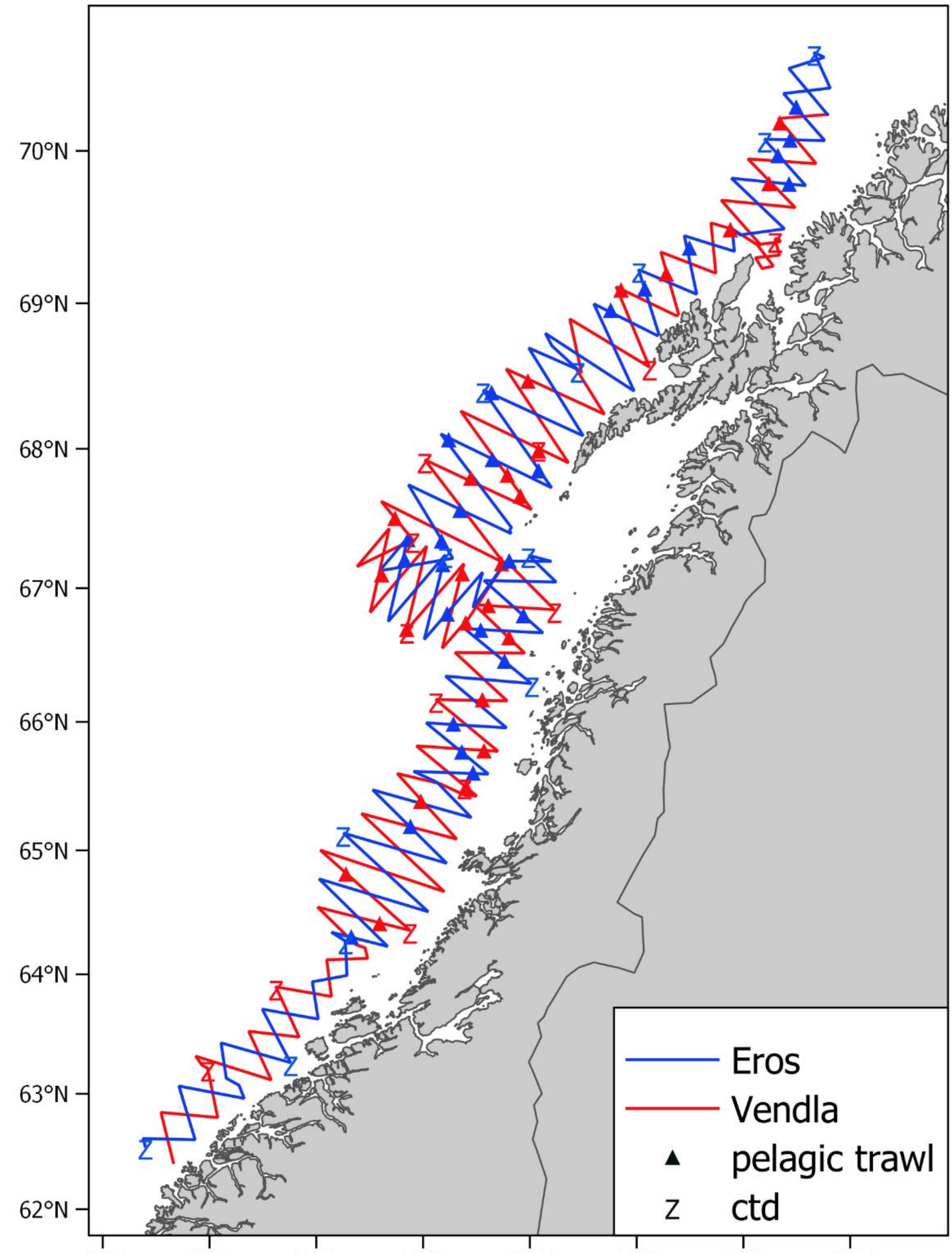

Figure. 2. Cruise tracks (mostly acoustic transects), pelagic trawl stations (triangles), and CTD stations (Z) covered by *Eros* and *Vendla* on the Norwegian spring-spawning herring spawning survey 12.-26. February 2021.

