



DISTRIBUTION AND ABUNDANCE OF NORWEGIAN SPRING-SPAWNING HERRING DURING THE SPAWNING SEASON IN 2022

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Summary (English):

During the period 14-27th of February 2022 the spawning grounds of Norwegian spring-spawning herring from Møre (62°15'N) to Troms (71°N) were covered acoustically by the commercial vessels MS Eros and MS Vendla. The estimated biomass was about 18 % lower, and the estimated total number was about 29 % lower this year compared to the last year's survey. The uncertainty of the estimates in 2022 was approximately equal to last year. The surveyed population of NSS herring was dominated by the 2016 year class; 52 % in numbers and 46 % in biomass. The 2016 year class was reduced by 37 % in numbers from last year's survey. Most of the spawning stock was found outside Lofoten and Vesterålen this year, further north and more concentrated than usual. The observed maturity indicates a bit later spawning compared to last year and like last year a more northern spawning than normal. 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 2022 are recommended to be used in this year's ICES stock assessment of Norwegian spring-spawning herring.

Summary (Norwegian):

I perioden 14. - 27. Februar 2022 ble gytefeltene til norsk vårgytende sild fra Møre (62°15'N) til Troms (71°N) dekket akustisk med de kommersielle fartøyene MS Eros og MS Vendla. Den estimerte biomassen var omtrent 18 % lavere, og det estimerte antallet omtrent 29 % lavere sammenlignet med fjorårets tokt. Usikkerheten i årets estimat er på samme nivå som i fjor. Gytebestanden var dominert av 2016-årsklassen med 52 % i antall og 46 % i vekt. Sammenlignet med toktet i fjor var antallet av 2016-årsklassen redusert med 37 %. Mesteparten av gytebestanden befant seg vest av Lofoten og Vesterålen i år. Sammenlignet med tidligere år stod silda lenger nord og var mer konsentrert. Sammenlignet med toktet i fjor var silda kommet noe senere i modningsprosessen i år. I likhet med tidligere år så var det mer eldre sild i den sørlige delen av gyteområdet og silda i nord var yngre. Det anbefales å bruke estimatene av relativ mengde fra toktet i 2022 i ICES sin bestandsvurdering av norsk vårgytende sild.

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1 - 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 using hired commercial fishing 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 2022 was to continue the time series of abundance estimates, both mean estimates and uncertainty, 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 variations in temperature.

2 - Material and methods

2.1 - Survey design

During the period 14-27th of February 2022 (same period as in 2017-2021) the spawning grounds from Møre (62°15'N) to Troms (71°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 2021 up to the survey start February 14th 2022 (Figure 1). The fishery prior to the survey in 2022 indicated that the herring wintering in the Norwegian Sea were entering the coast in the Træna deep south of Røst as observed in previous years. However, unlike previous years the fishery did not move south of Røst before the survey started. Like in the last winter season an extensive fishery in October-February 2021/2022 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 five 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 2022 mainly took place between Røst and Træna (66.3-67.4°N) which is farther north than usual at this time.

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 except the northernmost one 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_1.11` 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 2022 the fishing fleet was located west of Røst and it was estimated that the fleet had moved south to the Træna area around 66.5°N when the survey entered this area. Hence, the survey coverage (see Aglen 1989) was planned to be relatively low south of 65°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.

2.2 - 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. Both vessels used a Mulpelt 832 scientific sampling trawl with 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 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.

2.3 - Additional data collection

CTD casts (using Seabird 911 systems) were taken by both vessels, spread out haphazardly in the survey area. 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.

2.4 - Acoustic data processing

Echosounder data from the 38 kHz transducers was, as usual, the basis for measurement of fish density. The software LSSS version 2.12.0 was used for post-processing. Echogram scrutinization was carried out by the cruise leader and the chief instrument officer. Data was partitioned into the following categories: “herring”, “other” and “air bubbles” (upper 20 meters from the transducer near field).

2.5 - Abundance estimation methods

The acoustic density values were stored by species category in nautical area scattering coefficient (NASC) [$\text{m}^2 \text{n.mi.}^{-2}$] 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 3.3 (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:

$$\hat{S}_i = \frac{1}{n_i} \cdot \sum_{t=1}^{n_i} w_{it} s_{it} \quad (1)$$

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

$$L_i = \frac{1}{n_i} \sum_{t=1}^{n_i} L_{it} \quad (2)$$

The final mean NASC is given by weighting by stratum area, A_i :

$$\hat{S} = \frac{\sum_i A_i \hat{S}_i}{\sum_i A_i} \quad (3)$$

Variance by stratum is estimated as:

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

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

The global variance is estimated as

$$\hat{V}(\hat{S}) = \frac{\sum_i A_i^2 \hat{V}(\hat{S}_i)}{\left(\sum_i A_i\right)^2} \quad (5)$$

The global relative standard error of NASC

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

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_i) in each length group (L_i) within each stratum (i) is then computed as:

$$N_i = \frac{f_i \cdot \hat{S}_i \cdot A_i}{\langle \sigma \rangle}$$

Where

$$f_i = \frac{n_i L_i^2}{\sum_{i=1}^m n_i L_i}$$

is the "acoustic contribution" from the length group L_i 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_i . The conversion from number of fish by length group (L_i) to number by age is done by estimating an age ratio from the individuals of length group (L_i) 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, $TS = 20\log L - 71.9$ (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 $TS = 20\log L - 2.3 \log(1 + z/10) - 65.4$ 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.

3 - Results and discussion

3.1 - Survey coverage

The cruise tracks of the NSSH spawning survey in 2022, together with pelagic trawl stations and CTD stations are shown in Figure 2. As mentioned above, the coverage south of 65°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 65°N. The survey coverage (see Aglen 1989) of the first three strata was 5, 7 and 9 respectively (starting from south) and 11 in the four next strata with zigzag transects. The northernmost stratum with parallel transects had a survey coverage of 9. Pelagic trawl hauls were carried out regularly (Fig. 2) in the areas where herring like marks 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 34 CTD casts were carried out in the surveyed area (Fig. 2). Nautical area scattering coefficients (NASC) allocated to herring from acoustic transects by each nautical mile are shown in Figure 3. Significant herring marks on the echosounders started to occur slightly north of 66°N, which is unusually far north in mid-February, and herring was observed in the entire area north of this. South of Lofoten the herring was mainly distributed around the shelf edge of the Røst bank, but outside Lofoten and Vesterålen herring was also observed on the banks nearer land. North of Vesterålen the herring was distributed along the shelf edge as usual, and the zero-line was established in the north around 70.9°N. Capelin marks started to appear around 69.7°N (confirmed by trawl samples) and was observed regularly north of this, in particular around the shelf edge area in the northernmost part. The herring schools appeared to be deeper and clearly separated from the more shallow capelin schools, an observation that the trawl sampling also supported. No more capelin results are presented in this report as the focus is on herring.