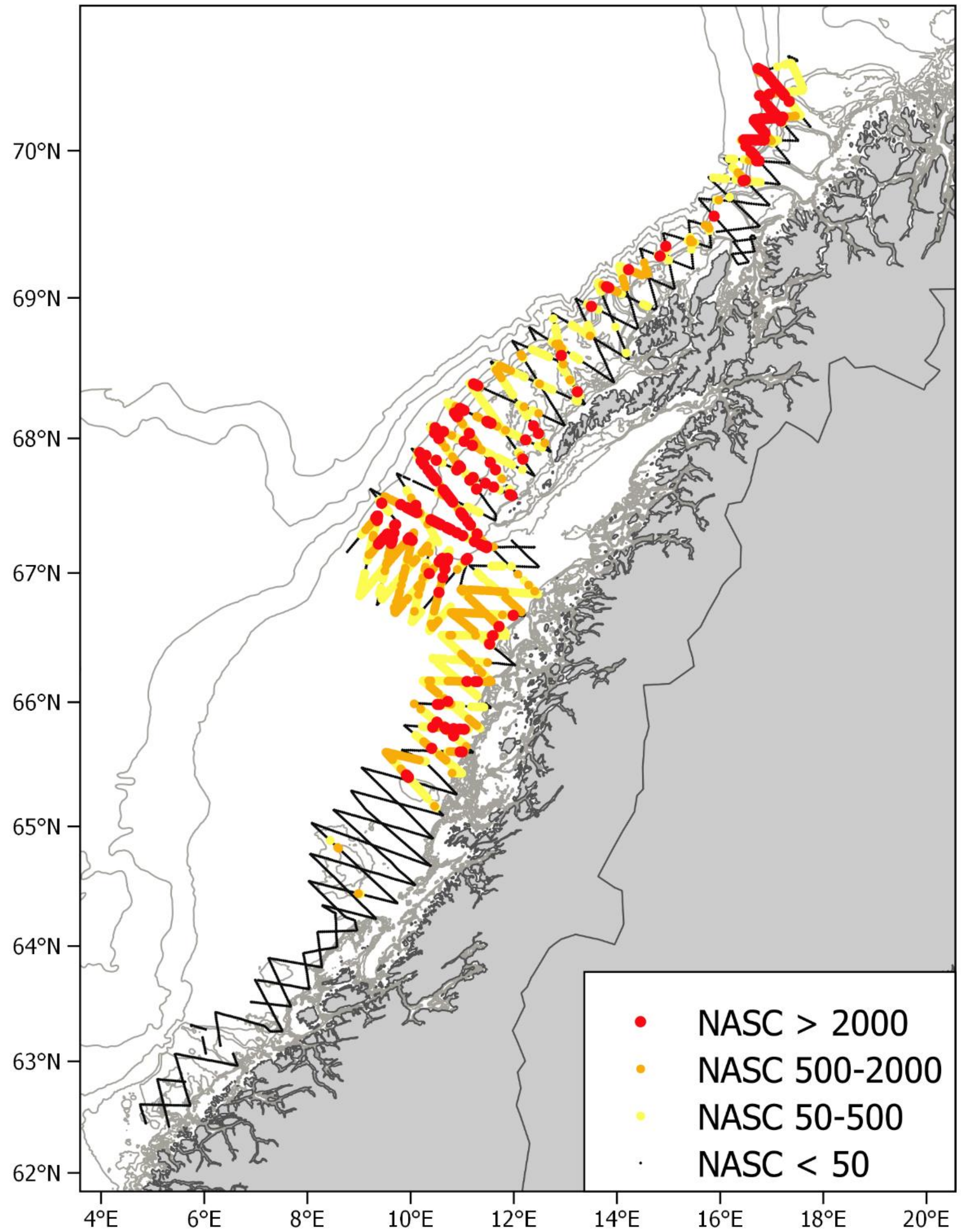

Figure 3. Acoustic densities (NASC) of herring recorded during the Norwegian spring-spawning herring spawning survey 12.-26. February 2021. Points represent NASC values per nautical mile. Depth contours are shown for 50 m, 100 m, 150 m, 200 m, 500 m, 1000 m, 1500 m and 2000 m.

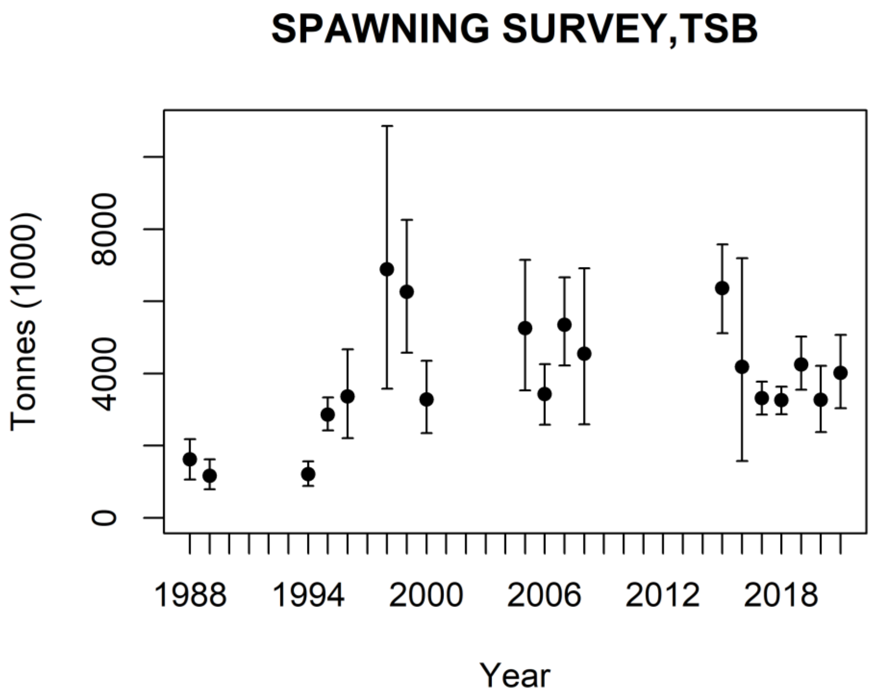

Figure 4. Estimates of total biomass from the Norwegian spring-spawning herring spawning surveys during1988-2021. The estimates are mean of 1000 bootstrap replicates and the error bars represent 90 % confidence intervals.

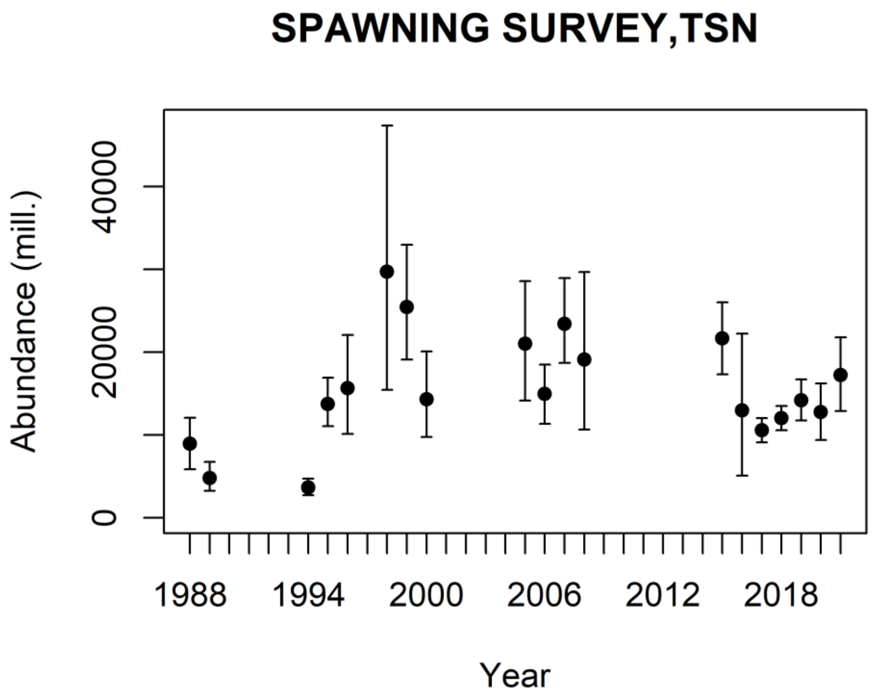

Figure 5. Estimates of total number from the Norwegian spring-spawning herring spawning surveys during1988-2021. The estimates are mean of 1000 bootstrap replicates and the error bars represent 90 % confidence intervals.