3.2 - 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. The 2016 year class (age 6) dominated both in numbers (52 %) and biomass (46 %), followed by the 2013 year class (age 9) which contributed 12 % in numbers and 15 % in biomass. Compared with the point estimates from last year (see Salthaug et al. 2021) the 2016 year class was reduced by 37 % in numbers and the 2013 year class by 22 %. The point estimate of total stock biomass (TSB) in the survey area was 3.302 million tons which is 18 % lower 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. The point estimate of total stock number (TSN) in the survey area was 12.2 billion which is 29 % lower than last year's estimate. The time series of total stock number from the survey is shown in Figure 5. This year's estimates of TSB and TSN are slightly below the respective means of the time series. The relative standard error (CV) of the TSB and TSN estimates in 2021 are both 17 % (Tab. 1 and 2). These estimates of sample uncertainty are quite similar to those from the two previous surveys. The CV per age (Tab. 1 and 2) shows the normal 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 6 shows estimates of number per year class in the eight most recent surveys. The estimated numbers from the survey in 2022 seems to decline as expected for the year classes that are fully recruited to the survey. In addition, like in the most recent surveys the 2016 and 2013 year classes are estimated to be the most abundant which shows that this survey is internally consistent. Mean weight and length from the 2021 spawning survey are shown in Table 3. The Stox project used to calculate abundance and related parameters is openly available and can be found here:

<http://metadata.nmdc.no/metadata-api/landingpage/2870f9f21da64f3a01641dfe12512b33>

3.3 - Spatial distribution of the stock

The relative distribution of the estimated biomass per stratum is shown in Figure 7. This year most of the biomass (84%) was found in the two strata west of Lofoten and Vesterålen, while only a small fraction was found in the strata to the north and south of these. The spawning stock was much more concentrated and further north than usual this year. Age compositions per stratum are shown in Figure 8. The southernmost stratum where herring was recorded was dominated by herring older than eight years, which is consistent with earlier observations; the largest and oldest fish are in the front of the spawning migration. The 2016 year class dominated in the rest of the strata, and the proportion of younger herring was as usual highest in the north.

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 9 shows the proportion of different maturation stages in each stratum. Most of the herring was classified as maturing or ripe, and the proportions of maturing herring were larger than last year which indicates later spawning this year. The old herring in the southernmost stratum was dominated by maturing individuals indicating that these fish would swim further south before spawning. The fishery also indicated that this was the case since catches moved further south after the survey covered the area (see Fig. 1). A small fraction of the herring outside Lofoten and Vesterålen were spawning and this, together with the large proportion of ripe individuals, indicate that much of the 2016 year class spawned in this area. Like last year this shows 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.

3.4 - Geographical variation in temperatures experienced by the herring

Temperatures experienced by herring from close to the surface and down to 250 m are shown in Figure 10 for the areas south and north of 67°N, for the years after 2016 when the survey has been carried out in the same period (latter half of February). The temperatures in 2022 varied from 7.7°C at 250 m depth south of 67°N to 5.4°C at 5 m depth north of 67°N. The temperatures near the surface were quite low this year, and also varied more with depth compared to earlier years. 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.

3.5 - Quality of the survey

In 2022 both vessels were equipped with multifrequency equipment on a drop keel. The weather conditions were exceptionally good this year so that acoustic data with good quality was recorded and trawling on registrations could be carried out all of the time. No correction for air bubble attenuation (as described in Annex 3 in Slotte et al. 2019) had to be carried out this year due to the nice weather. As opposed to last year the zero line was clearly established in the north, and we are not aware of any observations that indicates presence of mature NSS herring outside the survey area during the survey this year. To conclude, the acoustic and

biological data recorded in 2022 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 2022.

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5 - Tables

Table 1. Abundance estimates (million individuals) of Norwegian spring-spawning herring during the spawning survey 14.-27. February 2022, based on 1000 bootstrap replicates.

Age	5th percentile	Median	95th percentile	Mean	SD	CV
2	1	23	62	27	19	0.72
3	13	71	134	72	36	0.50
4	51	154	310	162	78	0.48
5	406	738	1148	760	234	0.31
6	4473	6314	8475	6393	1256	0.20
7	205	308	458	317	76	0.24
8	377	557	788	563	126	0.22
9	1066	1500	2063	1515	298	0.20
10	174	294	458	301	89	0.30
11	303	477	707	486	122	0.25
12	175	297	439	301	79	0.26
13	137	247	393	255	80	0.31
14	206	380	584	385	119	0.31
15	37	71	122	73	26	0.36
16	227	384	602	395	117	0.30
17	18	52	109	57	29	0.50
18	36	86	157	89	37	0.41
20	0	13	42	15	15	1.04
TSN	8910	12126	15591	12183	2051	0.17

Table 2. Abundance estimates (thousand tons) of Norwegian spring-spawning herring during the spawning survey 14.-27. February 2022, based on 1000 bootstrap replicates.

Age	5th percentile	Median	95th percentile	Mean	SD	CV
2	0	1	4	2	1	0.77
3	1	8	18	9	5	0.59
4	7	23	44	24	11	0.48
5	76	131	204	136	41	0.30
6	1083	1511	2035	1533	303	0.20
7	57	87	128	89	22	0.24
8	115	169	239	171	38	0.22
9	336	478	660	481	96	0.20
10	58	102	160	104	31	0.30
11	104	165	245	168	42	0.25
12	64	108	158	109	29	0.26

Age	5th percentile	Median	95th percentile	Mean	SD	CV
13	51	92	147	95	30	0.32
14	75	138	213	140	43	0.31
15	14	27	46	28	10	0.36
16	87	148	232	151	45	0.30
17	6	19	41	21	11	0.51
18	13	33	60	34	14	0.41
20	0	5	16	6	6	1.03
TSB	2424	3291	4246	3302	557	0.17

Table 3. Estimated length and weight of individuals by age group of Norwegian spring-spawning herring during the spawning survey 14.-27. February 2022, based on 1000 bootstrap replicates.

Age	mean weight (g)	CV weight	mean length (cm)	CV length
2	56.7	0.063	21.2	0.017
3	105.7	0.230	24.9	0.053
4	137.6	0.066	27.4	0.017
5	171.3	0.026	29.1	0.006
6	230.0	0.012	31.3	0.003
7	277.0	0.021	33.0	0.005
8	301.1	0.018	34.1	0.005
9	315.2	0.010	34.3	0.003
10	343.4	0.018	35.6	0.007
11	342.3	0.019	35.6	0.006
12	362.1	0.017	36.6	0.003
13	371.7	0.021	36.9	0.004
14	362.5	0.017	36.5	0.005
15	373.7	0.023	37.1	0.006
16	380.9	0.014	37.2	0.003
17	362.5	0.037	37.3	0.008
18	379.1	0.024	37.1	0.011
20	387.6	0.032	37.0	0.000

6 - Figures

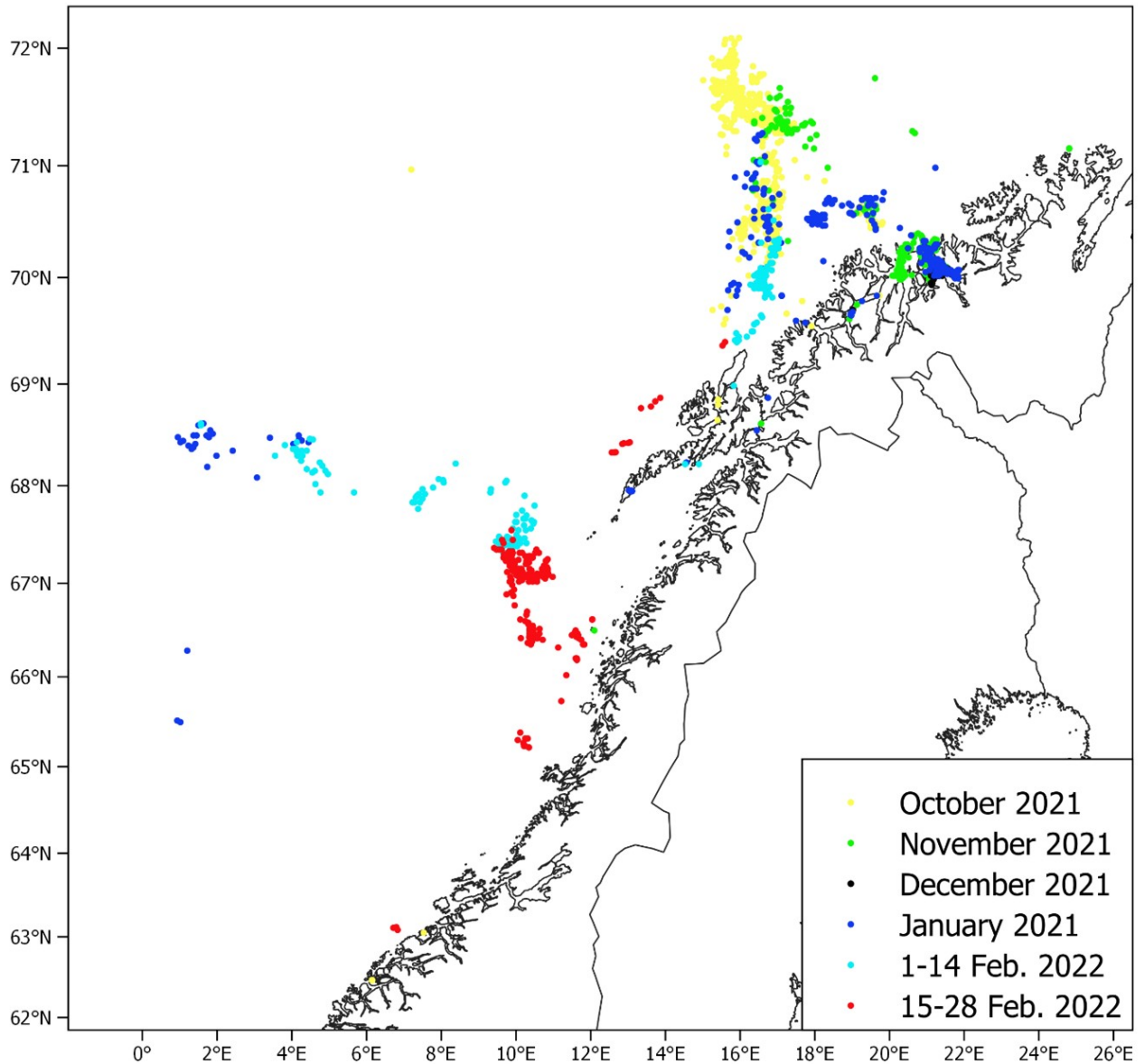


Figure 1. Distribution of commercial catches of Norwegian spring-spawning herring from October 2021 until February 2022, based on electronic logbooks. Each point represent one catch, only catches larger than 10 tons are shown.