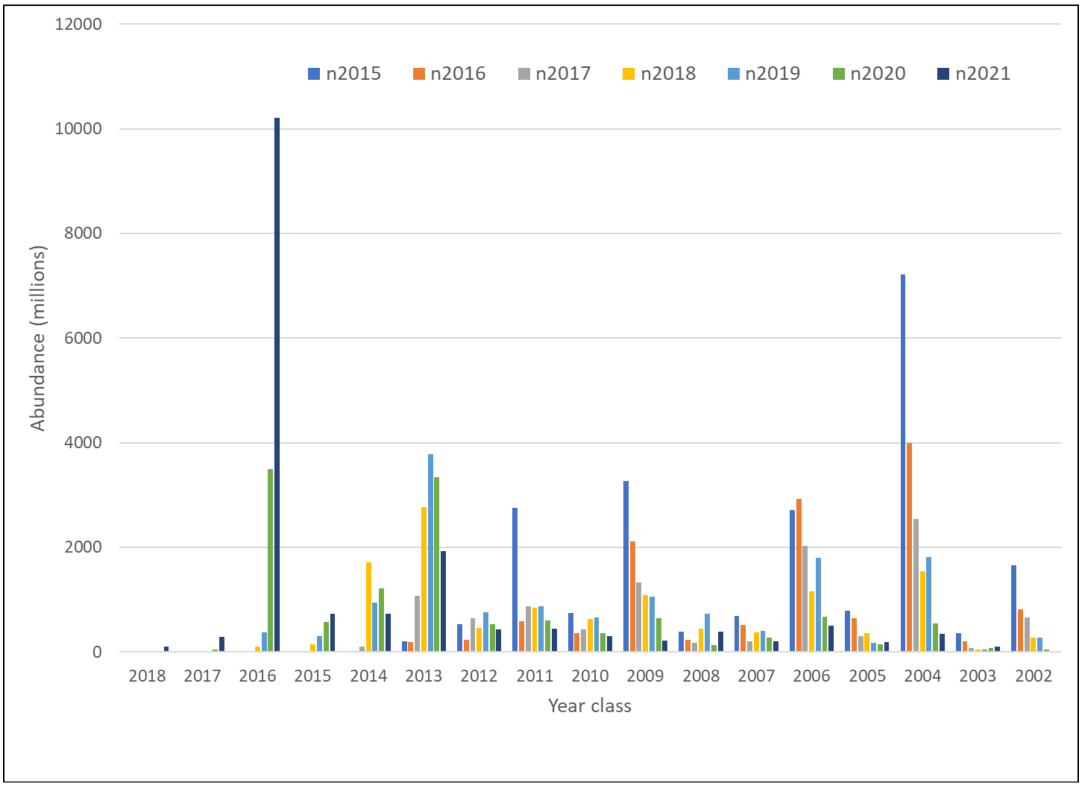

Figure 6a. Abundance by year class estimated during the Norwegian spring-spawning herring spawning surveys 2015-2021 (mean of 1000 bootstrap replicates). Legend: Separate colour for each survey year.

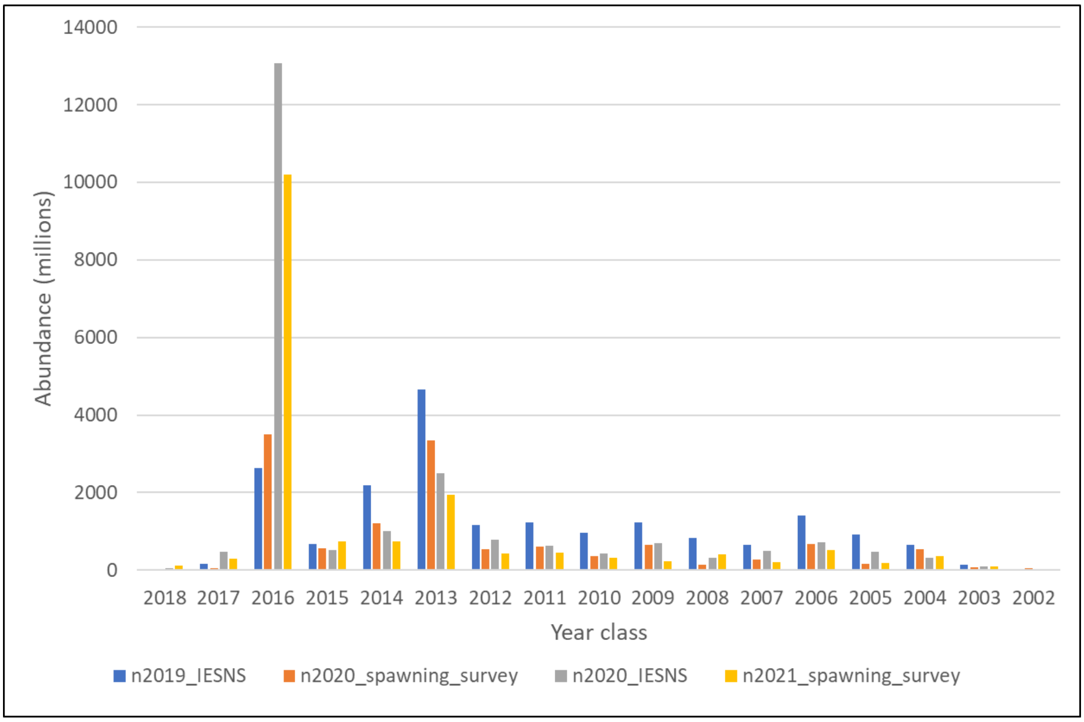

Figure 6b. Abundance by year class estimated during the International Ecosystem Survey in Nordic Seas (IESNS) 2019-2020 and the Norwegian spring-spawning herring spawning survey 2020-2021 (mean of 1000 bootstrap replicates). Legend: Separate colour for each survey and year.

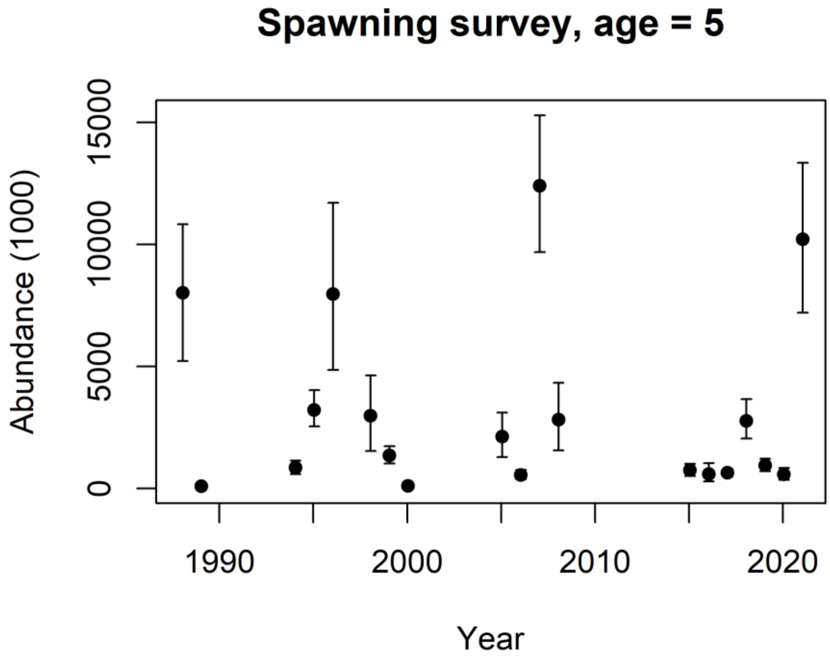

Figure 7. Estimated abundance of 5 year old herring from Norwegian spring-spawning herring spawning surveys during1988-2021. The estimates are mean of 1000 bootstrap replicates and the error bars represent 90 % confidence intervals.