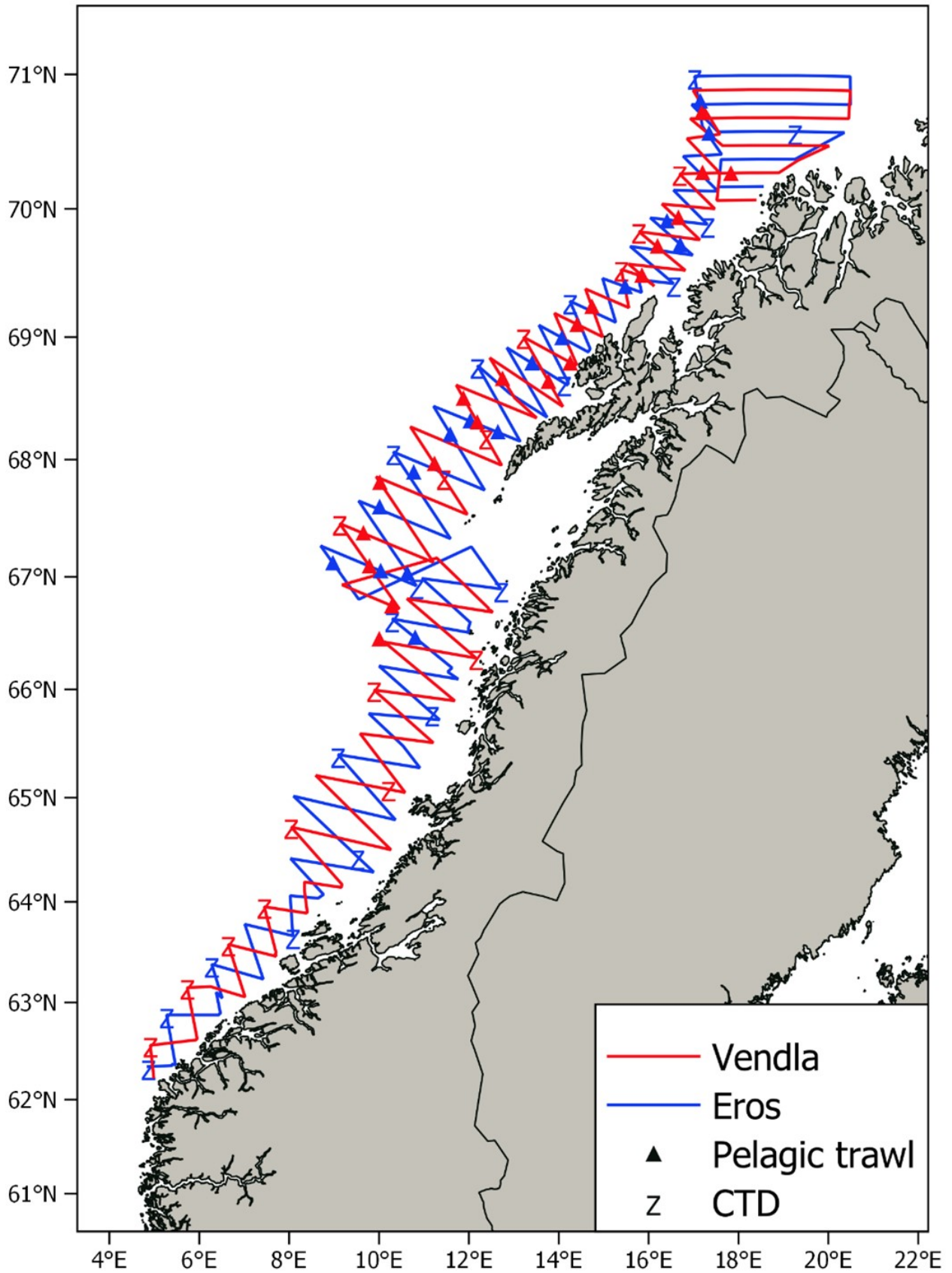


Figure 2. Cruise tracks (mostly acoustic transects), pelagic trawl stations (triangles), and CTD stations (Z) covered by Eros and Vendla on the Norwegian spring-spawning herring spawning survey 14.-27. February 2022.