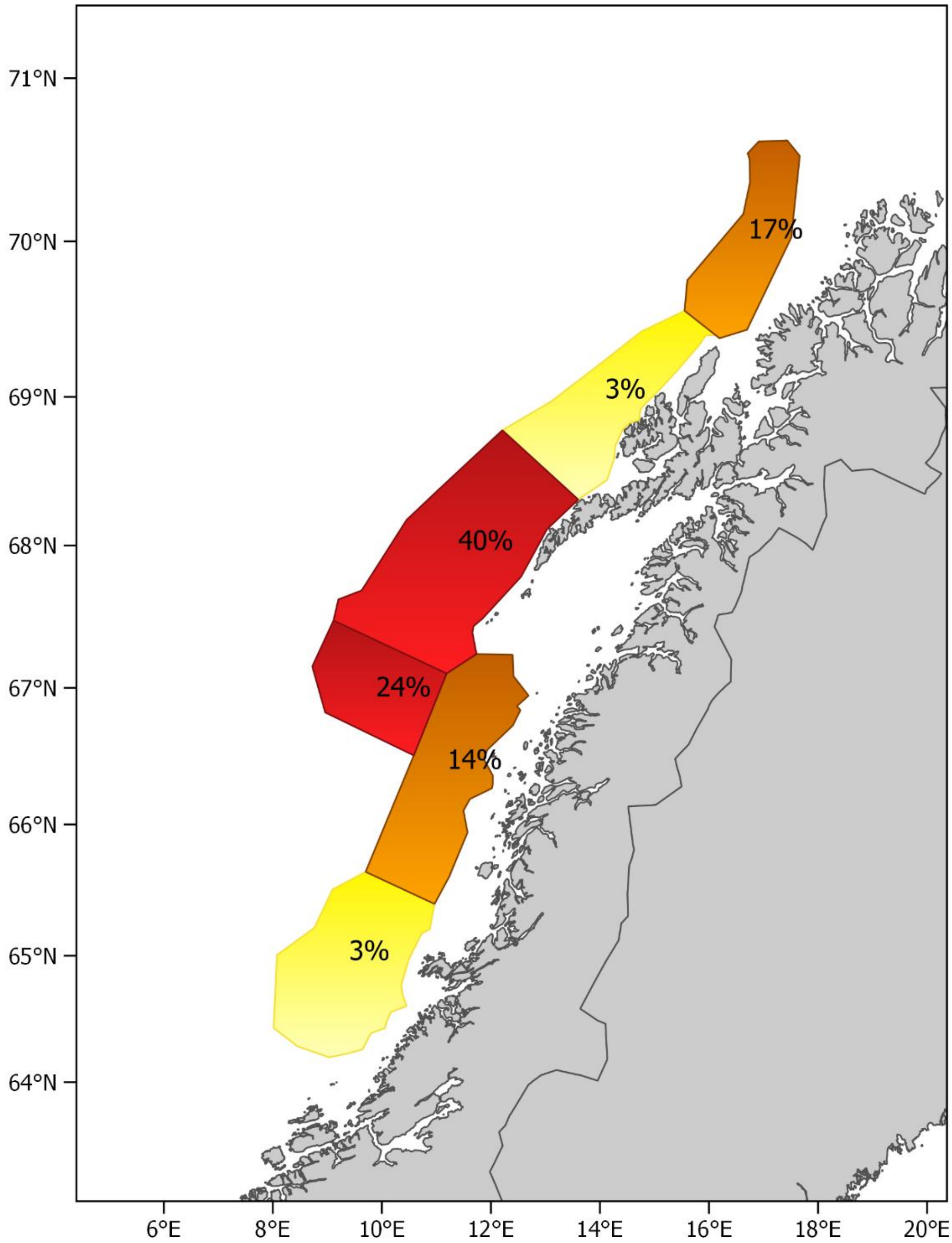

Figure 8. Relative distribution by stratum of the biomass of herring (mean of 1000 bootstrap replicates) from the Norwegian spring-spawning herring spawning survey 12.-26. February 2021.