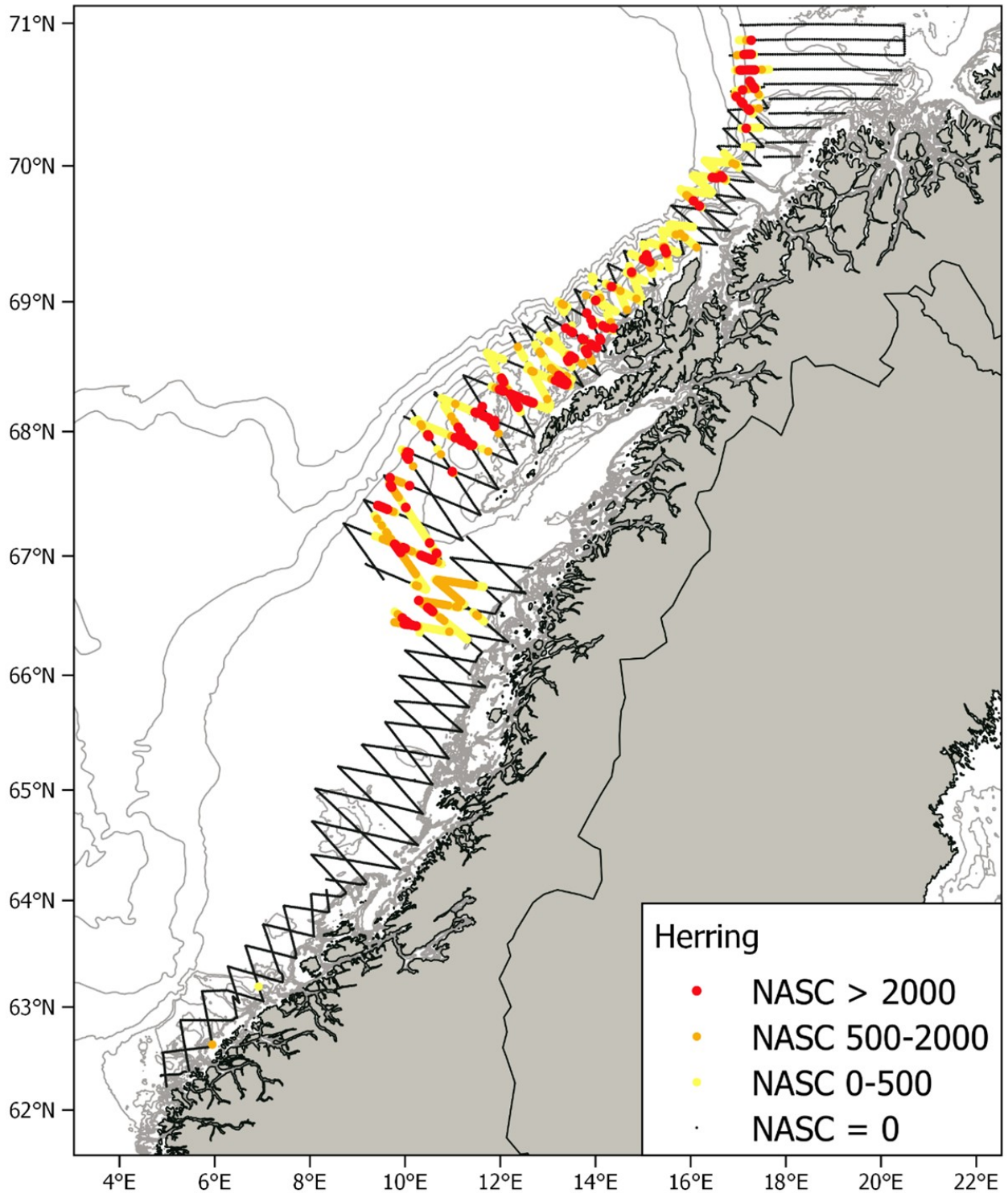


Figure 3. Acoustic densities (NASC) of herring recorded during the Norwegian spring-spawning herring spawning survey 14.-27. February 2022. Points represent NASC values per nautical mile. Depth contours are shown for 50 m, 100 m, 150 m, 200 m, 500 m, 1000 m, 1500 m and 2000 m.

SPAWNING SURVEY, TSB

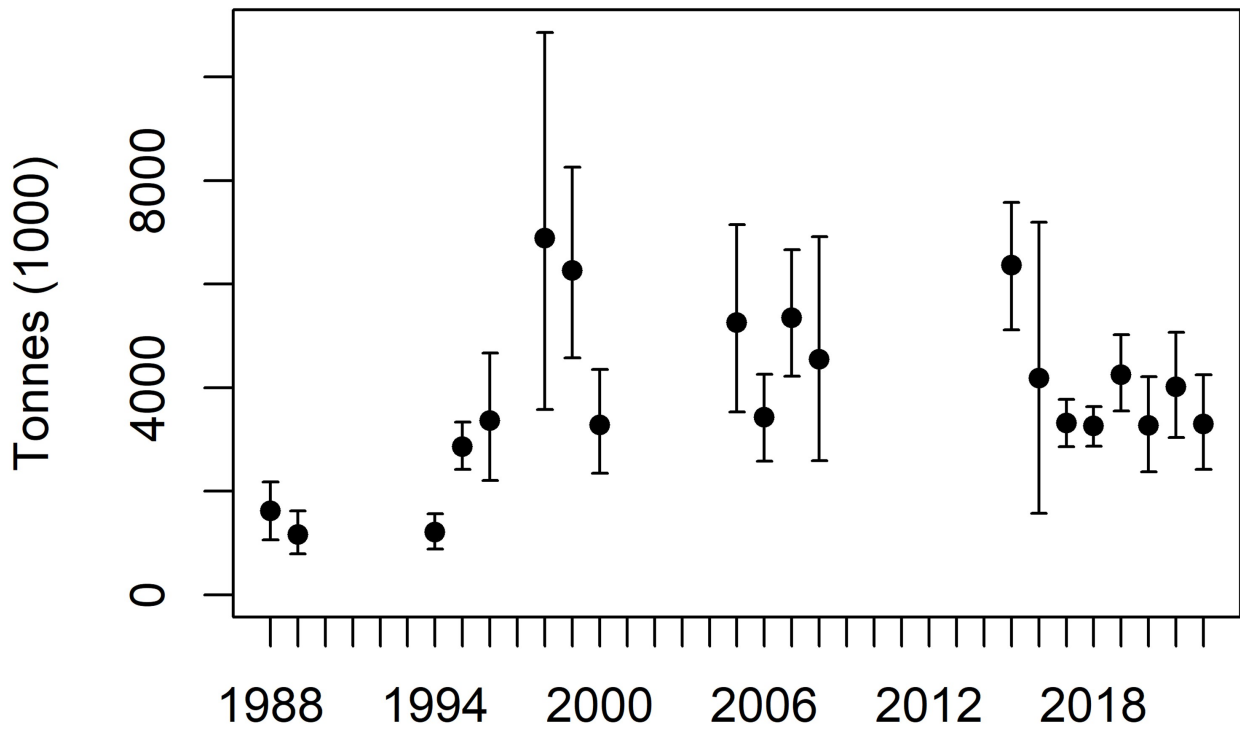


Figure 4. Estimates of total biomass from the Norwegian spring-spawning herring spawning surveys during 1988-2022. The estimates are mean of 1000 bootstrap replicates and the error bars represent 90 % confidence intervals.