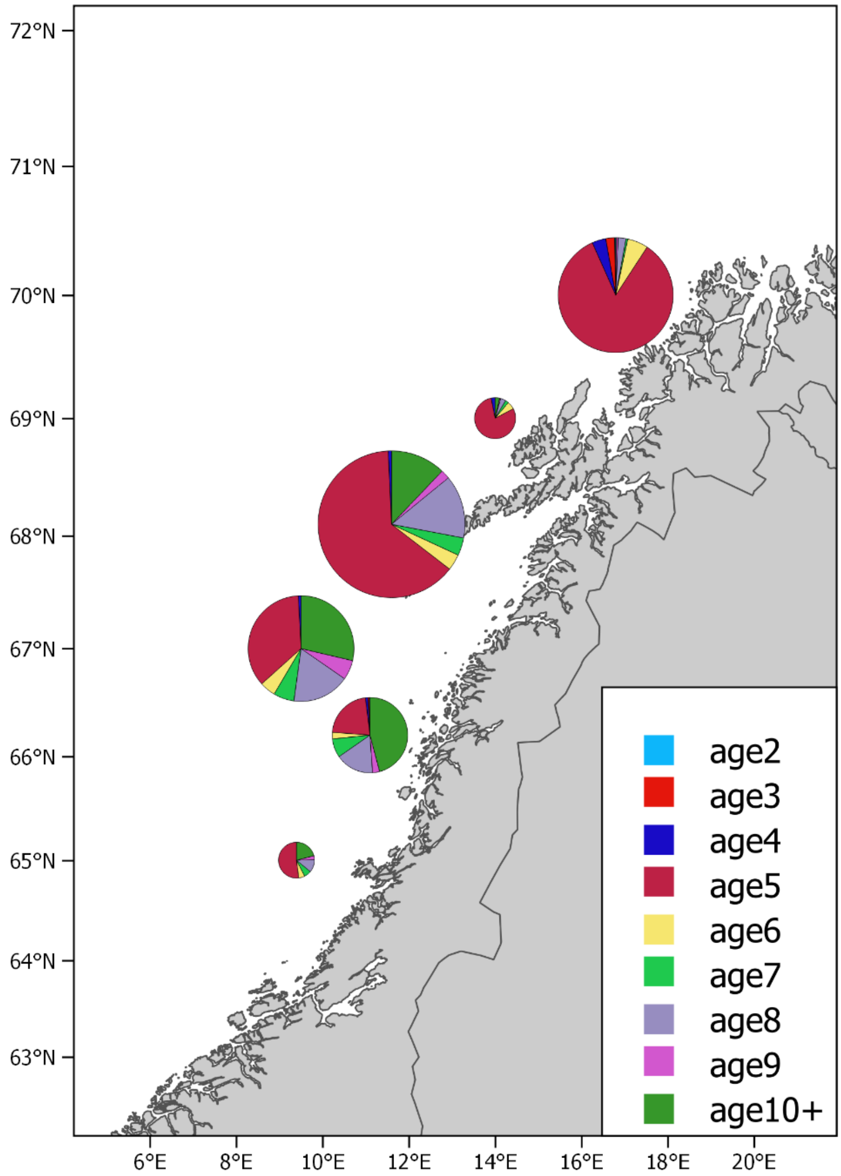

Figure 9. Age distribution per stratum from the Norwegian spring-spawning herring spawning survey 12.-26. February 2021. The area of the bubbles is scaled with the total number estimated in each stratum.

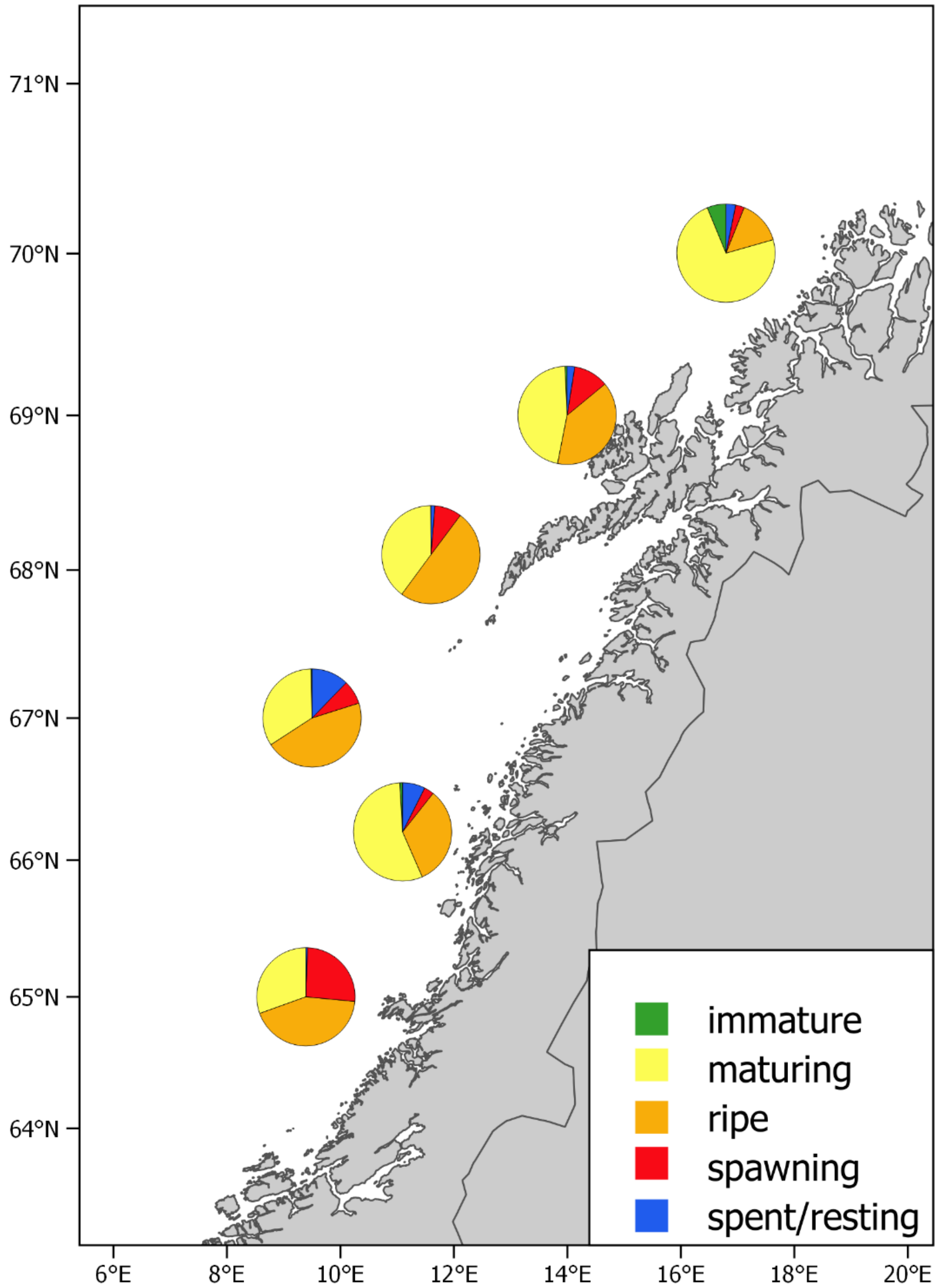

Figure 10. Proportions of different maturity stages from the Norwegian spring-spawning herring spawning survey 12.-26. February 2021.