SPAWNING SURVEY, TSN

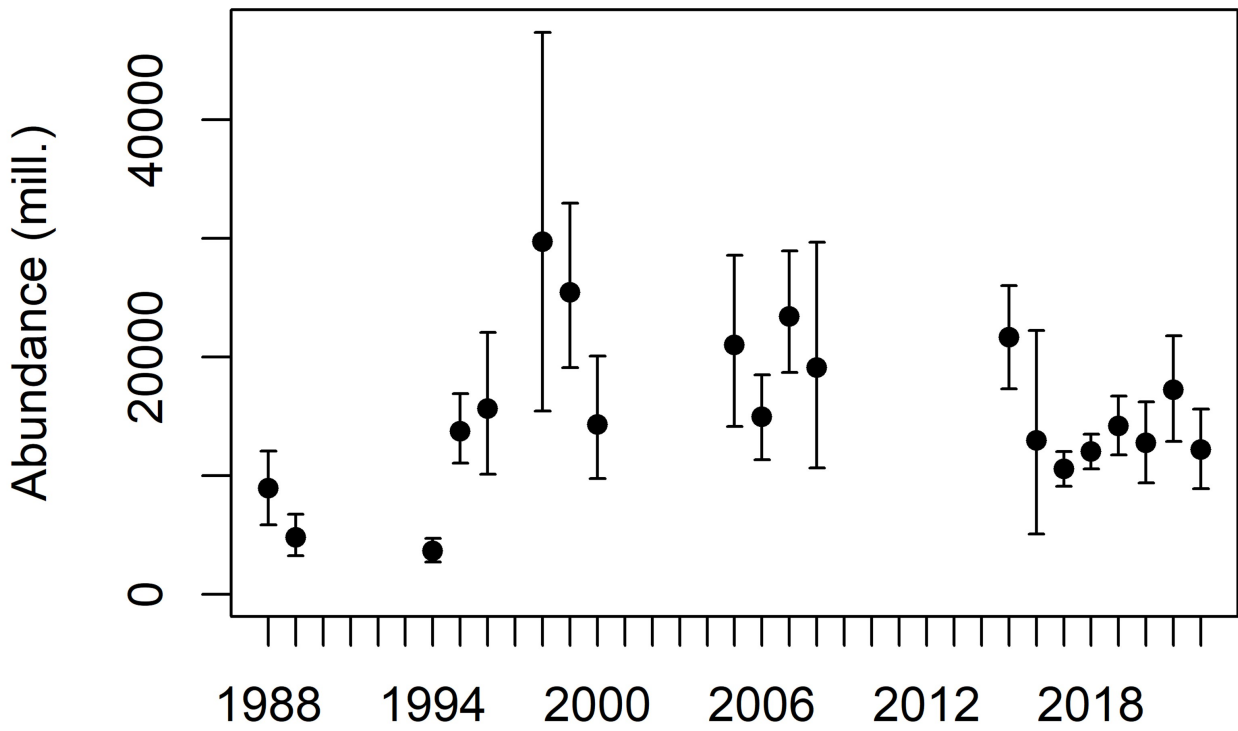


Figure 5. Estimates of total number from the Norwegian spring-spawning herring spawning surveys during 1988-2022. The estimates are mean of 1000 bootstrap replicates and the error bars represent 90 % confidence intervals.

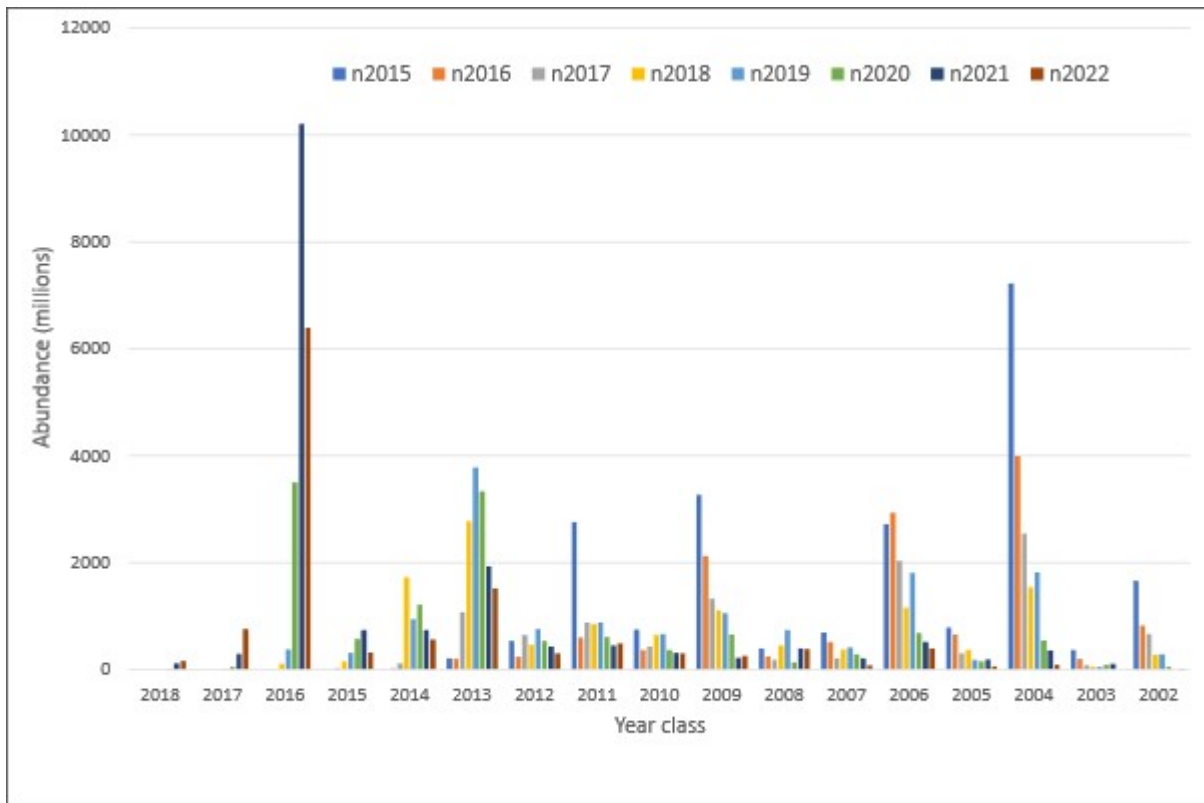


Figure 6. Abundance by year class estimated during the Norwegian spring-spawning herring spawning surveys 2015-2022 (mean of 1000 bootstrap replicates). Legend: Separate colour for each survey year.

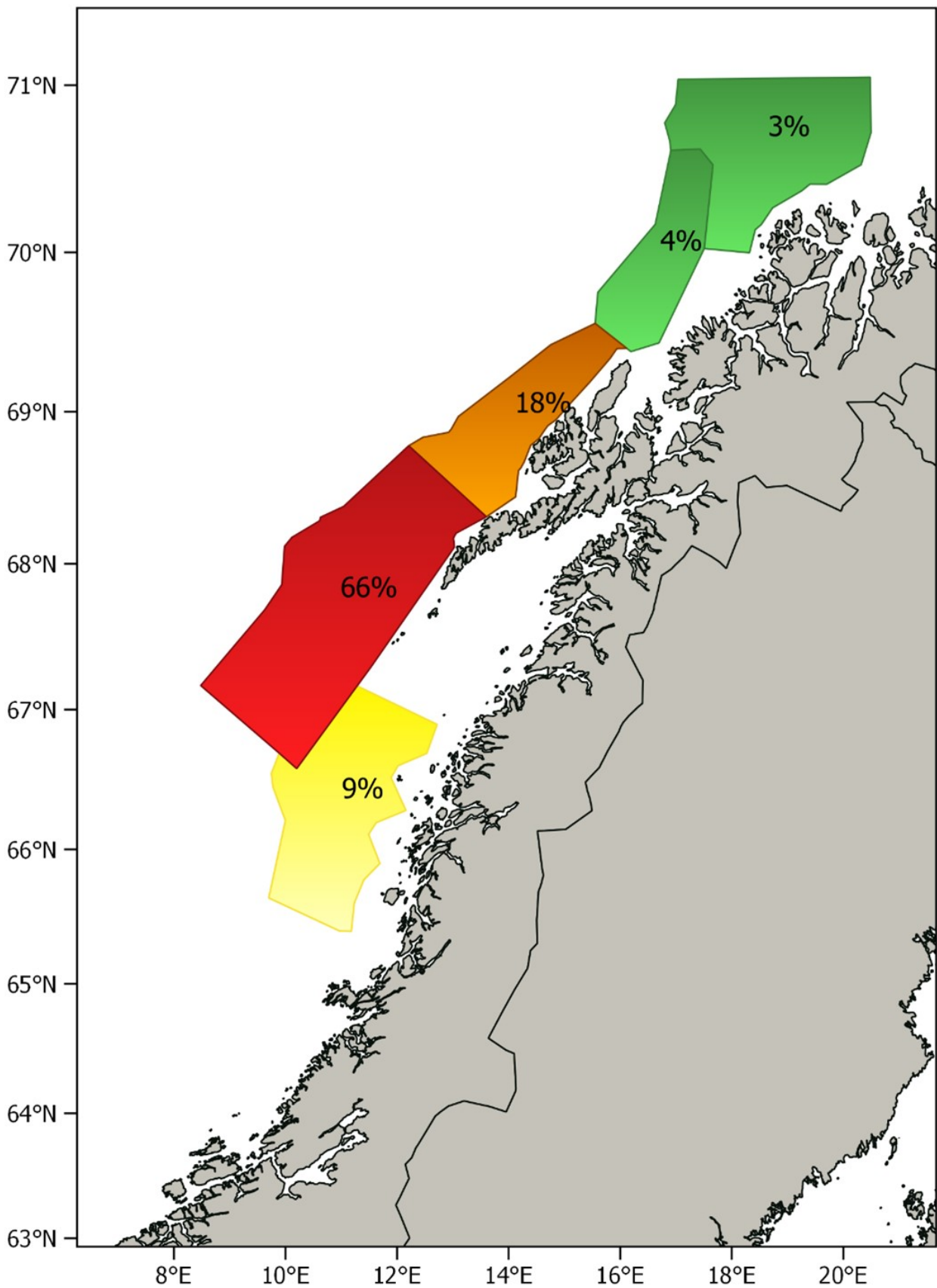


Figure 7. Relative distribution by stratum of the biomass of herring from the Norwegian spring-spawning herring spawning survey 14.-27. February 2022.

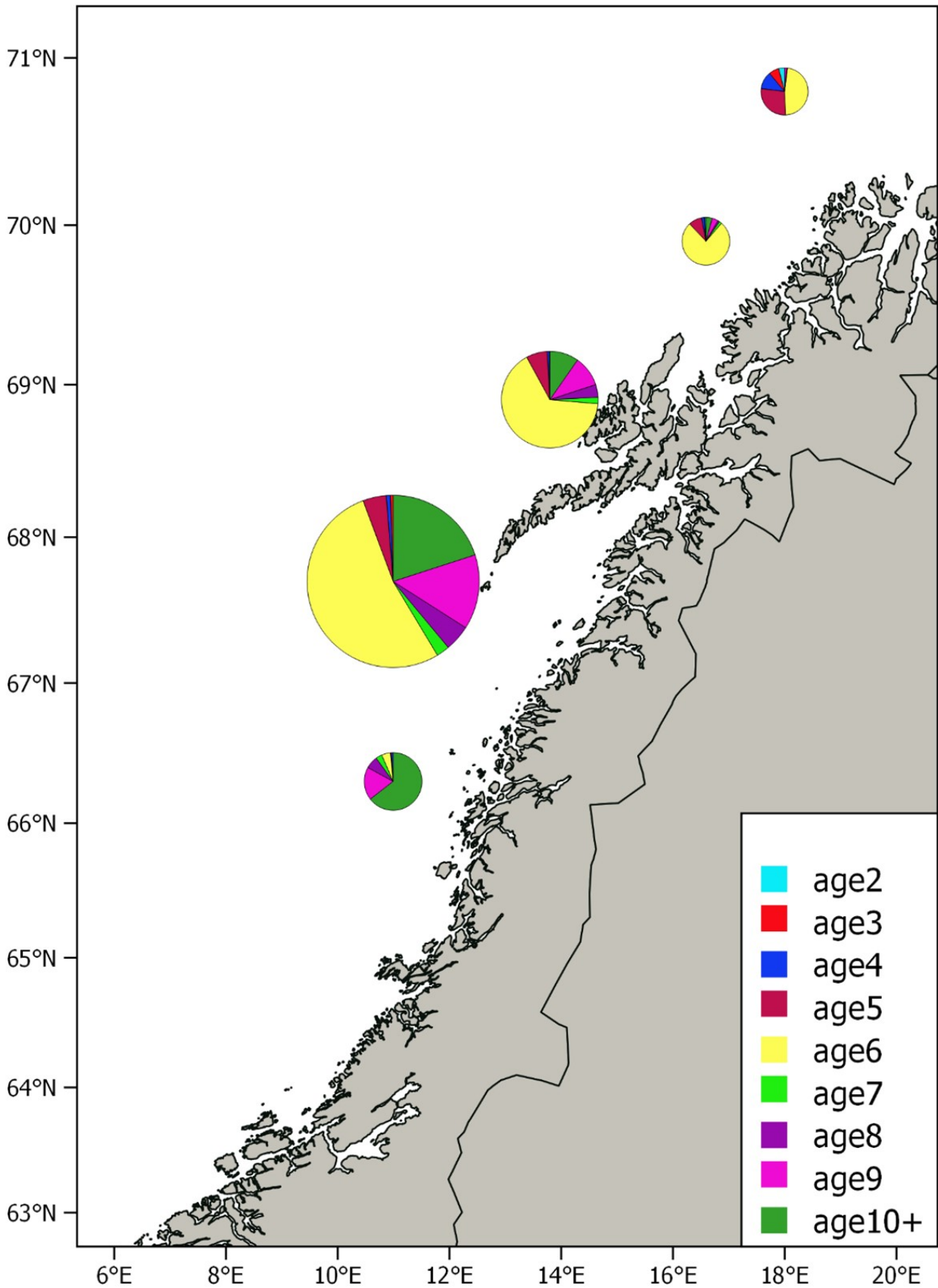


Figure 8. Age distribution per stratum from the Norwegian spring-spawning herring spawning survey 14.-27. February 2022 . The area of the bubbles is scaled with the total number estimated in each stratum.