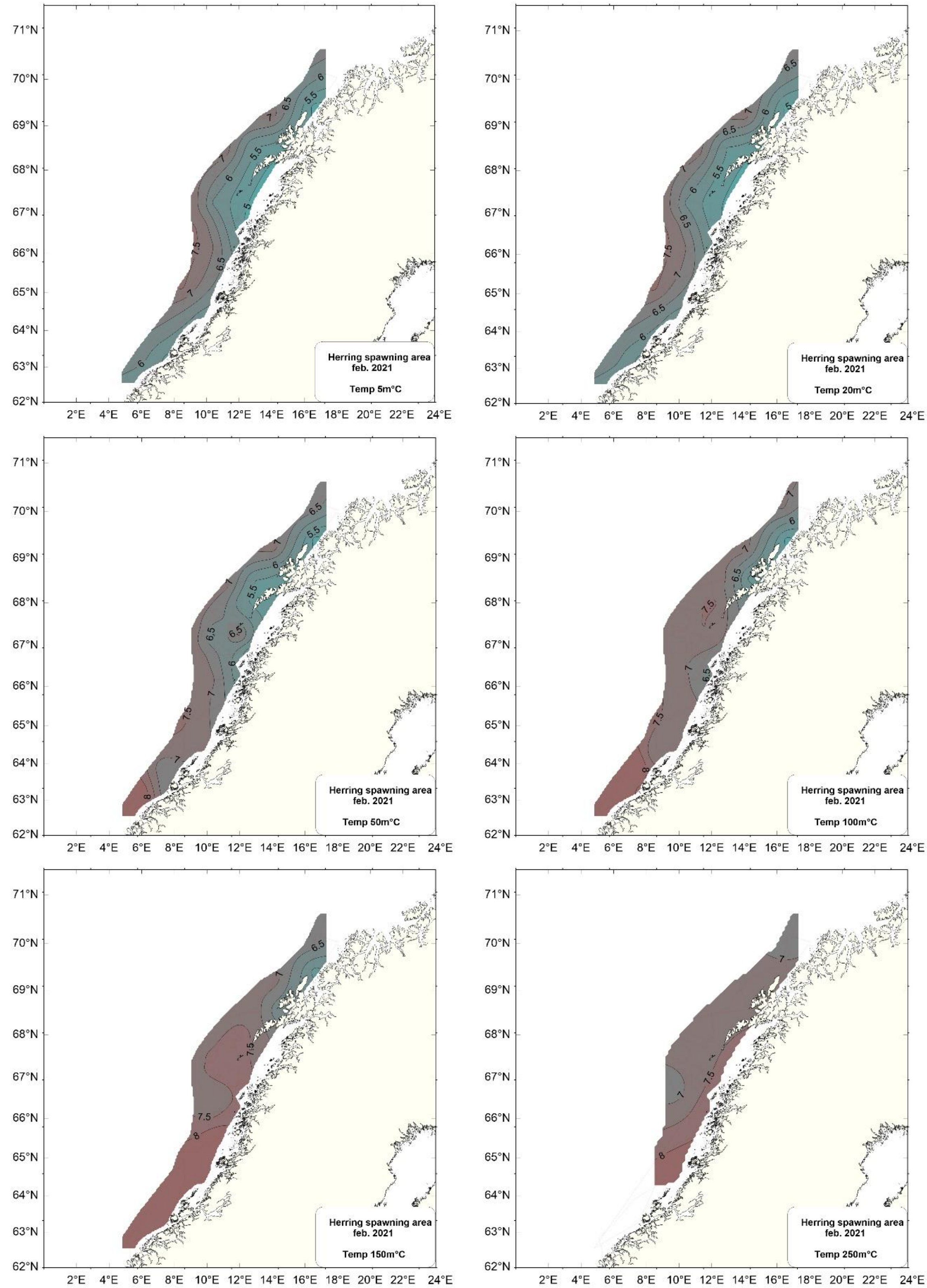

Figure 11. Temperature at 5, 20, 50, 100, 150, 250 m in the area covered during the Norwegian spring-spawning herring spawning survey 12.-26. February 2021.