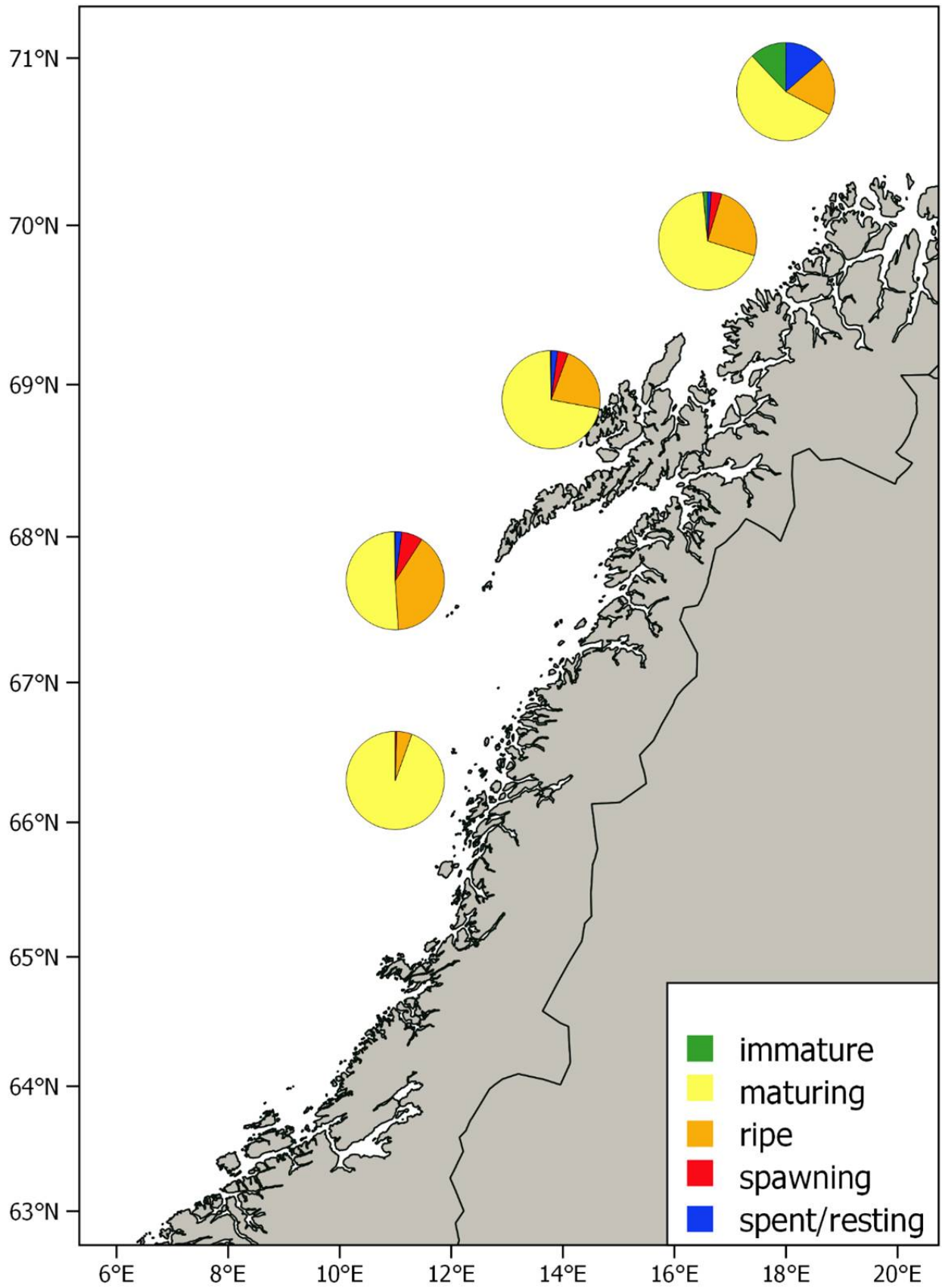


Figure 9. Proportions of different maturity stages from the Norwegian spring-spawning herring spawning survey 14.-27. February 2022

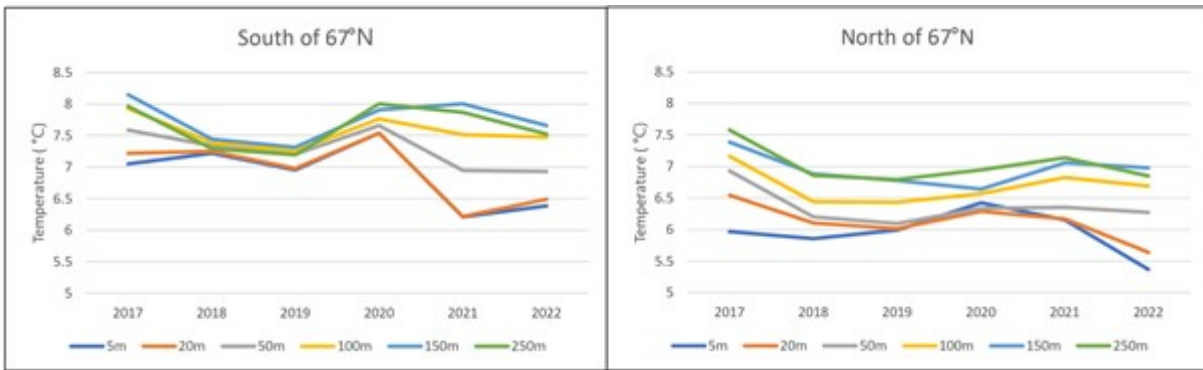


Figure 10. Mean temperatures at 5, 20, 50, 100, 150, 250 m in the area covered during the Norwegian spring-spawning herring spawning surveys in 2017-2022.



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